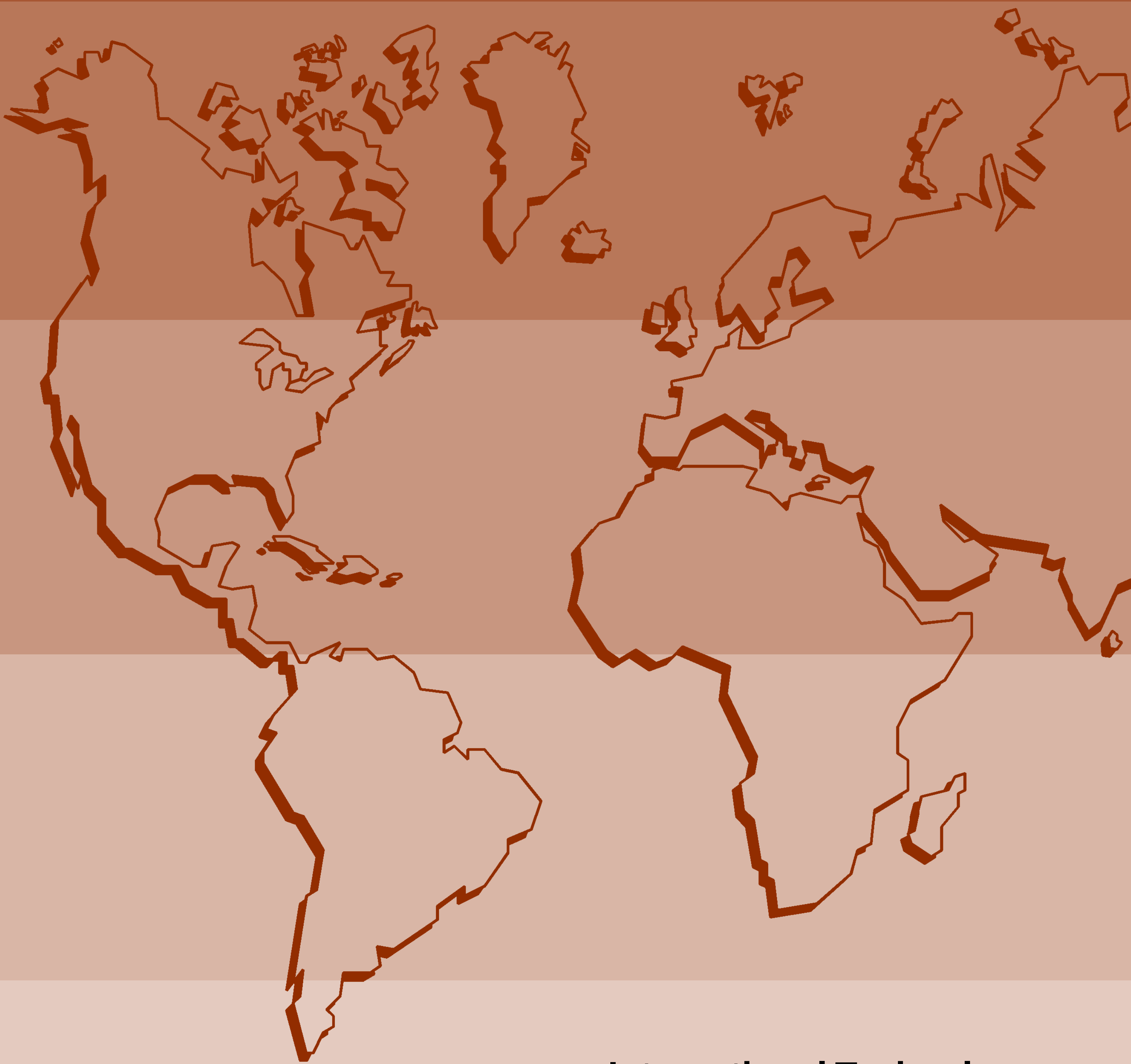
Geotechnical Engineering Practices in Canada and Europe



International Technology Exchange Program

U.S. Department of Transportation
Federal Highway Administration

March 1999

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FHWA-PL-99-013		

4. Title and Subtitle	4. Report Date
Geotechnical Engineering Practices in Canada and Europe	**March 1999**
	6. Performing Organization Code:
7. Author(s) Jerry DiMaggio, Tom Saad, Tony Allen, Barry R. Christoper, Al Dimillio, George Goble, Paul Passe, Terry Shike, Gary Person	8. Performing Organization Report No.
9. Performing Organization Name and Address **American Trade Initiatives** **P.O. Box 8228** **Alexandria, VA 22306-8228**	10. Work Unit No.(TRAIS) 11. Contract or Grant No. DTFH61-99-C-0005
12. Sponsoring Agency Name and Address Office of International Program Office of Policy Federal Highway Administration U.S. Department of Transportation	13 Type of Report and Period Covered 14. Sponsoring Agency Code

15. Supplementary Notes

FHWA COTR: Donald W. Symmes, Office of International Programs

16. Abstract

This summary report highlights the March 1998 FHWA scanning team organized to review and document developments in load and resistance factor design (LRFD) methods and alternative contracting practices related to geotechnical engineering features in Canada, Germany, France, Denmark, Norway, and Sweden. Scan team members represented geotechnical and structural engineering representatives from the Federal, State, and private industry sectors. Team members explored how countries applied Eurocode 7—the common geotechnical code recently introduced and based on a limit-state, LRFD approach—and used innovative contracting practices and design-build projects to counteract reduced role and funding by national transportation agencies. The report chronicles the team's findings, observations, and recommendations, including the importance of close communication between structural and geotechnical engineers on projects, the strong commitment to implement limit-state design, and the need to define characteristic soil properties based on measured distribution and quality of property. In terms of contracting innovations, members found that the countries visited have rejected low-bid awards in favor of best-bid awards that emphasize long-term performance and value. Contractors are generally prequalified and are often allowed to submit design alternatives on projects. The team also learned of innovative technical developments including Denmark's dewatering technology and German tunneling work. The report includes a bibliography and resource and contract information, by country.

17. Key Words	18. Distribution Statement
Key Words: Eurocode, load and resistance factor design (LRFD), limit state design, design-build, mechanically stabilized earth, partial factors, resistance factors, innovative contracting, performance-based specifications, geotechnical, soil cohesion, pile capacity, cone-penetration testing	No restrictions. This document is available to the public from the Office of International Programs FHWA-HPIP, Room 3325 US Dept. of Transportation Washington, DC 20590 international@fhwa.dot.gov www.international.fhwa.dot.gov

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	74	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

International Technology Exchange Program

Geotechnical Engineering Practices in Canada and Europe

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FHWA INTERNATIONAL TECHNOLOGY EXCHANGE PROGRAMS

The FHWA's 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 the FHWA is considered a world leader in highway transportation, the domestic highway community is very interested in the advanced technologies being developed by other countries, as well as innovative organizational and financing techniques used by the FHWA's international counterparts.

INTERNATIONAL TECHNOLOGY SCANNING PROGRAM

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 Transportation Officials and its Select Committee on International Activities, and the Transportation Research Board's National Highway Research Cooperative Program (Panel 20-36), the private sector, and academia.

Priority topic areas are jointly determined by the FHWA and its partners. 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, as well as members of the academic community.

The FHWA has organized more than 30 of these reviews and disseminated results nationwide. Topics have encompassed 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.

For a complete list of International Technology Scanning topics, and to order free copies of the reports, please see the last page of this publication.

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ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ASD	Allowable Strength Design
BASt	German Federal Highway Research Institute
BAW	Federal Research Institute of Germany
BMW	German Ministry of Transportation
CATQEST	Contract Administration Techniques for Quality Enhancement Study Tour
CEN	European Standard Organization
CERMES	Teaching and Research Center in Soil Mechanics
CPT	Cone Penetrating Testing Rig
DIN	German Industry Standards Group
EN	European Norm
ENPC	École Nationale des Ponts et Chaussées
ENV	European Norms Proposal
EU	European Union
FHWA	Federal Highway Administration
LCPC	Laboratoire Central des Ponts et Chaussées
LRFD	Load Resistance Design Factor
LSD	Limit State Design (Canadian designation for LRFD)
MOSES	Method of Obtaining by Emptying Storebælt
MSE	Mechanically stabilized earth
MTO	Ministry of Transport, Ontario
PDA	Pile dynamic analysis
RMC	Royal Canadian Military College
SETRA	Service d'Études Techniques des Routes et Autoroutes
TPM	Total Project Management (MTO)
ULS	Ultimate Limit State

EXECUTIVE SUMMARY

PURPOSE

In March 1998, the Federal Highway Administration (FHWA) organized a geotechnical engineering scanning tour of Canada and Europe. Its purpose was to review and document developments in load and resistance factor design methods and alternative contracting methods, as related to geotechnical engineering features. The tour also presented an opportunity to explore other new or improved geotechnical products or practices in developing areas, such as ground improvement methods, mechanically stabilized earth retaining walls, and in situ testing of geotechnical materials.

METHOD

The geotechnical scanning team members included both geotechnical and structural engineering representatives from Federal, State, and private industry sectors. Team members were invited to participate based on their positions as leaders in the development and implementation of new technologies. The team met with technical leaders of Canada, Denmark, Sweden, Norway, Germany, and France to acquire detailed design and construction information for possible application in the United States. To promote innovative geotechnical engineering worldwide, team members shared information with international counterparts on U.S. policy initiatives and research activities.

GENERAL FINDINGS

Load and Resistance Factor Design (LRFD)

In Canada, the Ontario Bridge Code is based on load and resistance factors and has been in use for about 20 years. It was the first structures code that used an analytically determined resistance factor approach. It is currently in its fourth version. In Europe, a common geotechnical code, Eurocode 7, has recently been introduced and is based on a limit-state, LRFD approach. The team found Eurocode 7 to be a difficult document to read and understand, which may explain the various interpretations that were expressed in the countries visited. The complications are related to the determination of the characteristic soil and rock property values used in design and to the definition of the partial factor. To avoid confusion, the scanning team found that the use of the term “partial factor” should be discouraged, and determination of characteristic value should be more clearly defined. To make Eurocode 7 more usable, some countries suggested separating property bias from model bias in determination of factors. In addition, the team found that structural load factors do not match geotechnical load factors in the Eurocodes. The load and resistance factors for geotechnical features appeared to be conservative. There may also have been inaccuracies in

> The team noted an absence of strong analytical calibration and verification of either the Eurocode or the Canadian code. Many of these findings are related to the absence of good communication in some countries between structural and geotechnical disciplines—a situation that is also prevalent in the United States.

the derivation because of differences in the determination of the characteristic soil and rock property values. The team noted an absence of strong analytical calibration and verification of either the Eurocode or the Canadian code. Many of these findings are related to the absence of good communication in some countries between structural and geotechnical disciplines—a situation that is also prevalent in the United States. Even with these shortcomings, there is a strong commitment in the countries visited to implement limit-state design. This method of analysis was deemed to offer significant potential for improved design, over time. In Europe, limit-state design is being taught in universities, and at least one country introduced the Eurocode at the university level.

Innovative Contracting

Canada presented the most information regarding design-build practice to the scanning team. In Canada, as well as in the other countries visited, however, design-build experience is currently limited in the public sector. In Europe, the owner completes much more of the design in a design-build project (50 to 90 percent) than is typically recommended in the United States. As much, or more, geotechnical information is provided, as would be in a conventionally contracted project. Specific performance objectives and required quality control procedures are clearly defined where design-build was found to be successful; however, when these items were poorly defined, there were significant problems. The general attitude was that quality should not be a variable in the bid process. With that in mind, detailed preliminary geotechnical investigations are often performed by the owner, for design-build, as well as most other innovative contracting practices. There is general support for design-build in large projects that feature significant engineering content. Consultants and contractors do not entirely support the design-build approach; many feel that the government is passing along significant up-front cost to them in development of proposals, along with the significant risk at the end of the project. To reduce the concerns from contractors, the countries visited usually used a staged approach with prequalification for the bidding process and some support for payment of proposals to the qualified bidders.

The team found that warranties were generally provided through bonds and were used on design-build contracts as well as conventional construction contracts in Europe. Warranties typically ranged from 1 to 5 years. In one case, a proposal to extend warranties to cover maintenance for up to 20 years was being considered. Problems with warranties included limited availability and magnitude of bonds, the financial solvency of contractors, and agreement, in terms of measured performance.

Alternate designs are widely accepted in some countries. Owners evaluate innovative proposals during the bidding process and often award contracts on the bases of quality, cost-effectiveness, and savings in contract time. Checking references to confirm the ability of low bidders to do the work is also commonly used by owners to establish the expected quality of performance. As in the United States, government laws, environmental regulations, and permitting requirements tend to restrict innovative contracting. Likewise, innovative contracting methods for public sector projects appear to be politically motivated and, in some cases, not well developed.

Other Geotechnical Practices

The professional contacts and the identification of good sources of information on current activities in Canada and Europe will significantly support ongoing work in the United States. Some examples of geotechnical activities and observations include:

- Germany presented significant testing and utilization of geofoam (EPS).
- The Germans have also developed an interesting new method for compaction control.
- Significant research on mechanically stabilized earth (MSE) structures is under way in Canada.
- Denmark reported some significant developments in deep, offshore dewatering methods, as well as a new method for mitigating beach erosion.
- There are a number of new tunneling projects in Europe that have the potential for significant development over the next few years.

The team also noted some general trends in geotechnical practice. Europeans rely less on static-load testing of piling for design verification. With regard to analytical procedures, one country is proposing that both the average and minimum geotechnical property values be provided by the geotechnical consultant. (In the United States, a single characteristic value is typically provided.) Representatives of most countries expressed concern for a trend in decreasing reliance on geotechnical exploration and testing, which will potentially compromise design safety and economy—a concern common in the United States.

RECOMMENDATIONS

On the basis of the team's findings, all team members' recommendations were agreed on and prioritized according to the need for action. The following summarizes the higher priority recommendations of the team; further discussion of these and other recommendations is contained in the body of the report.

The panel agreed that a calibration of the geotechnical load and resistance factors in LRFD code is the most urgent need and should receive immediate attention. The American Association of State Highway and Transportation Officials (AASHTO) should set verification of the codes against existing computer databases (e.g., the FHWA's database) as its top priority. Consideration should also be given to using a separate analytical model and soil parameter variability factors in the code to better coordinate structural load factors with geotechnical load and resistance factors.

To facilitate the implementation of LRFD in geotechnical engineering and allow for a smooth transition from current practice, AASHTO should establish a steering committee to develop an implementation plan. At minimum, the plan should include the following steps:

1. Modify the code to include model- and soil-reliability factors.
2. Clearly define the characteristic value for soil parameters, with consideration for requiring average and minimum values for each soil property.
3. Initially calibrate and compare to the current allowable stress design methods.

4. Institute reliability-based calibration using databases and separate verification of the LRFD code.
5. Improve readability and user-friendliness of the AASHTO code related to geotechnical engineering.
6. Coordinate all LRFD efforts, including ongoing National Cooperative Highway Research Program (NCHRP) projects and international work.
7. Approach lead States to showcase LRFD successes.
8. Establish promotional efforts to encourage immediate implementation of LRFD in geotechnical engineering with the message: At worst, you get what you had; at best, you get a better design.
9. Establish performance benchmarks for evaluation of future modifications, improvements, and measurement of success.
10. Establish a strong educational effort, including a program to train educators, demonstration projects for load and resistance factor design of substructures, and a method for periodic assessment.

A key goal of the steering committee as well as other civil engineering organizations should be to improve communication between geotechnical and structural engineers. While structural engineers tend to implement prescriptive methods, geotechnical engineers must be able to use site-specific knowledge and interpolate among results of several design methods to evaluate structural capacity. Therefore, some cross-functional LRFD training to bridge the implementation gaps is recommended for geotechnical, structural, and construction engineers. During the design process, communication requirements for geotechnical and structural engineers need to be documented in terms of what is expected from both groups and how they should interact, including methods for feedback. Team processes should be encouraged for design. Canned presentations should be developed clearly explaining where the factors come from in limit-state design, and training must begin at the university level.

