Special Issue on Bridge Inspection and Evaluation

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Guest Editor

Bridge inspection and evaluation are essential parts of a bridge management program to ensure public safety by making sure that bridges have sufficient capacity to safely carry loads allowed on them. National Bridge Inspection Standards (NBIS) set minimum standards for the inspection and evaluation of highway bridges in the United States to ensure bridge safety. These standards set requirements for type and frequency of bridge inspections, reporting requirements, personnel qualifications, organizational responsibilities, need for quality control and assurance, and follow-up procedures to address critical findings resulting from inspections. In most cases, the NBIS suggests a 24-month general inspection interval for bridges, and current inspections are mostly visual based.

These inspections also play a major role in cost-effective bridge management by providing the data required to develop appropriate maintenance and capital programming. All inspections, by federal mandate, require rating five major bridge components, including bridge deck, superstructure, substructure, channel and channel protection, and culvert condition. These data are used by the Federal Highway Administration (FHWA) for network-level condition assessment and allocation of federal highway bridge program funds. Most transportation agencies and owners go beyond the NBIS and federal mandates to collect more information to support their bridge management programs.

The failure of the I-35 bridge in Minnesota in 2007 brought considerable public attention to bridge inspection and evaluation programs. Following the I-35 bridge collapse, several studies have reviewed existing inspection and evaluation programs. ASCE/SEI also formed an ad-hoc group jointly working with AASHTO to review highway bridge inspection and rating methods and practices used across the United States (results of this group's recommendations were published in the January 2009 issue of the *Journal*). Most of these studies generally concluded that highway bridge inspection programs currently in place ensure public safety. But many of these studies advocated use and development of advanced technologies to augment current bridge inspection and evaluation programs to enhance safety and bridge management decisions. They also suggested using more rational, risk-based approaches to determine inspection intervals.

These recommendations highlighted the best existing practices and research efforts, and many studies have also been initiated by various agencies to make progress in this area. Following all these efforts, the ASCE/SEI Technical Committee on Bridge Management, Inspection, and Rehabilitation issued a call for papers to capture these advances in bridge inspection and evaluation. As a result of this call, ten papers focused on bridge inspection and evaluations are included in this special issue of the *Journal*. We believe that these papers will contribute to the state-of-the-art and practice in bridge inspection and evaluation.

According to the National Bridge Inspection Standards, all fracture critical members in bridges require inspections at intervals not to exceed 24 months irrespective of their age, structural condition, design standards, details, etc. It has been argued by several, including the ASCE/SEI-AASHTO ad-hoc group, that a rational alternative inspection cycle, based on risk factors, is needed that considers characteristics of new bridges that better reduce the risk of failure. The paper titled "Proposed Method for Determining the Interval for Hands-On Inspection of Steel Bridges with Fracture Critical Members" by Parr, Connor, and Bowman proposes an assessment procedure to establish inspection intervals for steel bridges with fracture critical members. The method is rather simple and provides an alternative procedure to the currently specified 24-month inspection cycle. The approach is not based on more rigorous damage tolerant design concepts or other fracture mechanics-based methods. Nevertheless, the method is a first step in providing a more rational alternative to fixed-interval-based inspection and allows owners to prioritize structures and resource allocation.

The paper titled "Evaluation, Rehabilitation Planning, and Stay-Cable Replacement Design for the Hale Boggs Bridge in Luling, Louisiana" by Mehrabi, Ligozio, Ciolko, and Wyatt presents the evaluation of cables in the Hale Boggs Bridge. An in-depth evaluation indicated that the condition of 39 out of 72 cables had a critical need for repair and timely action. The authors evaluated several strategies involving a range of repair and replacement options using life-cycle cost analysis and found that the strategy to replace all cables presented the best value among evaluated alternatives. The design of the complete 72-cable array replacement is the first time this process has been attempted in North America. This paper illustrates a situation in which long-term benefits outweigh the higher initial investment when all costs, rather than agency costs alone, are considered.

