The Long Term Bridge Performance Program – A Program Update

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Abstract. The LTBP program is a twenty-year research program initiated by the United States Federal Highway Administration to study several critical aspects of bridge performance. High priority performance issues have been identified with the assistance of bridge owners and other key stakeholders. A pilot program to validate inspection protocols has been completed and a unique data infrastructure to manage LTBP data has been created. Bridges to be tested will be selected using a statistically designed process and reference bridges will be selected. The long-term data collection phase of the program will be underway in late 2012.

Introduction

Understanding and improving bridge performance is a complex challenge. At different levels, bridge performance involves performance of materials and protective systems, performance of the individual components of the bridge, and performance of the structural system as a whole. Some important aspects of bridge performance are not well understood, partly because the performance of each component or characteristic of a bridge is governed by different combinations of different influencing factors. This is often true because the data necessary to characterize and quantify the relevant influencing factors and better understand the relationships that impact performance has never been collected or is not easily accessible.

The United States (US) Federal Highway Administration (FHWA) has initiated the Long Term Bridge Performance (LTBP) Program, a twenty year, multi-faceted research effort that is intended to study critical issues of bridge performance in order to better understand those issues and to improve performance related to those issues. The overall strategy of the LTBP program is to inspect, evaluate, and periodically monitor representative samples of bridges nationwide over an extended period of time. The high-quality quantitative performance data collected will be merged with other bridge related data that is available but not currently gathered into a single database. Analysis of the data gathered is intended to support new knowledge and create new tools for better understanding and prediction of bridge behaviour. The overarching objective of the LTBP program is to develop a better understanding of bridge performance and foster the

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development of materials, techniques and technology that will improve bridge performance over the long term. Some desired outcomes of the program include:

- Improved performance prediction and life cycle cost models
- Quantified benefits of bridge preservation strategies
- Enhanced design, construction and preservation practices
- Reliability-based inspection criteria

1. Critical Bridge Performance Issues

The different aspects of bridge performance can be loosely grouped into four general categories: structural durability and condition, functionality (safety and traffic capacity), structural integrity and risk, and costs – to the user and to the agency. Within each of those groups there many issues that could be studied. Therefore, in order to best serve the needs of bridge owners, it was necessary to determine what performance issues were most important to those bridge owners and other key stakeholders. Focus group meetings to identify top priority issues were held with 15 state departments of transportation (DOTs) geographically distributed around the U.S. In addition, FHWA maintained a continuing dialogue with relevant technical committees of the American Association of State Highway & Transportation Officials and the Transportation Research Board. Other opportunities were taken to discuss the high priority issues at engineering conferences and to receive feedback. Based on all of the input from the DOTs and the other key stakeholders, a list of twenty high priority issues for possible study under the LTBP program was developed (see Table 1).

Table 1. Long Term Bridge Performance Study Topics.

LTBP Bridge Performance Topic	**LTBP Bridge Performance Topic**
Untreated Concrete Bridge Decks	Prestressed Concrete Girders
Bridge Deck Treatments	Coatings for Steel Superstructure Elements
Precast Reinforced Concrete Deck System	Weathering Steels
Alternative Reinforcing Steels	Innovative Bridge Designs and Materials
Cracking on the Performance of HPC Decks	Scour Countermeasures
Bridge Deck Joints	Bridge Approach-Abutment Interface
Jointless Structures	MSE Walls
Bridge Bearings	? Durability of Foundation Elements
Bare/Coated Concrete Super- and Substructures	Risk and Reliability Evaluation for Structural Safety
Embedded Prestressing Wires and Tendons	Functionally Obsolete Bridges

After evaluation of all the input from the various correspondents, a short list of topics was developed for immediate consideration. Table 2 presents the six top priority study topics recommended for immediate study under the long-term phase of the program. If time and resources permit, additional topics may be incorporated into the program.

Table 2. Initial Study Topics for LTBP Program.