With regard to innovative contracting, the team agreed that a strong effort should be made to eliminate contractor selection based solely on low bid. An objective method should be used that considers contractors' qualifications and past performance. Steps should be taken to introduce a staged procurement process as a method of significantly improving the construction of geotechnical features, in terms of quality, cost, and time. A prequalification process, such as expression of interest and qualifications prior to request for proposals, should be established. Contractors should be required to give references to prove they can do the job. Lists of approved contractors, along with performance history, should be maintained.

Other high-priority items that should receive immediate consideration for implementation include:

- Establish owners' preliminary geotechnical exploration requirements for design-build contracts.

- Establish specific guidelines for determining load and resistance factors, based on the number of quality of geotechnical property tests. Geotechnical engineers should be required to provide average and minimum values for soil properties to help establish the variability of the characteristic values.
- Establish guidelines for developing quantitative performance criteria, including fully defined requirements, for an effective quality control plan for design-build contracts.
- Require proof from contractors that the desired level of quality has been accomplished, before receiving payment for the work completed. Consider including maintenance responsibilities or a warranty, for some duration, in the contract.

These recommendations should be considered for immediate implementation in any programs related to LRFD and alternative contracting methods as related to geotechnical engineering features.

CHAPTER 1

LRFD AND INNOVATIVE CONTRACTING: OPPORTUNITIES AND CHALLENGES IN GEOTECHNICAL PRACTICES

BACKGROUND

The geotechnical community in the United States has traditionally used global safety factors and performance limits to establish the adequacy of earthwork and structural foundation design features. Recently, the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Bridges and Structures developed a comprehensive Load Resistance Design Factor (LRFD) specification to replace its traditional, allowable-stress design specification. In the LRFD method, factors are applied to both the load and resistance sides of the design model, based on the designer's degree of confidence in the design protocol and parameters. The new LRFD specification contains comprehensive design and construction guidance on both structural and geotechnical features. Initial work on early projects using LRFD for geotechnical features has shown that the approach used in LRFD for structures is not fully compatible with geotechnical design needs, thereby impeding a smooth national transition.

LRFD methods for geotechnical features, in the form of limit-state design, have also been adopted in Canada and Europe, and team members had the impression that applications in those countries are in an advanced stage. The Ontario Ministry of Transportation (MTO) has been a leader in developing LRFD for bridge design; all bridge design in Ontario has been based on LRFD for several years. As a result of this development, a national bridge design code has been prepared and implemented by most Canadian provinces. In Europe, a new "Eurocode" based on the limit-state design approach (i.e., LRFD) has recently been introduced and will eventually form the basis for geotechnical practice throughout the European Union (EU). The experiences, opinions, and technical details associated with developing and implementing LRFD protocol in other countries is of great interest and benefit to geotechnical and structural engineers, who are responsible for implementing new technologies in the United States.

Also affecting the geotechnical engineering community are innovative contracting methods, such as design-build, value engineering, performance-based specifications, or alternative bids, which alter the traditional methods of subsurface exploration and geotechnical design. Traditional U.S. contracting practice for transportation projects has used a two-step process that clearly separated design from construction responsibility. The new methods combine these responsibilities with the objective of shared risk between the owner and the contractor (e.g., FHWA Special Experimental Project, No. 14). Unfortunately, individual experience with user satisfaction has been mixed. Based on a review of the 1993 FHWA Contract Administration Techniques for Quality Enhancement Study Tour (CATQEST), it is apparent that Canada and some European countries have also had experience with alternative contracting methods. Much could be gained from evaluating the successes and failures associated with implementing innovative contracting methods for geotechnical features, such as retaining structures, shallow and deep foundations, and soil and rock slopes.

PURPOSE

The primary objectives of the study tour were to review and document developments in methods of load and resistance factor design and alternative contracting in Europe and Canada, as related to geotechnical engineering features. More specifically, the team wanted to obtain information on the history of use, development, implementation, and performance. The tour also provided an opportunity to explore other new or improved geotechnical products or practices in developing areas such as ground improvement methods, MSE retaining walls, and in situ testing of geotechnical materials. The team's goal was to seek information on performance measures, best practices for implementation of innovative procedures and practices, and educational and training methods that assist in implementing the technology.

METHODOLOGY OF STUDY

The study tour provided an opportunity for face-to-face-meetings with key individuals who are recognized experts on the application of limit-state design and/or innovative contracting in countries where those technologies have been implemented.

The geotechnical panel included eight geotechnical and structural engineers, who are considered leaders with regard to development and/or implementation of new technologies. The team included representation from the FHWA, State transportation agencies, AASHTO, and the GeoCouncil (private industry). The team members, their representation on the panel, and their affiliations are shown in table 1. The team originally met in fall 1997, to compile a list of basic questions on each of the topics of interest; these are in appendix A. The questions were sent to each of the countries prior to the visits.

Table 1. Geotechnical engineering study tour team members.

Name	Representation	Organization
Jerry A. DiMaggio	Team Co-leader FHWA, Geotechnical Engineer	FHWA, Washington, DC
Tom Saad	Team Co-leader FHWA, Structural Engineer	FHWA, Indianapolis, IN
Tony Allen	State Geotechnical Engineer	Washington State DOT
Barry R. Christopher	Report Facilitator	Consulting Engineer
Al DiMillio	FHWA Research	FHWA, Washington, DC
George Goble	GeoCouncil (Industry Representative)	Goble, Rausche, Likins, & Associates
Paul Passe	State Geotechnical Engineer	Florida DOT
Garry Person	State Foundation Engineer	Minnesota DOT
Terry Shike	State Bridge Engineer AASHTO	Oregon DOT

Countries were selected by the panel based on their experience with implementing the technologies of interest and level of participation in the development of Eurocode. The panel met with technical leaders in Canada, Denmark, Germany, and France. The sessions in Denmark included representatives from Sweden and Norway. The principal representatives from each country and their affiliations are shown in table 2. A complete list of the names of all contacts, their addresses, and phone/fax numbers are included in appendix B.

Table 2. Host representatives.

Country	Principal Representative	Affiliation
Canada	Dr. David Dundas	Ministry of Transportation of Ontario
Denmark	Dr. Niels Krebs Ovesen	Danish Geotechnical Institute
Germany	Dr. Bernd Thamm	German Federal Highway Research Institute (BASt)
France	Dr. Roger Frank	Teaching and Research Center in Soil Mechanics (ENPC-CERMES)

The hosts extended a generous hospitality and consideration in response to the questions provided. In most countries, hosting agencies prepared an agenda of expert presentations, based on the questions that had been forwarded to them in advance. The panel shared information with international counterparts on U.S. policy initiatives and research activities to promote innovative geotechnical engineering worldwide. The U.S. group was, on several occasions, also asked to make presentations about U.S. practices. Most sessions were roundtable discussion (figure 1), but several site visits were arranged in response to the questions about new and innovative geotechnical practices.

Figure 1. Many sessions were roundtable discussions.

PREVIEW OF REPORT

The primary focuses of the tour were on LRFD and innovative contracting methods. Accordingly, the report includes more detail on these subjects than on the secondary goal of evaluating and exploring new or improved geotechnical products or practices. Following a summary of each country, the last two sections of the report present the major findings of the team, its conclusions, and recommendations for implementation.

Significant supporting literature was provided by each host country, and a bibliography is included at the end of the report.

CHAPTER 2

COUNTRY SUMMARY: CANADA

The first scanning sessions took place in Toronto, Ontario, March 2 and 3, 1998. The review involved formal meetings with and presentations by engineering and managerial transportation officials from the MTO; an engineer from Public Works and Government Services Canada; representatives from the private sector, consulting, and materials supply; and distinguished academics from several universities. The practices reviewed were mainly those in the Province of Ontario and may not apply to other parts of Canada.

LRFD

History of Use and Development

The MTO applied the AASHTO Bridge Code during Canada's major highway expansion in the 1950s and 1960s. That practice continued until the preparation of the first limit-states bridge design code in 1979. The first edition was not, however, used extensively, and the load and resistance factors were not calibrated. Reinforced concrete buildings had been designed by LRFD using the American Concrete Institute (ACI) Code, after its adoption in 1963, and the Canadian steel-design code converted to plastic design in 1969. When the load factor design (LFD) Bridge Code was adopted by AASHTO in 1973, it was not used widely in Canada.

In 1983, the second edition of the limit state design (LSD, as LRFD is known in Canada) code was adopted in Ontario, and its use became mandatory. This code was developed based on a safety index of 3.5 for superstructure elements. The results of its usage in the geotechnical area were not encouraging because foundation elements generally became larger. The third edition of the code was adopted in 1991, and its use indicates that the designs seem to be more reasonable, but often more conservative, than the previous AASHTO-based designs using allowable strength design (ASD). In the opinion of the Ontario representatives, the limit-state designs are better balanced and are designed to higher standards. One advantage of LSD comes from the emphasis on limit states, which causes more care to be given to important aspects of the design, in addition to strength, and that may produce designs less subject to serviceability problems. The third edition also contained an expanded commentary.

A calibration of the code with respect to ASD had been conducted for the third edition, but it seems that only a few example design checks were performed. It has become standard practice for bridge engineers to perform extensive superstructure designs to compare them before and after any code change. Very little of this type of work was done on the geotechnical part of the Ontario Bridge Code.

The MTO representatives believe that the most serious problems arose with the second edition because:

- There was inadequate communication between the structural and geotechnical engineers. Basically, geotechnical engineers were not involved in the development of the code.

- The designers did not sufficiently understand the service limit states.
- There was conflicting understanding on how to manage partial safety factor loads for geotechnical features.
- Inclination factors were much too conservative to be usable.
- The code did not recognize and follow the design process for driven piles, which caused problems for foundation engineers.
- Foundations based on LSD became larger.

The fourth edition of the Ontario Code was adopted in 1997, and is also the first edition of the national-level Canadian Highway Bridge Design Code. In this version, the load factors have changed and the term "partial factors" was eliminated because it had become apparent that the term was not clearly defined. In Canada, partial factors, now called "resistance factors," refer to the use of multiplicative factors on the resistance side of the basic design expression. Eccentricity limits were set for the resultant force on retaining-wall footings. Preliminary results indicate that changes in design limits have improved both the pile design and the commentary. More extensive training programs are planned, and design software is already available. Presumptive lateral pile capacities have been adopted, and the code also contains a seismic provision.

Implementation

The foundation design process for bridges within the MTO is:

1. Loads are furnished to the geotechnical engineer by the structural engineer.
2. The geotechnical engineer performs the analysis from soil samples, determines soil properties, and makes recommendations to the structural engineer for the ultimate soil-bearing capacity for spread footings or ultimate pile and drilled-shaft capacities for deep foundations.
3. The geotechnical engineer sends recommendations to the structural engineer, who reviews the report and asks questions to verify understanding. It is the responsibility of the structural engineer to make contact.
4. The structural engineer uses recommended criteria to design the substructure and the superstructure. The structural engineer talks with the geotechnical engineer to verify interpretation of criteria and practicality of designs.
5. The geotechnical engineer reviews the final plans/specifications sent by the structural engineer and talks with the structural engineer about comments, as appropriate.
6. Similar communication occurs during the construction phase.

Design manuals have not been prepared to amplify the content and assist in implementation of the Ontario Highway and Bridge Design Code. The 1983, 1991, and 1998 Ontario Highway and Bridge Design Codes are mandatory. LRFD is used for bridge design in all Canadian provinces, except British Columbia. It is not used outside the bridge design area; however, outside of the use for bridges and beyond the jurisdiction of the Ontario Code, there has been little use of LRFD in Canada. The team understood that few geotechnical engineers are actually practicing the use of LSD; most still use working stress because earlier limit state designs were more conservative than working stress designs.

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Canadian engineers familiar with Eurocode described it as a "factored-strength approach," as compared to describing the North American code as a "factored-resistance approach" (Becker, 1998). The North American approach is preferred because it accounts for the method of calculation and uses "real" (i.e., unfactored c and N) numbers in the analysis model rather than reduced numbers.

When the third edition of the Ontario Bridge Code was adopted, a 3-day educational seminar on limit-states design was held by the MTO. The seminar covered all aspects of the design of both superstructure and substructure to train MTO personnel, local engineers, and consultants on a volunteer basis. The program utilized a lecture format, but feedback from the course reviews indicated that a hands-on workshop would have been more effective. The MTO does not have an ongoing education, training, or marketing program to improve the implementation of LSD. However, the local professional societies, the Toronto section of the Canadian Society for Civil Engineering and the Southern Ontario Section of the Canadian Geotechnical Society have been active, holding a 1-day symposium on LSD earlier in 1998 (Limit State Design, 1998). The *Canadian Geotechnical Journal* has also published articles on limit-state design guidelines in relation to the design code (Becker, 1996a and b).

Performance

It has been difficult to evaluate the benefits of the implementation of LSD in terms of cost-efficient design. LSD was implemented during a period when design loads were increasing in Canada; therefore, the conservative results that were achieved from implementing LSD cannot be attributed strictly to the design methodology. One significant benefit identified is that the design process is more logical and consistent when LSD is applied to both structural and geotechnical elements.

The Canadian group identified several problems with respect to LRFD, including:

- Lack of understanding of the code.
- Lack of communication between structural and geotechnical engineers.
- Greater focus than necessary on statistical derivation of resistance factors.
- Lack of understanding of the failure methods.

Regarding foundation designs, LRFD appears to be more conservative; however, this cannot be attributed entirely to the design methodology because design loads have increased. The Canadians agreed that the key to success with LRFD is to educate the geotechnical engineers to ensure everyone understands the process being used.

INNOVATIVE CONTRACTING AND PERFORMANCE-BASED SPECIFICATIONS

History and Development

The MTO is in the process of streamlining its organizational structure. For a 3-year period, the MTO is under an edict to reduce staff by approximately two-thirds. Because of the significant reduction in force, the MTO has had to define and implement innovative contracting procedures to accomplish the same amount of work that it performed in the past. To date, most of the innovative contracting procedures have been implemented with the recognition that lessons will be learned and modifications to the processes will be made upon project evaluation.

In project development, the MTO has instituted a Total Project Management (TPM) approach that requires the consultant to perform all scoping services, in addition to project design. Such services include subsurface investigations, the establishment and purchase of land acquisition, and utility relocation needs. Under this approach, the standard contracting selection process for consultants is based on the best bid of registered consultants—that is, cost, qualifications, and additional evaluation criteria are used in the selection process. The first step is to prequalify consultants. A performance index assigned for each contract is based on the attributes of quality (60 percent), safety (15 percent), timeliness (15 percent), and contract execution (10 percent), as outlined in *Contractor Rating*, 1997 (MTO, 1997). Value engineering proposals are then reviewed, and the final selection is based on cost and quality.

The MTO qualifies engineering consultants and subconsultants and maintains a registry. Under the TPM process, points are assessed to consultants based on technical competence and cost. There are no qualification requirements, similar to the Brooks Act, for selection of engineering services.

For design-build projects, an adjusted best-bid award process is commonly used, and eight design-build projects have been awarded by the MTO. Bidders are prequalified, and, typically, three to five are selected to submit proposals. Unlike the prime contractor, subcontractors are not prequalified, but they are typically registered with the MTO and must be selected by the prime contractor prior to award. The MTO must approve changes if the prime elects to change subcontractors after award. This restricted bid practice was established as a result of a process evaluation of past performance of design-build projects. Awards are based primarily on low bid; however, in several cases, final selections have included quality criteria. In Ontario, no current legislation limits or directs the use of innovative contracting. On one design-build project, Highway 407, a Toronto bypass, a “buy Ontario” provision was required for 30 percent of the work.

Partnering and team concepts, like those used in the United States, have not been incorporated in the contracting process. For design-build projects, only preliminary design (approximately 20 percent), including baseline geotechnical information, utilities, and land acquisition information, is completed by the owner; but this information is provided to the contractor “for information only.” The baseline geotechnical information is developed by a consultant retained by the MTO, and contractors are required to submit the design codes and standards to be used as part of the bid package. On the initial design-build projects, the MTO attempted to place as much risk as practical on the contractor.

