Implementation of High-Performance Concrete Bridge Technology in the USA

by S.N. Vanikar and L.N. Triandafilou

Synopsis: The utilization of high performance concrete (HPC) has increased substantially in the last decade. HPC can provide enhanced mechanical and durability properties and at the same time allow efficient placement and finishing. HPC has been utilized for cost-effective construction of bridges, buildings and pavements in most countries. The Federal Highway Administration (FHWA) has played a key role in the HPC technology transfer from research and development to routine practice for bridge and pavement design and construction. FHWA's HPC implementation activities began in 1991. HPC implementation for highway bridges in the USA has been a success story. The success has been largely due to a long-term continuing partnership between FHWA, State Departments of Transportation, American Association of State Highway and Transportation Officials (AASHTO), local agencies, industry and academia.

This paper provides an historic perspective on the HPC implementation activities since the Strategic Highway Research Program (SHRP) in late 1980's and the subsequent programs and activities. Forty-four State Departments of Transportation have utilized HPC. HPC implementation has contributed significantly to improvements in highway infrastructure. Implementation of the long-term strategic plan developed by the industry will further contribute toward meeting the goals which include reduced congestion and improved safety, trained workforce, reduced life cycle costs and improved quality as well as reliability.

Keywords: bridges; construction; design; durability; high-performance concrete; implementation; mechanical properties; prestressed concrete; self-consolidating concrete; silica fume

ACI member Suneel N. Vanikar is a Professional Engineer and the Concrete Group Leader at the Federal Highway Administration (FHWA), United States Department of Transportation in Washington, D.C. He has been with FHWA for 25 years. He was with the New Hampshire Department of Transportation prior to the career with FHWA. He received a Masters Degree in Civil Engineering from Colorado State University and his area of interest is the design and construction of high performance concrete pavements and bridges.

Professional Engineer Louis N. Trandafilou is the High Performance Structural Materials Specialist in the National Resource Center of FHWA in Baltimore, Maryland. He has been with FHWA for 30 years. He received a Bachelors Degree in Civil Engineering from Rutgers--the State University of New Jersey. He leads FHWA's technology delivery team for high performance concrete for bridges.

INTRODUCTION

Use of high performance concrete (HPC) has mushroomed over the last decade. Rather than being seen as an experimental material, it is now routinely used in industry. Norway, Sweden, Denmark and Germany have utilized HPC technology for several decades. France has built more than 100 HPC bridges in the past 20 years. In Canada, the Ontario Ministry of Transportation started using silica fume HPC in 1992 and HPC implementation began under the Concrete Canada program. In the United States of America (USA), the Federal Highway Administration (FHWA) has played a key role in the HPC technology transfer from research and development to routine practice in bridge and pavement design and construction. This paper is limited to HPC bridges in the USA.

HPC has certain characteristics which are developed for a certain application and environment. These may include ease of placement, consolidation without segregation, early-age strength, long-term strength and other mechanical properties, permeability, density, heat of hydration, toughness, volume stability and longer life in a severe environment. High strength and high durability properties can be utilized in designing cost effective, aesthetically pleasing structures. Because a lower w/c ratio concrete is typically used, HPC usually provides higher strength than conventional concrete. However, high strength is not always the primary requirement. HPC is valuable where any of the following properties are required: high strength, high early strength, low permeability, resistance to freeze-than damage, resistance to chemical attack, such as sulphates, abrasion resistance, low absorption, high resistivity, high modulus of elasticity and volume stability.

FHWA's HPC implementation activities began in 1991. HPC implementation for transportation structures in the USA has been a well documented success. The success has been largely due to a continuing partnership between FHWA, State Departments of Transportation (DOT), American Association of State Highway and Transportation Officials (AASHTO), local agencies, industry and academia. This paper provides an overview of implementation activities, accomplishments and anticipated future activities.

