# MARKET-READY TECHNOLOGIES FOR BRIDGE DESIGN, CONSTRUCTION AND MANAGEMENT

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## Abstract

The U.S. National Bridge Inventory consists of about 600,000 highway bridges, carrying nearly 4 billion vehicles daily over public roads. These bridges represent a sizable investment of resources. The Federal Highway Administration has the challenging responsibility to provide leadership in renewing, maintaining and operating a safe, secure, reliable and efficient highway infrastructure. The Federal Highway Administration works collaboratively with partners and stakeholders to support research and advance innovative bridge technologies. The objective of this paper is to present some key market-ready technologies for bridge design, construction and management for extending the service life of new and existing bridges.

## Introduction

The vision of the Federal Highway Administration (FHWA) is to improve transportation for a strong America. In support of this vision, the FHWA's Bridge Community is dedicated to working together with national and international partners in research, development and deployment of innovative technologies to provide safe, secure, reliable and efficient highway bridges.

There are about 600,000 highway bridges in the public roads in the U.S. The average age of these bridges is about 48 years. Many of these bridges are being replaced or rehabilitated. New bridges are being added to the inventory. It is vitally important for us to protect, maintain, and preserve the aging population of highway bridges and to achieve durability in new construction. The FHWA bridge program strategic plan focuses our resources in research, development, deployment and implementation of innovative technologies to assure that highway bridges are designed, constructed and preserved to provide longer and more reliable performance, to reduce congestion, to improve safety, and to be sensitive to the environment.

The 1998 Transportation Equity Act for the 21st Century (TEA-21) established a 6-year Innovative Bridge Research and Construction (IBRC) program to encourage the use of innovative materials and construction methods in bridge repair, rehabilitation, replacement and new construction. The main goal of this program is to improve the condition and durability of highway bridges while enhancing safety, mobility and productivity. Through this program, many market-ready technologies have been applied and verified in the field.

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## Load and Resistance Factor Design[2]

The AASHTO Load and Resistance Factor Design (LRFD) is the result of continuous improvements since AASHTO adopted the first national bridge code in 1931. The code changed from Working Stress Design (WSD) to Load Factor Design (LFD) in 1975 and now to the LRFD in 1993. LRFD is based on technological advances in bridge engineering, sound scientific principles, and a systematic approach to ensure safety, durability, constructability, inspectability, serviceability, economy and aesthetics.

New bridges designed in accordance with LRFD has the inherent advantage of a more uniform level of safety, resulting in low life-cycle cost. LRFD allows the use of advanced methods in design and analysis. It provides flexibility for maintaining good and successful engineering practices or customizing load and resistance factors to meet the demands of a project.

The basic LRFD equation is given by the following expression:

$$\sum \eta_i \gamma_i Q_i \leq \phi R_n \tag{1}$$

where $Q_i$ = Load or force effects
$R_n$ = Nominal resistance
$\eta_i$ = A factor relating to ductility, redundancy and operational importance
$\gamma_i$ = Load factor, a statistically based multiplier

LRFD defines four limit states to be satisfied by the design to achieve safety, serviceability and constructability. The basic LRFD Equation 1 must be satisfied for each limit state. The four limit states are:

1. Service Limit State: This limit state imposes restrictions on stress, deformation, and crack width under service conditions. This is similar to Working Stress Design (WSD) to assure elastic behavior and little need for maintenance during the service life of the structures.
2. Fatigue and Fracture Limit State: This limit state imposes restrictions on stress range due to a design truck occurring at the number of expected stress cycles. Again, this is similar to the fatigue design requirements in Working Stress Design and Load Factor Design to assure that there is no premature fatigue cracking or failure in the members of the structure.

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[2] See Transportation Research Record 1688, Paper No. 99-0935 Why the AASHTO Load and Resistance Factor Design Specifications? By M. Myint Lwin.