Category	**Issue**
Decks	Untreated and Treated Concrete Bridge Decks
Joints	Bridge Deck Joints
Bearings	Bridge Bearings

Steel Bridges	Coatings for Steel Superstructure Elements
Concrete Bridges	Encapsulated Prestressing Strands & PT Tendons

2. Pilot Program

In order to achieve the LTBP program goals, it was first necessary to understand and plan for:

Program costs – realistic costs that would be associated with inspection and testing a large number of bridges.

Coordination with bridge owners – necessary permits, approved plans for maintenance of traffic plans and approval of testing plans.

Data to be collected – the type, quality, and quantity of data that meets the needs of the LTBP program experimental studies while avoiding excessive time and cost.

Data collection protocols –clear specifications for the LTBP inspections and data collection that can be consistently applied over the duration of the program and by different research teams.

Seven pilot bridges (Figure 1) were selected around the nation to act as a field laboratory. They represent a small sample of the bridge population, covering the bridge types, characteristics, and environmental conditions likely to be considered within the LTBP program. The purpose was to gain the critical knowledge noted above and to evaluate the proposed protocols for detailed inspection, sampling, instrumentation, testing, and monitoring on this cross-section of structure types and environments.

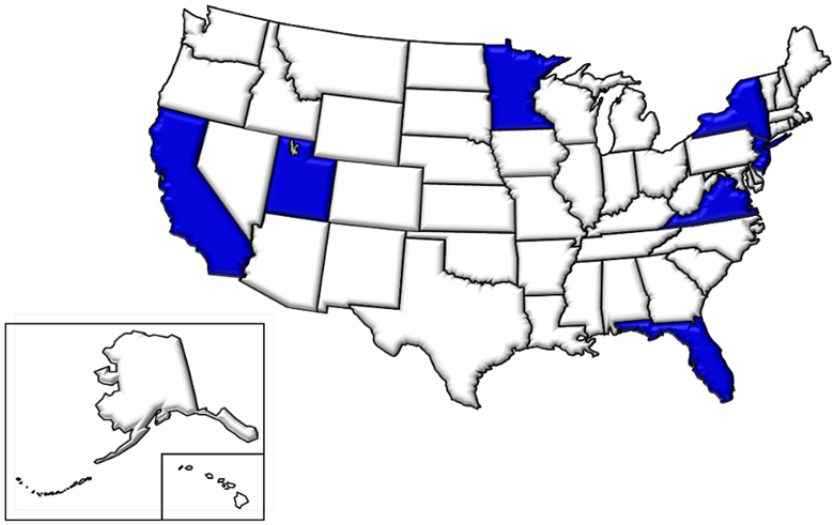

Figure 1. Seven LTBP Pilot Bridge States

Researchers used a complementary package of both traditional and state-of-the-art data collection techniques. At each pilot bridge, researchers first established a baseline condition for comparison during long-term instrumentation and periodic retesting, allowing researchers to track and model bridge deterioration and performance over time. Four data collection approaches were used to evaluate the baseline condition of all pilot bridges – detailed visual inspection, non-destructive evaluation (NDE) tools, physical (material) sampling and analysis, and live-load testing. Additionally, dynamic testing was used on several of the pilot bridges.

Use of multiple non-destructive evaluation techniques provided information about the condition of the reinforced concrete components often well before there were visible signs of deterioration. Eight different NDE techniques were used on the pilot bridges,

mainly on the concrete decks: ground penetrating radar (GPR), cover depth (CD), impact echo (IE), ultrasonic surface wave (USW), half-cell potential (HCP), electrical continuity of reinforcing steel (ECRS), electrical resistivity (ER), and moisture content. Several of these tools are shown in use on the Virginia pilot bridge in Figure 2.