BACKGROUND

Strategic Highway Research Program

In 1987, the United States Congress initiated the five-year Strategic Highway Research Program (SHRP) to integrate various products to improve the constructability and reduce the maintenance of the nation's highways and bridges. HPC or "engineered concrete " was one of the products from the SHRP program. To implement these products, Congress authorized additional funding over the following six years. AASHTO, in cooperation with FHWA, created a Task Force for SHRP implementation. The Task Force's approach for technology transfer was through the use of teams consisting of the States that took the lead on various products; hence the AASHTO Lead State Team for HPC Implementation was formed.

AASHTO Lead State Team for Implementation

The Team, along with other Lead State Teams, first met in September 1996 to put together a mission, goals, strategies, and action plans. The team members represented industry, FHWA and the States. The Team's mission was to promote the implementation of HPC technology for use in pavements and bridges and to share knowledge, benefits, and challenges with the States and their customers. In order to spread the word on HPC, the Team made presentations at various AASHTO meetings, to other professional organizations, and to States adjacent to the lead States; wrote papers for various publications; and supported other efforts such as publication of *HPC Bridge Views*. The Team conducted a survey about each State's current use of both conventional concrete and HPC. The team partnered with FHWA and industry to develop a generic HPC bridge implementation workshop. Working together, the Team contributed significantly to make HPC the standard product for use in bridges. The Team completed its activities in 2001.

FHWA Technology Delivery Team

FHWA's HPC Technology Delivery Team (TDT), through funding in the Intermodal Surface Transportation Efficiency Act (ISTEA), produced positive results in helping State DOTs implement HPC in their highway bridges. The TDT created, in 1997, helped 13 States build HPC bridges and host or participate in technology transfer activities such as showcases and workshops. Working with the AASHTO Lead States Team of HPC implementation, the TDT influenced many additional State DOTs and other public agencies to try HPC in their highway bridges.

When the ISTEA ended, about 25 States had used HPC. Though lacking a direct funding mechanism, the TDT continued to promote HPC and encouraged States to build HPC bridges through a new program for constructing bridges utilizing innovative materials – the Innovative Bridge Research and Construction (IBRC) Program. In addition to FHWA engineers, the TDT membership includes representatives from academia, State DOT's and industry. The TDT continues its activities and has formulated a business plan, which includes statements of the team's vision, mission, and goals. The emphasis of these statements is to provide leadership in advancing HPC technology and in implementing HPC for increased structural efficiency and durability, thereby leading to reduced life-cycle costs for bridges and pavements. The TDT has established an HPC community of practice website.

ACCOMPLISHMENTS

SHRP Implementation Program

In 1993, the FHWA initiated a national program to implement the use of HPC in bridges. The program included the construction of demonstration bridges in each of the FHWA regions and the dissemination of the technology and results at showcase workshops. A total of 18 bridges in 13 States were included in the national program. In addition, other States implemented the use of HPC in various bridge elements.

The bridges were located in different climatic regions of the United States and used different types of superstructures. The bridges demonstrated practical applications of high performance concrete. In addition, construction of these bridges provided opportunities to learn more about the placement and actual behavior of HPC in bridges. Consequently, many of the bridges were instrumented to monitor their short – and long-term performance. Additionally, concrete material properties were measured for most of the bridges.

A project report summarizing results and analysis from HPC bridge projects, recommendations for AASHTO specification revisions and needs for additional research was prepared by Russell, Miller, Ozyildirim and Tadros.[1]

Innovative Bridge Research and Construction (IBRC) Program

The 1998 Transportation Equity Act for the 21st Century (TEA-21) provided substantial funding to extend the service life of structures cost-effectively by incorporating high performance materials. Almost all State DOT's and several Federal and local agencies have participated in the IBRC program. [2]

Forty-one HPC-related projects were funded during the first five years of the IBRC program. Of the $72 million in project allocations, about one-fifth has gone to projects incorporating HPC bridge components or elements. Nineteen HPC projects were submitted for review and approval under the FY 2003 program.