The eight design-build projects that have been constructed in Ontario vary in size from a small bridge design to intersection modifications to a complete design and construction of Highway 407. Significant problems were experienced when design-build contracting was implemented on small-scale projects. Twelve contractors submitted proposals for a routine bridge construction project in northern Ontario, and the contracting industry was outspoken in its criticism of the use of design-build contracting for this project because eleven contractors received no compensation for the development of their proposals. Even so, the use of design-build contracting for the construction of Highway 407 was a success. Project bidders were prequalified and preselected, minimizing the number of proposals submitted. Stipends of CA$1.5 million (~US$1.125 million) were paid to each of the prequalified bidders for development of final proposals. Value engineering alternatives included in the proposals were evaluated, and final selection was based on a score comprising cost and quality criteria.

As mentioned earlier, to date, the MTO's rule for design-build projects is to place all responsibility on the contractor. From the contractors' perspective, the MTO does not accept any risk, but it will pay for this in the long run. Contractors believe that the MTO needs to develop a clearer scope of work and share some risk, particularly risks associated with varying subsurface conditions. The MTO does develop 20 to 30 percent of a design-build project to ensure that right-of-way, utilities, and land acquisition are established. The exception was on Highway 407, where the developer was responsible for, and paid for, utility modifications.

Based on its limited experience and success on larger projects, the MTO intends to do more design-build projects in the future, while continuing to evaluate its implementation processes. MTO representatives recognize that there are many issues that need to be addressed further, including preliminary development of plans, quality control, and performance requirements for job completion. Also, they recognize the need to comprehensively prequalify prime contractors and to limit the number of contractors submitting proposals on all projects.

In relation to performance requirements, performance-based specifications have not been developed and are not typically used. The MTO continues to experiment with performance-based specifications for pavements and bridge construction materials; however, most of the specifications are method based. The MTO confirmed its need to shift toward more performance specifications, especially for design-build projects.

To date, there have been no contractor claims on design-build projects. The Province of Ontario has paid for some changed conditions on the design-build projects in which it has participated. Initial efforts, however, have been to move most of the responsibility to the contractor.

Warranties have been required in some specifications for particular project items. For example, on Highway 407, a general 2-year warranty was required on bridges, and a 1-year warranty was required on the reinforced-concrete pavement. Contractors have, however, found it difficult to provide insurance for warranties exceeding 2 years. Performance bonds have also been required, usually to the extent of 20 percent of the total contract award.

The MTO does not currently have sufficient experience to determine the success of the established performance measurements. In most cases, sufficient time has not elapsed to monitor the performance requirements. Thus far, the evaluation of success with design-build is based on short-term cost savings; for example, significant time savings were realized in the construction of Highway 407.

Implementation

For engineering requirements, design-build contracts usually reference current limit-state design codes and Ontario standard specifications in the contract. Ontario's "terms of reference" are not usually included. (The terms of reference would provide more specific criteria for depth and spacing of borings for final design and required testing.) A preliminary, baseline geotechnical report for the project is usually provided to give the contractor enough subsurface data to bid the job, but not enough to design it. While MTO expects contractors to design in accordance with its terms of reference, the terms of reference are not part of the contract. The MTO does this in an attempt to make contractors, not the MTO, responsible for the design. Naturally, contractors would prefer to have comprehensive subsurface investigations completed by the MTO.

For design-build projects, contractors may perform a preliminary subsurface exploration if supplemental baseline data is required to properly bid the project. Currently, however, this is not a requirement. Incorporation of minimum design requirements for contractors' geotechnical services is being considered for future design-build projects. Additional subsurface exploration, after the bid, is usually expected, but it is not specifically articulated in the contract (as noted above), other than in general terms, through national codes. Nothing prevents contractors from using the baseline report data for final design, although doing so will not be desirable from the owner's (MTO) standpoint. It should be noted that minimum design requirements for the contractors' geotechnical services are being considered for upcoming design-build projects.

For conventional construction contracts where a design consultant is retained, the "terms of reference" are provided and must be followed, in addition to national design codes. Terms of reference may include detailed minimum requirements for depth and spacing of borings for the various types of structures and minimum geotechnical testing requirements. Justification to do less must be submitted by the consultant and approved by the MTO. The opinion of team members is that the terms of reference do not allow a lot of room to adjust for local site conditions, and the lack of flexibility can be a problem. At the national level, for consultant contracts, there is more negotiating of the exploration, testing, and design steps (similar to U.S. approval), and the process is generally more flexible.

Changed-condition claims are usually denied for design-build projects, unless they are quite obvious and result in severe impacts. The MTO expects the contractor to handle "routine" differences in site conditions as a consequence of a more complete investigation by the contractor. That is, the baseline geotechnical report provided by the MTO, prior to bid, gives general site conditions, and the contractor should expect some variations from the general characterization of the site.

In the implementation of design-build contracts, the MTO has had some interactive sessions with industry, consultants, and contractors to refine the process and to improve communication. It has also had several seminars for MTO staff. In 1996, the Canadian Geotechnical Society also held a symposium on “Contractual Issues in Geotechnical Engineering” (CGS).

For controlling the quality of the final product on design-build projects, the contractor develops a quality control plan, within guidelines set by the owner (MTO), as part of the bid package. The requirements are outlined in “Core Quality Control Plan Requirements for Qualification,” issued by the MTO in January 1998. The QC/QA plan includes identification and certification of consultants and labs doing QC/QA work and verification testing of geotechnical materials for contractors. This includes certifying the quality of the products, designs, and construction, which are submitted to the owner. Problems with this approach have been noted, such as contractors submitting certifications before work is completed. That particular problem has been addressed by clarifying milestones for ceritification in specifications.

For testing-lab certification, the MTO is considering using an ISO 9000 verification and/or an AASHTO verification process. In the past, an in-house certification process has been used to approve labs. For wet concrete, ACI certification is used.

The MTO generally has a “hands-off” approach to QC/QA regarding intermediate products such as the design. It reviews designs at intervals to ensure that deliverables meet the scope of work and contract intent (detailed design checks are not conducted by owner) and that appropriate standards are used. Most of the quality checking is by an independent consultant to the owner. Performance reviews are conducted after construction, which affects contractors’ ability to get future work. Poor performance reviews can result in limitation of future projects, in terms of maximum project size. Following two or three consecutive bad reviews, a contractor could be barred from work for 2 years. Geotechnical design consultant services are evaluated in a similar manner.

The MTO is considering doing an “after-the-fact” assessment of the contractors’/consultants’ design quality, which will factor into the consultants’ performance rating; i.e., whether design was over- or underconservative, well or poorly prepared.

Performance

The main obstacle that the MTO has experienced in trying to adopt design-build contracting has been opposition from trade unions. Contractors are happy because they get work that was previously performed by the MTO. Large contractors are satisfied because they get more work and have more control. The public has not voiced any opposition, mainly because the work is getting done.

There has been a learning phase for contractors, considering that the MTO is no longer checking everything. Contractors are totally responsible, and judging value with the “hands-off” mode has generated problems. From the contractors’ perspective, proposals are quite expensive. There may be a problem with the finished project meeting the owner’s expectations. Subcontractors have to spend a lot of time developing proposals with little chance of being involved in the final project.

From the MTO’s perspective, design-build projects have worked well on projects of CA$10 million or more (~US$7.5 million). Smaller jobs do not allow much opportunity for innovation and have not been effective, other than with shoring and temporary works. Design-build provides a good means to explore structural alternatives. As an example of cost savings, Highway 407 will be completed 20 years earlier, at a significant estimated savings. Approximately CA$300 million was saved (~US$225 million), based on a total cost of CA$928 million (~US$696 million). The cost savings are, however, not entirely attributable to the design-build contracting process; but they result in part from changes in the basic design, such as number of lanes and interchange plans.

GEOTECHNICAL PRACTICE

The Canadian presentations focused on geosynthetics, with three presentations on reinforcement applications and one on wick drains. With regard to geosynthetics in reinforcement applications, Professor Richard Bathurst gave a presentation on the ongoing research at the Royal Canadian Military College (RMC) in Kingston, Ontario (Bathurst, 1998). RMC built a 3m×4m×6m model box to test and monitor geosynthetic, reinforced-soil walls that are heavily instrumented. Air bags are used to surcharge the system for loading, and the structures are fully instrumented. Strain measurements are made on the geosynthetics using strain gauges and extensometers. Following loading the failure, the wall was carefully exhumed and the collapse mechanism evaluated. RMC is currently engaged in cooperative research with the FHWA and Washington State DOT.

Dr. Bathurst has also developed a connection-strength test method and has tested most kinds of connection methods. The Canadians appear to be ahead of the United States in this effort. Shear strength between segmental concrete units has also been tested at RMC, and a shake table was used to test wall facings in earthquake conditions. RMC also has a large, pullout testing box (1.5m×1m×2m) and has developed a "controlled-yielding" method for soil-retaining walls that uses compressible geofoam inclusions.

Two good case histories of geogrid reinforcement applications were presented in papers on each project (Kerr, et al., 1998, and Devata, 1985). Some of the geogrids were exhumed soon after construction and others excavated after many years to evaluate durability and installation damage. State-of-the-art specifications have been developed on building these types of projects. It has been confirmed that the highest stress concentrations are at the one-third point, rather than at the toe of the structure.

Dr. Jonathan Fannin, from the University of British Columbia, presented current results of a test wall/slope constructed more than 10 years ago, in cooperation with the Norwegian Geotechnical Institute (Fannin and Herman, 1992). The reinforcement spacing and length were varied over the height, and the reinforcements were very carefully instrumented, along with the soil. In this manner, the researchers were able to compare the creep in the reinforcement with stress levels in the soil and recommend design practices to be incorporated in the Canadian Foundation Engineering Manual (1995). Recent test findings of the FHWA's geosynthetic creep research of 1996 and 1997 (Elias, et al., 1998) confirmed the Canadian findings on force and strain in the geosynthetic reinforcing elements. Although in-soil creep tests were not performed, the unconfined, in-air test results on the geosynthetics tended to match the predicted values from the field walls reasonably well for the limited number of tests that have been conducted. Work is also ongoing at the University of British Columbia on seismic testing to determine dynamic failure potential (Raju and Fannin, 1997).

The “wick” drain presentation was on the development of an accurate analytical mode to predict pore pressures from initial stage to maximum. Good case history data was presented, but, unfortunately, written test protocols were not available.

Canada has a long-standing tradition of design practice using in situ testing that dates from the early research of Campanella and Robertson in the 1980s. No specific presentations were made on recent innovations such as resistivity, cone penetrometer, and the pressuremeter.

CHAPTER 3

COUNTRY SUMMARY: DENMARK

The second visit of the study tour was to Copenhagen, Denmark, on March 5 and 6, 1998, and meetings were held at the Danish Geotechnical Institute. The review consisted of a seminar on the history, development, and current status of Eurocode 7. The seminar was followed by a discussion with Dr. Niels Krebs Ovesen, Managing Director of the Danish Geotechnical Institute and current chief of the Eurocode 7 committee; Dr. Ulf Bergdahl, from the Swedish Geotechnical Institute; and Dr. Fritz Nowacki, of the Norwegian Geotechnical Institute. An excellent set of notes was provided (Ovesen, 1998). The group also attended an international seminar held by the Danish Geotechnical Society that included short presentations by Danish, Swedish, and Norwegian geotechnical engineers. Several presentations were also given by team members. A formal meeting was held with representatives of government agencies and private contractors to discuss innovative contracting methods. In addition, the team made a field visit to the tunnel element-casting factory for the Øresund Link Project, shown in figures 2, 3, and 4. The tunnel

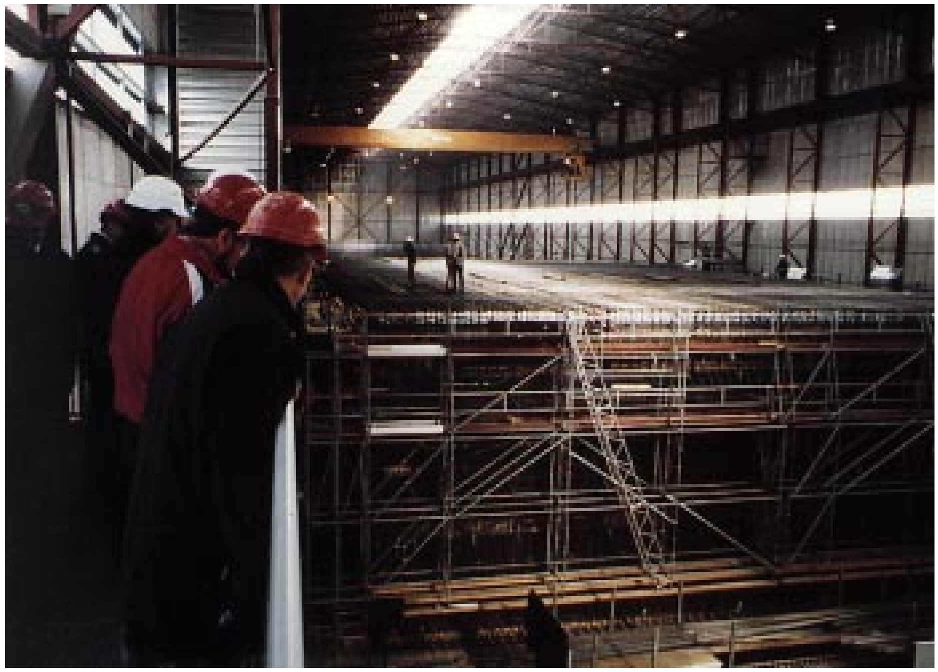

Figure 2. Inside the casting facility at the Øresund Link Project.

Figure 3. Tunnel element being pushed out of the casting area.

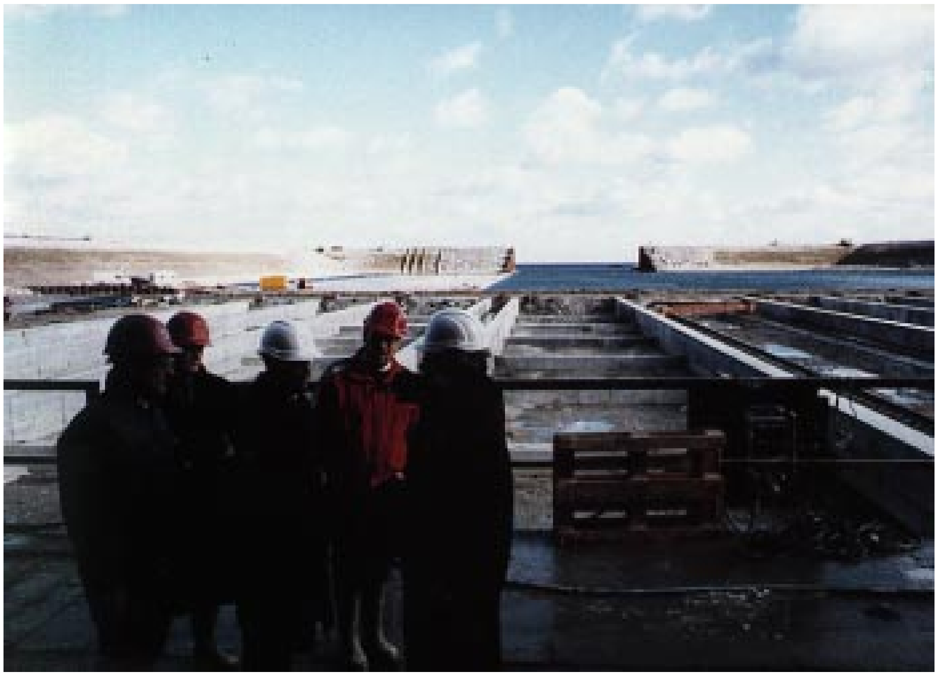

Figure 4. Staging area for floating tunnel elements and towing out to position.

will link Denmark to Sweden and is an example of Eurocode 7 procedures and design-build contracting in practice.

LRFD

History of Use and Development

The Eurocode system was developed to harmonize the design of civil engineering works (i.e., buildings, bridges, sign supports, and towers) among the EU countries. Thus, it applies to and, upon completion, will be mandatory for all EU countries—now numbering 15—and 4 non-EU countries. More are expected to join from the Eastern bloc.

The general features of the Eurocodes are:

- "Technical rules" are harmonized across materials.
- They are design codes.
- They have a limit-states format.
- They use partial safety factors.

As written, Eurocode features:

- Principal requirements that must be followed are paragraphs marked with a "P."
- Application rules indicate optional ways to satisfy the principal requirements.
- Partial factors, placed in brackets [ ], may be set by EU-member governments, because building safety is a government responsibility.