3. Strength Limit State: This limit state stipulates the strength and stability requirements to resist the specified statistically significant load combinations expected to be experienced by a bridge over its design life. This is similar to the Load Factor Design in assuring adequate ultimate load capacity.
4. Extreme Event Limit State: This limit state ensures the structural survival of a bridge during a major earthquake or flood or scour or when collided by a vessel, vehicle or ice flow. The designers are required to consider unique events to avoid major damage or collapse of the bridge.

FHWA and AASHTO have invested significant resources into developing the LRFD Specifications and providing training to the states in using LRFD. FHWA and AASHTO have jointly agreed to fully implement LRFD for Federal-aid bridge projects by October 2007.

## Load and Resistance Factor Rating

The AASHTO Guide Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges serves as a compendium to LRFD in setting the standards for condition evaluation and rating of bridges. LRFR provides procedures and policies for determining physical condition, maintenance needs, and load capacity for highway bridges. LRFR assists bridge owners in establishing inspection procedures and evaluation practices that meet the National Bridge Inspection Standards.

FHWA encourages bridge owners to use LRFR in the condition evaluation and rating of highway bridges designed by LRFD.

## High Performance Concrete Bridge Design and Construction

High Performance Concrete (HPC) is one of seven key technologies considered by the Strategic Highway Research Program (SHRP) for further development and implementation. In 1991, Congress provided funding to assist states in building HPC bridges and to showcase the beneficial results. HPC has enhanced durability and strength not normally attainable in conventional concrete. HPC is denser, stronger and less permeable. The advantages of HPC are: improved engineering properties, increased durability, longer spans, fewer piers, fewer beams, shallower beams and less overall cost than conventional concrete. With HPC we can design and build bridges and highways to achieve 100-year lives!

In the 1990's FHWA sponsored HPC showcases and participated in HPC Lead State activities to provide guidance and assistance to the States for implementing HPC. The IBRC program also provided funds to support the states in designing, constructing and monitoring the performance of HPC in bridges. Through these activities, most States are using HPC to take advantage of the durability and strength characteristics in substructures, superstructures and bridge decks. The results are: better long-term performance and reduced life-cycle costs.

In the last 10 years, HPC has made tremendous progress in technological advances and implementation. HPC is now the standard practice for many states. A recently survey indicates that all but six states have used HPC in project specifications in the last 10 years.

As the HPC Lead State activities were sunset by AASHTO, FHWA forms the HPC Technology Delivery HPCTD Team with a vision to provide leadership in advancing HPC technology. The HPCTD Team consists of members from FHWA, State DOT's, Industry and Academia, and maintains a website dedicated to the exchange of knowledge and information throughout the HPC community. The website address is: http://knowledge.fhwa.dot.gov/cops/hpcx.nsf/home.

## Self-Compacting/Consolidating Concrete [3]

Self-compacting/consolidating concrete (SCC) offers many advantages for the precast, prestressed concrete industry and for cast-in-place construction:

- Low noise-level in the plants and construction sites.
- Eliminated problems associated with vibration.
- Less labor involved.
- Faster construction.
- Improved quality and durability.
- Higher strength
- Lower cost.

Eliminating vibration cuts down on the labor needed and speeds up construction, resulting in cost savings and less traffic disruption. It also reduces the noise level in the concrete plants and at the construction sites. The overall quality of the concrete is improved, especially the surface finish. The surface finish of SCC is dense with little or no defects, which saves a lot of repair cost and gives a lot of job satisfaction to the workers.

Japan has developed and used SCC since the early 1990's. In the last few years, a number of SCC bridges, walls and tunnel linings have been constructed in Europe. In the U.S., SCC is rapidly gaining interest and use, especially by the precast concrete industry. Some precast plants have retooled and invested in SCC mixing plants to cost-effectively produce precast elements of all shapes and sizes, and level of intricacy. Ready-mixed SCC is being used in columns, walls, piers, crossbeams and drilled shafts of congested reinforcement. Properly engineered SCC flows into and completely fill intricate and

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[3] See FHWA FOCUS, December 2003 issue.

complex forms under its own weight, passes through and bonds to congested reinforcement under its own weight, and is highly resistant to aggregate segregation.

