CONDITION ASSESSMENT OF EXISTING BRIDGE STRUCTURES

GTRC Project No. E-20-K90
GDOT Project No. RP05 – 01

Report of Task 4 – Development of guidelines for condition assessment, evaluation and rating of bridges in Georgia

FINAL REPORT

Prepared for

GEORGIA DEPARTMENT OF TRANSPORTATION

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August 1, 2009

ABSTRACT

Condition assessment and safety verification of existing bridges and decisions as to whether posting is required currently are addressed through analysis, load testing, or a combination of these methods. Structural analysis-based rating is by far the most common method for rating existing bridges. Load testing may be indicated when the analysis produces an unsatisfactory result or cannot be completed due to a lack of design documentation, information, or the presence of deterioration. The current rating process is described in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Bridge Evaluation (MBE), First Edition* (2008). This recently published *Manual* permits ratings to be determined through either allowable stress (ASR) or load factor (LFR) methods (Section 6B), or the load and resistance factor (LRFR) method (Section 6A). The LRFR method is keyed to the *AASHTO LRFD Bridge Design Specifications, Fourth Edition* (2007) which has been required for the design of new bridges since October, 2007. The State of Georgia currently utilizes the LFR method, which was permitted under the *Manual for Condition Evaluation of Bridges, Second Edition*. These three rating methods which continue to be commonly used – ASR, LRF, LRFR - may lead to different rated capacities and posted limits for the same bridge, a situation that has serious implications with regard to public safety and the economic well-being of communities that may be affected by bridge postings or closures.

To address this issue, the Georgia Institute of Technology has conducted a research program, sponsored by the Georgia Department of Transportation, to develop improvements to the process by which the condition of existing bridge structures in the State of Georgia is assessed. The product of this research program is the *Recommended Guidelines for Condition Assessment and Evaluation of Existing Bridges in Georgia*. These guidelines address condition assessment and capacity evaluation by analysis, load test, or a combination of the two methods, depending on the circumstances and preferences of the GDOT. Part I of this report summarizes the technical approach taken to develop the *Recommended Guidelines*. Part II presents the *Recommended Guidelines*. An Appendix to Part II illustrates their use in typical rating situations.

KEY WORDS:

Bridges; concrete (reinforced); concrete (pre-stressed); condition assessment; loads (forces); probability; reliability; steel; structural engineering.

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EXECUTIVE SUMMARY

Bridge structures in the United States are at risk from aging, leading to structural deterioration from aggressive environmental attack and other physical mechanisms, service demands from increased traffic and heavier loads, and deferred maintenance. Condition assessments of an existing bridge may be conducted to develop a bridge load rating, confirm an existing load rating, change a rating for future traffic, or to determine whether the bridge must be posted in the interest of public safety. Changes in traffic patterns; concern about faulty building materials or construction methods; discovery of a design/construction error after the structure is in service; concern about deterioration discovered during routine inspection; and damage following extreme load events may prompt such evaluations. In the State of Georgia, rating calculations have yet to be performed on 1,587 of the bridges that the Georgia Department of Transportation (GDOT) monitors. Moreover, approximately 1,982 of the 8,988 bridges monitored by the GDOT have been determined to require posting. Posting or other restrictions may have a severe economic impact on the State economy, which depends on the trucking industry for distribution of resources and manufactured goods. The economics of upgrading or posting a bridge makes it imperative that condition assessment criteria and methods (either by analysis or by testing) be tied in a rational and quantitative fashion of public safety, functional requirements, and economics.