The Eurocodes for Civil Engineering Works are numbered as follows:

- Eurocode 0: Basis for Design.
- Eurocode 1: Actions.
- Eurocodes 2–6 and 9: Structural Design (concrete, steel, etc.).
- Eurocode 7: Geotechnical Design.
- Eurocode 8: Earthquake Design.

Part 1 of Eurocode 7, which deals with the common rules for geotechnical design, includes nine sections:

- General.
- Basis of geotechnical design.
- Geotechnical data.
- Supervision of construction.
- Fill.
- Spread footings.
- Piles.
- Retaining structures.
- Embankments.

Parts 2 and 3 of Eurocode 7 deal with geotechnical design, assisted by laboratory and field testing, respectively.

Development of Eurocode 7 began in 1981, and, in 1995, it was adopted as a prestandard. It consists of 113 pages of text, but it is not specific about calculation procedures. Of course, political considerations are very important and often influence the code's development.

Eurocode contains both ultimate- and serviceability-limit states, and it uses partial factors. Dr. Ovesen explained that the term "partial factor" refers to the division of the "safety factor" into partial factors on the load side and partial factors on the resistance side. The partial factors, γ, on the resistance side are applied to the basic soil parameters (e.g., ϕ and c). Thus, the resistance side is calculated by using the design soil parameters ϕ_d and c_d:

$$\tan \phi_d = \frac{\tan \phi_c}{\gamma_\phi} \; ; \; c_d = \frac{c_c}{\gamma_c} \tag{1}$$

where ϕ_c and c_c are the so-called characteristic values of the soil parameters.

The load side is expressed as:

$$G_d = \gamma_g G_c \; ; \; Q_d = \gamma_q Q_c \tag{2}$$

$$E_d = \gamma_g G_c + \gamma_q Q_{c1} + \sum \gamma_q \Psi Q_{cn} \tag{3}$$

where G refers to dead loads, Q refers to live loads, and E is the total load. Ψ is a factor aimed at taking into account that normally only one live load (Q_1) acts with its full value, while, at the same time, the other live loads ($\sum Q_n$) act with somewhat reduced values. R values are given in Eurocode 1 and are of the magnitude 0.5.

The difference between the European and North American approach, as viewed by Dr. Ovesen, is:

$$R_d \geq E_d \quad European\ format \tag{4}$$

$$\phi R_c \geq E_d \quad North\ American\ format \tag{5}$$

where R_d is the factored resistance (from equation 4), E_d is the factored load (see equation 3), and ϕ is a factor applied to the resultant of the unfactored resistance values, R_c.

The term "actions," which includes loads as well as effects other than loads (e.g., temperature or shrinkage), has been used in Denmark and, later, in the rest of Europe, instead of the term "load." The design evaluation process has four basic components: loads, material parameters, calculation models, and safety elements.

As defined in Eurocode 7, the characteristic value of a soil or rock parameter is selected as a cautious estimate of the material property affecting occurrence of the limit state. Later in the Code, it is stated that this value often corresponds to a cautious estimate of the mean value over a certain surface or volume of the ground. To obtain characteristic ground properties, "statistical methods may be employed," but, then, "include a priori knowledge" of the properties. When using statistical methods, the characteristic value should be derived such that the calculated probability of a worse value governing the occurrence of a limit state is not greater than 5 percent. (Reference to a "calculated probability" of property value appears to have caused some differences among European countries in the interpretation of characteristic soil value.) The group went through an exercise in selection of the characteristic soil properties to point out that a cautious estimate would be on the order of the 5 percent fractile for the mean value (Ovesen, 1998).

The partial factors currently given in Eurocode 7 are shown in table 3 (CEN, 1994). Eurocode 7 requires that the design be verified separately, as relevant, for each of the three cases, A, B, and C, shown in the table. The most conservative result should then be used.

Table 3. Proposed partial factors in Eurocode 7 ultimate limit states in persistent and transient situations.

Case Types	Actions			Ground Properties			
	Permanent		Variable	$\tan \phi$	c'	c_u	q_u *
	Unfavorable	Favorable	Unfavorable				
Case A	[1.00]	[0.95]	[1.50]	[1.1]	[1.3]	[1.2]	[1.2]
Case B	[1.35]	[1.00]	[1.50]	[1.0]	[1.0]	[1.0]	[1.0]
Case C	[1.00]	[1.00]	[1.30]	[1.25]	[1.6]	[1.4]	[1.4]

*Compressive strength of soil or rock.

Case A is related mainly to the stability of structures, where strength of ground and structural materials are of minor importance (e.g., buoyancy problems). Case B is the standard case for structural design in accordance with Eurocodes 2–6. Case B is also relevant to the design of the strength of structural elements involved in foundations or retaining structures. Case C originates from geotechnical design and was developed to accommodate designs where the weight of large soil volumes are involved. Case C is most relevant to instances such as slope-stability problems, where there is no strength of structural element involved. Case C is also often relevant to the sizing of structural elements involved in foundations or retaining structures.

Case C was developed to accommodate geotechnical features not addressed previously by the structural Eurocodes. The basic problem in applying the structural factors to geotechnical features was in relation to dead loads, due to gravity. Under the structures code, a relatively high factor of 1.35 would be applied to the unit weight of soil and to the unit weight of water, which is physically unreasonable. Many in the European geotechnical community feel that the structures codes (Case C) should be changed to allow lower factors for gravity loads, particularly water loads. In Denmark and Norway, in particular, it is believed that this load factor should equal to 1.0.

In its initial stages, the Eurocodes allow for modification of factors to accommodate differences in national building traditions and regulations. As previously indicated, numbers that can be modified are shown in brackets [] in the Eurocodes, as shown in table 3.

Most of the calibration for Eurocode 7 was conducted on a national basis by comparing designs to previous practice. There has also been some probabilistic analysis.

The same basic geotechnical code is used for buildings as for bridges. There is no limit on the location of the resultant of the load (eccentricity) for retaining walls or spread footings. A rectangular stress distribution is used for the resisting force under a retaining wall or a spread footing, and the magnitude of the stress is all that must be limited.

According to Dr. Ovesen, the future plans for Eurocode 7 should be to keep it simple and user-friendly. (Several members of the U.S. team did not find the current version to be user-friendly.) It should also be flexible; that is, it should be qualitative and allow the designer freedom to choose the design methodology. One of Eurocode's strengths is that it provides a design language that is common among the member countries. Eurocode 7 should be allowed to differ somewhat from other Eurocodes because geotechnical engineering is a relatively new discipline that is highly dependent on local geology.

One of Eurocode's strengths is that it provides a design language that is common among the member countries. Eurocode 7 should be allowed to differ somewhat from other Eurocodes because geotechnical engineering is a relatively new discipline that is highly dependent on local geology.

The schedule for completion of Eurocode 7 is as follows:

1994-1997	Part 1, prestandard.
1997-2000	Revision, Parts 2 and 3 available—termed European Norms Proposal (ENV).
2000-?	European Norms (ENs) adopted, but coexisting with national codes.
?	ENs only, replacing national codes.

The partial factors in Eurocode 7 are meant to account for both variability in the soil properties and the design model used. The Eurocode writers believe, however, that the variability caused by the soil properties is the main variability and that design model variability is not as important. This is why the writers do not have different factors for different design models (methods). But the model variability does make the partial factors bigger than would be the case if they only accounted for soil property variability. Regarding the application of uncertainty factors directly to the soil properties (N and c), the Eurocode writers feel that doing so helps to address applying partial factors to soil-structure interaction problems and slope stability. That is, the partial factor is automatically distributed properly to all of the forces in the slope, for example, reducing concern about what is a stabilizing force and what is a driving force for application of partial factors. In Sweden, the national code does have a separate design model factor that is applied to the resultant design, separate from the property and load factors, to account for model bias and uncertainty.

Implementation

Eurocode 7 provides general design principles and application rules but does not prescribe specific design methods. Principles are identified by a "P" in front of the paragraph, and alternatives are not permitted. Application rules are general and alternatives are permitted. The overall limit-state design process is presented in Eurocode 1 and requires the geotechnical and structural engineers to communicate. Danish representatives agreed that communication is critical, but difficult to achieve. Neither Denmark nor Sweden had a written document that defines specific design processes.

Both Denmark and Sweden have separate national codes of practice for limit-state design that are legally binding in both countries. These are "Code of Practice for Foundation Engineering," Danish Geotechnical Institute, 1985, and "Design Regulations of Swedish Board of Housing, Building and Planning," Swedish Board of Housing, Building and Planning, 1997.

Denmark has a tradition of geotechnical design, according to Limit States and Partial Factors, going back to the early 1950s. The late Professor Brinch Hansen introduced partial factors in geotechnical practice at the Technical University. From there, the use spread, first to concrete masonry and timber design and later to steel design. In 1983, all Danish codes for loads and for structural and geotechnical design were rewritten into one, harmonized limit-state format with partial factors. For this reason, Danish engineers will have little difficulty adapting to the Eurocodes. The following numerical values of the partial factors for structural and geotechnical design have been used in Denmark since 1983. The factors given have remained virtually unchanged for geotechnical design in Denmark for more than 40 years.

Gravity of structure and soil	1.0
Variable loads	1.3
Concrete (strength)	1.8
Reinforcement steel (strength)	1.4
Structural steel (yield)	1.28
Structural steel (rupture)	1.56

Soil friction	1.2
Soil cohesion (footings)	1.8
Soil cohesion (stability and earth pressures)	1.4
Pile capacity, without load tests	2.0
Pile capacity, with load tests	1.6

Sweden adopted the partial factor approach in 1989 and prepared a manual on how design should be performed. Resistance factors for the structural limit state (piles) are contained in the concrete and steel codes. Some calibration was made with respect to ASD (Bengtsson, Bergdahl, and Ottosson, 1993).

To enable implementation of limit-state design, Sweden organized a training program based on the written design guidelines previously mentioned. Two-day courses were presented throughout the country, and answers to questions arising from the courses were incorporated into the guidelines' text. The texts are now used by practitioners and at universities. No information was received about the cost of implementing limit-state design (or LRFD) methods in Sweden.

In addition to work on the Eurocodes, the European Standard Organization (CEN), has ongoing work on geotechnical execution standards. These standards will not be called "Eurocodes" and will not contain design aspects. The work on execution codes began around 1993, and standards are being prepared for the following items:

- Diaphragm walls.
- Ground anchors.
- Bored piles.
- Sheet piles
- Grouting.
- Jet grouting.
- Downdrag—use the upper limit of the shear resistance.

Performance

The primary advantage of using limit-state design, as outlined in Eurocode 1, was described as the harmonization of design across materials or systems. As previously indicated, the major problem in implementation has been getting structural and geotechnical engineers to communicate with each other during design. Sweden has not seen much difference in foundation designs, and such differences were not anticipated because the factors were adjusted to give the same results. For both Denmark and Sweden, LRFD has been found to be a more logical design that follows through with the same principles for the entire structural and geotechnical system.

The Danes and Swedes advise countries that are just beginning to use LRFD for geotechnical features to keep the code simple and user-friendly—keep the code and process flexible, thereby, providing a common dialog language.

IINNOVATIVE CONTRACTING AND PERFORMANCE-BASED SPECIFICATIONS

History and Development

Denmark has experience with design-build contracting. The most recent and advanced experience has been gained on the Øresund Link Project, which has been undertaken by the federal government. A second project for a new Copenhagen metro is in the initial construction stage and is a joint venture among state and local governments and industry. Øresund Link is a 16.2-km series of tunnels and bridges for both road and railway traffic constructed to connect Denmark and Sweden at a cost of DKr22 billion (US$3.2 billion). Several Internet sites have been constructed around this project, search on “Øresund Link.”

A prequalified, low-bid award process was used, and EU laws prevailed on this international project. The EU established procedures for awarding public contracts, under Council Directive 92/50/EEC, 1992. Any contractor, including a new cadre of former Eastern bloc contractors, could develop a proposal; however, final proposers were prequalified and preselected. The final selection was made on the basis of low bid, as required by EU law.

The design-build contracting process for the Øresund Link involved establishing a directory/supervisory, private-management consortium to control the project. The consortium is a private entity working for the governments. Predesign was a complete “illustrative” design in which 80 to 90 percent of one potential design strategy was completed. Potential bidders attended a discussion meeting where they were informed of the detailed project scope and told specifically what was required—and what was not allowed—in terms of innovative designs. Potential bidders were prequalified and, if their submission demonstrated understanding of work, were allowed to bid. Subcontractors were also reviewed, including geotechnical engineering firms, but no rules required subcontractors to be prequalified and preselected. The final contractor was selected solely by sealed, low bid, as required by the EU directives.

Partnering and team concepts were incorporated into the project. For example, the management consortium (private) and the contractor are resolving disputes and other issues through a partnering approach. Disputes are resolved during construction. Appeals will be referred to a three-member expert panel; however, the appeal process has not been invoked. There is a shared risk between the owner and the contractor, with the owner taking the responsibility for the initial geotechnical work and its accuracy, as well as uncontrollable weather conditions.

For the Copenhagen Metro, the other Danish design-build project, a private-public partnership was established. The contracting award process will use continual discussions, design refinement, and prequalification. The number of prequalified proposers will be continually reduced, and discussions are held at each level until the final proposer is awarded the project. All meetings are confidential.

Norway and Sweden also use design-build and other innovative contracting methods. Sweden, of course, is involved in the Øresund Link Project.

Both performance- and method-based specifications were applied on the Øresund Link Project. For example, a performance specification was used for the amount of contamination from dredged materials being placed back into the sea. A 5 percent requirement was specified; that is, no more than 5 percent returned to the sea. Performance-based specifications were introduced by the management team on this project, but use was somewhat limited in favor of well-established method specifications.

By law, warranties are required in the specifications, including 1 year on pavements, and 10 years on overall performance and on electrical/mechanical works. Again, warranty performance is expected to be established through a partnering effort and by resolution and agreement between the contractor and management team. The management team intends to provide performance quality primarily through construction quality control rather than long-term performance measures and risk assignment to the contractor. A very small performance bond was required, approximately DKr1 million (~US$150,000), for the tender and 15 percent for the contract execution.

Implementation

Regarding pre-engineering requirements provided to the contractor, in Denmark, the owner normally provides a detailed geotechnical report for the project and 90 percent of the design. For example, the locations of foundations are indicated. With regard to geotechnical design requirements, foundations must currently be designed in accordance with the Danish Foundation Code. Eurocode 7, however, was required for foundation design on the Øresund Link Project. Functional criteria are primarily provided in the contract to define the desired quality for what is being built. For example, a structure must be able to tolerate a certain amount of settlement, and the foundation soil must not settle more than that value.

As the owner performs a thorough geotechnical bid-basis subsurface exploration, the contractor only performs a post-bid exploration for verification purposes, if required. In case of disputes over unanticipated conditions on the Øresund Link Project, a dispute review board would be used. For quality control on design-build projects, the contractor develops and submits a quality-control plan for the owner’s approval, after the award. The qualifications for the laboratory (-ies) performing the tests (including verification testing of geotechnical materials) are specified by the contractor in the quality-control plan, and the contractor must demonstrate that a quality lab is being used. Once the quality-control plan is in place and approved by the owner, the contractor must show evidence that the completed design or constructed element meets the quality requirements or functional criteria indicated in the contract. Quality-assurance reviews are performed at intervals outlined in the contract, and the contractor does not get paid until the quality control records are submitted and approved. In fact, the quality-control reports must be attached to the invoice, and the owner must accept quality provided by the contractor before the contractor is paid.

Performance

The most significant obstacle that the Danes have encountered in trying to implement design-build contracting has been environmental concern. Permits are especially difficult to obtain and require a certain amount of design ahead of time. For example, on the Øresund Link Project, the number of piers on the Swedish side had to be known before permits could be obtained. For this reason, an illustrative design was completed by the owner, prior to obtaining bids.

Overall, the Danes feel that design-build has worked well. It fosters a partnership between industry and the owner and helps them operate more efficiently. From a contractor's perspective, it works best on a large and unique project with significant engineering content. A standard project does not allow enough innovation for design-build to be practical. Both time and cost savings have been realized on projects involving innovation, but standard projects, such as a two-lane bridge, do not present opportunities for innovation and, therefore, no opportunities for cost or time savings.

