Advances in Highway Bridge Technologies for Design, Inspection, and Management: FHWA's Research and Development Program – 2006 Through 2009

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Abstract

With recent passage by the U.S. Congress of surface transportation legislation, the Federal Highway Administration has been charged with providing new technologies and solutions for improving the performance of highway bridges, through a combination of new design and construction approaches, and development of improved tools for condition assessment, management, and rehabilitation of existing highway infrastructure. A range of research, development, and technology deployment programs have been initiated by the FHWA as a result. This paper discusses the broad range of activities being initiated and conducted during fiscal years 2006 through 2009, and their anticipated impacts on highway practice.

Introduction

The Federal Highway Administration (FHWA) has a long history in the development of advanced highway technologies and supporting the application of technical innovations and advancements into practice. This is continued under the recently enacted Safe, Accountable, Flexible, and Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU), which authorizes the Federal surface transportation programs through the end of Fiscal Year 2009. SAFETEA-LU provides the basis for continuing the FHWA's stated mission, which is "Enhancing Mobility Through Innovation, Leadership, and Public Service."

FHWA is aggressively pursuing this mission by focusing on six strategic goals:

- Safety – Continually improve highway safety.
- Mobility and Productivity – Preserve, improve, and expand the Nation's highway transportation system while, at the same time, enhancing the operation of the existing highway system and intermodal connectors.
- Global Connectivity – Promote and facilitate a more efficient domestic and global transportation system that enables economic growth.
- Environment – Protect and enhance the natural environment and communities affected by highway transportation.
- National Homeland Security – Improve highway security and support national defense mobility.

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- Organizational Excellence – Advance FHWA's ability to manage for results and innovation.

In the Bridge and Structures arena, FHWA has developed a *Bridge and Structures Program Strategic Plan*, which provides the focus and roadmap for which all research, development, and deployment activities must support. There are four primary outcomes defined in the Bridge Program Strategic Plan, which are as follows:

Outcome 1 – Highway structures are designed, constructed, and rehabilitated with standards and materials that provide longer and more reliable performance.
Outcome 2 – Highway structures are constructed or rehabilitated with systems, methods, and practices that reduce congestion and improve safety.
Outcome 3 – Highway structures provide a high level of safety and service under all conditions.
Outcome 4 – Highway structures fit their environment through the application of context sensitive solutions (CSS) principles.

FHWA Structures Research Approach

All research conducted by FHWA follows the basic tenets and processes outlined in the FHWA *Corporate Master Plan for Research and Deployment of Technology & Innovation*[2] (the Plan). The purpose of the Plan is to continue to improve the effectiveness and efficiency of FHWA research and technology development, including the end goal of deploying and implementing technologies and innovations that improve the quality, cost-effectiveness, and timeliness of products, procedures, processes, and practices.

The Plan presents a role, new focus, and clear direction for the FHWA's research and technology program within the context of improving highway transportation. In addition, it outlines FHWA's corporate strategy for investing in and conducting research in cooperation with its partners and stakeholders.

To achieve the outcomes contained in the Bridge Program Strategic Plan, the FHWA structures research program is conducted by researchers working within three interdisciplinary teams. Each team is focused on the strategic goals noted above, but from different perspectives. These teams are:

- *Bridge Design & Construction Team* – The primary focus of this team is on the development of more durable and higher-performing bridge systems for new and replacement construction. The team is comprised of specialists in structural engineering with expertise in traditional highway structure materials (steel and concrete) and innovative materials (e.g., fiber reinforced polymer composites),

[2] The Plan is available at www.fhwa.dot.gov/legsregs/directives/policy/cmp/03077.htm

geotechnical applications and foundation design/construction, and long term durability of structural materials. The team also has expertise in full scale structural testing, instrumentation, failure analysis, and advanced analytical modeling techniques. The research conducted by the Bridge Design & Construction team is supported by the main structures laboratory, geotechnical laboratory facilities, materials testing laboratory, and a machine shop. (Team Leader: Bill Wright, 202-493-3053, bill.wright@FHWA.dot.gov)