SCC has high potential for greater acceptance and wider applications in highway bridge design and construction. A National Cooperative Highway Research Program (NCHRP) project titled "Self-Consolidating Concrete for Precast, Prestressed Concrete Bridge Elements" has started in August 2004. The objective of this research is to develop guidelines for the use of SCC, including design mixes, test methods, and design and construction specifications. The South Carolina Department of Transportation has received an IBRC grant to study the use of SCC in drilled shafts. The Kansas State Department of Transportation has also received an IBRC grant to study the use of SCC in prestressed concrete girders. Many other State DOT's and research organizations are interested and experimenting with SCC.

FHWA has co-sponsored, in collaboration with state DOT's, industry and academia, SCC workshops in Texas and Hawaii to disseminate SCC information on bridge and highway construction. FHWA will continue to organize workshops and conduct training to meet the needs of the states that are interested in incorporating SCC in their projects.

## High Performance Steel Technology[4]

Structural steels have high strengths enabling engineers to design and build skyscrapers and long span bridges. However, extra care must be taken in welding, corrosion protection and crack prevention. To overcome these weaknesses in structural steels, a cooperative research program between the Federal Highway Administration (FHWA), the U.S. Navy and the American Iron and Steel Institute (AISI) was launched in 1994 to develop HPS for bridges and structures. In three years' time, the research program resulted in high performance steel (HPS) with improved weldability, excellent corrosion resistance, high toughness, high crack tolerance, and high strengths. The combination of these improved properties of HPS leads to cost effective applications in bridge design and construction. Three grades of HPS are now available: HPS 50W, HPS 70W and HPS 100W. Many states are already taking advantage of these properties in new bridge designs to improve long-term performance, lower first cost and reduce life-cycle cost.

The following four documents cover the design, fabrication and construction of steel bridges using high performance steels:

1. AASHTO LRFD Bridge Design Specifications, 3rd. Edition, 2004.
2. AASHTO Standard Specifications for Highway Bridges, 17th. Edition, 2002.
3. AASHTO Guide Specifications for Highway Bridge Fabrication with HPS 70W

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[4] See High Performance Steel Designers' Guide by Myint Lwin at http://www.fhwa.dot.gov/bridge

Steel (An addendum to the Bridge Welding code).

4. AASHTO/AWS D1.5-2002 Bridge Welding Code.

These documents reflect the findings and experiences on the applications of HPS by researchers, fabricators, manufacturers, owners and engineers working with high performance steels, and are the best references, as they are modified over time. The designers must make sure that all or parts of these documents are made a part of the contract document and add any supplemental requirements in the project special provisions.

Presently over 40 states are using HPS in over 200 projects. Many of these projects are in service, while the others are in various stages of design and construction.

The development of HPS is a very successful story of putting research into practice in a very short span of time. It exemplifies the vision and leadership of a strong collaborative partnership between governmental agencies, industry and academia. HPS is justifiably claimed to be "The Bridge Construction Material for the New Century."

## Fiber Reinforced Polymers [5]

Fiber reinforced polymers (FRP) has unique properties, such as high strength, light weight, corrosion resistance, high toughness, etc., which make it very attractive for strengthening, repair and seismic retrofit of bridges and structures. However, it has a high first cost and the long-term performance is not well established. FRP is adversely affected by environmental factors, such as ultraviolet light, alkalines, etc. FRP behaves quite differently than the conventional structural materials, such as concrete and steel. New design codes have to be developed for FRP.

FRP has great potential for providing engineering solutions to rebuilding our aging infrastructure. It has attracted the interest and attention of the research community, government and private industry to find ways to successfully integrate FRP in structural applications. The collective effort has resulted in many new developments and field applications of FRP composites. In recent years, FRP composites have been used as rebars and prestressing tendons in concrete structures, sheets and laminates for strengthening concrete and steel members, wraps and shells for seismic retrofit of concrete columns, structural shapes for bridges and pultrusions for bridge decks.