GEOTECHNICAL PRACTICE

There have been numerous recent geotechnical developments in Scandinavia, several of which have arisen from the Storebælt and the Øresund Link Projects. Advances in ground-improvement technologies include:

- The Danes developed a new method, known as "MOSES," Method of Obtaining Safety by Emptying Storebælt. MOSES is a dewatering technique used to construct tunnels under the sea bottom using deep wells into the sea bottom for temporary reduction of high-pore pressures.
- A new method for ground freezing, also developed by the Danes, was used on the Storebælt Link Project in an innovative way to stabilize the water-bearing strata for tunneling purposes.
- A good QA/QC procedure for controlling the construction of lime columns and shallow soil mixing has been developed by the Norwegians.
- In Sweden, some improvements have been made in monitoring methods for making deep excavations to keep track of deformations that occur as a result of the excavation process. This method is currently in use on a big project in Stockholm.
- A coastal stabilization method has been developed in Denmark that uses nature's own forces in a positive way to counteract the destructive forces that usually result in beach erosion and damage. The awesome power of the sea waves is used to arrive at eco-friendly and invisible coastal stabilization. The patented technique, called "Beach Management System," is used to control the development of a sandy beach or where erosion is threatening agricultural or infrastructure assets. The system consists of buried drain pipes that are connected to collector wells and pumping stations. By lowering the ground water level below the coastline level, downwards percolation of water from the wave runup is introduced, whereby the soil is stabilized in the same way as by a standard dewatering operation for an excavation. This reduces the backwash on the beach face and limits the erosion process while deposing more sand on the beach. The concept has also been applied successfully at four sites in the United States by Moretrench American Cooperation.

With regard to in situ testing of geotechnical materials, recent developments have included the following:

- Development by the Danes of a cone-penetration testing rig (CPT) that can be lowered about 1000 m below water to measure soil parameters below sea muds.
- Numerous correlations of CPT with piezocone and pore pressure measurements in Norway.
- Development of equipment and procedures for taking large, undisturbed block samples for lab testing has been a focal point for Denmark, Norway, and Sweden. Norway has a special sampler with a special cutting tool that yields good, undisturbed samples for larger scale investigations.
- Software has been developed by the Danes for their CPT rig that will automatically stop the advance of the cone when it hits a rock, which protects the cone from damage.
- In the past several years, improvement in interpretation methods for borehole logging developed out of the increased popularity and experience of the Danish with using geophysical testing.
- An improved ground-penetrating radar device, developed in Norway, can be mounted on a helicopter to detect cavities in subsurface rock formations.

The Swedes are concentrating on pile dynamic analysis-type (PDA) testing for high-capacity, end-bearing piles, to reduce reliance on static-load tests. The Swedes have a lot of good information and data on comparing PDA tests with static-load tests, which would be valuable for the FHWA data base on deep foundations and for future calibration of limit-state methods.

It is surprising that very little work is ongoing in the area of mechanically stabilized earth walls (reinforced soil walls) in any of the Scandinavian countries.

CHAPTER 4

COUNTRY SUMMARY: GERMANY

The study tour visited Cologne, Germany, on March 9 and 10, 1998, for meetings at the German Federal Research Highway Institute (BASt), which is similar to the Turner-Fairbank Highway Research Center. The review included formal meetings and presentations by representatives of various departments within the BASt; the Ministry of Transport (BMV); the Federal Research Institute of Germany (BAW); the German Industry Standards group (DIN); and Professor Dr. H.U. Smoltczyk, a consulting geotechnical engineer and former professor of the Geotechnical Institute of the University of Stuttgart. Prior to the visit, the BASt set up a Web-based workspace on the Internet to exchange ideas and information ahead of time—an excellent idea that significantly enhanced the visit and its organization. The team also toured the BASt facilities and its research laboratories, see figure 5.

LRFD

History of Use and Development

Figure 5. The U.S. team visits the BASt.

Prof. Smoltczyk presented the German perspective on limit-state design in a manner similar to that of Dr. Ovesen, in Denmark. In developing the German limit-state practice, it was necessary to harmonize the Eurocode with the national needs and the structural code with the geotechnical needs. The Germans have developed a quite complete and detailed set national standards called the German Industrial Standards (DIN). The DIN includes construction design standards that are quite mature and encompass all aspects of engineered construction. The previous practice was to use a global load factor for the persistent, transient, or accidental load cases on resistance (i.e., Load < Strength/FS). This is similar to that used in the United States for working-stress design. The global factors from the German national standards are shown in table 4.

From the German perspective, the shortcomings of the global-factor design include:

- No consideration of uncertainty on load and resistance.
- Bearing capacity varies exponentially with soil strength.

- Sliding and overall stability depend linearly on soil strength. LRFD, a term that refers specifically to the U.S. approach, takes this into consideration, but it is nonlinear.

Table 4. Factors of safety for different load types, from the German National Standards.

Behavior Mode	Global Factors for Each Load Type		
	Persistant Load	Transient Loads	Accidental Loads
Bearing Capacity	2.0	1.5	1.3
Sliding	1.5	1.35	1.2
Uplift by Water Pressure	1.1	1.1	1.05
Compression Piles	2.0	1.75	1.5
Tension Piles	2.0	2.0	1.75
(The above values can be reduced if more than one test, i.e., confirmation or verifications tests, is performed. By using large factors and allowing this reduction, testing is encouraged.)			
Overall Stability	1.4	1.3	1.2
Anchored Retaining Walls (Active earth pressure)	1.5	1.33	1.25

The Eurocode 7 approach to limit-state design was reviewed in terms of the same three cases as reviewed in the Denmark section and shown in table 3.

Case A: Material strength is not significantly involved. Example: toppling of rigid structure on rigid base.

Case B: Factored actions (i.e., loads plus effects of temperature and shrinkage), unfactored soil weight, and soil strength. Example: effect of actions on the design of a footing.

Case C: Unfactored permanent actions, factored variable actions against factored soil strength. Example: design of the width of a footing.

Typically, both Cases B and C need to be analyzed. The Germans have disagreed with the approach because, in most cases, it is too conservative; but, in some cases, it is less safe than the established German practice—sliding. The Germans propose an LRFD approach that uses a modified factored resistance for all structural elements (Case B). The German National Applications Document for implementing Eurocode is written using this approach. The method uses a factored strength for overall stability and unit weight of soil not factored. Load factors are mainly applied to the effects of actions rather than to the actions themselves.

Tables 5 and 6 provide the partial factors used in the National Applications Document. The partial factors were developed by trying to stay close to the global allowable stress design factors; plans are to do the statistical analysis later. Part of the proposed revisions for Eurocode appeared to be very similar to the LRFD approach proposed in the United States.

Table 5. Partial safety factors for actions, from the German National Applications Document.

Ultimate Limit State (ULS)	Action	Sym.	Load* Case 1		Load* Case 2		Load* Case 3	
			Unfavorable	Favorable	Unfavorable	Favorable	Unfavorable	Favorable
1A	Permanent Liquid Pressure Variable	γ_G γ_F γ_{Qsub}	1.00 1.00 1.05	0.90 ------ ------	1.00 1.00 1.00	0.90 ------ ------	1.00 1.00 1.00	0.95 ------ ------
1B (failure in structure)	Permanent Liquid Pressure Variable Perm. Lateral Press. Perm. Skin Friction Perm. Earth Press. Variable Earth Press. Earth Pressure at Rest	γ_G γ_F γ_{Qsub} γ_H γ_M γ_{Eg} γ_{Eq} γ_{EOg}	1.35 1.35 1.50 1.35 1.35 1.35 1.50 1.20	1.00 ------ ------ ------ ------ ------ ------ ------	1.20 1.20 1.30 1.20 1.20 1.20 1.30 1.10	1.00 ------ ------ ------ ------ ------ ------ ------	1.00 1.00 1.00 1.00 1.00 1.00 1.00 1.00	1.00 ------ ------ ------ ------ ------ ------ ------
1C (failure in ground)	Permanent Liquid Pressure Variable Perm. Lateral Press. Perm. Skin Friction	γ_G γ_F γ_{Qsub} γ_H γ_M	1.00 1.00 1.30 1.00 1.00	------ ------ ------ ------ ------	1.00 1.00 1.20 1.00 1.00	------ ------ ------ ------ ------	1.00 1.00 1.00 1.00 1.00	------ ------ ------ ------ ------

* Note: Unfavorable loads are destabilizing loads that must be resisted, and favorable loads provide restoring forces that may help in resistance.

Table 6. Partial safety factors for soil resistance, from the German National Applications Document.

ULS	Soil Resistance	Symbol	Load C.1	Load C.2	Load C.3
1B (failure in structure)	Passive Earth Pressure Bearing Capacity Sliding Capacity Piles, axially Injection Anchors Soil Nails Flexible Reinforcement	γ_{Ep} γ_S γ_{St} γ_P γ_A γ_N γ_B	1.40 1.40 1.50 1.40 1.10 1.20 1.40	1.30 1.30 1.35 1.20 1.10 1.10 1.30	1.20 1.20 1.20 1.10 1.10 1.05 1.20
1C (failure in ground)	tan φ c' c_u Piles, axially Injection Anchors Soil Nails Flexible Reinforcement	γ_φ γ_c γ_{cu} γ_P γ_A γ_N γ_B	1.25 1.60 1.40 1.60 1.30 1.30 1.40	1.15 1.50 1.30 1.40 1.20 1.20 1.30	1.10 1.40 1.20 1.20 1.10 1.10 1.20

Existing DIN standards providing calculation models have been adapted to the principles of Eurocode 7 by attaching reviewed standards (see section on Implementation below) to the National Applications Document. The current status of these documents is as prestandard for experimental application; therefore, engineers can use the older DIN standard or the new DIN standards, based on Eurocode 7.

The German practice to find the characteristic soil values is to assess the values by engineering judgment, starting from experience collected in databases and verified by spot-check laboratory and field tests. Tables of standard, empirically derived soil and rock values for simple structures are provided in the National Applications Document (NAD-DIN 1054-100, appendix B). For developing standard values, databases were used as much as possible so that a rough statistical evaluation could be made. Deriving a cautious estimate of the mean characteristic values from these findings should not shift by more than 5 percent from the “true” mean value to be found in cases of a statistically relevant number of tests, which normally are not available.

Examples of footing-bearing capacity and settlement were presented to the team. The Germans currently have curves for presumptive bearing capacity of strip footings on sand, with respect to footing width and embedment depth and a limit on sand density, which were provided with the handout (Smoltczyk, 1998). They are also available for other soil types.

For piles, capacity estimated only by earth-pressure analysis is not permitted. The allowable design load is based on load tests or a table of values based on extensive experience with actions (i.e., load, plus any other effects), according to Case B. The method for determining pile capacity comes from the principles stated in Eurocode 7, but applying different numerical values to account for Case B, factored actions (while the intention of Eurocode 7 was to derive the capacity from Case C, unfactored actions). For simple applications, design capacities may be taken from tables based on extensive comparative tests and site experience. For applications that are not “simple,” characteristic load-displacement curves are provided. From these curves, design capacities may be derived, accordingly, to head displacements tolerable for the superstructure. Lateral loads are either transmitted into ground by raking piles or by using the bending strength of the pile.

Implementation

Communication between structural and geotechnical engineers does not appear to be a problem in Germany. While there is no written process, most design firms have both engineers working in the same office, and, in many cases, the geotechnical engineer provides the structural design for the foundation. There are some problems with subcontractor geologists writing geotechnical reports from inadequate soil data. This leads to very conservative designs, such as using piles when spread footings would suffice.

The DIN requires that designs be subjected to review by “proof engineers” (Prüfingenieur), which serves as a design-quality check. The engineer must have a special registration to be a proof engineer; responsibility for the design, however, remains with the design engineer, not the proof engineer.

As previously indicated, the Germans have a national code to implement limit-state design (i.e., Eurocode 7, Part 1). The National Application Document is supported by DIN standards contained in its appendix, including the following:

- DIN V 1054-100: Soil: Verification of the safety of earthworks and foundations-Part 100: Analysis in accordance with the partial-safety concept.
- DIN V 4017-100: Soil: Calculation of design bearing capacity of soil beneath shallow foundations.
- DIN V 4019-100: Soil: Analysis of settlements.
- DIN V 4084-100: Soil: Calculation of slope and embankment failure and overall stability of retaining structures.
- DIN V 4085-100: Soil: Calculation of earth pressure.
- DIN V 4126-100: Diaphragm Walls.

The letter "V" in the code numbers indicates that the specifications are "prestandard," for experimental applications. DIN standards are mandatory and legally binding; however, even with the "V" designation, the new codes can be used as an alternate to the old standard, making implementation relatively straightforward.

To assist with implementation, a national training program was established. Two seminars have been held with 200 people attending each. In fact, a seminar on Eurocode 3 was to be held the day after the scanning team's visit. These are hands-on, problem-solving, workshop-type seminars. It is usual to wait until each Eurocode is more settled before holding additional seminars and workshops.

In terms of industry and agency resistance, as previously discussed, Germany does not completely embrace Eurocode 7 in its present form. The compromise provided by its National Application Document will, however, help with implementation and accuracy.

Performance

The Germans consider the main advantage anticipated from the LRFD approach to be the ability to apply uncertainty to different actions (i.e., load plus any other effects) and resistance values. As previously indicated, some of the action and resistance factors in Eurocode 7 are in question—some values are too conservative, others are too extreme. Because of these issues, the Germans are currently calibrating to their old designs and, therefore, do not observe any differences in foundation designs using LRFD. Some differences may appear in the future when they calibrate with respect to databases, but those differences are expected to be small.

The Germans advise countries just beginning to use the LRFD method to separate work into two types: simple jobs, with general, accepted values; more complicated jobs, involving more testing and soil investigation.

CHAPTER 4

INNOVATIVE CONTRACTING AND PERFORMANCE-BASED SPECIFICATIONS

History and Development

The German federal highway authority is responsible for the autobahn system (approximately 11,300 km) and about 42,000 km of federal trunk roads. It has had only limited experience with contracting methods such as design-build. Part of the limited experience is because of the absence of new road construction, resulting from lack of space and negative public opinion. To date, the only design-build project contracted resulted in poor-quality construction and significant litigation, casting a very negative impression of the utility of design-build contracting. Even so, the 16 German states may use innovative contracting, and design-build contracting is widely used in the private sector.

On some occasions, the low bid can be discarded if an alternate design promotes improved long-term performance. A contractor's only incentive to develop alternate or innovative designs is to win award of the contract; however, it is not unusual for contractors to submit alternate proposals.

It is normal practice on routine projects to allow for alternate designs, based on prescriptive detail (base) designs that owners prepare. Base offers are accepted from prequalified contractors and awarded to the low bidder. Alternative offers must be examined for equivalence, in terms of the base works, with a view to the long-term technical and economic aspects. On some occasions, the low bid can be discarded if an alternate design promotes improved long-term performance. A contractor's only incentive to develop alternate or innovative designs is to win award of the contract; however, it is not unusual for contractors to submit alternate proposals.

The federal government intends to continue experimenting with new contracting procedures. Initially, it will move toward performance specifications; however, there is a tendency to lean toward prescriptive approaches, which may preclude innovation. Germany has national laws requiring contract awards based on low bid. In addition, on new construction contractors must warrant pavements for 4 years and bridges for 5 years.

At the time of bid, contractors must prove that they are qualified, based on past experience; that is, they can demonstrate previous success on the specific type of work. Contractors lacking construction experience on federal projects must provide references to prove that they are able to complete the work for which they submit proposals. Although subcontractors are not prequalified, at the time of bid they must also demonstrate, to the owner's acceptance, successful past performance on projects of similar work. Prime contractors are only interested in qualified subcontractors because the contractors must also provide a warranty for the subcontractors' work. It is the same for geotechnical subcontractors and design consultants. Partnering concepts have not been used in German public sector projects, primarily because of the prescriptive approach commonly used for design and construction control.

Only one design-build project has been undertaken—the design and construction of a road in eastern Germany. The award was based on a cost-plus approach, and the contractor received a fixed sum (stipend) for a design-build proposal. Several deficiencies in the contracting approach resulted in significant problems and cost overruns for the project. Those deficiencies were shared with the scanning team and include:

- A comprehensive formulation of the scope of work was not established, prior to award.
- No clear performance specifications and measures of performance were in place at the time of the project.
- The contractor did not have adequate quality control procedures in place.