By far, cast-in-place bridge deck construction has been the most common application of HPC with 40 bridges constructed under the IBRC program. In a few instances, HPC full-depth precast, prestressed concrete deck panels have been used. Virginia is planning to construct a HPC lightweight concrete bridge deck and one with fibers. State DOTs are seeking ways to extend the service life of existing sound concrete bridge decks by using HPC overlays in seven bridges. In addition, HPC has been used in the parapets and railings of three bridges.

Prestressed concrete girder superstructures are the next most common application of HPC with 20 bridges built under the IBRC program. HPC substructures and foundations, including piling, bents, solid piers and precast abutments have been funded on ten additional bridges. In at least two instances, HPC has been used in all components and elements of a bridge.

Silica Fume Program

Under the United States Department of Transportation (USDOT) Appropriations Act provisions, Congress for a number of years made funds available for research and development on the use of silica fume in concrete. Additional usage will decrease waste materials and increase the quality and durability of concrete structures and pavements. The silica fume program will highlight development of the following partial list of products: Website, guide specification, service life prediction model, user manual, and other technology transfer materials. FHWA and the Silica Fume Association are working together to accomplish the program goals.

Other Accomplishments

To establish a clear understanding of HPC, the FHWA proposed a HPC definition in 1996. Goodspeed, Vanikar and Cook proposed the definition for use on the HPC bridge projects.[3] The definition generated a healthy discussion in the engineering community. Subsequently, the American Concrete Institute and several State DOTs have defined HPC.

Based on recommendations provided in Reference1, appropriate AASHTO Subcommittees are considering changes in the current specifications for concrete materials, structural design and construction related to HPC.

Implementation Status

Since the initiation of the SHRP implementation program for HPC over 10 years ago, there has been an aggressive effort by the concrete industry, State DOTs and the FHWA to achieve nationwide implementation of HPC on bridge projects. Outstanding progress has been made in response to the FHWA Executive Director's 1997 challenge to construct at lease one HPC bridge in every State by 2002. Recently the FHWA's HPC Technology Delivery Team conducted a 14 question national survey to track the progress and other related concrete issues.[4] Figures 1, 2, 3 and 4 provide some of the details from the survey.[5] The following are the highlights of the survey results:

- Forty-four States have utilized HPC specifications in last 10 years.
- Thirty-seven respondents selected HPC for low permeability, 30 for high strength, and 26 for both performance criteria.

- As background on why HPC was being used, respondents ranked deck cracking at ages less than 5 years as the most common distress, followed by reinforcing steel corrosion, cracking of girders and substructure elements, and freeze-thaw-damage.
- Over the past 10 years, 77 percent of the respondents have made changes in their bridge deck curing requirements, 72 percent have made changes in their specified concrete strengths, and 64 percent have made changes in testing and acceptance requirements.
- Lightweight concrete has been used by 26 percent of respondents.
- Eighty-one percent of respondents utilize chemical and/or supplementary cementitious materials.
- Thirty-eight percent of respondents specify permeability requirements for bridge decks whereas 19 percent specify permeability requirement for precast, prestressed members.

Thirteen HPC bridges constructed under the FHWA program utilized concrete with design compressive strengths ranging from 55MPa (8,000psi) to 97MPa (14,000psi) for girders and 28MPa (4,000psi) to 55MPa (8000psi) for decks.

As a result of various Federal and State programs and routine Federal-aid funding, some States are using HPC on a regular basis. Virginia has over 100 HPC projects constructed, under construction or in the design phase. Ohio and New York have incorporated HPC specifications for routine bridge deck use for several years. Sixty-four percent of respondents have made changes in testing and acceptance requirements.

