Load and Resistance Factor Design in Geotechnical Engineering

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Load and Resistance Factor Design (LRFD) is a relatively new approach used in civil engineering. Engineers at state departments of transportation are beginning to design various infrastructure (e.g., bridges, retaining walls, and slopes) using LRFD methods. As transportation agencies have shifted to LRFD methods, they have faced new challenges and experienced mixed levels of success.

In civil engineering design, some variability is inherent in the design parameters used. Because of this variability, a value for each parameter must be selected as normal, and limits set on the extent to which variation from the normal is acceptable. When designing a bridge, for example, an engineer needs to know the magnitude of the load the structure is expected to carry and the necessary strength of the material used for construction. If the load is denoted as L, then L is multiplied by a number termed the *load factor* to account for its variability from the normal value. Similarly, if the strength of the material is denoted as R (for resistance), then R is multiplied by a number termed the *resistance factor*, again to account for its variation from the normal value.

Usually, the load factor is greater than 1, and the resistance factor is smaller than 1. This ensures that the design will accommodate the biggest load to which the item may be subjected and that the weakest part (lowest resistance) of the item will be able to carry that load.

Development and Implementation

In the late 1980s, some of the first significant work on LRFD in the geotechnical engineering area was performed. In 1991 the results of this work were published in National Cooperative Highway Research Program Report 343, *Manuals for the Design of Bridge Foundations*. The American Association of State Highway and Transportation Officials adopted the LRFD procedures for bridge design in 1994. LRFD was a logical and somewhat easier extension of Load Factor Design for structural engineering. LRFD for geotechnical engineering, however, required a significant change from the allowable stress design (ASD) methods then in use.

The states are not required to use LRFD, but it is the only approach AASHTO will support after the year 2000. Therefore, it is desirable for all states to change their procedures to LRFD to remain current with the new technology and to ensure quality design methods.

To date only a handful of the state DOTs, including those in New York and Pennsylvania, have formally implemented LRFD. Many states, however, are considering making the change. Meanwhile, a number of questions have arisen that must be addressed. These questions relate to the values of load and resistance factors, and to calibration procedures necessary to ensure that these factors are in line with acceptable and safe methods currently in use. In addition, procedures for the implementation of LRFD need to be defined.

Most agencies appear to be unsure of the impact of the new methods on their normal operations. Since some of the methods, particularly in the geotechnical and substructures area, are significantly different from those used at present, the transition to LRFD is not easy. Moreover, many load and resistance factors, such as those for general slope stability analysis, are not clearly defined or established. There is a considerable need for additional research and development on procedures required to shift to LRFD methods.

AASHTO recently funded several NCHRP research projects to address these concerns. Among these are projects on LRFD Specifications for Retaining Walls; LRFD Bridge Design Specifications Support; LRFD Deep Foundation Design; and Thermoplastic Drainage Pipe, Design, and Testing. Completion of these projects should help answer some of the questions related to LRFD. However, a concerted effort in the implementation of the new methodology is urgently needed if its benefits are to be realized in practice.

LRFD at Pennsylvania DOT

Prior to LRFD, PennDOT used ASD for geotechnical engineering. The state conducted parametric studies to ensure that the LRFD procedures would lead to a reasonable design, in line with the results of the ASD method. Several consultants working under a PennDOT contract performed the parametric studies, whose results served as the basis for acceptance or revision of the LRFD procedures at PennDOT. Necessary changes to the LRFD procedures were made to meet PennDOT criteria. Other changes were made to the DOT's policies, procedures, design manual, standards, specifications, and computer programs.

The PennDOT design manual was revised to address the changes in the design procedures due to LRFD. The revisions were made to policies and procedures regarding the submission of a geotechnical report, specifically items related to the foundations, loads, and load factors; consideration of service and strength limit states; resistance factors and the influence of soil/rock type; foundation type; and analytical method used. In addition, the test data needed for the factors were addressed. The new PennDOT approval procedure requires many other items in addition to the allowable foundation pressure used under ASD. With the LRFD procedures, approval is required for soil types, foundation type, subsurface boring data, soil and rock properties, settlement-of-strata estimates, analytical procedures, load factors, and resistance factors. Earlier computer programs, such as Abutment and Retaining Walls, have been replaced with new programs. Other agencies will very likely have to make such changes to adopt the LRFD procedures.

Training of design personnel is a key element of the implementation strategy. Many issues are not obvious from the design guidelines. Design examples and the correct interpretation of codes and manuals are critical for successful use of the new concepts. As a result, many training sessions were held for PennDOT engineers.

A cooperative LRFD implementation effort between New York and Pennsylvania is currently under way. Other states and agencies are expected to participate in this effort, which should help make the transition to LRFD both efficient and economical. Cooperation of the states and others is critical to minimize the difficulties associated with such a major change in design procedures and to ensure uniformity among agencies. Such cooperation will also minimize costs as the participating agencies work toward a common goal.

