Dynamics and Field Testing of Bridges

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The nation's highway network contains more than 3.9 million miles of public roads and more than 8.1 million lane miles. These roads are heavily used, with over 2 trillion vehicle miles traveled each year. The highway network is the backbone of the U.S. economy, of paramount importance to national security, and essential during natural disasters. There are more than 590,000 bridges on the nation's highways, with all bridge structures exceeding the 1 million mark, making more than 3.2 billion square feet of bridge deck in the United States. Every 3 seconds, 1 million bridge crossings take place. The National Highway System (NHS) consists of 161,000 miles (or about 4 percent of U.S. highways) and includes the Interstate system, about half of the primary system, and important links to airports, military installations, ports, and international borders. The NHS carries about 60 percent of all traffic and about 80 percent of all truck traffic. Significantly, although the NHS represents only 4 percent of total highway miles in the country, it contains over 20 percent of all bridges. This fact underscores the importance of highway bridges as critical links in the U.S. highway system and, correspondingly, why testing and evaluation of bridges are critical.

BACKGROUND

The United States has been replacing deficient bridges at a rate of about 5,600 per year, and substantial quantitative progress has been made (*1*). However, in order to achieve the strategic goals established by the Federal Highway Administration, deficient bridges must be replaced at a rate of 7,000 per year. This goal cannot be achieved under current conditions. New policies, programs, and initiatives are needed. In order to eliminate deficient bridges at an efficient accelerated rate, it is essential to evaluate bridge deficiencies. Armed with this knowledge, we can identify the most important research needs for the next 10 to 20 years.

Of the 591,548 structures in the National Bridge Inventory (NBI), 473,594 are bridges and 115,954 are large culverts; 373,682 bridges (79 percent) and 92,734 culverts (80 percent) in the NBI are off the NHS, of which 89,633 bridges are structurally deficient. Of the 99,912 bridges on the NHS, 8,344 (28 percent) are structurally deficient. The overall condition of large culverts is much better than it is for bridges. Only 7 percent of culverts off the NHS and 6 percent of culverts on the NHS are deficient, with the majority of these culverts being functionally deficient. To reduce the number of deficient bridges, different strategies are required for structures on the NHS than for those off the NHS. To identify research focus areas and technologies needed to facilitate a reduction in the deficient bridge population, a more detailed analysis of structurally deficient and functionally obsolete bridges has been conducted, with the discussion focus herein on the structurally deficient bridges.

Inadequate load capacity is the most significant factor contributing to structural deficiency. There are five possible reasons for a bridge to be classified as structurally deficient: bad deck, bad superstructure, bad substructure, a waterway appraisal rating of 2 or less, and a structural evaluation appraisal rating of 2 or less. The predominant factor leading to structural deficiency is a low structural evaluation appraisal rating or, more accurately, a low load rating (Figure 1). Over 21,000 bridges are classified as structurally deficient solely because of a low load rating. The second most frequent factor leading to structural deficiency is a poor substructure condition rating, which accounts for approximately 14,000 bridges, and the third most frequent factor is a bad deck, accounting for over 8,000 bridges. The two most frequently found reasons for NHS bridges to be classified as structurally deficient are a bad deck and a bad substructure.

An analysis of structurally deficient bridges based on total deck area (Figure 2) reveals 400 million square feet of bridge deck attributable to structurally deficient bridges, representing a $24 billion expense. Although only 8 percent of the structurally deficient bridges are on the NHS, 43 percent of the structurally deficient deck area is on the NHS. This fact is a critical consideration when research and technology needs are evaluated.

An analysis of structurally deficient bridges based on total daily traffic (Figure 3) reveals that 315 million vehicles cross structurally deficient bridges each day, with structural evaluation appraisals now much less significant. NHS bridges now account for 62 percent of the structurally deficient bridges the traveling public is exposed to. The single most important exposure on the NHS is poor decks; over 50 million vehicles each day cross highway bridges where the sole deficiency is a bad deck.

This analysis has made extensive use of the NBI database. The NBI provides useful and important summaries of bridge deficiencies to support general recommendations. However, these data are based almost exclusively on subjective visual inspections. Current practice is to record structural conditions when deterioration has progressed until there are visible symptoms. There is a need to develop new technologies to provide rapid, reliable, accurate, and quantitative measurement of bridge performance and condition as an ongoing practice.