The Innovative Bridge Research and Construction (IBRC) Program, established and funded by Congress, provides opportunities to the States to experiment, demonstrate and document the applications of FRP composites in the construction of bridges and other structures. Currently, over 60 FRP demonstration projects are funded by the IBRC Program.

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[5] See FHWA Focus, May 2004 issue

We expect to see FRP gaining wider acceptance and greater applications in the years ahead.

## Ultrasonic Impact Treatment[6]

Ultrasonic impact treatment (UIT) equipment is now commercially available for improving fatigue strength of welded details. The UIT technique is easy to learn. It uses easy to handle tool, and produces much lower noise level than air hammer peening. It achieves reproducible results.

UIT has great potential for shop and field applications in improving the fatigue resistance of new and existing welded steel bridges. Fatigue tests conducted at the ATLSS Center of Lehigh University indicated that the UIT technique improved the fatigue strength of the welded details tested. For example, a Category E' (2.6 ksi) coverplated detail was improved to Category C (10 ksi) detail.

Many existing steel highway bridges have low fatigue category details, such as, Detail Categories D, E and E', which are susceptible to fatigue cracking, if not already cracked. New steel bridges are designed under the constraint of Detail Categories D, E and E'. These details can potentially be improved to Detail Category C by using UIT. There will be significant savings in expensive repair of existing bridges, and in effectively utilizing the higher strengths of modern steels in new bridges. The greatest benefit is in extending the service life of steel highway bridges with less disruption to the traveling public.

The test data on improvement by UIT is very limited at this time. Further research is needed to categorize fatigue details after UIT. A research is needed to develop and conduct a fatigue testing program to statistically determining the improvement of fatigue strengths of welded details after UIT. The results of this research would lead to wider acceptance and application of UIT.

## Accelerated Construction Technology[7]

Accelerated construction technology (ACT) is aimed at exploring innovative ways to reduce construction time on major highway projects, improving construction quality and workzone safety, and reducing adverse impacts on the traveling public. ACT uses prefabricated elements and systems extensively to assure quality in the constructed projects, minimize on-site disruption to traffic and improve safety in the workzone.

Prefabricated elements, substructure, superstructure, including deck and even complete bridge systems for rapid replacement are available and being used today.

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[6] See FHWA FOCUS, July 2003 issue

[7] See FHWA FOCUS, July 2003 issue

Prefabricated systems allow bridges to be built in days rather than weeks or months. The FHWA and AASHTO have been sponsoring workshops and have presented many project case studies on the use of prefabricated bridge systems. There are cases where heavy-lifting equipment is used to install a complete bridge in a very short time.

In 1999, the Transportation Research Board (TRB) formed Task Force A5T60 to promote accelerated construction in the highway infrastructure. The Task Force uses a process called Accelerated Construction Technology Transfer (ACTT) with the aim of reducing construction time dramatically, saving money and improving safety and quality by minimizing delays and hazards associated with work zones. The Task Force defines ACTT as a strategic process that uses various innovative techniques, strategies and technologies to minimize actual construction time, while enhancing quality and safety on large, complex multiphase projects. In 2002, the Task Force completed two very successful ACTT workshops. Since then, FHWA in collaboration with the AASHTO-TIG continues the effort and conducts workshops in various states. Interest among State DOT's has been very high. Three workshops were conducted in 2003. Six workshops are scheduled to be completed in 2004. Many more are planned for 2005

The ACTT process begins with a 2- to 2 ½-day workshop in which a multidisciplinary team of 20 to 30 national transportation experts works with an equal or greater number of their local counterparts to evaluate all aspects of a project and develop recommendations for reducing construction time and enhancing safety and quality. After the workshop, the host state will consider the various workshop ideas/recommendations, and develop an implementation plan accordingly.

