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Behavior of instrumented prestressed high performance concrete bridge girders

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ABSTRACT

A comprehensive monitoring of the behavior of four prestressed high performance concrete (HPC) bridge girders, with higher compressive strength, during construction and while in-service, is presented. The monitoring program covered instrumentation and monitoring of a series of four girders during the casting operation, after construction, under the effects of traffic and thermal loads, as well as under controlled load conditions. Information regarding transfer length, prestress loss, heat of hydration, compressive strength, modulus of elasticity (MOE), modulus of rupture (MOR), creep, shrinkage, coefficient of thermal expansion, and chloride permeability of the concrete used is obtained and presented. Furthermore, the in-service monitoring and controlled load tests and details regarding thermal expansion, bridge stiffness, and load distribution factors are also presented. This paper provides details of testing of the concrete properties and field instrumentation of the bridge girders as well as a discussion of service level monitoring and controlled load testing. Comparisons are made between experimental and theoretical results.

1. Introduction

According to the Federal Highway Administration (FHWA), as much as 30% of the USA highway bridges are rated structurally or functionally deficient. To replace some of these deficient bridges or to construct new ones, it has been found that high performance concrete (HPC) can be utilized to great advantage in terms of structural efficiency and durability. However, there is a need for more field data on high performance concrete and on the structural behavior when high performance concrete is used.

High performance concrete (HPC) is any concrete that satisfies certain performance requirements that cannot be achieved by conventional concrete, however, there is no unique definition of HPC. The American Concrete Institute (ACI) defines HPC "as concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials and normal mixing, placing, and curing practices." HPC does not simply mean high strength concrete (HSC), but also includes other enhanced material properties such as early-age strength, increased flowability, high modulus of elasticity (MOE), low permeability, and resistance to chemical and physical attack (increased durability). HPC is usually high strength concrete (HSC), but HSC may not always be of high performance [1].

In 1973, the first generation of HSC bridges was built for the Japan National Railway. The second Ayaragigawa Bridge used post-tensioned bulb T-beams with 60 MPa (8600 psi) concrete. The Iwahana Bridge was a single span Warren truss made with over 80 MPa (11,500 psi) concrete. The Otanabe Bridge was a single span Howe-truss built with a HSC mix of 80 MPa (11,500 psi) concrete. These historically significant bridges utilized HSC in order to lower dead load, reduce deflection and reduce vibration, as well as noise [1]. HSC bridges have also been constructed in Germany, Canada, Norway, France, and Denmark. A summary of some notable bridges built worldwide is provided in Table 1.

USA also boasts a fair share of HPC bridges. The Cross Westchester Expressway Bridge in Westchester County, New York exhibits the benefits of using HPC. The typical 28-day strength of the concrete mix was 43.4 MPa (6300 psi). Though this seems to reside on the lower end of compressive strength for a HPC, the mix is considered of high performance due to other factors. Reduced permeability, enhanced workability, controlled heat of hydration, and reduced creep and shrinkage effects are all very important considerations that were incorporated into the design of this mix. The Cross Westchester Expressway showed that using a precast, post-tensioned, high performance concrete deck system results in an accelerated construction schedule, better quality control, a more durable structure, and the same approximate cost as a cast-in-place deck system [2]. Table 2 gives a summary of some notable bridges and their attributes in the USA.

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Table 1
Notable HPC bridges built worldwide.

Bridge	Country	Year completed	Girder length and type	28-day compressive strength
Dwutzer Bridge	Germany	1978	Free cantilever construction with three spans of 132, 185, and 121 m (435, 610, and 399 ft)	Normal weight: $f_c' = 69$ MPa, (9890 psi); Lightweight: $f_c' = 73$ MPa, (10,500 psi)
Portneuf Bridge	Canada (Quebec)	1992	Precast post-tensioned beams of 24.8 m (81.5 ft)	$f_c' = 75$ MPa (10,750 psi)
Stovset Bridge	Norway	1993	Prestressed cantilever bridge with center span of 220 m (725 ft)	$f_c' = 74$ MPa (10,600 psi)
Elorn Bridge	France	1994	Cable-stayed bridge spans 400 m (1320 ft)	$f_c' = 97$ MPa, (13,900 psi)
Great Belt Bridge	Denmark	1998	Consists of two 8000 m (26,247 ft) railway tunnels and a 1624 m (5328 ft) suspension bridge	

Table 2
HPC bridges in the United States as of April 2001.

