

MoDOT Research Program to Improve Design of Bridge Foundations

*J. Erik Loehr, John J. Bowders, William J. Likos, and Brent L. Rosenblad
University of Missouri*

*Ronaldo Luna, Louis Ge, Norbert Maerz, and Richard W. Stephenson
Missouri University of Science and Technology*

Introduction

Like other state departments of transportation, the Missouri Department of Transportation (MoDOT) has recently transitioned to load and resistance factor design (LRFD) methods for design of bridge foundations and other geotechnical structures within the state. With this transition, the opportunity exists to evaluate and improve upon traditional design procedures and methods to produce substantial cost savings for the agency and taxpayers of the state while maintaining appropriate and consistent performance and risk. With this objective in mind, MoDOT has recently embarked on a comprehensive research program intended to holistically look for ways to improve design procedures (interpreted broadly) for the benefit of the agency and public. The geotechnical aspects of this research are being collaboratively performed by the authors along with their students from the University of Missouri and Missouri University of Science and Technology. The specific geotechnical applications selected for the research program include design of bridge foundations including drilled shafts, driven piles, and spread footings, and design of earth slopes and embankments. The deliverables to be produced through the work include a revised design specification for bridge foundations, a new design specification for earth slopes and embankments, and several design commentary documents that will provide justification and explanations for the provisions in the design specifications themselves. Principal funding for the research is being provided by MoDOT with additional funding being provided by the National University Transportation Center at Missouri S&T and the University of Missouri. The two year research program began in November 2008 and will be completed in October 2010. This article provides a summary of the motivation and objectives for this ongoing research program along with a summary of the major activities being undertaken with a focus on the aspects of this work related to using drilled shafts for bridge foundations.

Motivation and Objectives

The overarching motivation and objective for the research program is to achieve significant and recurring cost savings for MoDOT by developing improved, technically sound design specifications. In essence, the proposed program is expected to help MoDOT do better engineering to reduce costs while maintaining adequate safety and performance of state transportation facilities. The means to implement the improvements to engineering design will be the new and substantially revised design specifications. The new specifications will be based on LRFD concepts that produce consistent and appropriate performance/risk for the local conditions and consequences involved.

The present opportunity for realizing substantial cost savings for foundations and earth slopes arises from the recent adoption of LRFD approaches and increased awareness and acceptance of risk-based design concepts. Risk has of course always been implicitly considered in engineering design. However, the traditional approach employs “engineering judgment” in an ad-hoc manner to balance risks and costs based on the information and knowledge available. Unfortunately, this seldom produces the desired result of consistent and appropriate performance and risks but instead leads to cases that are substantially over-designed and other cases that may be under-designed, both of which cost agencies unnecessarily.

At its best, the LRFD approach produces appropriate and consistent risks for engineered facilities without requiring formal risk analyses for specific projects. This approach can lead to substantial cost

savings by avoiding excessive conservatism in cases where it is not warranted, and avoiding excessive maintenance and rehabilitation costs in cases where performance is unacceptable. However, achieving this desirable result requires explicit consideration of all factors contributing to risk. For geotechnical applications, the primary factors that contribute to risk include (1) uncertainty in soil properties and site conditions, (2) uncertainty in design and construction methods, and (3) the consequences (costs) of unacceptable performance or failure for a particular case. The MoDOT research program aims to explicitly address each of these specific factors in order to achieve substantial cost savings for bridge foundation applications.

The technical premise upon which this work is based is that “local” or regional design specifications, calibrated based on local conditions and issues, can be made more efficient than broader “national” specifications for geotechnical applications because variability due to differences in regional practices and conditions is reduced when considering only a specific locality or region. This premise is illustrated in Figures 1 and 2. Figure 1 shows a collection of measurements of unit side shear for drilled shafts in shale obtained from load tests performed for state DOTs throughout the central U.S. Also shown in the figure is a prediction method for estimating unit side shear from uniaxial compression tests of shale cores. The scatter in the data arises from several potential sources that include: (1) variability in side shear capacity due to differences in the specific conditions encountered at the respective load test sites; (2) variability in measurements of shale strength as a result of different sampling and testing methods; (3) variability in side shear capacity due to differences in construction methods; and (4) variability in side shear capacity due to the load testing methods. Restricting the data to a specific state generally reduces the amount of scatter because some of these variabilities are reduced (Figure 2). In this specific comparison, the variability in ultimate unit side shear, as measured by the coefficient of variation (COV) of the data about the prediction method shown, is reduced from 46 percent for the entire collection of data to 26 percent for the data set that includes only tests performed for MoDOT. Of course this premise is complicated somewhat by the fact that greater numbers of measurements will generally increase variability even at a single site and there has to be some balance between collecting sufficient data to establish a reasonable estimate of variability and restricting that data to be representative of a reasonable set of conditions. Nevertheless, the idea of isolating the sources of variability and reducing these to the extent possible is strong motivation since it is this variability that primarily dictates the resistance factors that can be used and, in turn, the efficiency of the resulting designs.