DIRECTIONS AND CHALLENGES

This overview of national bridge deficiencies is presented in order to identify the significant problems facing the nation with regard to bridges and to identify future directions and challenges for bridge testing and evaluation research. The most significant challenge on the basis of absolute numbers is bridge undercapacity. This situation has developed primarily on off-system bridges and consequently will not be resolved in the near future. Bridge engineers recognize that load rating, especially in the absence of the original design calculations and construction drawings, is not exact. An analysis of the reported design load for structurally deficient bridges reveals that the design load for most bridges is often unknown. This suggests that the load ratings in the NBI are based more on engineering judgment than on detailed calculation and testing. It has been demonstrated that bridges perform as structural systems and that the interaction between structural elements of a bridge often results in a structure that is stronger than predicted on the basis of simplistic analytical models assuming load distributions to individual girder lines. This analysis supports the following conclusions and observations:

- There is a need to more accurately determine the load-carrying capacity of off-system bridges through field load tests,
- Load rating by load testing could be beneficially applied to a large population of bridges,
- Technologies and methods exist to perform these tests but are not widely used, and
- Programs, policies, and practices need to be developed to promote and improve the application of load testing.

These observations point to several conclusions regarding research needs. The previous structural deficiency analysis indicates that there is a need for research on low-cost, rapid, field-based evaluation methods of shorter-span bridges. New methods, materials, and technologies to cost-effectively strengthen bridges are also needed. There are apparent opportunities for the application of fiber-reinforced composites and other new materials to strengthen deteriorated bridges, but the widespread use of new materials will depend on demonstration of their long-term performance. There is a need for sensing and monitoring technologies to collect long-term performance data on these new-generation materials and a need for site-specific, suitability, and load-rating methods and criteria. The development of load-rating methods using load and resistance philosophy is indicated. Site-specific loading spectrums can be developed using low-cost monitoring systems. Site-specific resistance distributions based on in situ materials testing and characterization using nonintrusive and nondestructive materials characterization methods are needed. It is an inevitable conclusion that a number of deteriorated off-system bridges should be replaced, resulting in a need to develop rapid bridge replacement systems with very low cost.

As previously noted, the largest problem identified for the NHS bridges is bridge decks, which are either in poor structural condition or too narrow. It is estimated that over $1 billion is spent on bridge decks each year. Over 88 percent of all bridge deck area (2.8 billion square feet) is concrete, and about half of those bridge decks have a wearing surface over the concrete. Current network-level bridge deck evaluation and condition assessment methods are based on visual inspection, but it is impossible to accurately assess the condition of an overlaid bridge deck using visual inspection. There is a need to develop network-level bridge deck evaluation methods that can provide an accurate assessment of bridge deck condition for decks with wearing surfaces. New radar tomographic imaging technology is promising, but additional development is needed. In addition, cost overruns are very common on bridge deck replacement projects, resulting in a need for improved project-level deck evaluation technologies. In view of the needs of the motoring public and costs of construction delays, rapid bridge deck replacement systems must be developed to allow minimum disruption times.

The present analysis identifies poor substructure condition as a significant contributor to the structurally deficient bridge population; however, the NBI data do not detail the specific problems encountered. Research is needed to specifically identify whether the deficiency is the result of corrosion, bad bearings, excessive hydrostatic pressure leading to wing wall and abutment cracking and failure, general concrete deterioration due to alkali-silica reactivity, excessive settlement, or some other problem. With this detailed substructure deterioration information, research and technology programs can be developed to efficiently target problem areas. It is suspected that substructure problems are due in large part to leaking deck joints. Low-maintenance, high-performance joint seals, and methods eliminating joints need to be developed.

The basis of the substructure condition rating, as it is for all condition ratings, is a visual inspection of the substructure. It is not possible to differentiate between benign or serious problems solely on the basis of a visual inspection. Results of a study providing detail and definition of specific substructure problems will target new test methods, technologies, and procedures that will be needed to provide a reliable substructure condition assessment.

Bridge structure vulnerability and reliability are not adequately considered in current bridge management systems. Methods and criteria to accurately and consistently measure and incorporate reliability into national and statewide bridge management systems are needed. Self-monitored structures and materials are under development in several arenas that hold great promise for bridges constructed in the 21st century. The integration of the sensor with the structure creates a self-monitoring condition system that can be coupled with bridge management systems to allow on-line decisions. Piezoelectric sensors, including ceramic and polymetric, and optical sensors, including microbend, Bragg grating, and interferometric, are promising technologies that have been successfully used to monitor loads in bridges, buildings, dams, and even aircraft.

SUMMARY

Nationally, numerous bridge structural deficiencies exist. Although resources are continually allocated to alleviation of the deficiencies, much work remains. In order to make the best use of scarce resources, promising new technologies must be pursued and proven to enable efficient improvement of the infrastructure. New nondestructive technologies that more accurately define the problems, as well as innovative engineering solutions, both material and schematic, will bring the nation’s bridges and highway infrastructure into the next millennium with much improved health.