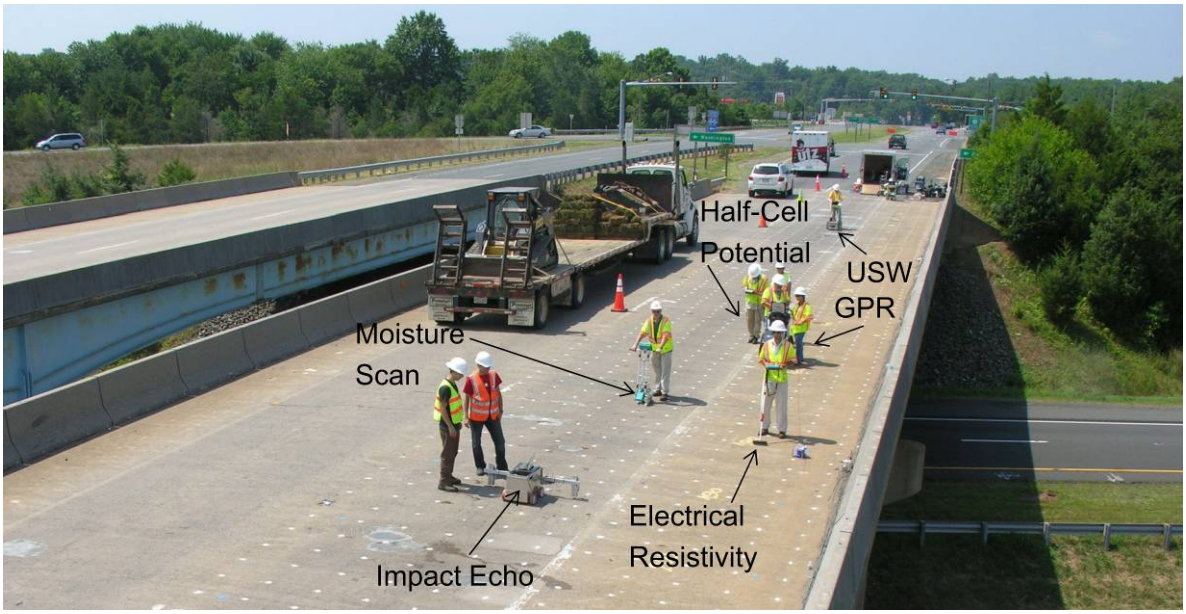

Figure 2. Multiple NDE Techniques Used on Pilot Bridge

Physical sampling and analysis were conducted on the decks of all the pilot bridges, the superstructures of the California and New York pilot bridges, and the substructure of the Florida pilot bridge. Laboratory testing on the samples provided information on concrete strength and density characteristics, permeability, and chloride contents. The combination of physical sampling and NDE testing resulted in complementary data that could be layered to produce a more detailed and reliable evaluation of the current bridge condition and the potential for future deterioration.

Used in concert, the suite of finite element modelling, live-load testing, and dynamic testing tools produced a calibrated model and information on the structural response of the bridge, including bearing performance, amount of composite action, and dynamic properties. The baseline data may be compared to future bridge response after degradation has occurred.

In addition to baseline testing, long-term instrumentation was installed at the California, New Jersey, New York, Utah, and Virginia pilot bridges to monitor climate, loading and load history, and deck condition/deterioration over time. Instrumentation of these bridges employs reliable sensor technologies to measure performance characteristics under routine traffic conditions.

The primary objectives of the pilot phase of the LTBP program - to validate the data collection protocols, to streamline the data collection process, and to develop tools and procedures for data analysis – were successfully met. In addition many valuable lessons were learned about factors such as the bridge selection process, coordination with bridge owners, the relative value and usefulness of various physical sampling and NDE methods, appropriate data sampling rates, data management and storage, and realistic costs of field testing necessary to meet LTBP program goals.