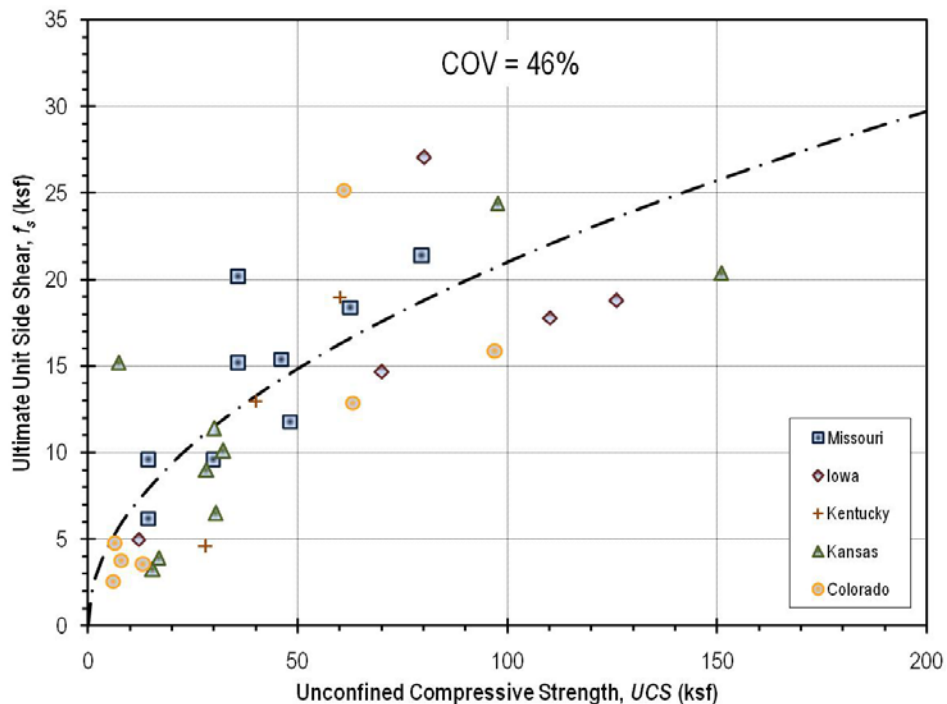


Figure 1. Measurements of ultimate unit side shear collected from load tests performed in shale in the central U.S.

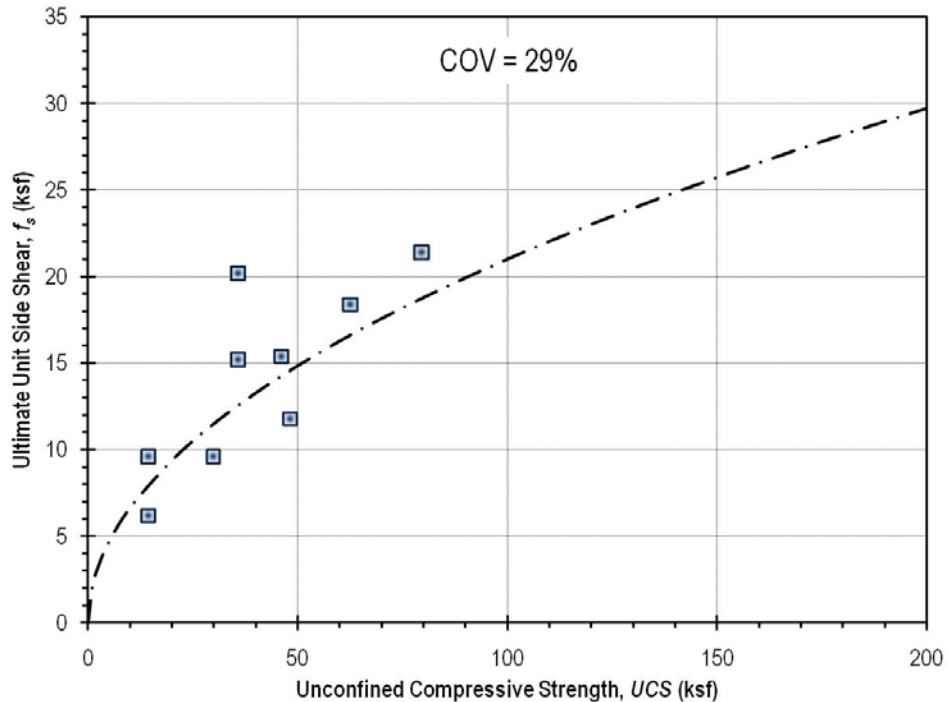


Figure 2. Measurements of ultimate unit side shear collected from load tests performed in shale in Missouri.