Condition assessment and safety verification of existing bridges, and decisions as to whether posting is required, are addressed through analysis, load testing, or a combination of methods. Bridge rating by structural analysis is by far the most common (and most economical) procedure for rating existing bridges. Load testing may be indicated when analysis produces an unsatisfactory result of when the analysis cannot be completed due to lack of design documentation, information, or the presence of deterioration. Until recently, the bridge rating process was described in the American Association of State Highway and Transportation Officials (AASHTO) *Manual for Condition Evaluation for Bridges, Second Edition,*[1] which permitted ratings to be determined through either the Allowable Stress Rating (ASR) or Load Factor Rating (LFR). The State of Georgia traditionally has utilized the load factor (LFR) method for those bridges that have been rated. A third and more recent method, found in the *Manual for Condition Evaluation and Load and Resistance Factor Rating*,[2] was keyed to the new *AASHTO LRFD Bridge Design Specifications, Fourth Edition*.[3] The recently issued *Manual for Bridge Evaluation, First Edition* (*MBE*, 2008),[4] consolidates the existing rating methods and permits ratings to be determined by either ASR or LFR methods (Section 6B) or the load and resistance factor (LRFR) method (Section 6A). The ASR, LFR and LRFR rating methods may lead to different rated capacities and posted limits for the same bridge,[5] a situation that cannot be justified from a professional engineering viewpoint and carries

[1] American Association of State Highway and Transportation Officials (2000). *Manual for Condition Evaluation of Bridges*, *Second Edition* (including 2001 and 2003 interim revisions).

[2] American Association of State Highway and Transportation Officials (2005). *Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges, First Edition.*

[3] American Association of State Highway and Transportation Officials(2007). *AASHTO LRFD Bridge Design Specifications, Fourth Edition.*

[4] AASHTO Highways Subcommittee on Bridges and Structures. *Manual for Bridge Evaluation, First Edition* (2008)

[5] Wang, N., Ellingwood, B.R., Zureick, A.-H. and O'Malley, C. (2008). "Condition assessment of existing bridge structures: Report of Task 1 – Appraisal of state-of-the-art of bridge condition assessment." Report of Project GDOT No. RP05-01, Georgia Department of Transportation, Atlanta, GA.

serious implications with regard to the safety of the public and the economic well-being of businesses and individuals who may be affected by bridge postings or closures.

The Georgia Department of Transportation has an urgent need for condition assessment tools that can be used with confidence to determine whether or not to post certain bridge structures. To address this need, the Georgia Institute of Technology has recently completed a multi-year research program, sponsored by the GDOT, aimed at making improvements to the process by which the condition of existing bridge structures in the State of Georgia is assessed. The end product of this research program is a *Recommended Guidelines for Condition Assessment and Evaluation of Existing Bridges in Georgia*. The *Recommended Guidelines* address condition assessment and evaluation by analysis, load test, or a combination of the two methods, depending on the circumstances. Consistent with the *AASHTO LRFD Bridge Specifications*, they have a sound basis in structural engineering and structural reliability principles, allowing them to be updated as changing circumstances (traffic demands, additional data, material deterioration, and other factors) warrant. The *Recommended Guidelines* are presented in a relatively simple, practical and familiar form that is suitable for implementation in routine bridge rating assessments.

The research program undertaken by Georgia Tech for the State of Georgia consisted of four tasks:

Task 1: Review and critically appraisal of the state-of-the-art of bridge condition assessment
Task 2: Bridge evaluation by load testing
Task 3: Bridge evaluation by advanced analysis
Task 4: Development of *Recommended Guidelines for Condition Assessment and Evaluation of Existing Bridges in Georgia*

The results of Tasks 1, 2 and 3 have been reported previously.[5,6] The review in Task 1 revealed common rating practices and difficulties that States encounter in applying the alternative AASHTO bridge rating procedures consistently. On the international scene, it was found that modern bridge rating procedures worldwide have adopted reliability principles as their basis, utilize the limit state (as opposed to allowable stress) philosophy in strength calculations, and allow the ratings to be performed using a deterministic format with an underlying reliability basis. These approaches are consistent philosophically with the LRFR method, although the load and resistance factors may differ. The ultimate limit states are typically required as the governing limit states for safety checking for majority of the bridge types. Tasks 2 and 3 ran concurrently. A key ingredient of the research program was development of advanced finite element models of bridges and the validation of such models by means of load tests, with the objective of using similar finite element modeling techniques to extend the scope of the investigation to a broad selection of bridges, to conduct “virtual load tests” of bridges in that extended group, and to use those evaluations as a basis for critically appraising and revising, as appropriate, the current bridge rating process. To this end, the GDOT bridge database was screened to identify candidate bridges for load testing, with the assistance of GDOT bridge engineering staff. Four bridges representing the type of structures that currently are of most concern to GDOT staff were identified, based on a series of primary and secondary criteria such as structural and material types, age (design load), condition ratings and span lengths, and FE models of these four bridges were developed. Concurrently, the four bridges were load-tested with the assistance of GDOT maintenance staff. These bridges include reinforced concrete T-beam, pre-stressed girder, and