FUTURE

Strategic Plan

In 2000, the HPC Lead States Team published a Transition Plan that listed several goals. One of the main goals was to "develop a long-term strategic plan for HPC bridges in partnership with government, industry, and academia." Under the leadership of the National Concrete Bridge Council (NCBC), a focus group of Federal and State bridge engineers, professors, and industry representative met to identify critical issues in the design and construction of long-life bridges to help solve the deficient bridge problem in the United States.[6] Discussion at the focus group meeting provided the foundation for a strategic plan prepared by NCBC. The strategic plan focuses on the public's expectations for the present and future. This outlook translates into the following four goals for HPC bridges:

1. Reduce congestion and improve safety:
    - Replacing bridge decks with minimal interference with traffic..

- Constructing entire short-span bridges within one week.
- Reducing the average use delay by 20 percent for typical urban bridge reconstruction projects.

2. Train the workforce:
   - Transferring HPC technologies to all 50 States by building several HPC bridges in each State.
   - Training 500 bridge engineers per year in HPC technology through seminars.
   - Training 2000 construction personnel per year in HPC bridge technology.
   - Adding HPC technology course to the engineering curricula at ten universities.

3. Reduce life cycle cost:
   - Establishing a life cycle cost analysis procedure.
   - Improving service life prediction models
   - Collecting cost data on various conventional bridge systems.
   - Developing tools to perform life cycle cost analysis.

4. Ensure bridges meet expectation:
   - Developing reliable materials tests.
   - Developing reliable quality assurance methods for construction.
   - Developing certification programs for products, procedures, and personnel.
   - Training 500 bridge engineers per year in HPC technology through seminars.
   - Training 2000 construction personnel per year in HPC bridge technology.

This ambitious but realistic plan provides a framework for the next decade's HPC program in the public and private sectors.

Self-Consolidating Concrete (SCC)

As the industry has gained confidence with using HPC over the last decade, new generations of the technology have emerged such as self –consolidating or self-compacting concrete. When properly proportioned and controlled, SCC can flow significant distances and consolidate to normal density without the use of vibrations and without segregation. It can fill intricate formwork shapes, especially when casting heavily reinforced elements and sections with restricted access, and still result in high-quality, smooth surfaces that are free of honeycombing and signs of bleed. It reduces labor demand and noise on construction sites and in precasting yards.

SCC has already been used in the high-rise buildings and bridge construction industries, and more transportation agencies are now learning about it and taking advantage of its properties. A recent AASHTO/FHWA European scanning tour of accelerated bridge construction methods noted the extensive use of SCC in drilled shaft foundation construction.

Lightweight HPC

While a relatively new technology in the US, incorporation of lightweight aggregates into HPC mix designs has had an excellent performance record for more than 15 years in Norway. Lightweight HPC translates into lighter superstructures and smaller loads for substructure design. Lightweight concrete improves constructability and hydration due to internal curing. Although the aggregates are more expensive than conventional concrete aggregates, this small percentage materials premium is offset by the reduced size and cost of girders, piers and foundations.

Ultra High Performance Concrete (UHPC)

On the horizon is the development of UHPC for bridges. UHPC usually provides strength levels in excess of 150MPa (22,000psi). The FHWA Turner – Fairbank Highway Research Center's structures laboratory has implemented a testing program to verify the material properties of UHPC. FHWA has also funded an analytical study to determine an efficient highway bridge girder shape for UHPC.

CONCLUSIONS

In conclusion, the State DOTs and the industry have made enormous progress over the past 10 years with implementing some form of HPC into their everyday usage on concrete bridge projects. They have taken advantage of the benefits related to higher strengths for prestressed concrete girder elements and, and improved durability for reinforced concrete bridge decks. The researchers and academia have contributed tremendously in providing solutions to design and construction problems and in the technology transfer efforts. The widespread national use of this technology is consistent with industry, state and FHWA goals of mitigating congestion and improving safety at construction sites. HPC addresses these goals by extending service life, reducing costly maintenance activities, and lowering life cycle costs.

A strategic plan for HPC bridges has been proposed by NCBC. The successful implementation of the strategic plan and subsequent action plan will require management support and resource commitments over several years. The public and private sector partnership in the implementation of HPC technology during the recent past has been highly successful. This partnership needs to be maintained so that the general public continues to benefit from HPC bridges.