The owners also discovered that the effort required for review was the same as if they had designed the project themselves.

The Germans believe that design-build is only appropriate for large projects with strong design components. (Also see Heiermann, 1997, for further discussion on where and how design-build should be applied.)

Performance-based specifications are in the development stage and some have been used. For example, measures for pavements include noise, skid resistance, freedom from ruts and cracks, thickness, density, and durability. Contracts incorporating performance measures, as with most other contracts, are based on shared risk. In most cases, owners provide a prescriptive design with method specifications and are responsible for the soil, climate, and traffic. Contractors are responsible for materials, mixtures, etc., plus the required performance measures. Claims, however, are most often resolved through the court system, not unlike the situation in the United States.

As previously indicated, the law requires performance warranties, and reviews are conducted at the time of construction completion and at the end of the warranty period. The real key is the measure of performance. Performance bonds of 2 percent of construction costs are required, which is lower than the 5 percent required in the past. The reason for the reduction is, in theory, a concern for putting contractors out of business. Several examples were cited in which the contractor's value was well below the claim amount.

The Germans have organized a large industry group to study contracting methods and recommend a better approach.

The Germans have organized a large industry group to study contracting methods and recommend a better approach. This group is evaluating a performance-contracting approach that includes maintenance (i.e., a design/build/maintain-approach) over, for example, a 20-year contract period. This would let the contractor choose whether to improve initial construction quality or repair more frequently over the maintenance period.

Implementation

The pre-engineering information provided to a contractor by the owner or the owner's consultant includes a baseline geotechnical report. The report includes conceptual geotechnical design recommendations as well as detailed geotechnical characterizations of the subsurface conditions. Some performance requirements may also be included. An exception would be if contractors offer an alternative design, then they must perform their own subsurface investigation. Contractors are required to design in accordance with Eurocode or DIN standards, and a proof engineer performs an in-depth review of the design. Quality control by the contractor is required, but may not be very specific. Contractors must also prove that products and works proposed are in accordance with the requirements in the contract and must use third-party labs to do so. The testing labs must be approved by the road administration. The owner has the right to perform quality-assurance testing to check any materials.

The Germans were somewhat surprised by the team's question about allowing contractors to perform their own subsurface exploration. They indicated that allowing the contractor to bid the subsurface exploration would essentially be bidding quality. In their experience, the building costs (claims) increase considerably if the subsurface investigation is inadequate. On one occasion, a bridge collapsed because of inadequate subsurface investigation. Thus, the Germans are very cautious about the importance of obtaining an adequate subsurface exploration. The owner must provide the baseline report. German construction laws proceed on the assumption that "an owner must describe the foundation soil so exhaustively that all bidders will arrive at the same understanding of the description and will be able to calculate their prices with confidence and without extensive preliminary work" (Heiermann, 1997).

Contractors only do the additional explorations necessary to perform final foundation design for alternative bids, and general, minimum exploration requirements are found in the code. No fixed program is specified for exploration, so contractors decide on what is needed for the alternative designs. Unanticipated conditions have not usually been a problem, but, if proven to be justified, the owner pays for additional work required.

Because of its limited use, no specific training for innovative contracting methods has been attempted in Germany. Some general courses on this subject are provided at universities and, sometimes, by engineering organizations.

Performance

Based on limited experience with design-build, the Germans found that some contractors complained because they could not compete. Many contractors are not qualified for the design portion, and small contractors have trouble competing because they cannot afford to prepare a design and not win the bid. Contractors have complained that the compensation was inadequate to cover the cost for preparing the proposal. As already mentioned, one project did not work very well and design-build may not be tried again.

In Germany, the alternative-proposal approach may be considered for small, design-build contracts. The Germans have had positive experiences with such contracts, because the responsibilities clearly revert to the contractors. Rather than move toward design-build, the Germans would prefer to develop performance-based specifications, addressing end-of-construction and end-of-a-4-year-period criteria, as well as exploring the build-and-maintain contract approach.

GEOTECHNICAL PRACTICE

The BASt has conducted a lot of research-quality work on the application of geofoam materials as lightweight fill for bridge approaches over very soft ground. Special impulse, load-generating test equipment was developed to apply numerous repeated loads that simulate traffic loads. This equipment has also been used to evaluate pavement-thickness requirements over geofoam. BASt also has the ability to freeze soil and has conducted research in this area.

The BASt has developed a new soil-stiffness device that uses a falling-weight input measuring system. After applying a dynamic force, a readout device gives both a deformation value and a stiffness modulus value.

In the 1980s, an interesting research project was performed on an instrumented MSE wall using nonwoven geotextile reinforcements. An instrumented, steep-sloped (5V:1H), geogrid-reinforced soil wall with a vegetated face was also presented. BASt is also evaluating geosynthetic reinforcing materials that are not affected by adverse pH values in the soil. A recent book (available only in German) incorporates a limit-state design approach to geosynthetic reinforcements (Empfehlungen fuer Bewehrungen aus Geokunststoffen – EBGEO; Deutsche Gesellschaft für Geotechnik e.V. - DGGT, 1997, ISBN 3-433-01324-1).

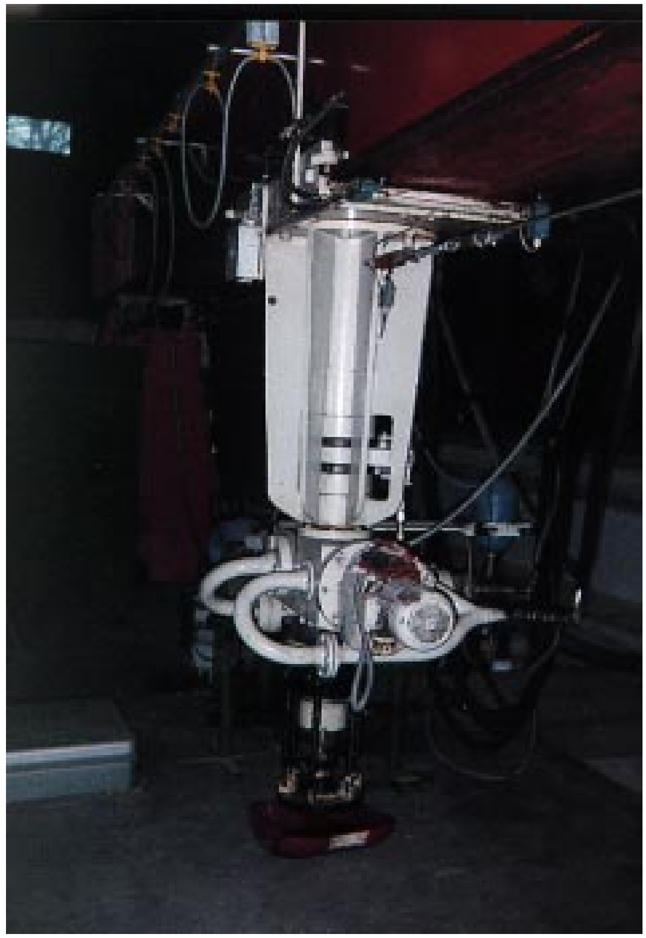

Figure 6. Full-Scale test pit at BASt.

Figures 6 and 7 show a full-scale test pit and compaction equipment for full-scale studies at the BASt.

Figure 7. Compaction equipment for full-scale studies at BASt.

CHAPTER 5

COUNTRY SUMMARY: FRANCE

The last visit of the study tour was to France on March 12 through 14, 1998, where the program consisted of formal and informal meetings and presentations at several locations in Paris. The group met with representatives of Service d'Études Techniques des Routes et Autoroutes (SETRA), the service agency responsible for the design and construction of roads and bridges; Laboratoire Central des Ponts et Chaussées (LCPC); the Teaching and Research Center in Soil Mechanics (CERMES); and, Terrasol, a geotechnical consulting firm. The team also toured the laboratory at CERMES, located at the national engineering school, École Nationale des Ponts et Chaussées (ENPC).

LRFD

History of Use and Development

At SETRA the team met with structural engineers concerned with bridge design to discuss the structural aspects of Eurocode. A presentation was made by Dr. Joel Raoul, who sits on the drafting panel of Eurocode 3-2 (steel bridges) and Eurocode 4-2 (composite bridges), and Mr. Vu Bui, who is involved with Eurocode 2 (concrete structures). An overview of Eurocode Standardization was presented (Calgaro, 1998), which focused on the bridge parts of the code, Eurocode 2 and 3.

In France, limit-state design for structures preceded Eurocode. It is basically the standard design approach and is taught in the schools. Most of the parameters for Eurocode matched the existing approaches in France.

At SETRA, the Eurocode has been used in the design of bridges as a trial of the code. In particular, in the design of a concrete-deck bridge, according to verification classes, 3 to 15 percent more prestressed strands were required than are in the national code. However, the design loads used were higher than those previously used.

At present, SETRA is busy with trial designs. There are three load types: those with a long return period, those that are infrequent, and those that are common (1 week). A 50-year return period for the characteristic ultimate limit-state (ULS) load is used, for example, when performing an elastic verification of stresses. The combination of actions at the ULS is:

$$\text{ULS} = 1.35\ \text{DL} + 1.5\ \text{Q} \qquad \text{and} \qquad \sigma < f_y/\gamma_m \qquad (6)\ (7)$$

where DL is the dead load, Q is the live load, σ is the design stress for steel, F_y is the yield strength for steel, and γ_m is the factor of safety.

In France, the safety factor for reinforcement is 1.15 and 1.0 or 1.1 for steel structures, but this varies among other countries. The bases for the 1.35 dead-load factor is 1.2 for variability, and 1.125, for model.

Load factors for truck weights were determined through probability analysis. There will be an attempt to achieve a European standard truck design load, but each country will have an opportunity to adjust that load through a factor, at least through the experimental stage.

The staff at SETRA have not found Eurocodes 2 and 3 to be user-friendly, especially for a first-time user. Eurocodes are written on a very general basis; for example, a variety of different analyses are permitted.

In cooperation with private industry, SETRA will be developing the national application document for France for Eurocodes 2 and 3. Private industry representatives are included on the subcommittees, which feed into the technical committees. The current version of Eurocode is an "ENV" phase (European Norms Proposal), which will last about 2 to 3 years, while awaiting consensus on the various issues. At that time, the code will become an "EN" code, European Norms. The EN document will be an acceptable code and can be used in place of a national code, but will not be mandatory. Following 5 years of EN code, it will become mandatory. Because it will be 7 to 8 years until the code becomes mandatory, it is difficult to get people to take it seriously at this time. Also, the lack of funds for travel makes it difficult to fully incorporate both public and private input to the subcommittees.

The ENV is in place for all national codes. Its original intention was to have the optional values in brackets [ ], removed. That will probably not happen. An excellent reference source for use of limit state in the design of deep foundations in Europe is the conference proceedings from "Design of Axially-Loaded Piles—European Practice" (Cock and Legrand, 1997). The proceedings contain 15 national reports.

Perspectives on the history and development, from the geotechnical side, were provided by Dr. Roger Frank, Director, ENPC-CERMES; Mr. Jean-Pierre Magnan, Ingénieur en Chef des Ponts et Chaussées; and by Mr. François Baguelin, Chairman of the French Working Group on Eurocode 7.

The French wrote the first LRFD geotechnical design standard about 10 years ago, and it used the limit-state design loads from structures. A foundations standard, however, existed about 20 years ago (Frank, 1993). The French have a standard for soil nailing and reinforced earth that uses partial factors, which was calibrated based on present design procedures. In the early 1980s, reinforced-earth guidelines were issued by the ministry.

Design requirements in France are very structured, and it is quite clear which design codes or test standards are to be followed to satisfy legal requirements. Technical rules for public works are as follows:

- Published annually.
- Compulsory: Includes technical documents.

Example: Fasicule 62—Title V (foundations), which took 10 years of work and was completed in 1993.

- National Design Standards: Starting to develop these for limit-state design.
- Test standards: Example pressuremeter (very few of these).

Partial factors have been calibrated to match previous design. Partial factors came about because people were used to a global factor of safety. But with limit states design, there are factors for safety in load, resistance, and soil parameters, so safety is split. There seems to be a misunderstanding among Europeans on this term, which is also the case with U.S. engineers.

The Eurocode 7 load and resistance factors for each load case (as presented in the section on Denmark) were discussed. The French geotechnical engineers have tried to merge Case B, the structural case, and Case C, the geotechnical case, in Eurocode 7. They see problems with variability in the actions. There is some agreement that model factors should be used; that is, Case B only, with a factor on c and N, but, additionally, a model factor. Other cases can be different. For example, in slope stability, use 1.05 on unfavorable loads (i.e., destabilizing loads to be resisted) and 0.95 on favorable loads (i.e., restoring loads that may help in resistance). Table 7 shows the single values proposed.

Table 7. Load and resistance factors proposed by French geotechnical engineers.

Load	July 1996		October 1996	
	Unfavorable Loads	Favorable Loads	Unfavorable Loads	Favorable Loads
Weight of structure	1.2	0.9	1.2	0.9
Weight of soil	1.1	0.9	1.0	1.0
Weight of water	1.05	1.0	1.0	1.0
negative friction	1.2	1.0	1.2	1.0
Lateral load	1.2	0.6	1.2	0.6
Other variable	1.3 or 1.2	-----	1.3 or 1.2	-----

French engineers used pile-load test data, indirectly, to get resistance factors. When asked what the resistance factors would be if every pile were tested, the response was 1.4 (1/1.4 for the United States). It was suggested that a load factor of 1.2 be used on downdrag.

For the characteristic soil value, French engineers use a 5 percent exclusion value for defining soil properties, as specified in Eurocode 7. This quantity can be determined, without confusion, from subsurface investigation data. It was interesting that, in Denmark, the team was given an example in which the characteristic soil value was determined at a value of 5 percent below the mean. It appears that different interpretations are applied to Eurocode in determining this essential value. Using the 5 percent exclusion value for soil properties will produce rather small values that should not be reduced very much to obtain a safe strength.

*(**Note:*** In an interesting comparison, the U.S. timber industry has typically used 5 percent exclusion values to define timber ultimate strength. For example, round timber strength for piles is defined by the 5 percent exclusion value. In that case, the 5 percent exclusion value is taken as the ultimate and then reduced by 60 percent to arrive at a working strength.)

French engineers reported on an interesting approach, now in development, to approximate geotechnical characteristic values to handle spacial property variation, given limited information.

x_{meas} test	———>	x_i representative	———>	x_k dispersion

$x = m_x - k\, s_x$	s_x - the standard deviation	(8)
$k = k(N,p,\alpha)$	p - fractile 50 percent, 5 percent α - statistical risk: 25 percent	(9)
$k=k(N,\beta)$	β = 5 percent	(10)

If there are only a few values, it is better to use the range (x_{mix}, x_{max}):

$$m_x = (x_{max} + x_{min})/2 \tag{11}$$

$$s_x = (x_{max} - x_{min})/m_q \tag{12}$$

where m_q (N) is given by a table.

A homogeneous layer can be characterized by two values of the so-called “local parameters”:

x_m (mean) p = 50%, α = 25%
x_b (low) P = 5%, α = 25% or β = 5%

These values are independent of any structure interacting with the soil. When a structure is considered, the “extended parameter” is defined in relation to the limit state and to the extension of the failure surface, with the characteristic value:

$$x_k = x_m - (x_m - x_b)/\sqrt{n} \tag{13}$$

where *n* is the number of independent values on the failure surface.

For soil or rock information with depth, data points on the order of 100 to 300 mm apart can be linked. If they are spread far apart (e.g., 1.5 m), they would be independent. In the horizontal direction, the distances are generally far greater. (The distance where data are considered independent appears rather small to several U.S. team members.)

Implementation

Most structural design groups have both structural and geotechnical engineers on staff. SETRA has geotechnical engineers within its staff who work closely with the structural engineers on a project/team basis. They work on a technical basis together, but are not supervised by the same manager.

It does not appear that communication is a big issue. The bridge engineer gives the geotechnical engineer the loads to consider, the geotechnical engineer performs the analysis and then provides recommendations to the bridge engineer. These recommendations include specifics, such as the number of piles. The two work together to achieve an integrated design. It is policy to involve young engineers on design teams, though some concern was expressed for a decline in the quality of geotechnical work in France.