All the states that hosted ACTT workshops are very satisfied with the results and benefits of the workshops. These states can now conduct their own workshops to achieve similar results.

Accelerated construction technology can effectively reduce construction time while enhancing quality and safety.

## Seismic Design of New Bridges

Strong earthquakes, such as the Loma Prieta Earthquake of 1989, Northridge Earthquake of 1994, Kobe Earthquake of 1995, the Turkey Earthquake of 1999, have taken hundreds of lives, caused billions of dollars of damages, and incurred other indirect costs as a result of damage to buildings, bridges, highways and other public facilities. The structural engineering community is intensifying efforts to minimize the loss of lives, property and commerce due to structural failures in future earthquakes.

FHWA has been sponsoring research and seismic design criteria development since 1970s. The first seismic design guidelines for highway bridges were developed and adopted by AASHTO as Guide Specifications in 1983. Bridges designed in accordance with these new guidelines performed well in the Loma Prieta and Northridge earthquakes. AASHTO incorporated these seismic design provisions in the AASHTO Standard Specifications for Highway Bridges in 1991 and in the AASHTO LRFD Bridge Design Specifications in 1994.

In 1998, NCHRP initiated Research Project 12-49 to develop a new set of seismic design provisions for highway bridges to reflect the latest seismic design philosophies and approaches to assure a high level of seismic performance. The research was completed in 2001. To assist in the implementation of the research findings, FHWA funded the development of a stand-alone set of seismic design criteria for adoption by AASHTO. This document is titled "Recommended LRFD Guidelines for the Seismic Design of Highway Bridges", which contains seismic design criteria for all regions of the United States. The document is being refined under the guidance of the AASHTO Technical Committee T-3 Seismic Design. It is anticipated that the document will be presented to the AASHTO Highway Subcommittee on Bridges and Structures for adoption in 2006. Meanwhile, some states are using these recommended guidelines in designing seismic resistant structures.

## Seismic Retrofit of Bridges

The Bridge Engineering Community learned some very valuable lessons from the 1971 San Fernando earthquake in California. Over 60 bridges on the Golden State Freeway suffered major damages with some collapsed spans. The spans collapsed because of inadequate support widths at the in-span hinges and at the supports over the piers. Many columns with inadequate capacity and confinement reinforcement suffered severe cracking, spalling and loss in axial capacity, resulting in excessive deformation or collapse. Liquefaction, subsidence and lateral spread of soil have also caused extensive damages to bridges and structures.

The 1989 San Francisco earthquake and the 1994 Los Angeles earthquake confirmed that older bridges with in-span hinges, with narrow support widths over the piers and with inadequate confinement and shear capacity in the columns are highly susceptible to major damage and collapse. These earthquakes also showed that older bridges retrofitted to meet current retrofit philosophy and techniques performed well.

FHWA has provided support for research and development of retrofit guidelines and manuals for evaluating and upgrading the seismic resistance of existing highway bridges. FHWA has published the following three manuals to provide guidelines of seismic retrofit of highway bridges:

1. FHWA, (1983), Seismic Retrofitting Guidelines for Highway Bridges, Publication No. FHWA/RD-83/007, Washington, D.C.
2. FHWA, (1995), Seismic Retrofitting Manual for Highway Bridges, Report No. FHWA-RD-94-052, Washington, D.C.

3. FHWA/MCEER (2004), Seismic Retrofitting Manual for Highway Structures, Part I: Bridges, Multidisciplinary Center for Earthquake Engineering Research.

Seismic retrofit is a cost effective way to protect our investments in bridges and structures. States with high seismicity are encouraged to assess the vulnerabilities of their bridge inventory and develop a program for seismic retrofit.

