COMPONENTS OF THE LONG-TERM BRIDGE PERFORMANCE PROGRAM

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Abstract

With the recent passage of the highway bill called the "Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU)", the Federal Highway Administration (FHWA) is initiating the Long-Term Bridge Performance Program (LTBPP). The LTBPP is an ambitious 20-year research effort that is strategic in nature and has both specific short-term and long-range goals. It will be similar to the Long Term Pavement Performance Program that has been underway for more than 15 years. The objectives of the LTBPP are to collect, document, and make available high-quality quantitative performance data on a representative sample of bridges nationwide. The collected data will be used to develop greater knowledge regarding bridge performance and degradation, develop better design methods and performance predictive models, and support advanced management decision-making tools.

Background

The National Bridge Inventory (NBI) database and recent element-level data collection efforts by state highway agencies have succeeded in identifying deficient bridges and providing a tool for managing our highway bridge system. However, this data, which is typically collected using visual inspection techniques, is quite general and subjective and does not provide detailed, quantitative information about the condition and/or performance of the individual elements or of the bridge itself. Hidden or otherwise invisible deterioration, subsurface condition, and loss of structural integrity are therefore not usually noted. The subjective, highly variable, and general nature of this data makes it less reliable for comprehensive, long-term (> 20 years) life-cycle decision support for operation and maintenance and for supporting advances in design, materials selection, construction practices, and quality control. To address these shortcomings, the FHWA has proposed the LTBPP, which is an essential part of the research necessary to support the information needs for bridge management of the future.

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Program Objectives

The overall objective of the program is to collect, document, and maintain high-quality quantitative performance data over an extended period of time from a representative sample of bridges nationwide. The quantitative data will enable bridge owners to solve a variety of qualitative bridge condition assessment and management problems, including the following:

- Determining how and why bridges deteriorate.
- Determining the effectiveness of various maintenance, repair, and rehabilitation strategies, as well as management practices.
- Determining the effectiveness of durability strategies for new bridge construction including material selection.
- Enabling more effective bridge management by providing
    - quantitative data that can be used to develop improved deterioration models and enhance life-cycle cost analysis;
    - quantitative data that can be used in conjunction with decision-making tools and algorithms that support optimal allocation of resources;
    - quantitative data to support performance measures at both the service and extreme event limit states; and
    - data that will enable design provisions to be validated and improved.

Program Vision

The original FHWA vision for the program included the following:

- A representative sample of bridges that would be subjected to a long-term (at least 20 years and preferably longer) program of detailed inspection and evaluations. The resulting database would provide high-quality, quantitative performance data for highway bridges to support improved designs, predictive models, and bridge management systems. This group of bridges would number in the thousands.
- A subset of that representative sample that would be instrumented to permit continuous monitoring of operational performance. This group of bridges would number in the hundreds.
- A small set of decommissioned bridges that would undergo forensic autopsies to help improve our knowledge base and our capabilities for determining the capacity, reliability, and failure modes of bridges in a variety of condition states including those that have deteriorated from corrosion, overloads, alkali-silicate reaction, fatigue, and fracture. The bridges in this category would be destructively tested as they became available.

In all three areas, the LTBPP will take advantage of sensing technologies and NDE/NDT tools. In the originally envisioned program, data will be collected supplementing the NBI database. However, due to funding limitation, the scope of work will be modified.

Funding Realities

The LTBPP was created by SAFETEA-LU as a 20-year program, with funding authorized for FY2006 through FY2009. While the funding requested was approximately $20M per year, the amount authorized was only about $7.75M per year. Due to an over-authorization of funds, the funding available for the first four years will be approximately $5.4M per year. Thus, the actual funding is only about 25 percent of the requested amount, which means that decisions need to be made regarding which aspects of the program to initiate immediately using the existing $5.4M per year of funding (Phase I) and which aspects will be put on hold pending the authorization of additional funding (Phase II).

