RESEARCH PROBLEM STATEMENT

I. PROBLEM NUMBER

(To be assigned by TRB)

II. PROBLEM TITLE

Calibration of AASHTO *LRFD Specifications* Considering Loads Transferred to Bridge Foundations

III. RESEARCH PROBLEM STATEMENT

Previous researchers have addressed the uncertainty associated with modeling errors and corresponding calibration of resistance factors needed for the design of foundations using the AASHTO LRFD Highway Bridge Design Specifications (*LRFD Specifications*). These efforts have assumed that the magnitude of loads and the load factors used for the design of bridge superstructures are equally applicable for the design of substructures. However, limited data suggest that the magnitude of loads, and vehicle live loads in particular, are less than assumed for design. In addition, the calibration of resistance factors for foundation design has assumed that the load statistics (i.e., mean, coefficient of variation, bias and type of load distribution) developed for superstructure design, are also applicable for substructure design. These assumptions were never validated. Consequently, the goal of the *LRFD Specifications* to achieve a more consistent level of safety in the design of structure components has not been fully realized for structure foundations because the reliability of loads used for foundation design have not been properly considered. Research is needed to evaluate loads transferred to bridge foundations and to calibrate load factors considering the appropriate foundation loads and load statistics. The proposed research should employ analytical modeling, controlled load testing, or performance monitoring of in-service bridge structures to study the magnitude and variability of foundation loads.

Considering the load sources for bridge foundations, vehicle live load is probably the most uncertain because numerous factors affect the magnitude of the live load transferred to the foundation level. The most significant of these factors are probably from (1) the time lag in transmitting transient vehicle load effects from the bridge deck, through the superstructure, bearings and substructure features, and (2) soil-structure interaction between the structure abutments and the soil backfill. As a result, live loads transferred to bridge foundations are likely to be lower than the loads considered for design of superstructure components. The uncertainties associated with other load types should also be studied, but these uncertainties should be less than for live loads. Further, because bridge foundations are designed assuming that all, or nearly all, permanent and transient loads are transferred to the foundations, their design for both the strength and service limit states may be overly conservative. The following example illustrates some of these issues.

Superstructure components are designed by considering a combination of transient and permanent load effects. The load factor used for vehicle live load represents an exclusion load that has a 98 percent or greater probability of not being exceeded during the 75-year structure life assumed for design. This approach is applicable for the design of elements such as bridge girders, diaphragm, decks and bearings where the load path between the

vehicle and element is direct and not substantially attenuated throughout the superstructure. But before vehicle loads can reach the foundation level they are attenuated by:

- The transient nature of vehicle loads as they travel across a bridge
- Soil-structure interaction between the bridge substructure and soil backfill
- Damping and intensity reduction due to live load redistribution

The proposed research will also address the target reliability needed to calibrate the design of bridge foundations. Bridge superstructure components are calibrated for a target reliability index, β_T = 3.5 which represents a probability of component failure, p_f, of about 1:5000. However, calibration studies conducted during NCHRP 24-4 for the first version *LRFD Specifications* in 1994, and more recent efforts such as those for NCHRP 24-17, have shown the need to use β_T = 2.0 to 3.0 to achieve reasonable consistency with traditional allowable stress design methods for foundations supported on driven piles or drilled shafts. The need to calibrate to a lower β_T may be due to the redundancy of foundation elements (e.g., group of many piles versus an individual footing or large diameter drilled shaft), and/or the effects of soil-structure interaction (e.g., between bridge abutment and structure backfill or pile cap and foundation soil). Thus, part of the uncertainty inherent in the selection of target reliability index is related to the mechanism of load transfer. If the loads transferred to the bridge foundations are properly considered, the need to calibrate load and resistance factors for foundation design to a lower β_T than for superstructure components could be minimized.