3. LTBP Inspection and Testing Protocols

During the span of the LTBP program, hundreds of bridges will be investigated using different combinations of various types of analysis, finite element modelling, in-depth visual inspection, non-destructive evaluation, sampling and analysis of physical properties, live load testing, dynamic testing, and long term instrumentation. These investigations will continue for as much as 15 years and over time, different teams of researchers will be employed on different groups of bridges. In order to maximize the validity of the LTBP data and ensure consistency and repeatability of testing between research teams, it is necessary to clearly specify how each type of testing shall be done, the type of data to be collected, spatial and temporal data sampling rates, required accuracy of measurements, etc.

Therefore, a set of testing and inspection protocols has been developed to cover all aspects of field testing that may be utilized on the LTBP bridges. This includes: site preparation, the instrumentation plan, finite element modelling, detailed visual inspection, non-destructive evaluation, live load testing, dynamic testing, long term instrumentation plus data collection and management. Consistent with the high priority performance topics identified for the first several years of the long-term data collection phase, the current protocols are designed for application to the bridge deck, expansion joints, and bearings as well as for inspection of steel superstructure members for corrosion and/or section loss. Additional protocols for inspection and testing of superstructure members, including prestressed concrete beams, are being developed. Following that, detailed protocols for the substructure will be developed.

The current suite of LTBP protocols was thoroughly evaluated during LTBP pilot phase. They represent an optimal balance among the accuracy of results, speed of field work, ability to validate or verify accuracy and repeatability of results, and overall cost for the inspection and testing efforts. Over the course of the 20 year program it is reasonable, even prudent, to expect that existing technologies will evolve and new technologies for bridge investigations will be developed. When it is deemed appropriate, the LTBP protocols may be modified to respond to such changes. Any changes of this nature will be carefully evaluated to ensure that the value of previously collected data will not be lost.

The LTBP Investigations will produce a wide variety of data depending on the performance issue being studied. The LTBP research team, and eventually other interested researchers will use this data to conduct in-depth studies on issues such as the performance of untreated concrete decks and how it is affected by environment, traffic, different maintenance strategies, etc. A unique data infrastructure, named the Bridge Portal will be the repository for LTBP data and the engine for analysing the LTBP data. The Bridge Portal will capture data from external sources such as the US National Bridge Inventory, state-based element level condition data, weather and traffic data as well as all experimental data collected during the LTBP field experiments. Data will be stored at several levels of processing and analysis starting with the raw experimental data. The different levels of data condition are shown in Figure 3.

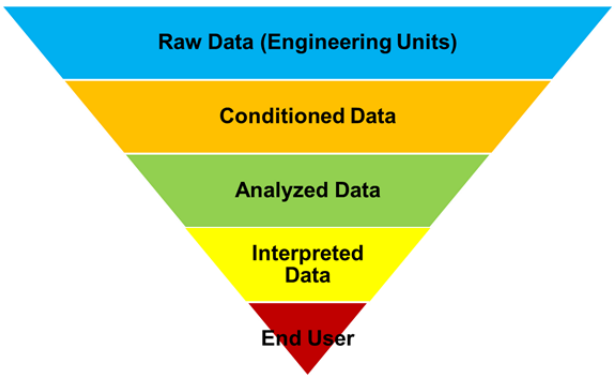

Figure 3. Stages of Data Processing and Analysis

The Bridge Portal will allow different types of data to be layered in different combinations to create more nuanced definitions of component condition. An approach being considered for use in defining component condition is known as the Bridge Condition Index, Ci.

4. LTBP Reference Bridge Program

The transition from the pilot phase to the long-term data collection phase is being done systematically in order to address a number of high priority performance issues over the next few years. The LTBP Program must first develop a strategy to focus the first phase of the program, which ensures the maximum impact in the near-, mid- and long-terms. The Reference Bridge Program concept has been developed to implement such a strategy.

Given the large and diverse population of bridges throughout the U.S., one of the most significant challenges to the LTBP Program is sample selection. To address this concern the Reference Bridge Program will use a variety of sampling methodologies, which range from heuristic-based to rigorous statistical approaches, in concert with one another. Still, the relatively small sample size envisioned for the near-term (compared to the overall bridge population) remains a significant challenge. As a result, to ensure the selection of meaningful and representative samples of bridges, two mitigation approaches will be employed by the Reference Bridge Program.