Implementation of Eurocode was not really a problem in France because limit-state design is the standard of practice. National codes are mandatory, so when Eurocode is adopted in its final form, implementation will be automatic. At this time, there is no education or training effort given to implement Eurocode 7 because it is not useable. Once the text is clarified and finalized, some training will be established, presumably by the federal government.

Performance

The existing method of design in France is LRFD, and, as long as the European code is calibrated to existing practice, there should be no changes in performance or cost savings. As Eurocode is currently written, a few items are a little hard to analytically calibrate based on available factors and dictated loads. The greatest benefit of Eurocode is to help everyone understand the differences among various countries and national codes. Eurocode provides a common language for discussion.

INNOVATIVE CONTRACTING AND PERFORMANCE-BASED SPECIFICATIONS

History and Development

An interesting historic note concerning low-bid contracting explains the philosophy deployed by the French government. It may also account for the government's interest in and implementation of innovative contracting approaches that are readily used today. In the 1600s, Sébastien le Prestre de Vauban, one of France's most famous civil, military engineers, addressed a letter to the king in which he complained about low-bid contracts on public works projects. Vauban pointed out that the quality of construction was inferior, the workers complained of low pay forced on them by the contractors to keep costs down, and many delays were encountered in the completion of the work. The result was that the king declared that low bid would no longer be practiced. The current public sector philosophy in France is to ensure equality of opportunity for all firms while obtaining the highest quality/price ratio for each project. This often negates the use of low bid awards.

SETRA has significant experience with various methods for awarding contracts, including low bid, best bid (established from technical, quality, cost), negotiated, and purchase order. Simple projects continue to use the low bid or purchase order approach. A trend toward using a best bid award mechanism has been established and is common for both routine and complex projects. It is most often used with design-build contracts. The bid costs, technical and performance value, time for completion, and medium- and long-range maintenance costs are all factored into the evaluation of submitted bids. Other selection items include user cost, execution time, durability, traffic noise and volume, and innovation. Prime contractors are evaluated by examining financial records from a 3-year period and by technical capacity.

The evaluation criteria for measuring proposals under the best-bid scenario is clearly specified in the invitation to bid. Bidders must submit a quality assurance manual with a proposal. The owner has flexibility in assessing technical merits of the proposal; however, all bidders are assured of compliance with competitive bidding rules. Along with their proposals, contractors provide certificates of professional and financial guarantees; bid amount (not always required), which may often include long-term anticipated maintenance costs; and a summary quality assurance plan. In addition, contractors are also asked to submit the documented technical value of a proposal and utilization costs (life-cycle costs), when alternative schemes are allowed.

For public works projects, complete designs are provided in the bidding package. Contractors may then design alternate or substitute bids, which is allowed. Normally, significant oversight is provided during design and construction, but the trend is to reduce oversight because of reductions in staff within public agencies.

Four design-build projects are in progress, including two bridges and one ITS project. The procurement process is developed and documented, but it is available only in French.

There are legal requirements that will affect innovative contracting practice. Currently, there is a 36-day period for bid letting in France, but, when the EU laws prevail, the period will increase to 53 days. In France, five bidders are prequalified, but, under the EU laws, that will increase to ten bidders. Also, the EU Council Directives require that no preferences be given to any contractor; and the Eurocode contract requirements will prevail in the future.

For design-build projects, SETRA may allow for an open call for bids. When the project is routine, however, a restricted call for bids is used for complex projects with significant engineering content. Design-build does appear to be more frequently used in France than in other European nations; however, the private-sector engineers with whom the team met felt that the trend is away from design-build, in favor of alternative bidding.

Implementation and Performance

Very few specifics were provided in relation to geotechnical engineering contracting practice. One note that was provided indicates that SETRA negotiates with consultants for subsurface investigations and provides the information to all bidders, or prequalified bidders, if the project is a restricted call for bids. Warranties are used, but little information was provided.

GEOTECHNICAL PRACTICE

Several innovative geotechnical products and technologies were discovered during the tour. In the area of ground improvement, the French have developed a clever way to remove water from soft, wet clays and bay muds by applying a natural suction. Inserting pipes into the ground and circulating a predetermined, relative-humidity controlled air system will absorb moisture from the soil and transport it to a pumping area. The technique works like a giant dehumidifier.

There have been, and continue to be, several cooperative efforts on MSE structures between the FHWA and the French, so there were few surprises or lessons to be learned in this topic area. The French subsurface investigation practice, however, differs from the U.S. practice. For in situ field testing, they mostly use pressuremeter and piezocone, with no new developments.

The team was impressed by its tour of the CERMES. The quality of the laboratory for research testing, equipment, and layout were admirable. The calibration and testing chamber facility is excellent in terms of the size of equipment available to calibrate geotechnical instrumentation and in situ testing equipment, shown in figures 8 and 9.

Figure 8. Calibration test at CERMES.

CERMES was working with an interesting new and innovative method of determining soil shear parameters. The shear resistance of the test soil specimen is measured against a series of different surface roughness values by rotating a central disk in a circular motion. Normal stress is not applied in a vertical, mechanical manner, as in the standard direct-shear test in the United States, but, rather, in a lateral, confining manner, such as in a triaxial test. The method could provide a test for accurately evaluating skin friction on piles or other materials under large strain, such as in reinforced soil materials.

Figure 9. Large-scale calibration room at CERMES.

CHAPTER 6

MAJOR FINDINGS

LESSONS LEARNED: LRFD

One of the primary interests of the scanning team was to better understand the Eurocode and the national application documents of the individual countries visited. Meeting with the authors of the Eurocode, and becoming familiar with the codes in each country, provided the team with a much clearer understanding of the concepts and structure of the Eurocode. It also became clear to the team that the understanding of Eurocode 7 varied significantly among the countries visited. Primary areas of misunderstanding were the definitions of characteristic soil and rock properties and of "partial factors." The team also found differences of opinion among European geotechnical engineers on how the following geotechnical issues or aspects of limit-state design should be handled:

- Application of maximum and minimum load factors to destabilizing and restoring forces to assess, for example, foundation bearing capacity and slope-stability effects.
- Magnitude of load factors applied to soil and water forces.
- Application of resistance factors solely to soil properties, rather than to the resulting soil resistance.
- Separation of soil-property uncertainty from method bias and uncertainty. (Eurocode currently does not separate these, but some national application documents do, such as in Sweden.)
- Structural load factors (Load Case B) and the geotechnical load factors (Load Case C) do not match and require a dual solution for both cases by the Eurocode in an attempt to resolve the conflict. Some countries are attempting to combine the two load cases, so that only one calculation is needed to meet both geotechnical and structural needs.
- In general, it appeared that the load factors for soil were too conservative and may even contain errors, arising from the conflict between structural and geotechnical needs regarding limit-state design.

Many of the areas of conflict are related to the absence of good communication in some countries between structural and geotechnical disciplines. A similar situation is also prevalent in the United States. Even with these shortcomings, there was a strong commitment in the countries visited to implement limit-state design, which was perceived to offer the potential for significant improvements in design, over time. In Europe, limit-state design is being taught in the universities, and at least one country has introduced the Eurocode at the university level.

Through the tour, the team had hoped to obtain the data used to calibrate the geotechnical load and resistance factors in the Eurocode or in the national codes in each country. Unfortunately, for the most part, it was found that the Canadian and European codes had only been "calibrated" to previous practice and that little statistical calibration of load and

> . . . based on the measured distribution and quality of property data, there appear to be misunderstandings among the various countries regarding how to determine the characteristic strength [of soil properties] and how to implement it in [the Eurocode]. In spite of this confusion, the quantification of a characteristic strength was an improvement over AASHTO and current U.S. geotechnical practice . . .

resistance factors, based on measurements, had been performed. The team unanimously agreed that if limit-state design (or LRFD) is to be fully implemented and areas of disagreement are to be resolved, statistical calibration of geotechnical load and resistance factors is a real need worldwide.

The team found that the Eurocode attempts to define characteristic soil properties, based on the measured distribution and quality of property data, but there appear to be misunderstandings among the various countries regarding how to determine the characteristic strength and how to implement it in the code. In spite of this confusion, the quantification of a characteristic strength was an improvement over AASHTO and current U.S. geotechnical practice, wherein variations in soil properties are not considered. The U.S. LRFD code, and U.S. geotechnical practice in general, does not address the issue of characteristic soil/rock properties. For example:

- How many tests per unit volume of soil are needed to have confidence in the design property being used?
- Should both an average and minimum or maximum soil/rock properties be provided to the structural designer, along with geotechnical recommendations?
- How does geotechnical engineering experience, especially site-specific experience (e.g., load tests), apply to the determination of the characteristic soil/rock property?
- How should this affect the soil/rock load or resistance factors?

The team felt that this was an issue that needs to be addressed in U.S. practice and that the guidance provided in the Eurocode is a good starting point. Overall, there was a general concern in the countries visited regarding the decrease in geotechnical exploration and testing (amount and quality) to support geotechnical designs. The team had similar concerns about U.S. practice. This is a trend that needs to be reversed because of its adverse effect on probability of failure and quality.

There was also significant concern expressed by the U.S. team regarding just how specific the code should be regarding geotechnical design and practice; that is, the U.S. code should not be too prescriptive, hindering, or eliminate the use of good engineering judgment, where good judgment should be applied. This issue tends to magnify the differences between structural and geotechnical engineering needs in a design code and in practice. Some aspects of geotechnical engineering require more professional judgment and do not lend themselves as well to being codified as does structural engineering. However, because there is a desire for and an advantage to having a uniform level of safety for all structures defined and achieved through the AASHTO LRFD Code, the team believes that geotechnical resistance values in the code should be calibrated and verified.

Regarding the issues of using maximum and minimum load factors for destabilizing and restoring forces and use of Load Cases B and C in the Eurocode, the approaches being attempted in the countries visited to resolve the problems include:

- Application of a single load factor only to the resultant force, rather than to individual soil forces.
- Use of a load factor of 1.0 for all soil forces.
- Separation of uncertainty of soil properties from model uncertainty, with the model factors applied at the end of the calculation rather than to individual forces.

Distinguishing destabilizing and restoring forces for soil was viewed as a significant problem in the Eurocode. For example, using the Eurocode and the concept of maximum and minimum load factors, it could easily be concluded that flat ground is unstable in terms of slope stability. This absurd example was mentioned in several countries to illustrate the problem. The situation makes factoring individual soil forces using limit-state design problematic, at best. Although work on this problem was identified by several agencies, a solution is neither simple nor forthcoming.

LESSONS LEARNED: INNOVATIVE CONTRACTING

The review of contracting policies and projects in which innovative contracting methods have been used provided the team with significant insight that could greatly assist the U.S. practice by avoiding pitfalls experienced in other countries. The lessons learned from the study tour include:

- Low bid, without some form of prequalification, is not used in most countries. For complex projects, the tendency in Canada and Europe has been to discard the use of low-bid awarding and to use a best-bid award practice to ensure long-term performance and value.
- Checking references to confirm the ability of low bidders to do the work is a novel and somewhat refreshing approach.
- Allowing contractors to submit design alternatives with bids is widely used in some countries. When allowed, a contractor’s alternate is often selected.
- As in the United States, it was found that government laws, environmental regulations, and permitting requirements tend to restrict or impede innovative contracting.
- Innovative contracting methods for public sector projects are often being implemented hastily and, primarily, to make up for shortages in staffing and overhead, without having well-developed process and technical details.
- Canada provided the most information regarding design-build practice. In Canada, however, as well as in the other countries visited, design-build experience is currently limited to the public sector.
- In Europe, owners typically provide a greater amount of design detail for design-build projects than is customarily provided in the United States.
- Specific performance objectives and required quality control procedures are clearly defined where design-build was found to be successful; however, when these items were poorly defined or quality control and assurance procedures were lax, owners incurred much of the same responsibility for correcting design and construction

errors and funding corrections as for conventional method-based, low bid award contracts.

- The persons interviewed had the general attitude that quality should not be a variable in the bid process. Detailed geotechnical investigations are often performed by the owner, prior to bidding (for design-build as well as most other innovative contracting practices).
- Generally, design-build is endorsed for large projects of significant engineering content or project complexity. Design-build was not viewed to be advantageous for simple projects.
- Consultants and contractors do not entirely support of the design-build approach because many early implementation efforts have placed the burden of unwarranted and unacceptable development costs and long-term performance risks on contractors.
- For the most part, the countries visited used a staged approach for design-build contracts that included prequalification, prior to the bidding process, and compensation for proposals by the qualified bidders to reduce the concerns from contractors.
- Quality control and assurance processes for geotechnical work appear to be well documented, at least in several countries that the team visited. Performance-based specification and performance measures for geotechnical features do not appear to have been comprehensively established.

One of the key areas of focus regarding innovative contracting methods was the amount of project information, design detail, and performance requirements provided by the owner to the contractor, prior to bidding on public works contracts. The team found that the extent and detail varied among the countries visited, but, in most cases, these countries provided a more complete design package and explicit performance requirements to prequalified bidders than has been typical in the United States. In both Canada and Europe, a geotechnical baseline report was provided by the owner in design-build contracts that, except in Canada, included preliminary geotechnical design and constructability recommendations. All of the individuals contacted felt that doing this was necessary to provide an adequate and fair basis for bidding and to avoid conflicts, disputes, and claims.

In Canada, a representative from the Deep Foundations Institute and the Canadian consultants indicated that the amount of geotechnical information provided for design-build contracts by the MTO was too sparse to provide an adequate basis for bidding. Based on the discussions, the MTO had provided only enough information to define the basic soil stratification, which did not include design properties or support values for the soil. This frequently placed too great a burden of risk on the contractor. The design of other project elements in Canadian design-build projects was carried out, prior to bid, by the owner (or consultant) to what would be considered the 30 percent PS&E level in the United States. At Øresund (Denmark/Sweden) an 80 to 90 percent complete design is provided—for guidance only—in the contract documents (geotechnical, structural, and general civil), but the contract specifications were more performance oriented than is typical in the United States. Geotechnical information was found to be a key element in obtaining designs of consistent quality among bidders. Based on experiences in the countries visited, generally, the more geotechnical subsurface and design (e.g., soil strength properties and compressibility properties) information provided to potential bidders prior to bidding, the more likely the design-build contract is to be successful.

Allowing contractors to submit design alternatives with bids was considered to be a successful form of contracting in Denmark, Germany, and France. This approach allowed a direct comparison of design alternatives from several bidders with the base design, while using the bidding process to define the real value of these alternatives.

In all the countries visited, the team observed that the only successful design-build projects were those in which detailed design/construction performance and required quality control objectives or criteria were specified. The better these objectives/criteria were defined, along with follow up to confirm implementation, the more likely the contract was to be successful. Although, the German government's only experience with design-build was not successful and featured poor quality and cost overruns. Performance requirements and control measures were apparently not adequately defined on that project, and little quality assurance was implemented.

Denmark provided a good example of performance-based specifications and quality control. In a submerged, cut-and-cover tunnel crossing from Denmark to Sweden, the following four performance and quality-control requirements were included in the contract:

- The contract specified that all designs must be in complete conformance to the Eurocode and the Danish design code.
- Contractors are required to verify and/or accept the accuracy of the conditions specified in the contract documents, including geotechnical conditions, as provided in the geotechnical baseline report. Any additional drilling, however, is usually post bid to verify foundation conditions. Once contractors produce satisfactory verification of the foundation conditions, they are required to "buy off" on the conditions and take legal responsibility for the geotechnical investigation, prior to construction.
  - Examples of how the contract specifies the desired performance include:
  - Structure must be designed to tolerate ___ mm of settlement over ___m length.
  - Foundation bearing pressure must be no greater than ___kPa, with a settlement of no more than ___mm.
  - Erosion of any fill placed must be no more than 5 percent of the fill volume placed. The method of measurement would be specified.
  - The desired performance of the structure over the first year of its life was specified (deflection, cracking, material durability, leaking, etc.).
  - After award, contracts require the contractor to provide a detailed QC/QA plan. Plans should include how performance criteria in the contract will be met and verified, who will check quality, what standards or procedures will be used (if the specific standards are not provided in the contract), how frequently quality will be checked, and how it will be reported and to whom. Owners review and approve the quality control plan and hold contractors accountable for it. When

> contractors send invoices to the owner to be paid for each portion of the work accomplished, the contractor must also submit detailed evidence that the quality control plan requirements for that portion of the work have been met. The contractor does not get paid until proof of quality control has been approved by the owner.