Bridge	State	Status	Girder length and type	28-day compressive strength	Instrumentation	Benefits of using HPC & comments
Alabama Highway 199 over Uphaupee and Bulger Creek, Macon County	Alabama	Open April 2000	34.7 m AASHTO BT-54	$f_c' = 69$ MPa, (10,000 psi)	Thermocouples, ERSGs, VWG, external gages	Eliminates one pier and requires 35–34.7 m girders instead of 40–30.5 m girders
Interstate 25 Over Yale Avenue, Denver	Colorado	Open June 1998	34.5 m and 30 m box	$f_c' = 69$ MPa, (10,000 psi)	Yes, but undecided	Eliminates two column/pier lines. More durable-resistant to wear and de-icing chemicals
Bridge Over Interstate 75, Henry County	Georgia	Not yet open	Still being designed	Possibly $f_c' = 97$ MPa, (14,000 psi)	Thermocouples, VWG, external gages	Smaller girder depth. Increased durability
120th Street and Giles Road Bridge, Sarpy County	Nebraska*	Opened to traffic in 1996	22.9 m NU1100 (metric bulb-tee)	$f_c' = 83$ MPa, (12,000 psi)	Thermocouples, ERSGs, VWG, external gages	Fewer girders. Increased durability
Route 104 Bridge over the Newfound River, Bristol	New Hampshire	Opened in 1996	20 m Type III AASHTO	$f_c' = 55$ MPa, (8000 psi	None	Concrete material properties measured at casting to determine durability
Route 3A Bridge over the Newfound River, Bristol	New Hampshire	Opened to traffic 6/25/99	18.3 m NE bulb-tee	$f_c' = 55$ MPa, (8000 psi	VWGs, thermistors	Strong field basis for monitoring structure in harsh northern climate
State Route 22 at Mile Post 6.57, Guernsey County	Ohio	Opened Nov, 1998	36 m 1219 mm × 1067 mm deep box beams	$f_c' = 69$ MPa, (10,000 psi)	Yes, but undecided	Eliminates two substructure units with a single-span
Louetta Road Overpass State Highway 249, Houston	Texas*	Opened to traffic in May, 1998	40 m U-shaped	$f_c' = 69$—90 MPa, (10,000–13,000 psi)	None	Allowed for simple-span construction eliminating more complicated/costly substructure. U-beams & single pier aesthetically pleasing
San Angelo Bridge, US Route 67, San Angelo	Texas*	Opened to traffic in Jan 1998	19.4–47.9 m Type IV AASHTO	$f_c' = 40$—101 MPa, (5800–14,700 psi)	None	Reduced number of beams and reduction of one span. Improved durability
Route 40 Over the Falling River, Lynchburg District	Virginia	Open to traffic in May, 1996	24.4 m Type IV AASHTO	$f_c' = 55$ MPa, (8000 psi)	None	Five girders instead of seven. Four percent savings over normal bridge material
Virginia Avenue Over the Clinch River, Richlands	Virginia	Opened to traffic in Dec, 1997	22.6 m Type III AASHTO	$f_c' = 69$ MPa, (10,000 psi)	None	Four girders instead of seven
Eastbound State Route 18 Over State Route 515, King County	Washington	Opened to traffic in Jan, 1998	42 m and 24 m WSDOT W74G I-girders	$f_c' = 69$ MPa, (10,000 psi)	None	Five lines of girders instead of seven

* All girders are prestressed using 15.2 mm strand (0.6 in.) except in Nebraska and Texas. 12.7 mm (0.5 in.) strand was used in Nebraska, and in Texas both size strands were used, depending on span length.

This paper demonstrates the use of HPC in the superstructures of two parallel bridges located just north of Raleigh, North Carolina over the Neuse River in Wake County for the divided highway US 401. Each bridge consists of four spans — two spans of 28.0 m (91.9 ft) and two spans of 17.5 m (57.4 ft). Each bridge is 14.4 m (47.1 ft) wide and carries a 12.0-m (39.4-ft) roadway section and a 1.9-m (6.2-ft) sidewalk. The bridges used simple-span prestressed concrete I-girders made continuous for live load. American Association of State Highway and Transportation Officials (AASHTO) Type IV prestressed concrete I-girders were used in the 28.0-m (91.9-ft) spans, while AASHTO Type III prestressed concrete I-girders were used in the 17.5-m (57.4-ft) spans. Girder spacings were five girders per span at 3.12 m (10.25 ft) on center and the deck thickness was 215 mm (8.5 in.).

By using HPC with high concrete compressive strength, each bridge needed only five lines of girders rather than six lines of girders if conventional normal strength concrete was to be used. The bridge carrying three northbound lanes was completed and opened to traffic first. Fig. 1 shows the bridge for three southbound lanes under construction, which forms the basis for the work described in this paper. Figs. 2 and 3 show the plan of the bridge and a typical cross section, respectively.