In the paper "Investigation of Large Web Fractures of a Welded Steel Plate Girder Bridge," Zhou and Biegalski conducted an evaluation of a highway bridge in Maryland comprising seven welded steel plate girders of a constant web depth of 90 in. In March 2003 web fractures of two steel girders were discovered in a three-span continuous superstructure unit. A full-height web fracture occurred in an interior girder at a cross-frame connection plate, and a partial-height web fracture occurred in an exterior girder at an intermediate transverse stiffener next to a cross frame. Fracture mechanics analysis indicated that a brittle web fracture could occur at a high stress level with either a surface crack or a through-thickness crack of certain dimensions. Finite element analysis using a global model and submodels investigated three possible causes: (1) localized distortion of the unsupported web gap owing to the lateral forces of cross-frame members; (2) fabrication induced out-of-flatness of web plate under in-plane loading; and (3) residual stresses at the fracture origin area owing to the stiffener-to-web welds. The investigation concluded that one or a combination of these can result in high local tensile stresses to trigger a brittle web fracture with certain crack dimensions at the fracture origin area. Several retrofit concepts were investigated for their effectiveness in reducing stresses in the fracture origin area.

Remote evaluation of the underside of a bridge deck is very useful to augment current bridge inspections in order to avoid

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unnecessary traffic closures that negatively affect mobility. In the paper titled "Effects of Solar Loading on Infrared Imaging of Subsurface Features in Concrete," Washer, Fenwick, and Bolleni research the detection of subsurface deterioration in concrete bridge components using infrared thermography (IRT). IRT technique relies on thermal gradients developing in the concrete such that a temperature contrast exists between damaged concrete and sound concrete. The environmental conditions at the bridge, such as direct solar loading, ambient temperature variation, and wind, affect the thermal gradient in the concrete and hence the ability to image subsurface features. The effects of direct solar loading on the detection of subsurface targets in a concrete test block have been studied in this paper. Quantitative measurements of the thermal contrast that appear in thermal images of the test block are reported and analyzed. The effect of the depth of the embedded target is discussed as well as the timing of inspection (relative to sunrise) that resulted in maximum contrast in thermal images. These results are useful for determining the optimum inspection times for portions of a highway bridge exposed to direct solar loading and complement existing data reported in the literature.

Nondestructive evaluation (NDE) methods are becoming popular in augmenting the visual inspections and subsequent evaluations advocated. Each of the NDE methods has its own advantages and disadvantages. Combining several methods may yield better results by taking advantage of the efficiencies of individual methods. The paper "Nondestructive Testing of GFRP Bridge Decks Using Ground-Penetrating Radar and Infrared Thermography" by Hing and Halabe shows that more detailed and accurate subsurface condition assessment of glass fiber-reinforced polymer (GFRP) bridge decks can be achieved by combining ground-penetrating radar (GPR) and IRT. Their test results showed that GPR was capable of detecting water-filled defects as small as 5×5 cm in plan size and as thin as 0.15 cm. Furthermore, tests showed that the GPR system offers some promise in detecting bottom flange defects as far down as 10 cm deep. IRT, on the other hand, showed that it is capable of finding both water-filled and air-filled defects in the top layers of the deck with solar heating as the main source of heat flux. While test results showed IRT is more sensitive to air-filled defects, water-filled defects can still be detected with a large enough heating mechanism.

The paper titled "Predictive and Diagnostic Load Rating Model of a Prestressed Concrete Bridge" by LeBeau and Wadia-Fascetti presents a probabilistic model of the load rating process incorporated with field inspection observations applied to a prestressed concrete bridge to capture deterioration characteristics. The main computational tool used is a Bayesian network. The model is developed around the main load-carrying member, an interior beam, and the effects of corrosion of its interior steel. Bridge load ratings are calculated as variables based upon the following design methodologies: Allowable Stress, Load Factor, and Load and Resistance Factor Design. Two investigations on an actual bridge are conducted and demonstrate the predictive and diagnostic capabilities of the model useful for bridge management.