A general conclusion regarding quality is that it should not be a variable in the bidding process, but should be precisely defined, up front, through complete geotechnical information provided to the bidders, the contractors' quality control plans submitted as part of the bid, and reasonable long-term performance measures. A key item is the extent to which the scope and details of the design, specification, and quality control requirements can be changed during construction.

Other key factors in the success or failure of design-build and other innovative contracting techniques observed are the qualification and bidding processes. In general, a two-stage (or "two-envelope") system is used in Canada and Europe. Contractors submit a statement of interest and qualifications, contractors are short-listed to the top three to five bidders, and the short-listed bidders submit comprehensive project bids that include design and construction details. In some cases, the top bidders are paid stipends to help defray some of the costs to develop bid packages for this type of contract.

The issue of payment for developing bid packages was raised by the contractors interviewed as an area of significant concern because of the high cost of developing design-build bids. Small contractors simply cannot afford to submit a bid for this type of contract, and even larger contractors cannot afford to lose too many of these types of contracts. For geotechnical specialty subcontractors, the issue is made worse by the fact that one geotechnical subcontractor or consultant may be asked by several bidders to submit a design for bidding purposes, each of which could be a different design, substantially driving up the bidding cost for geotechnical subcontractors and consultants. This poses a dilemma for geotechnical subcontractors and consultants: To get work, one must submit bids; but, if enough bids are lost, the cost of the bidding process could easily exceed the amount gained by winning the bid. Contracting authorities in some countries did, however, express concern about paying for bids, up front, because of the potential for abuse of the system.

Canada appeared to have the most developed system for reviewing and rating contractor proposals. Proposals submitted by the short-listed contractors are initially evaluated for technical merit, and a technical score must meet a minimum allowed. All proposals meeting the minimum score are then evaluated for cost. Performance appraisals of the contractor's work is performed during and after the work is completed. Three consecutive bad ratings can result in a contractor being banned from work for 2 years. Canada would like to incorporate performance ratings based on past work, as well as the technical score for the proposal, into the bid—a best-buy approach—and is working to refine the criteria.

One case, in Denmark, used a best-buy approach, adjusting the bid to include technical merit of the proposal and, possibly, other factors. Furthermore, the Danes negotiated with the top three bidders and had them resubmit bids using a best-and-final-offer approach to make the final selection.

In all of the countries visited, the size and type of a project significantly affected the chances of success in design-build contracting. The general trend was that projects smaller than US$5 to US$10 million are probably not good candidates for design-build. Furthermore, the project should have significant opportunities for engineering alternatives in terms of alignment, structure types, and/or foundation conditions. Paving or road-widening projects are probably not the best types of projects on which to apply design-build techniques. Design-build was not recommended as a routine method of contracting, and projects where design-build is applied should be carefully selected. Moving to a more performance-based specification method and allowing alternative bids may, however, be more widely applicable, based on the experiences in Canada and Europe.

In general, most of the individuals the team met with agreed that design-build contracting has the potential to reduce design/construction time and, possibly, cost, for the right kinds of projects. Based on their experience, however, environmental constraints, permits, and environmental approvals can reduce or eliminate the benefits of this contracting technique.

One observation related to innovative contracting was the high degree of outsourcing being attempted in Canada, especially at the MTO. Following recent staff reductions, approximately 70 percent of design work and more than 90 percent of construction administration work is now outsourced. When asked what effect this high degree of outsourcing has had on the ability to control the quality of the projects and the engineering needed to accomplish those projects, MTO representatives conceded that they did not have a clear picture of how the changes are affecting project quality or cost—they haven't been in this situation long enough to know yet. The same is true regarding the ability to retain engineering expertise. Although much of the staff has been reduced, the effect on the engineering expertise they have retained is currently unknown. However, the consultants and contractors present at the meetings indicated that, if anything, the MTO has become more autocratic and bureaucratic, and, in general, it appears that changes in the MTO are viewed as negative. In addition, the contractors observe that too much risk being placed on them because of the high degree of outsourcing. The ministry staff that the team met, both from Ontario and British Columbia, foresee serious negative effects resulting from the changes. Again, however, the changes have not been in place long enough to observe the results.

LESSONS LEARNED: INNOVATIVE GEOTECHNICAL PRACTICES

The contacts made and the identification of good sources of information on current activities in Canada and Europe will significantly support ongoing work in the United States. The team felt it would be worthwhile to continue interaction and follow up with individuals regarding geotechnical innovations in the areas listed below:

- Canada, in particular the Royal Military College in Kingston, Ontario (Dr. Richard Bathurst), and the University of British Columbia (Dr. Jonathan Fannin), are quite active in MSE wall and reinforced-slope research, both for static and seismic design. Some teamwork between the United States (i.e., Washington State DOT and the FHWA) and Canada (i.e., RMC) is already under way in the area of geosynthetic wall research. Other cooperative efforts should be explored.
- Europeans are developing the concept of characteristic soil property values. The United States could learn from this practice.

- Germany is researching the use of expanded polystyrene (EPS) as a lightweight fill material and roadbed material. The information obtained could supplement ongoing U.S. research efforts on this subject, such as a current NCHRP study.
- Germany is developing a portable compaction quality control device, which uses a concept similar to FWD testing. The device measures the modulus of the soil and appears to be applicable to a wider range of soils than the nuclear-density test. This device could prove to be a valuable alternative to the devices currently used in the United States. Furthermore, modulus may correlate better to good fill performance than the currently measured parameter of density.
- Load-test data in Sweden may be a valuable addition to the pile load-test database that the FHWA is assembling.
- Denmark's dewatering technology appears to be well-advanced, especially for high-flow rate sites that are difficult to dewater. The Danish beach erosion techniques could also prove useful in the United States.
- There appears to be a lot of future work in tunneling in Europe. It would be worthwhile to keep in contact, especially with the Germans, for new technological developments in this area.

Figure 10. Interesting foundation approaches were also observed.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS FOR IMPLEMENTATION

All team members agreed to the recommendations below, which are prioritized according the need for action.

The team agreed that a calibration of the geotechnical load and resistance factors in LRFD code is the most important issue and should receive immediate attention. AASHTO should set verification of the codes against existing computer databases (e.g., the FHWA's database) as a top priority. Consideration should also be given to using a separate analytical model factor and soil parameter variability factor in the code to better coordinate structural load factors with geotechnical load and resistance factors.

To facilitate the implementation of LRFD in geotechnical engineering, and allow for a smooth transition from current practice, AASHTO should establish a steering committee to develop an implementation plan. At minimum, the plan should include 10 steps:

To facilitate the implementation of LRFD in geotechnical engineering, and allow for a smooth transition from current practice, AASHTO should establish a steering committee to develop an implementation plan.

1. Modify the code to include model and soil reliability factors.
2. Clearly define the characteristic value for soil parameters, with consideration for requiring average and minimum values for each soil property.
3. Carefully calibrate and compare to the current allowable stress design methods.
4. Use reliability-based calibration and separate verification of the LRFD code.
5. Improve readability and user friendliness of the AASHTO code related to geotechnical engineering.
6. Coordinate all LRFD efforts, including ongoing NCHRP projects and international work.
7. Approach lead States to showcase successes with LRFD design.
8. Establish promotional efforts to encourage immediate implementation of LRFD in geotechnical engineering with the message that: At worst, you will get what you had; at best, you get a better design.
9. Establish performance benchmarks for evaluation of future modifications, improvements, and measurements of success.
10. Establish a strong educational effort, including a program to educate educators, demonstration projects for load and resistance factor design of substructures, and a method for periodic assessment.

A key goal of the steering committee and other civil engineering organizations should be to improve communication between geotechnical and structural engineers. Training is required for everyone associated with design, including geotechnical, structural, construction, and administrative personnel. Communication requirements for geotechnical and structural engineers need to be documented in terms of what is expected from both groups and how they should interact, including methods for feedback during the design process. Team processes should be encouraged for design. “Canned” presentations should be developed that clearly explain the origins of the factors in limit-state design. Training must begin at the university level.

With regard to innovative contracting, the team agreed that a strong effort should be made to eliminate contractor selection based solely on low bid. A method should be used that considers contractors’ qualifications and past performance. Steps should be taken to introduce a staged contracting procurement process as a method to significantly improve the construction of geotechnical features, in terms of quality, time, and cost. A prequalification process that includes expressions of interest and qualifications, prior to request for proposals, should be established. Contractors should be required to give references to prove they can do the job, and lists of approved contractors, along with past-performance history, should be maintained.

Other high-priority items that should receive immediate consideration for implementation include the following:

- Establish owners’ upfront geotechnical exploration requirements for design-build contracts.
- Develop more specific guidelines on the number of tests and quality of geotechnical properties, along with the effects of these issues on load and resistance factors. Geotechnical engineers should be required to provide average and minimum values for soil properties to help establish the variability of the characteristic values.
- Establish guidelines for developing quantitative performance criteria, including fully defined requirements for an effective quality control plan for design-build contracts. Contractors should be required to prove that the desired level of quality has been accomplished before receiving payment for the work completed. Consider including maintenance responsibilities or a warranty, for some duration, in the contract.
- Develop quality control and assurance requirements for geotechnical features.
- Develop guide performance measures for geotechnical features.

While the following items were considered to be of lower priority, they are important for future study:

- More detailed scanning should be conducted in Canada to study innovative contracting. A scan to Australia should be undertaken to study LRFD.
- For LRFD, develop guidelines for geotechnical practice for inclusion in the commentary section of the AASHTO bridge specifications. The guidelines should include some presumptive spread-footing bearing capacities and lateral pile capacities for well-defined, routine conditions.
- Regarding design-build projects:

  - Prepare a list of do's and don'ts for design-build practice.
  - Develop a practice for paying reasonable stipends for detailed proposals to establish ownership rights of innovative ideas.
  - Promote the use of dispute review boards for design-build projects.
  - Establish geotechnical performance benchmarks (e.g., life-cycle costs) for design-build projects.

- Consider allowing alternative bids as a method of encouraging contractor innovation.

APPENDIX A: AMPLIFYING QUESTIONS

TOPIC 1. LOAD RESISTANCE FACTOR DESIGN (LRFD)

1.1 Please provide a brief history of the use of LRFD in your country, including its use for design of structures and geotechnical features.

1.2 What methods (for example, reliability theory, calibration to previous allowable strength design methods, etc.) were used to determine and validate load and resistance factors for geotechnical design, such as footings, piles, shafts, walls, etc.

1.3 If available, please include information on the determination of load and resistance factors for geotechnical design, where load and resistance are coupled together, such as in soil structure interaction problems, slope stability, downdrag loads, etc.

1.4 Do you have measured data for establishing the factors for various types of geotechnical structures, and are these data available to our group?

1.5 How have you incorporated the effect that variability/reliability has on load and resistance factors, due to:

- site variability.
- soil testing methods used (laboratory and field).
- design method used, such as for pile design, slope stability, etc.
- construction technique used, such as various downdrag and corrosion mitigation.
- methods, slurry versus casing for drilled shaft construction, etc.
- the construction quality control used such as pile driving formulas versus wave equation or pile driving analyzer, type of drilled shaft inspection implemented, qualifications of inspection organization as well as the amount of quality control implemented.

1.6 What are your specific LRFD design provisions for geotechnical features, including:

- driven piles, drilled shafts, and spread footings. (Information on how the nominal strength is defined and what limit states are used would be very useful to our study.)
- ground water effects for bearing capacity in cohesionless soils, water level fluctuations in slope stability analysis, etc.
- seismic design.
- lateral loads on piles and drilled shafts, including how scour and ship impact loads are handled.
- pile and shaft group efficiency for both axial and lateral loading conditions.

1.7 What process do you use to make changes in your LRFD codes?

1.8 What are some of the load or resistance factors that have significantly changed since LRFD was first used in your country? Why did they change? In what areas are the factors still questionable?

1.9 Please describe the design responsibility and communication process between the structural and geotechnical engineer in terms of design loads and soil properties required to determine resistance values for foundation design of structures such as bridges, cantilever retaining walls, and mechanically stabilized earth (reinforced soil) retaining walls.

1.10 Have you established design guidelines, standards, or codes for implementation of LRFD? Please, indicate the status of each document (i.e; recommended procedure, standard, or code of practice). Are documents legally binding or guidance oriented? Could you please provide us with a brief summary of any of these documents in English?

1.11 How does your national code differ from the European Code?

1.12 What education and training programs for LRFD have you implemented for agency personnel, consultants, and design-build contractors? Please provide us with a copy of any of your education and training materials.

1.13 Have specific industries or agencies resisted the change to LRFD? How has any resistance been overcome?

1.14 What was the cost associated with implementing LRFD?

1.15 What benefits/advantages, such as cost savings or improvements in foundation designs, have resulted from the use of LRFD versus previous methods?

1.16 What problems have you identified with respect to LRFD? Has there been a de crease (or increase) in foundation "failures" after implementation of LRFD?

1.17 Please provide us with your opinion on LRFD versus previous design practices. Is LRFD a better method?

1.18 What advice would you give to a country that is just starting to use the LRFD method for design of geotechnical features?

TOPIC 2. INNOVATIVE CONTRACTING AND PERFORMANCE-BASED SPECIFICATIONS

2.1 Please describe your current contracting and bidding practices, including:

- details of the contractor selection process (such as low bid, best bid, qualified bid, or prequalified bidder).
- contractor and subcontractor evaluation procedure.
- use of partnering and team concepts.

- basis for the final selection (price, quality, etc.).
- any legal requirements (Do laws dictate the bidding procedure?).

2.2 Please describe your design-build contracting practice, including a brief history of its use with examples of successes and failures.

2.3 Is design-build used for both large and small projects? Does design-build apply to both large and small contractors?

2.4 Are design-build firms prequalified, prior to bid? Are subcontractors prequalified, and, if so, what are the qualification requirements for geotechnical subcontractors (design consultants and specialty contractors)?

2.5 Are performance-based specifications used (especially for design-build contracts)? How are performance requirements established?

2.6 Are contracts based on "sole risk" by the contractor, or "shared risk" with the owner? Are warranties required in the specifications and, if so, for what length of time? Are performance bonds required?

2.7 What pre-engineering requirements are provided to the contractor (subsurface investigation. load limits, codes of practice, etc.)? Is the contractor required to perform his own preliminary subsurface exploration prior to bid, or is he required to make a post-bid detailed exploration?

2.8 Are minimum geotechnical exploration/evaluation requirements established in specifications? If so, can you please provide us the minimum qualifications usually required for various types of geotechnical works?

2.9 How are unanticipated subsurface conditions handled, especially in design-build contracts?

2.10 In implementing design-build contracting, what education and training programs have been established for your agency's personnel?

2.11 How is quality of the final product controlled in design-build contracting? Please provide any available information and documentation on provisions for quality control and quality assurance programs pertaining to:

- design and construction quality control guidelines for the contractor.
- quality control plan requirements for the bid submittal.
- contractor verification requirements for geotechnical materials.
- testing lab certification or qualification requirements.
- quality assurance reviews performed by the agency to ensure that the product meets the owner's requirement during 1) design, 2) construction, and 3) post-construction.

2.12 What obstacles (such as public approval) have you experienced in trying to adopt design-build contracting methods?

2.13 What problems have been encountered with design-build contracts?

2.14 Where has design-build worked well for constructed geotechnical features? Where has it not worked well?

2.15 Have you identified significant cost savings, time savings, or better solutions using specific innovative contracting methods? Please provide some examples and any details that might be available.

2.16 Please describe any new or improved contracting methods that you are currently evaluating.

TOPIC 3. GEOTECHNICAL PRACTICE

3.1 The panel is also very interested in any new or improved geotechnical products or practices (materials, design or construction related) which you may currently be evaluating, or have recently implemented. Areas of special interest include:

- ground improvement: methods and evaluation of final product.
- mechanically stabilized earth (reinforced soil) walls: types, design, codes of practice, evaluation and approval process, construction methods, geosynthetics versus steel, and instrumented case histories.
- in situ testing of geotechnical materials and their relation to design.

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Publication No. FHWA-PL-99-013
HPI-10/3-99(3.5M)EW