Funding Implications

- Based on the limited funding, it is recommended that the Phase I of the program (i.e., the first four years) should focus on collecting data only through detailed bridge inspections. In anticipation of increased funding in the future, Phase I should also include the development of detailed protocols and experimental designs for bridge instrumentation and monitoring, as well as for decommissioned bridges using forensic autopsies (Phase II).
- An effort should be made to leverage existing programs (e.g., University Transportation Centers), or to partner with other funding agencies (e.g., National Science Foundation) to increase impact with limited funding.
- Instrumented bridges, long-span bridges, and extreme events should not be studied under Phase I unless existing programs can be leveraged.
- Existing instrumented bridge programs should be leveraged as long as the data provided is consistent with the developed protocols. This would allow the instrumented bridge portion of the program to begin during Phase I with minimal funding.

Scoping Study

In order to initiate the LTBPP, specifics regarding many aspects of LTBP criteria and program goals will need to be developed and publicized throughout the United States. To assist in the development of this, the FHWA has employed the University of Delaware through its Center for Innovative Bridge Engineering (CIBrE) to prepare an overall proposed framework for the program. A draft framework, defining components of the LTBPP and activities and goals in both the short and long-term, has been provided.

The draft framework will be discussed with stakeholders and others in the public, private and academic segments of the highway bridge community including the international community, before final approval. This will be facilitated by a series of workshops to seek feedback from participants on all aspects of bridge performance data collection and analysis, long-term monitoring, bridge selection criteria, the use of sensing technologies and NDE/NDT tools, and expected outcomes and deliverables.

<u>Components of the LTBP Program</u>

The LTBP program has two components: 1) Program management and administration, and 2) Technical execution. The administration component will not be discussed here but in general is responsible for overseeing the program, dissemination of information, archiving data, technology transfer, etc. The technical component addresses issues related to;

1- Specific data to be collected
2- Bridge sampling
3- Performance measures
4- Technology to support data collection
5- Data quality and collection strategies
6- Data mining and analysis

Hereafter, the first four issues will be discussed briefly.

<u>Specific data to be collected</u>

Some of the measurement and detection needs currently not very well addressed by our present programs of visual inspections are tabulated in Table 1. These measurement and detection needs exist at many levels and can serve many purposes.

There are also additional needs for quantitative and reliable data on maintenance activities and life cycle costs. Data on maintenance should be related to type, timing, effectiveness of preventive maintenance, rehabilitation, etc. Data on costs should include initial costs and other costs borne indirectly by users of the bridge.

Obtaining such databases, on a representative sample of bridges over a long period, requires resources that are not readily available now or in the future. With the current available resources, decisions have to be made on what information to collect and why should they be collected in order to maximize information collection using multi-objective optimization methods. A recommendation on what data to collect could be based on the relationship between bridge performance and deterioration. Establishing such a relationship requires quantitative information on environment and climate; maintenance and rehabilitation activities; truck weights, ATT, etc. Perhaps acquisition of

Table 1

Damage	Deterioration	Operation	Service
Impact	Corrosion	Traffic counts	Congestion
Overload	Fatigue	Weight of trucks	Accidents
Scour	Water absorption	Maximum stress	Reduced traffic capacity
Seismic	Loss of prestress force	Stress cycles	Delay
Microcracking	Unintended structural behavior	Deflection	Unreliable travel time
Settlement	Chemical changes (e.g. ASR, DEF)	Displacement	Reduced load capacity
Movement	Environment and climatic	Detours	
Lack of Movement		Reduction in speed	

such information should be a higher priority. Another goal is to better quantify operational performance. The required information could be traffic counts, truck weights, maintenance activities, geometrics, etc. These two examples show the importance of truck weights and maintenance activities on bridge performance and deterioration and support as to the collection of information must be collected.