Noncomposite adjacent precast prestressed concrete box beam bridge systems became popular in the late 1950s. An accelerated construction schedule was possible since the majority of the precast fabrication could be done off-site and on-site concrete placement was limited to grouting of the shear keys. However, many of these structures are now approaching the end of their service life, and thus deterioration is a big concern. The failure of a fascia beam of the I-70 bridge in Pennsylvania, under service loads, in 2005 brought considerable national attention. The bridge was decommissioned, and a number of beams were saved for forensic investigation. The paper "Forensic Examination of a Noncomposite Adjacent Precast Prestressed Concrete Box Beam Bridge" by Naito, Sause, Hodgson, Pessiki, and Macioce identifies the cause of the corrosion observed on the beam strands and provides recommendations for improved inspection methods of the beams by an in-depth forensic investigation of the decommissioned bridge beams. The forensic investigation indicated that strand cover was reduced owing to the construction methods of the time. The chloride level in the concrete at the lower layer of strands was high enough that corrosion would be expected. The chloride attack was identified as coming from leakage of water between beams from the bridge deck surface above. Based on the research findings, recommendations are made for visual inspection and guidelines are provided for condition rating of noncomposite prestressed concrete box beam bridges.

Understanding the deterioration of bridge systems and components using the available bridge inspection data is essential for cost-effective bridge management through planning appropriate maintenance, rehabilitation, and replacement programs. The paper titled "Deterioration Rates of Typical Bridge Elements in New York" by Agrawal, Kawaguchi, and Chen develops deterioration curves for highway bridges in New York State using the historical inspection data dating back to 1981. The authors use an approach based on Weibull distribution and compare the results with the traditionally used Markov chains approach. They observed that the Weibull-based approach performs better for developing deterioration curves for different bridge elements. Both Markov chains and Weibull-based approaches have been incorporated into a computer program that generates deterioration curves for specific bridge elements and are currently used by the NYSDOT in their bridge management software. Case studies on deterioration rates of various bridge elements in New York State bridges are presented to demonstrate the two approaches. These case studies show that element deterioration rate information can be used to determine the expected service life of different bridge elements under a variety of external factors. This information is extremely valuable for making bridge management decisions.

Successful development of damage prediction models, trained/calibrated using historical inspection data, can be very useful for effective management of both new and existing bridges. The paper "Using Soft Computing to Analyze Inspection Results for Bridge Evaluation and Management" by Li and Burgueño presents soft computing methods applied to develop damage prediction models for bridge abutment walls using the NBI database. The methods are based on a multilayer perceptron network, a radial basis function network, a support vector machine, a supervised self-organizing map, a fuzzy-neural network, and ensembles of neural networks. An ensemble of neural networks with a novel data organization scheme and voting process was found to be the most efficient model, identifying damage with 86% accuracy. They showed that reasonable deterioration curves can be developed through the presented soft computing methods to predict the degradation of bridges over their service life.

North American railways are primarily public investor-owned businesses. Hence, they must show adequate financial returns not only to satisfy their investors but also to secure the necessary funding to adequately maintain structures. This requires generating sufficient profits, by providing appropriate services to their customers, in contrast to most transportation agencies that own highway bridges, which rely on public funding. In the technical

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note titled "Bridge Inspection Practice: Two Different North American Railways," Sweeney and Unsworth illustrate the bridge inspection philosophy of two different large railways. Bridge inspection criteria are based primarily on providing safe and reliable operation, appropriate response, and the information with which to ensure adequate funding for maintenance and replacement. Two examples are illustrated, one on a railway with many bridges of fairly robust design and relatively good carrying capacity where bridge inspection policy is relatively straightforward, and the other on a railway where great care has been taken to concentrate inspection resources on weaker though adequate structures based on traffic volumes and bridge component capacity. Both policies, though clearly not interchangeable, seem to have been successful, and these criteria might be of use to other bridge owners.

The editor thanks the authors for their submissions and their patience during the review process. He also thanks the committee members and others that reviewed the papers and provided constructive comments. These comments have improved the quality of these papers and have ensured that the papers are useful to the bridge community. Finally, the editor thanks Bruce Peterson (previous editor of the *Journal*) and Dr. Anil Agrawal (current editor of the *Journal*) for giving him the opportunity to develop this special issue and providing required assistance.

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