REFERENCE

1. Brei, D. Smart Structures: Sensing Technologies for Structural Health Monitoring. *Proc., 1998 Earthmoving Industry Conference and Exposition*, Peoria, Ill., April 1998.

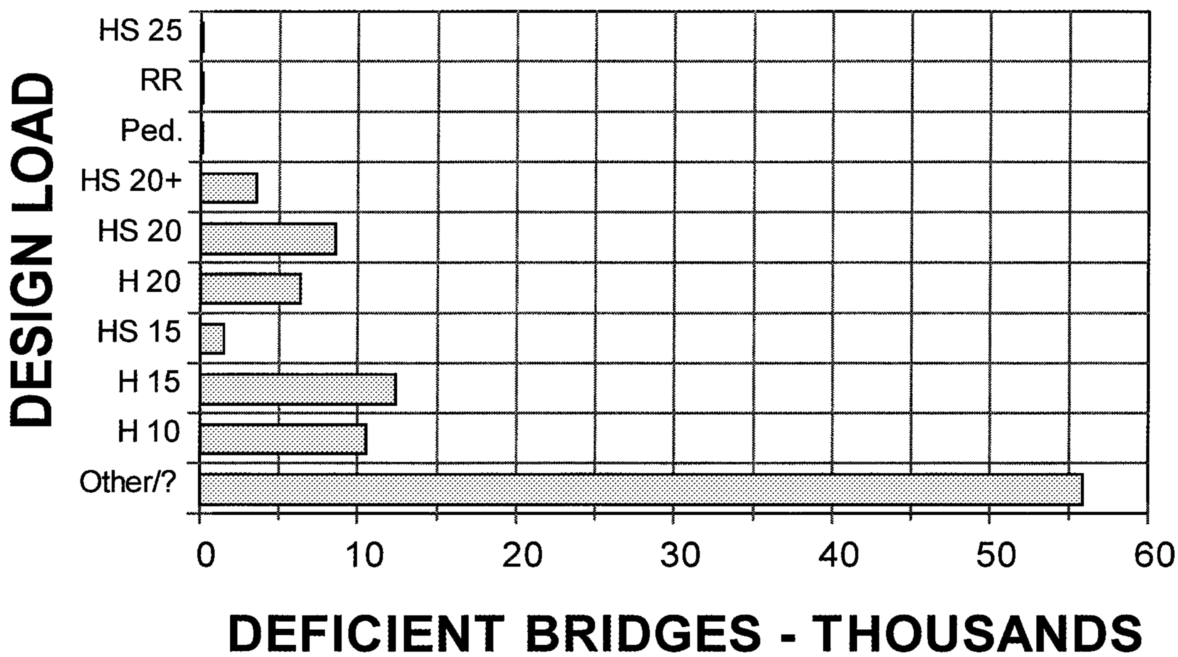

FIGURE 1 Histogram of structurally deficient bridges relative to design load.