It is clear that the success of the LTBPP, with today's limited resources, depends heavily on acquiring proper types of data. This data should provide a fundamental understanding of bridge behavior, capacity, failure modes and reasons for performance deficiency. Therefore, it is important to understand why such data is not available today and decide how to acquire what is needed under the LTBP program.

Bridge sampling

It will not be feasible to monitor and collect detailed data on all 478,000 bridges in the NBI. This is primarily due to resource limitation. Therefore, a study is needed in selecting a sample of bridges, utilizing the NBI database and other relevant available databases, to provide a solid representation of the nation's bridge inventory. It is necessary to exploit other databases in sampling bridges since the information in the NBI is not as complete as is needed. For example, the Freight Analysis Framework (FAF) database contains information on ADT and ATT, tonnage, and traffic volume which are more quantitative and reliable than NBI. The FAF was created by the USDOT as a comprehensive database and policy analysis tool to examine geographic relationships between freight movement and infrastructure capacity. It provides detailed information on freight flows for the truck, rail, water, and air modes and various commodities. Other databases are also available and well maintained by many States with quite detailed information on their inventories.

It is important to recognize that in selecting bridges there needs to be a departure from current classifications based on how bridges look. Considerations should be given for classifying bridges into populations based on what is known about the performance of various bridge types. This would include critical details, for example, continuous integral abutment stringer bridges may have excellent performance while simple-span stringer bridges may have poor performance. Both are slab-on-girder bridges. Also, continuous stringer bridges may have excellent reliability while similar bridges with pins or hangers may have poor reliability in seismic region.

Another important factor in selecting bridges is their importance to the transportation system whether they are situated on NHS or other roads (i.e. county). Nevertheless, after classifying bridges into populations and utilizing all available databases, the final representative sample may have the following characteristics;

- Different age distribution (i.e., year of construction should be carefully selected to reflect the evolution of design methodologies from 1960's to present)
- Different material types (steel, concrete, prestressed concrete, etc.)
- Different foundation types
- Location in different climatic and environmental zones (i.e., temperature range, wet, dry, snowfall, etc.)
- Exposure to different hazard (i.e., flood, seismic, and hurricanes areas, etc.)
- Different annual truck traffic
- Difference in maintenance strategy

Again, the number of bridges to be inspected and monitored will greatly depend on the funding constraints and therefore will not be discussed here. However, it is envisioned that the number could not exceed 1000 in total.

Performance measures

Evaluation and measurement of bridge performance is the most critical attribute in addressing bridge deficiencies and in providing the ability to design and build bridges with optimal life cycle costs, higher performance, lower maintenance, and generally optimal operation in the future. The States are very much aware of this attribute but are in need of quantitative relevant data to measure performance. As stated earlier, the NBI was originally intended as a sieve to catch the most critical bridges and not for assessing the performance of bridges. The Sufficiency Rating (SR) in the NBI is the only indirect indicator for measuring bridge performance which is based on subjective data and does not consider many important factors in its rating. SR determination relies heavily on bridge load ratings reported to the NBI. To be eligible for rehabilitation under the federal bridge program, a bridge must have an SR of 80 or less and be classified as structurally or functionally deficient. To be eligible for replacement, a bridge must be structurally or functionally deficient and have an SR less than 50.

Generally, there is a lack of agreement on how to measure performance of a bridge which can be related to many factors. These are bridge type and geometry, material properties, design and construction, environment, traffic volumes and loading, congestion, maintenance activities, costs (user and agency), vulnerability to hazards, etc. These factors collectively impact bridge safety and level of service.

As the FHWA implements the LTBP program, it plans to work with its stakeholders to develop a set of bridge performance measures that will measure bridge condition, operational performance, and life cycle costs. Table 2 presents a set of possible performance measures and their relevant factors.