- *Infrastructure Inspection & Management Team* – The primary focus of this team is on a wide array of technologies associated with the management and preservation of the Nation's existing inventory of highway structures. The team is comprised of specialists with expertise in bridge inspection methods, tools, and data analysis; bridge and asset management systems and data mining; corrosion and corrosion protection; and structural rehabilitation. The research conducted by the Infrastructure Inspection & Management team is supported by the Nondestructive Evaluation (NDE) Validation Center, corrosion and structural coatings laboratory, and the Bridge Management Information Systems laboratory. (Team Leader: Joey Hartmann, 202-493-3059, joey.hartmann@FHWA.dot.gov)

- *Safety, Reliability, & Security Team* – The primary focus of this team is on the protection of new and existing bridges and highway structures from the damaging impacts resulting from both normal day-to-day and extreme events, including natural and man-made hazards like earthquakes, floods, hurricane-force winds, and terrorism. The team has significant expertise and knowledge regarding the phenomena associated with these extreme events, and in providing engineering solutions that provide a high level of resilience to resist them. This team is also charged with leading the research agenda for issues associated with bridge security. The research conducted by the Safety, Reliability & Security team is supported by the hydraulics laboratory and the aerodynamics laboratory. (Team Leader: Sheila Duwadi, 202-493-3106, sheila.duwadi@FHWA.dot.gov)

FHWA Structures Research Programs

SAFETEA-LU authorized a number of research programs in the structures field that address FHWA and stakeholder needs and priorities. Among these are the:

- Long-Term Bridge Performance (LTBP) Program,
- Innovative Bridge Research & Deployment (IBRD) Program,
- High Performance Concrete (HPC) Bridge Research and Deployment Program,
- High Performing Steel (HPS) Bridge Research and Technology Transfer Program, and
- Steel Bridge Testing Program.

The ***LTBP Program*** is an ambitious multi-year research program which is being modeled somewhat after the Long Term Pavement Performance program, which was initiated in 1989. The LTBP Program has been designed as a 20-year effort that will include detailed inspections and periodic evaluations and testing on a representative sample of bridges throughout the United States in order to monitor and measure their performance over an extended period of time. The LTBP Program will also include a set of instrumented bridges that can provide continuous, long-term, structural bridge performance data, and detailed forensic autopsies on bridges, using some of the structures that are decommissioned by State transportation agencies. The intent is to collect actual performance data on deterioration, corrosion, or other types of degradation; structural impacts from overloads; and the effectiveness of various maintenance and improvement strategies typically used to repair or rehabilitate bridges. It is anticipated that the resulting LTBP database will provide high quality, quantitative performance data for highway bridges that will support improved designs, improved predictive models, and better bridge management systems.

The ***IBRD Program*** was established to encourage highway agencies to more rapidly accept the use of new and innovative materials and technologies or practices in highway structure construction. The intent of the program is to promote, demonstrate, evaluate, and document the application of innovative designs, materials, and construction methods in the construction, repair, and rehabilitation of bridges and other structures. The intended goals are to increase safety, durability and reduce construction time and traffic congestion; reduce maintenance costs and life-cycle costs of bridges. Part of the IBRD Program will support innovative research in the areas of hydraulics, aerodynamics, and geotechnical engineering; another part of the program will support the deployment of innovative approaches in bridges to be constructed throughout the United States.

The ***HPC research and deployment program*** is a subset of the IBRD program; it is intended to continue the advancement of HPC applications through targeted research that addresses needed improvements in design, fabrication, erection and long-term performance in order to achieve the Bridge Program strategic outcomes. HPC research will focus on material and casting issues, including improved performance criteria, lightweight concrete, curing, and test methods; structural performance concerns, including compression, shear, and fatigue behavior for both seismic and non-seismic applications; and concepts related to accelerated construction and bridge system design and performance.