Scope of Work and Progress to Date

The scope of work for the research program includes four broad tasks. The first three tasks are respectively focused on quantifying contributions to risk from variability and uncertainty in measurements of soil or rock properties, variability and uncertainty in the capacity of bridge foundations from design and construction methods, and the costs/consequences of unacceptable performance. The final task is focused on development of design specifications to allow implementation of the improvements provided by the research. This scope of work is expected to isolate different contributions to risk, address the contributions that can be reduced or eliminated, and account for the remaining contributions with appropriate load and resistance factors to produce more efficient designs. The following paragraphs describe the ongoing and planned activities for each task with specific focus on application to bridge foundations in general and drilled shafts in particular.

Task 1 – Uncertainty from Site Characterization

The primary objective of Task 1 is to quantify the variability in relevant design parameters so that this contribution to risk can be appropriately accounted in the design process. This work is expected to quantify “hidden” conservatism or “bias” in measurements of design parameters from current MoDOT practices and identify potential improvements to those practices that will reduce or eliminate bias and/or variability in design parameters. Specific procedures for establishing site specific variability in design parameters from laboratory and/or field measurements will also be produced for use with the LRFD design specifications.

To achieve these objectives, the research team has conducted extensive characterizations of sites that are generally reflective of geotechnical conditions encountered throughout the state. These characterizations have been completed at two different levels. The first level of site characterization is consistent with current MoDOT practices, while the second represents characterization using the “best available” site characterization techniques. Comparison of results from these two characterizations will allow the team to establish potential bias in measurements of design properties (e.g. from sample disturbance, interpretation methods, etc.) as well as to quantify potential differences in the variability of

design parameters established from different site characterization techniques. The specific site characterization techniques being utilized in this task include:

- special boring, sampling, and sample care techniques such as careful use of drilling mud, use of fixed piston and Pitcher samplers, and careful transportation and storage of acquired samples;
- laboratory tests on high quality, trimmed specimens including conventional drained and undrained triaxial, direct shear, direct simple shear, and 1-D consolidation tests on soils and confined and unconfined compression tests on rock;
- in situ tests such as standard penetration tests, continuous push and dynamic cone penetration tests, pressuremeter tests (Figure 3), and “Texas Cone” penetration tests in soil and/or weak rock; and
- a wide range of index and classification tests such as point load index tests, X-ray diffraction tests, carbonate content tests, and Atterberg limits, etc.

When characterizing shale materials, which are found across the state, laboratory tests are being performed in the field to reduce the potential for degradation of the rock that is common with such materials upon exposure (Figure 4).



Figure 3. University faculty and graduate students performing pressuremeter tests at field test site in Kansas City, Missouri.



Figure 4. Graduate student Kerry Magner and MoDOT's Sherri Stevens performing point load index tests at test site in Kansas City, Missouri.

Task 2 – Uncertainty from Foundation Design/Construction

The general objective of Task 2 is to quantify and potentially reduce the bias and variability of design estimates for foundation capacity. Work for this task includes collection, evaluation, and analysis of results from existing load tests as well as a program of full-scale field load tests to enhance the quantity and quality of data available for these evaluations. The bulk of these load tests will be performed on drilled shafts socketed into weak rock because of the prevalence of such conditions across the state and because drilled shafts were deemed to be the foundation type where the greatest cost savings can be realized. A secondary objective of the load testing program is to help establish the value of field load tests to help MoDOT decide when design and/or construction phase load tests will produce lower cost structures. The approach taken for Task 2 is conceptually similar to that for Task 1, except that the load test program will quantify variability and conservatism in foundation design procedures themselves (many of which are empirically based) while the site characterization program will quantify the variability and conservatism in the input parameters that are used in those design methods. The combined effects of the input parameters and design procedures will be integrated as part of Task 4.

Planning for the drilled shaft load testing program is currently underway with the expectation that all testing will be completed in spring 2010 to allow time for the results to be incorporated into the development of the LRFD specifications. Current plans are to perform a total of twenty load tests, with ten of these tests planned for a site that is generally representative of conditions commonly encountered in the western half of the state and ten planned for a site that is generally representative of sites in the eastern half of the state. Test shafts for the load test program are expected to be 3 to 4 feet in diameter. The test shafts will be tested using both the O-Cell and conventional top-down loading methods.