Geotechnical Related Development and Implementation of Load and Resistance Factor Design (LRFD) Methods

National Cooperative Research Program Synthesis of Highway Practice 276 documents a review of geotechnical-related Load and Resistance Factor Design (LRFD) specifications and their development worldwide. Design procedures for foundations, earth-retaining structures, and culverts are summarized and compared with the current AASHTO LRFD Bridge Code. Information for the synthesis was collected by surveying U.S. and Canadian transportation agencies and by conducting a literature search using domestic and international sources. Interviews of selected international experts were also conducted. The limited experience with LRFD to date in the United States and information from international practice are reviewed to clarify problems that have arisen so that solutions can be developed. Suggestions for further work are offered on the basis of a review of various LRFD codes.

Pros and Cons

It is as yet too early to tell how well the new LRFD approach will serve its intended purpose and the extent to which it will improve design in the geotechnical area. The PennDOT *LRFD and Metric Training Manual* states the following as the chief advantages of LRFD:

- More uniform level of safety throughout the system
- Safety as a function of the variability of loads and resistance
- Ability to estimate the probability of meeting or exceeding the design criteria during the design life
- Potential to place all structural materials and construction methods on an equal basis
- Opportunity to have a framework for future development of specifications
- Availability of a measure of reliability to be used in future development of specifications
- Better understanding of the sources and reasons for load and resistance factors

The LRFD approach separates the different aspects of design, such as load types, material types, and the analytical procedures and factors that contribute to the design outcome. A large number of items are required as input information for the design. Ideally, if the input parameters are obtained using rigorous testing and data collection methods, the LRFD procedures should result in an improved design. Conceptually, the procedures should provide a uniform probability of failure for all aspects of the design. In the geotechnical area, however, there are a number of practical difficulties associated with the LRFD concept:

◆ Many types of loads must be considered and the associated load factors determined. Loads associated with earth pressures are not readily available. The LRFD procedures suggest different load factors for vertical and lateral (horizontal) earth pressures. Often a single earth load has components in both vertical and horizontal directions. It is unclear how these load factors are to be applied under LRFD.

◆ Resistance factors are calibrated, assumed, or based on information available in the existing literature. Calibrations are often made on the basis of factor-of-safety concepts, which LRFD is intended to replace.

◆ The design effort is likely to take longer to complete with LRFD because of the additional information required. The cost of geotechnical investigations will probably increase as well because of the larger number of soil properties needed as input.

◆ Slope stability analysis is currently not addressed in LRFD; therefore, the existing factor-of-safety methods will continue to be used.

◆ Most geotechnical engineers are not fully familiar with LRFD, and it will be some time before the procedure is generally accepted.

Conclusion

The LRFD method is based on the probability of failure of each component of a design item. Hence the method provides uniform design procedures for superstructures and substructures. Use of the LRFD approach in geotechnical engineering can therefore result in better designs than those derived through existing procedures.

Geotechnical Engineering
Related Websites

Federal Highway Administration: www.fhwa.dot.gov/bridge
Contains information on the FHWA geotechnical program, including publications, software, and training. This is also the current site for the Transportation Research Board's Committee on Foundations of Bridges and Other Structures.

Turner-Fairbank Highway Research Center: www.tfhrc.gov
Provides information on the facilities, program, and various ongoing activities at the Center.

U.S. Army Corps of Engineers: www.erdc.usace.army.mil/
Links are provided to the geotechnical engineering laboratory at the Waterways Experiment Station and the Cold Regions Research and Engineering Laboratory. The WES site provides information relevant to dam and levee construction; military vehicle mobility and trafficability; pavements; earthquake engineering; and groundwater protection, contaminant abatement, and materials testing. The CRREL site provides information on theoretical, experimental, laboratory, and field investigations.

U.S. Geological Survey: www.usgs.gov
This is the website for USGS, with links to such subjects as biology, geology, mapping, and water; a search engine; and more.

U.S. Geological Survey National Earthquake Information Center: earthquake.usgs.gov/neis/epic/epic.html
Permits searches of the worldwide epicenter database maintained by USGS. Searches may be performed for the entire world, for square areas defined by geographic coordinates, or for circular areas defined by radii about geographic centers.

U.S. Environmental Protection Agency: www.epa.gov/epahome/Data.html
This is the Database & Software portion of EPA's website. Geographic information system (GIS) data, metadata, and technical tools are provided. One of the most useful datasets is BASINS (Better Assessment Science Integrating Point and Non-Point Sources), available from the Media Specific Databases & Tools link. This dataset includes many components of topography, geology, soils, and hydrology on a drainage-basin basis. Drainage basins are indexed by the eight-digit USGS Cataloging Unit, selectable by clicking on an interactive map.

Natural Resources Conservation Service: www.nrcs.usda.gov/TechRes.html
Serves as the gateway to the soils database, including GIS-based polygon data with extensive data tables.

United States Universities Council on Geotechnical Engineering Research (USUCGER): www.usucger.org
Pertinent information about geomedia research at 96 member universities in the United States is provided. USUCGER's mission is to provide advocacy for the continued development and expansion of high-quality geomechanical, geotechnical, and geo-environmental engineering research and education.

Transportation Research Board: www4.national-academies.org/trb/onlinepubs.nsf
TRB's website provides a searchable index of the Board's publications and articles, which cover all modes and aspects of transportation, including geotechnical engineering.