In addition to the HPC program, but funded separately from IBRD, the ***Ultra-High Performance Concrete*** (UHPC) program will continue research and development of optimized applications for the use of UHPC. UHPC, also known as reactive power concrete, is a unique material which is reinforced with short steel fibers, but requires no conventional steel reinforcing. Prior FHWA research on UHPC focused on basic material characterization, and the development of optimized structural systems using this very high performance, but costly, material. Under the UHPC program, additional work

will be conducted to further characterize the material and assess its corrosion-resistance properties, while addressing its use in other structural components including precast bridge deck panels and prestressed I- and bulb-tee girders.

The ***HPS research and technology transfer program*** is a broad-based program focused on resolving a number of issues and concerns with the design, fabrication, erection, and long-term performance of both conventional and High Performance steels. The program will focus on research and technology transfer/education in the areas of materials and joining (e.g., optimized welding processes and procedures); long-term performance (including advanced knowledge on performance limitations of weathering steels and the potential development of a 100-year shop-applied permanent steel coating system); innovative design (including testing and deployment of modular steel bridge super- and substructure systems); and fabrication and erection tools and processes.

The ***Steel Bridge Testing program*** is focused on the further development and deployment of advanced non-destructive evaluation (NDE) tools that can be used to detect and quantify growing cracks in steel bridge members and weldments. As defined in SAFETEA-LU, the NDE technology will need to be able to detect both surface and subsurface cracks, in a field environment, for flaws as small as 0.010 inches in length or depth.

In addition, SAFETEA-LU directed the FHWA to conduct research in two specific areas with designated research institutions: the University of Nevada, Reno and the University at Buffalo will be conducting seismic research programs intended to increase the resilience of bridges and reduce earthquake-induced losses due to highway damage; and the University of Maine will conduct a research program focused in the development and application of wood-FRP composite materials as primary structural members in highway bridges.

Selected Research Program Details

High Performance Concrete (HPC) Research

The HPC research program will look at both material property research issues and structural/system performance issues. Among the material property issues to be addressed are the following:

- High-performance lightweight concrete material properties – The objective of this research is to amend or establish predictor equations for the material properties of lightweight and sand-lightweight concrete. Research matrices should include the various readily available coarse and fine lightweight aggregates. Material testing will cover appropriate limit states, strength (compressive, tensile, flexural, modulus, etc.), serviceability (freeze-thaw, scaling, abrasion, chloride ion penetration, ASR, air void,

others), stability (shrinkage, creep, thermal expansion), production issues (QC, curing, etc.).

- Deck curing – The objective of this research is to establish effective curing methods for HPC. It will evaluate if a curing compound or waterproof covers with certain reflectance and moisture retention can be successfully used in HPC with different cementitious materials and water/cement ratios, and if water curing reduces drying and autogenous shrinkage.

Structural and system research issues to be addressed in the HPC program include:

- High-performance lightweight concrete for prestressed beams and bridge decks – The objective of this research is to verify or extend the prestressed girder design limit states to include the use of lightweight and sand-lightweight concrete. Component and structural testing to include bond/development of reinforcement, transfer of prestress, shear (vertical, horizontal, punching…non-p/s and p/s), flexural and axial loads, p/s losses, confinement requirements etc.

- Shear of non-prestressed elements – Extend the applicability of the shear provisions for reinforced and prestressed concrete structures (other than prestressed beams) to compressive strengths of normal weight concrete up to 20ksi.

High Performance Steel (HPS) Research

Similar to the HPC program, the FHWA HPS research program will consist of studies addressing materials, fabrication, and structural/system issues. Among the materials and fabrication research tasks are the following:

- Optimized welding processes and procedures for automated bridge fabrication – The objective of this research is to investigate the performance welding processes and procedures to improve fabrication efficiency and facilitate automation in the steel bridge fabrication industry. This will set the framework for implementation of robotics and automated fabrication practices to support modular construction projects.

- Improved HPS steel with enhanced corrosion resistance – This research will conduct a screening study to identify possible approaches to development of an economical steel grade with enhanced corrosion resistance. If successful, a complete research and development program will be conducted to develop the steel that will broaden the range of suitable applications for use of unpainted steel in bridge structures. This will reduce fabrication time and cost, as well as reduce life-cycle maintenance costs.