As a result of the proposed research, bridge foundations could be designed considering lower loads and/or different load factors than prescribed in the *LRFD Specifications*. Consequently more economical foundation designs may be achieved compared to current design practice, especially for shorter span bridges. This cost savings would be the direct result of a consistent level of reliability used to design components of the bridge superstructure, substructure and foundation considering both the load and resistance side of the LRFD equation.

IV. RESEARCH PROPOSED

The objectives of the proposed research would be to:

- Survey published and unpublished sources to obtain information regarding field and laboratory measurements of loads supported by highway bridge foundations

- Conduct parametric numerical analyses to estimate effects of vehicle loading on steel and concrete bridges of variable structure geometry, support, substructure height, foundation type and foundation support conditions to assess loading at the foundation level and into individual foundation elements

- Conduct a field testing program of 4 to 6 bridges to measure loads transferred from the superstructure to the foundation level and to individual foundation elements

- Develop statistical properties of structure loads that affect the design of bridge foundations

- Determine the reliability for substructure foundations using existing or new models for loads from bridges at the foundation level by comparisons with measured foundation performance under strength- and service-load conditions

- Calibrate the load factor for live load for the design of bridge foundations at the strength and service limit states

- Revise the *LRFD Specifications* to reflect the calibration results

Key Words

LRFD, foundation design, reliability, calibration, resistance factor, load factor, soil-structure interaction, redundancy

Related Work

The *LRFD Specifications* have been or are being revised to recalibrate load and resistance factors for design of substructures at the service, strength and extreme event limit states as part of:

- NCHRP 20-7, Task 88 – Developing New AASHTO LRFD Specifications for Retaining Walls (completed)
- NCHRP 24-17 – LRFD Deep Foundation Design (NCHRP Report 507 (completed)
- NCHRP 12-55 – Load and Resistance Factors for Earth Pressures on Bridge Substructures and Retaining Walls (completed)
- NCHRP 12-48 – Design of Highway Bridges for Extreme Events (on-going)
- NCHRP 12-49 – Comprehensive Specification for the Seismic Design of Bridges (completed)
- NCHRP 12-47 – Redundancy in Highway Bridge Substructures (NCHRP Report 458 (Completed)
- NCHRP 12-66 – Calibration of AASHTO *LRFD Specifications* for Serviceability in the Design of Bridge Foundations and Substructures (on-going)
- Task Order FHWA DTFH61-02-T-63040 – Develop Updated Shallow and Deep Foundation Design and Construction Guidelines for AASHTO LRFD Specifications (On-going)

V. ESTIMATE OF PROBLEM FUNDING AND RESEARCH PERIOD

Recommended Funding: It is estimated that the cost to complete the research proposed herein will be approximately $750,000.

Research Period: The estimated time needed to complete the research described here will be on the order of 48 months.

VI. URGENCY, PAYOFF POTENTIAL, IMPLEMENTATION AND SUPPORT FOR BUSINESS NEEDS

Initiation of this work is urgent. The reliability-based calibration of load and resistance factors for the strength event limit states in the *LRFD Specifications* were developed to achieve consistent levels of safety in the design of structure components for a given limit state, and proportionate levels of safety between the limit states.

Because the load factors for vehicle live load used for design at the strength limit states were not calibrated specifically for foundation design, a primary feature of the LRFD approach (i.e., proportional safety margins in the design of structure components) is not completely possible due to the origins of the load factors for vehicle loading in the *LRFD Specifications*.

The results of the proposed work will result in recommended revisions to the *LRFD Specifications* for foundation strength design for possible adoption by the Highway Subcommittee on Bridges and Structures (HSCOBS) of AASHTO. The proposed project also addresses a strategic objective of the HSCOBS to fully implement LRFD through enhanced specifications for improved structural performance.

This project should be implemented through NCHRP.

VII. PERSON(S) DEVELOPING THE PROBLEM

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VIII. PROBLEM MONITOR

To be determined by TRB.

IX. DATE AND SUBMITTED BY

March 1, 2005
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