The intent of performing a large number of tests at relatively few sites as opposed to individual tests at a larger number of sites is to allow for isolation of the contributions to variability (risk) from design and construction methods and to obtain reasonable estimates for "site specific" variability in foundation capacity at each site. In addition to being reflective of conditions encountered in different regions of the state, the test sites were selected to provide results that will reasonably span the range of shale strengths commonly encountered and to provide sites that have different levels of variability in shale strengths so that the site specific variability of shaft capacity can be related to site specific variability in shale strength.

Task 3 – Establishing Target Reliabilities

The primary objective of Task 3 is to establish appropriate target levels of reliability for bridge foundations and earth slopes and embankments. The fundamental basis for this task is the widely held notion that acceptable and appropriate levels of reliability are dependent on the consequences (costs, or rewards) associated with a specific situation. Current design specifications unfortunately ignore this relationship between appropriate reliability and cost/reward by mandating or recommending constant levels of reliability. While this position simplifies design to some extent, it also produces the undesirable

situation where high consequence situations (e.g. major bridges across major waterways) are designed for reliabilities that are lower than may be warranted by the potential consequences while low consequence situations (e.g. small stream crossings on rural highways) are designed for reliabilities that may be much greater than is warranted by the potential consequences. While use of a constant target reliability can be appropriate for typical situations, the “one size fits all” approach tends to promote potential over spending on smaller, less critical structures and under spending on larger, more critical structures. The intent of this task is to try to remedy this situation by using target reliabilities that depend on the consequences involved with different classes of structures.

Since there is a general relationship between the reliability of bridge foundations and the cost of those foundations, selection of target reliabilities is really a policy decision that must be made by the agency charged with construction and maintenance of those structures. This is the case with this program in that MoDOT will be responsible for making the final selection of appropriate target reliabilities for bridge foundations. Work performed for this research program has therefore focused on acquiring and developing information to guide and support these policy decisions. This work has included collection of information regarding the relationship between acceptable risks from a societal perspective (i.e. what risk is generally acceptable to the traveling public) in addition to analyses performed to establish “optimum” risks from a purely economic perspective. The “acceptable” reliabilities established from these two perspectives will then be combined to generate recommendations for target reliability levels for bridge foundations, with MoDOT making the final decision regarding the target reliabilities to be used for final calibration of load and resistance factors.

Task 4 – Final Calibrations and Development of Design Specifications

The objectives of the final task are to integrate the results of Tasks 1 through 3 to develop new, MoDOT-specific load and resistance factors and to develop new or revised design specifications that, when implemented, will produce substantial and recurring cost savings for MoDOT. Specific work to be performed as part of this task primarily consists of calibration analyses to develop load and resistance factors that will allow MoDOT to design for the target risk levels established in Task 3 and to account for the variability and bias established for relevant design parameters and design methods in Tasks 1 and 2. The design commentary documents that will provide documentation and support for the design specifications will also be prepared as part of this task. Thus, efforts within this task really serve to integrate results of the tasks described previously and to provide the practical means for implementation of the results of this research.

Current Status and Path to Completion

The overall research program is currently proceeding according to schedule. The bulk of the field work for Task 1 has been completed and laboratory testing is progressing as generally anticipated. Analysis of the results of field and laboratory tests is ongoing and is expected to continue through the spring and summer of 2010. The field load testing efforts for Task 2 are current being planned with the anticipation that field load tests will be performed in early 2010. Results of the field load tests will then be analyzed for use in developing calibrated load and resistance factors that incorporate the knowledge acquired from the load tests. A notable result of the preliminary work performed using available load tests data as part of Task 2 is that resistance factors for design of drilled shafts have been increased on an interim basis pending the completion of the research program to permit some cost savings to be realized while the research is ongoing with an expectation that additional savings can be realized when the research program is completed. Work being performed to develop recommendations for target levels of reliability is largely complete as of this writing and MoDOT is expected to consider these recommendations and establish final target reliability levels in the first quarter of 2010 in preparation for the calibrations to be performed as part of Task 4. Preliminary calibrations of load and resistance factors based on the anticipated results of the research are currently being performed as part of Task 4, with the final calibrations to be completed next summer. Draft design specifications and the associated commentary documents will be completed by the end of summer 2010, with the final design specifications being completed in October 2010 following a review and comment period.

Acknowledgements

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