- One-coat shop paint system – A one-coat paint system offers the potential to improve the economics of steel bridge fabrication. Compared to typical three coat systems, a

one-coat approach promises to reduce the time it takes to apply the coating system. The challenge is to develop and test the performance of one-coat systems and to understand the expected life or long-term performance of the system. The research will be conducted via accelerated coupon testing at the FHWA's Turner-Fairbank Highway Research Center Coatings Laboratory

- 100-year permanent paint system – The goal of this research is to develop advanced coating systems that can be considered permanent for a projected 100-year service life. This will provide a steel alternative that will greatly reduce future maintenance and environmental concerns.

Among the structures and systems research being conducted under the HPS program are the following studies:

- Testing and evaluation of modular, rapid construction bridge concepts – Several promising steel bridge design concepts that show promise for rapid construction of bridges will be evaluated and constructed. These will then be subjected to experimental evaluations to determine their constructability, performance, and long-term durability. For successful concepts, design details and guidance documents will be developed.

- Steel bridge design concepts to promote rapid construction for short span, integral abutment bridges – A construction system that integrates geo-synthetic reinforced soil (GRS) abutments and piers with a modular steel superstructure will be developed and tested. This will provide a rapid construction option for short span steel bridges.

Hydraulic, Aerodynamic, and Geotechnical Research

As noted earlier, the IBRD program will support a combination of advanced research, and technology deployment in bridge construction projects. Among the research studies to be supported via the IBRD program in the areas of hydraulic, aerodynamic, and geotechnical engineering are the following:

- Bridge deck lift and drag studies and optimum bridge deck shapes to minimize pressure flow – As a result of the significant bridge damage which occurred in 2004 and 2005 in the Gulf Coast areas of the United States (in Florida, Louisiana, Mississippi, and Alabama), the FHWA has initiated a series of studies to better define the loads that occur during strong hurricanes and other wind events (e.g., storm surge impact and drag, uplift), and the resistance of typical highway bridges to these forces. Some of these studies will attempt to provide guidelines for optimizing bridge deck shapes to minimize the impact and drag forces, while others are developing new design and retrofit solutions to improve bridge performance.

- Parametric studies of bridge geometric details and their aerodynamic significance – In Japan, many parametric aerodynamic studies of various deck geometries and details have been conducted and the information from these studies has been used in the development of the Japanese "Wind Design Guide for Long Span Bridges." In the United States, a similar systematic study of geometry and details, and the cataloguing of typical bridge and structures aerodynamic properties has yet to be done. The objective of this project is to conduct a program of parametric studies to investigate a variety of generic bridge geometries, actual bridge sections, and details. The research involves special static and dynamic studies in the FHWA Aerodynamics Laboratory to extract and catalogue aerodynamic properties such as force coefficients, flutter derivatives, and Strouhal number. The research will serve as a basis for later development of draft design criteria.

- Application of advanced materials to bridge foundations – The objective of this research is to investigate the application of high performance (e.g., HPS, HPC, lightweight concrete) and other advanced materials in the design and construction of bridge foundations. The research will also focus on the use of these materials in substructures in corrosive environments or in design schemes where the use of these materials can reduce the cost of foundation construction, while improving durability or reducing construction time. The research will start in 2006 with a workshop with appropriate foundation design and construction experts, advanced materials researchers, and others, to identify potential applications for high performance and advanced materials, and to then develop a research and development (R&D) roadmap for the program. Following the development of the roadmap, research will be conducted to explore and evaluate applications of high performance materials in foundation construction.

Summary

The research programs and studies described in this paper provide a "snapshot" of an ambitious multi-year program to be conducted by the Federal Highway Administration over the period of 2006 through 2009. While the focus of this paper has been on research, the program actually provides a balance between research, deployment of new and innovative technologies in bridge construction practice, and in education and training in the use of these new technologies.

Through the conduct and completion of these programs and projects, and the deployment and education on the advances in technology anticipated by the end of 2009, the FHWA envisions that bridge engineering practice in the United States will result in an inventory of better designed, maintained, and managed highway bridges throughout the country, and in improved decision-making with respect to financial investments. The result will be longer-lasting, better-performing, highway bridges in both normal and extreme event environments.