The first will be to reduce the overall population that will be considered within the LTBP Program in the near-term. Although the population of U.S. bridges is quite diverse, multi-girder steel and prestressed concrete bridges and prestressed box girder bridges represent the most common bridge types. Focusing on their performance will enable the LTBP Program to make the largest impact in the near- and mid-terms.

The second approach to mitigating the sampling challenge is more novel. The concept involves the selection of a Reference Bridge along with a representative cluster of bridges in the same vicinity that have similar characteristics (age, type, maintenance practices, etc.). These reference and cluster bridges will be chosen from various regions across the U.S. to allow the examination of spatial influences related to climate, truck traffic, maintenance practices, etc, as well as comparisons across different bridge types.

The general approach to data interpretation and performance assessment for the Reference Bridge Program will involve three levels:

(1) Comparison of the Reference Bridge to its cluster in order to identify detailed, bridge-specific behaviour/performances (illustrated in Figure 4)

(2) Comparison of clusters of similar bridges from different regions across the U.S. to identify the influences of climate, maintenance practices, truck traffic, etc. (illustrated in Figure)
(3) Comparison of clusters across bridge classes to identify the relative performance of one bridge type to another

In this approach the Reference Bridge will undergo periodic detailed inspection and monitoring through advanced methods that utilize sensor, NDE, and simulation technology. In contrast the supporting cluster of bridges will only undergo detailed visual inspection and limited NDE and will be compared directly to their Reference Bridge to ascertain consistency. This approach not only places the Reference Bridge in context, but it also allows for the assessment of variability, alleviates the potential for non-representative/ anecdotal findings, and is cost effective as each bridge cluster is located

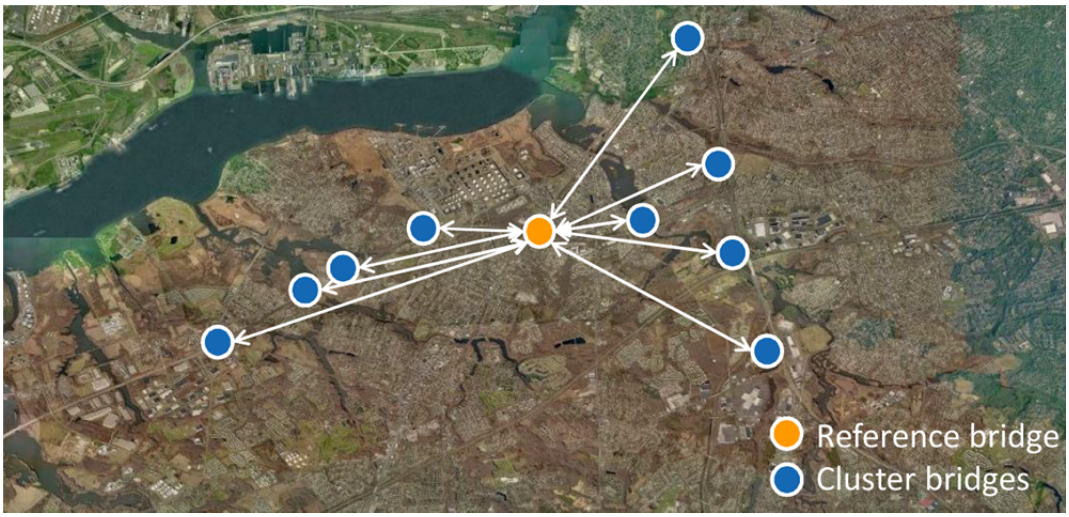

Figure 4. Comparison of cluster bridges to the reference bridge to assess the influence of traffic, materials, protective systems, structural form, etc.