Table 2

Performance Measures	Attributes
Bridge Condition	- Load-deflection relationship - Presence of a damage - Maintenance - Environment - Loads
Operational Capacity	- Traffic counts - Geometrics (width, approach alignment, etc) - Vertical over-clearances - Vertical under-clearances - Maintenance activities: type, effectiveness, and frequency
Costs	Agency - Initial construction project costs - Inspection & routine maintenance costs - Painting & repair costs Users - Lane closure - Detour time - Congestion - Accidents - Creating delay - Increased travel mile Risk & Vulnerability

It is clear that the bridge management of the future should rely on quantitative data, proven technologies, collaboration with other agencies (i.e., pavement, materials, ITS), and a system performance approach. This means taking advantage of SHM and other tools to acquire information on system conditions in real- or near-real time (i.e., traffic flow, weather conditions, traffic incidents, overloads, other disruptions). Such information could provide valuable resources in monitoring performance of bridges cost-effectively.

Technology to support data collection

The use of NDE/NDT and SHM tools and techniques for testing, monitoring, and evaluating bridges to augment visual inspection will be a major element of the program. It is also envisioned that the LTBP program will help foster technology development and integration for civil engineering applications. Technologies selected for use should enable data to be recorded in a format that will be useful to State DOTs in the evaluation of maintenance and repair needs.

Modern NDE techniques

Recent studies indicated increased usage of NDE techniques by highway agencies since 1993.   Each of the technologies has been used in conjunction with one of the three predominant bridge construction materials—steel, concrete, or timber. The following section describes NDE technologies used to inspect steel and concrete bridges; timber bridges will not be considered in the LTBPP.

In steel bridges, the most common types of deterioration are corrosion and fatigue cracking. Investigative techniques include radiography and ultrasonics, both suited to detecting internal defects. Procedures for detecting surface cracks include magnetic particles, eddy currents, and dye penetration. Considerable progress has been made in refining ultrasonic test procedures and acoustic emission measurements, which are very useful for long-term monitoring of steel structures.

Concrete deteriorates by cracking, spalling, scaling, corrosion of embedded reinforcement, and disruptive chemical reactions between the mixture constituents or between the concrete and the external environment. Techniques for detecting defects and deterioration range from striking the concrete surface to detect delamination to radiography of post-tensioned members. Other procedures may reflect technological progress in other fields, such as infrared thermography and radar, which have demonstrated considerable potential.

In addition, newer NDE techniques have been explored, including; 1) HERMES II—Ground-Penetrating Radar System for reliable detection, quantification, and imaging of delaminations in bridge decks, 2) Laser Bridge Deflection Measurements—Uses a frequency-modulated laser to measure bridge deflection from a range of up to 30 meters. The system enables measurement resolutions of up to 1 mm, and 3) Stress-Measurement Technologies—Used for evaluation of load distribution and stress levels in load-carrying members. This method is based on ultrasonic birefringence and used in conjunction with steel bridges.

Opportunity for collaboration

As stated earlier, the FHWA desires to insure that the needs of its stakeholders and others in the public, private and academic segments of the highway bridge community are addressed and their technical input and recommendations obtained in order to make LTBP program investment successful. A compilation of the information needed will be done by a series of workshops seeking feedback from participants on all aspects of data collection and analysis, bridge performance, long-term monitoring, bridge selection criteria, the use of sensing technologies and NDE/NDT tools, and expected outcomes and deliverables. It is anticipated that two additional workshops, one in Europe and one in Japan, will be held to reach out to the international community to obtain collaboration and cooperation.

Conclusion

To summarize, long term bridge monitoring can provide quantitative data for network and bridge level management. This could contribute to a much greater level of reliability and utility of data necessary for asset management. Bridge safety, especially during extreme events, is enhanced by measurement and monitoring of critical bridge components. Enhanced safety, reliability and efficient maintenance can result from improved incident detection and assessment. Global bridge health and performance assessment in support of asset management, enhanced specifications and realistic life-cycle cost analysis must be, and arguably can only be, accomplished using quantitative measurement methods. Subjective assessment simply is not adequate to meet these needs. The proposed Long-term Bridge Performance Program is intended to meet these needs.