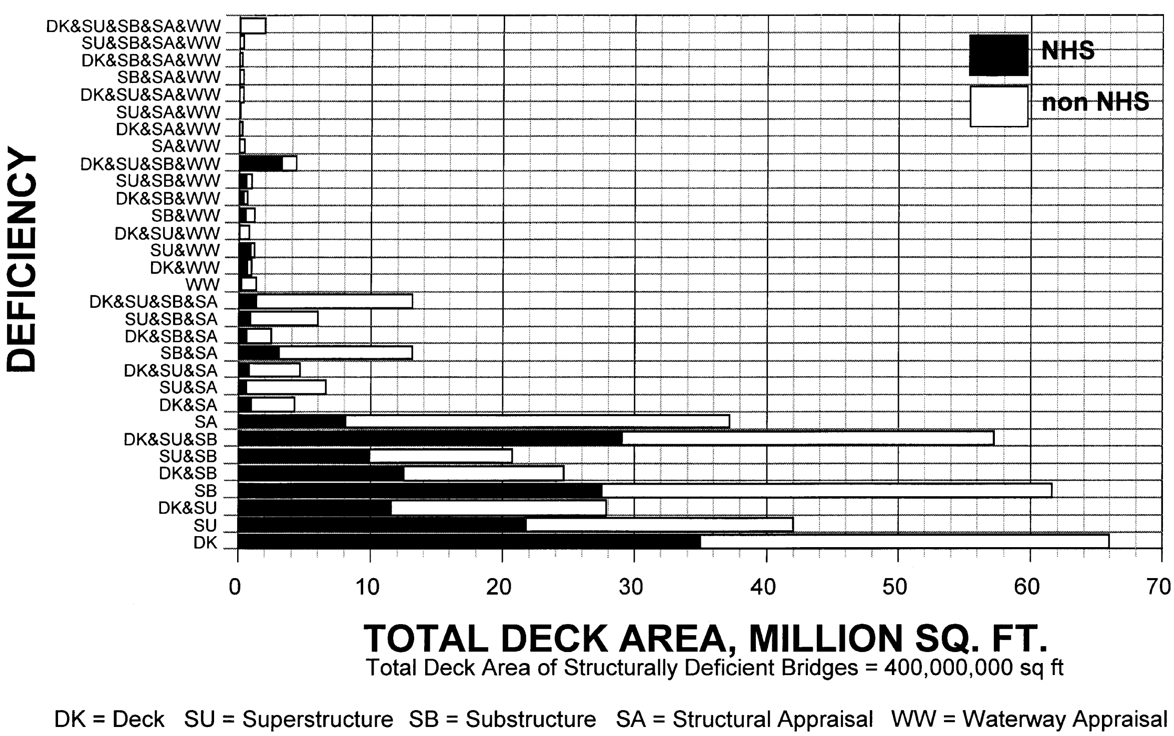

FIGURE 2 Histogram of NHS and non-NHS bridge deficiency relative to deck area (excludes culverts).

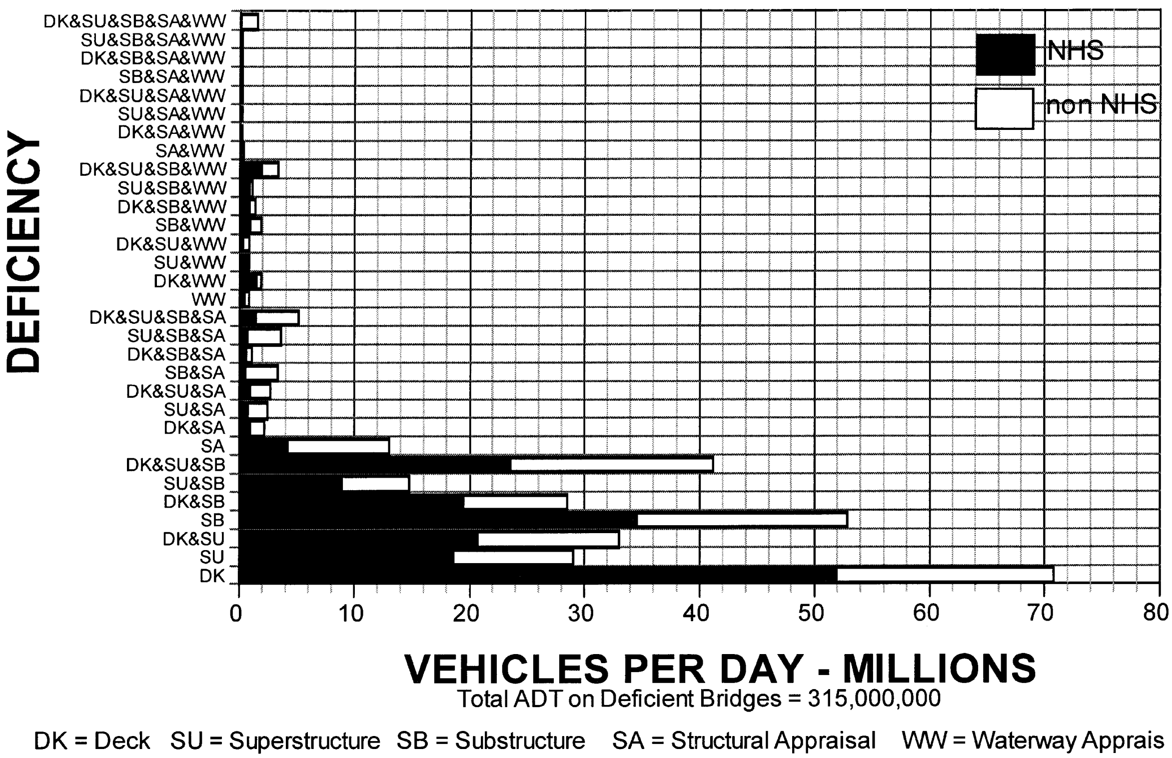

FIGURE 3 Histogram of NHS and non-NHS structurally deficient bridges by major component relative to vehicles per day.