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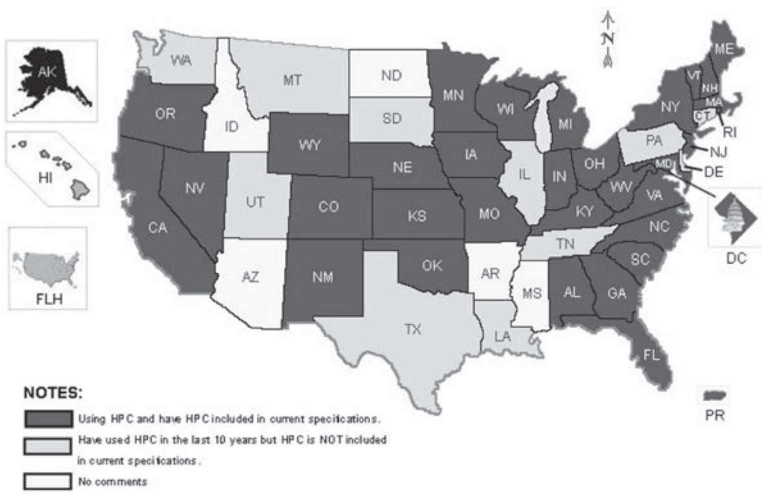

Figure 1 – States implementation of high-performance concrete

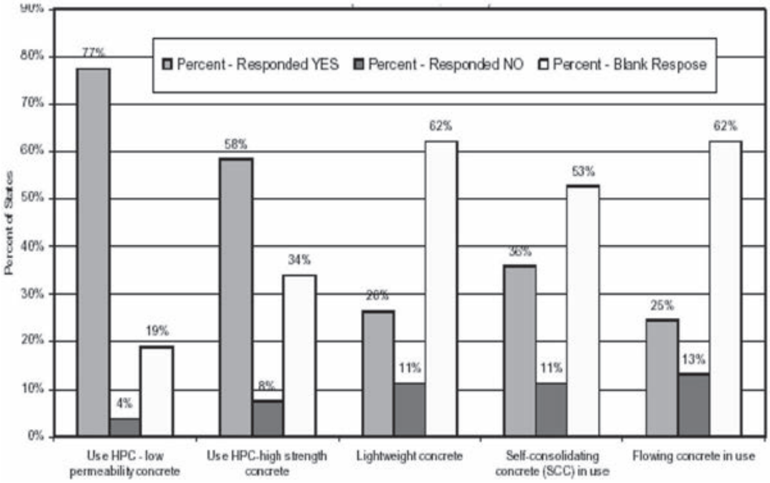

Figure 2 – Changes made in last 10 years

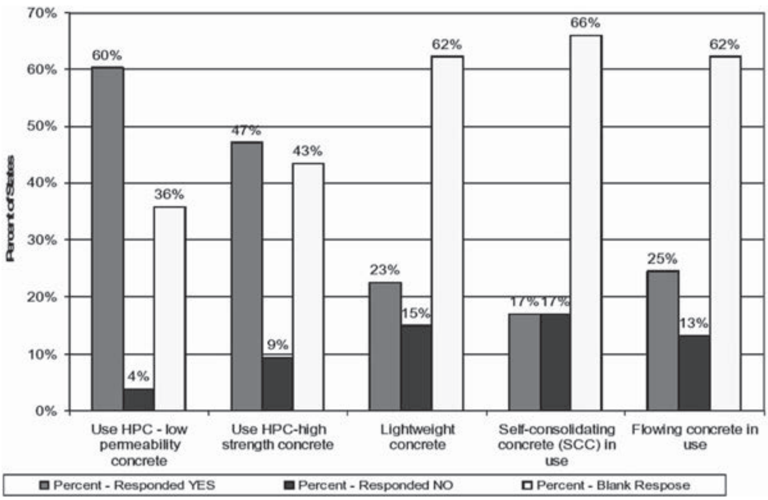

Figure 3 – Concrete characteristics included in current specifications