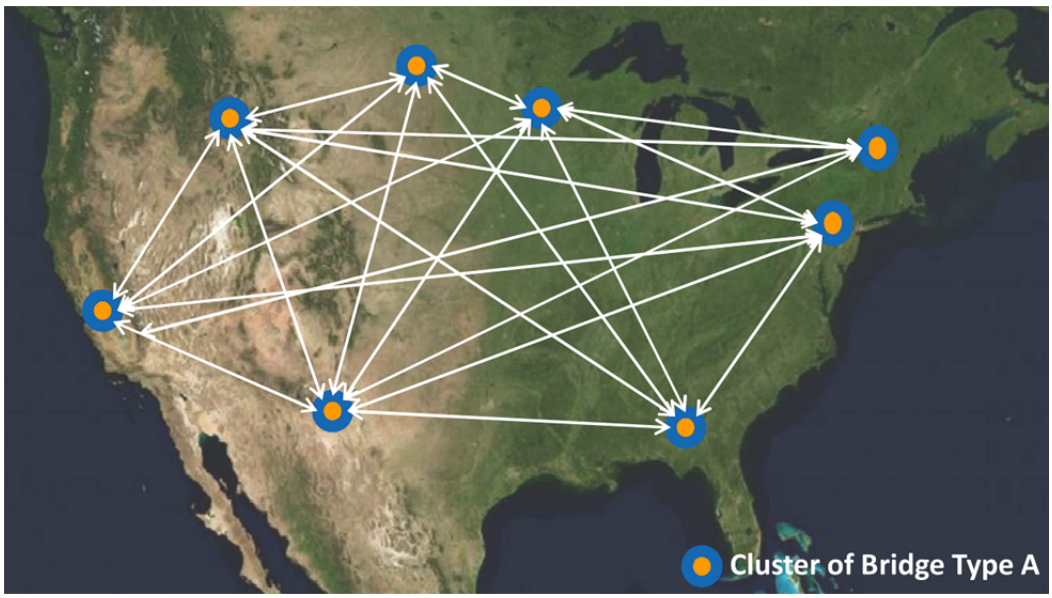

Figure 5. Comparison of different clusters to assess the influence of climate, maintenance practices, etc.

within a small geographical area. Assuming that the Reference bridge and its cluster are consistent in terms of performance, reliable comparisons can then be made to other Reference Bridges (and clusters) of similar type to ascertain influences such as climate, truck traffic, maintenance practices, etc.

In cases where discrepancies are identified, certain cluster bridges may be subjected to more advanced assessment approaches to further examine the discrepancies and to identify the root cause. Such investigations have great promise to begin to establish the expected variability of bridge performance within a given region and to identify the reasons why seemingly identical bridges in some cases perform quite differently.

In the near-term the Reference Bridge Program will focus on examining the performance of three common bridge types (likely multi-girder steel and prestressed concrete bridges – girders or box beams). For each type of bridge between five and ten Reference Bridges will be selected across the U.S. (using the sampling methodologies developed) to allow the influences of bridge maintenance practices, climate, age, truck traffic, etc. to be established. For each Reference Bridge a supporting cluster of approximately ten bridges will be chosen within the same local region and with the same characteristics. Over the course of the LTBP program, additional clusters bridges are expected to be added over time, reaching a size of approximately 75 bridges per cluster.

5. Conclusions

The key components of the LTBP program are in place. A list of high priority bridge performance issues have been identified with input from bridge owners and other key stakeholders. Detailed inspection protocols have been written for inspecting bridge decks and some superstructure components. Future protocols for superstructure and substructure will be developed. A pilot program of inspection and testing of seven different types of bridges has been completed. Lessons learned on bridge access, cost of testing, coordination with owners, maintenance of traffic and application of the LTBP protocols will be applied during the upcoming long-term data collection phase of the program. A statistically sound method of sampling the US bridge population has been developed. A unique concept of reference bridges and associated cluster bridges will broaden the base of the investigation without requiring excessive costs. The long-term data collection phase of the program will begin in late 2012.