## National Bridge Inspection Standards

Title 23 Code of Federal Regulations, Part 650, Subpart C establishes the National Bridge Inspection Standards (NBIS). These regulations cover the minimum requirements for inspection programs, frequency of inspection, minimum qualifications for bridge inspection personnel, inspection report and inventory. Each highway department is responsible for complying with these regulations. NBIS applies to all bridges, fixed and movable, more than 20 feet in length on public roads. Each state is required to prepare and maintain an inventory of all bridges subject to the NBIS. FHWA maintains a National Bridge Inventory (NBI) based on data supplied by the states.

FHWA publishes a "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges" and a "Bridge Inspector's Training Manual" to help the highway departments carry out bridge inspection and evaluation. Consistent and uniform inspection data are necessary to assure complete and thorough inventory for an accurate report to Congress on the number and the state of the Nation's bridges.

## Bridge Management Systems

Bridge Management System (BMS) is a system designed to optimize the use of available resources for the inspection, maintenance, rehabilitation and replacement of bridges. A BMS can help bridge owners make sound decisions to the tough questions often raised as the bridge population becomes larger and older. A BMS can address questions like: What are the needs? What type of work should be performed? What is the impact of deferring work? Which bridges should be replaced first?

Some key benefits of a BMS are:

1. Systematic approach to decision making and resource planning
2. Repeatable results
3. Development of a sound preservation program
4. Support for asset management
5. Increased efficiency and effectiveness in collection and management of bridge data.

Several BMS are used by the states. However, **PONTIS** is by far the most popular BMS software - being used by over 40 states, counties and cities, and a few international users. **PONTIS** was developed under the sponsorship of FHWA in the early 1990's. In 1994, AASHTO incorporated **PONTIS** into the AASHTOWare program and is maintained by AASHTO.

**PONTIS** is a bridge management software tool. (The name is derived from the Latin word "**PONTIS**" meaning "Bridge") It is a data application relying on collected cost data, and inspection and condition evaluation data of bridge elements. This data is analyzed to arrive at optimal cost models for long-term preservation and improvement policies for a network of bridges.

**PONTIS** has gone through many years of improvement since the first Windows version was released in 1995 as **PONTIS 3.0**. **POINTIS 3.4** was released in 1998. **PONTIS 4.0** and **4.1** were released in 2001 and 2002 respectively. **PONTIS 4.2** and **4.3** were issued to the licensees in 2003. These new versions include multimedia capability, supporting links to photos and drawings, and enhanced security. Data can be entered in metric or English units. **PONTIS 4.4** is being developed and tested. It is expected to be available to the licensees in late 2004 or early 2005.

FHWA sponsors the development and offering of an NHI training course for the latest version of **PONTIS**. Scheduling of the training course may be made through NHI.

## Closing Remarks

The FHWA mission is Enhancing Mobility Through Innovation, Leadership and Public Service. As innovators, FHWA continually researches, evaluates, reevaluates and improves the effectiveness and efficiency of technologies and innovations. FHWA provides leadership for the deployment and implementation of market-ready technologies and innovations for enhancing the safety and mobility of the traveling public.

Several market-ready bridge technologies are presented in this paper. They are ready for use and have proven benefits. Emerging technologies, such as, fiber reinforced concrete, nondestructive evaluation, structural health monitoring, automated fabrication and inspection, modular construction, and so on, are at various stages of research, development and deployment. FHWA is supporting these efforts in moving technologies and innovations forward. For the latest list of FHWA market-ready technologies and innovations for highways, please visit: http://www.fhwa.dot.gov/rnt4u/index.htm.

## References

- AASHTO, Load & Resistance Factor Design (LRFD) Bridge Design Specifications, 3rd. Edition.
- AASHTO, LRFD Bridge Construction Specifications 1st. Edition and Interims.
- AASHTO, Guide Manual for Condition Evaluation and Load Resistance Factor Rating (LRFR) of Highway Bridges.

- AASHTO, Guide Specifications for Highway Bridge Fabrication with HPS 70W Steel.
- AASHTO, Guidelines for Bridge Management Systems.
- AASHTOWare, Pontis Software for Bridge Management.

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