[6] O’Malley, C., Wang, N., Ellingwood, B.R. and Zureick, A.-H. (2007). “Condition assessment of existing bridge structures: Report of Task 2 – Summary of bridge testing program.” Report of Project GDOT No. RP05-01, Georgia Department of Transportation, Atlanta, GA.

steel girder bridges. The predicted and observed deflections agreed closely for all four bridges tested; discrepancies can be attributed to various uncertainties associated with experimental data collection under field conditions and the many assumptions that were required in the FE analyses, including homogeneity and magnitude of *in situ* material properties, and idealized boundary conditions. For all four bridges tested and analyzed, it was found that the current load rating procedures lead to unnecessarily conservative bridge ratings.

This Task 4 report is presented in two parts. Part I summarizes the research accomplishments described in detail in the previous task reports and provides the archival technical basis for the *Recommended Guidelines*. Part II presents the *Recommended Guidelines* and commentary. The *Recommended Guidelines* are keyed to the LRFD option in the *Manual for Bridge Evaluation, First Edition (2008); they* modify selected portions of the *Manual for Bridge Evaluation* to make it specifically applicable to condition assessment and rating of reinforced concrete, pre-stressed concrete, and steel girder bridges in Georgia. In addition, a new Section permits a direct reliability-based approach to bridge rating where circumstances warrant; the provisions in this section are somewhat more complex than those in the standard formula-driven rating process, but are likely to result in a less conservative rating if used, thus justifying the additional effort. Appendices to Part II of the report illustrates the use of the *Recommended Guidelines* in specific rating situations, and compares the ratings thus obtained to those that would be obtained using the existing AS, LF and LRFR methods. Implementation of the *Recommended Guidelines* in Georgia is likely to result in less conservative bridge ratings and posting requirements for most bridges in the State; for the four bridges studied in detail, the current ratings are 20 to 30% more conservative than the *Recommended Guidelines* would suggest. The main reasons for the less conservative ratings are: more realistic girder distribution factors; an improved procedure for permitting the use of in situ material properties through an enhanced statistically-based sampling plan; a newly derived condition factor, φ_c, which is keyed to the latest bridge inspection; and the use of structural evaluation methods (e.g., strut-and-tie analysis, finite element analysis) that capture the mechanics of structural behavior more accurately in limit states that govern the rating process (e.g., pier cap shear capacity, bridge system level capacity).

During the period in which the research reported herein was conducted (August 2005 – May, 2009), the two available AASHTO rating manuals were the *Manual for Condition Evaluation for Bridges, Second Edition*[1] and the *Manual for Condition Evaluation and Load and Resistance Factor Rating.*[2] The *Manual for Bridge Evaluation, First Edition* (2008) (*MBE*) was adopted by the AASHTO Highways Subcommittee on Bridges and Structures in 2005, but was disseminated to the state bridge offices in mid-2009 and was unavailable to the research team. Accordingly, Part I of this final report is based on the AASHTO documents that were available at the time that the research was performed. A close scrutiny of the provisions in the new *MBE* has revealed that none of the findings and recommendations in Part I are affected by the new document. In contrast, the *Recommended Guidelines* in Part II are keyed to the organization and provisions in the *MBE* (2008), in recognition that they are likely to be used with this more recent AASHTO document and to facilitate their adoption by bridge engineering staff.