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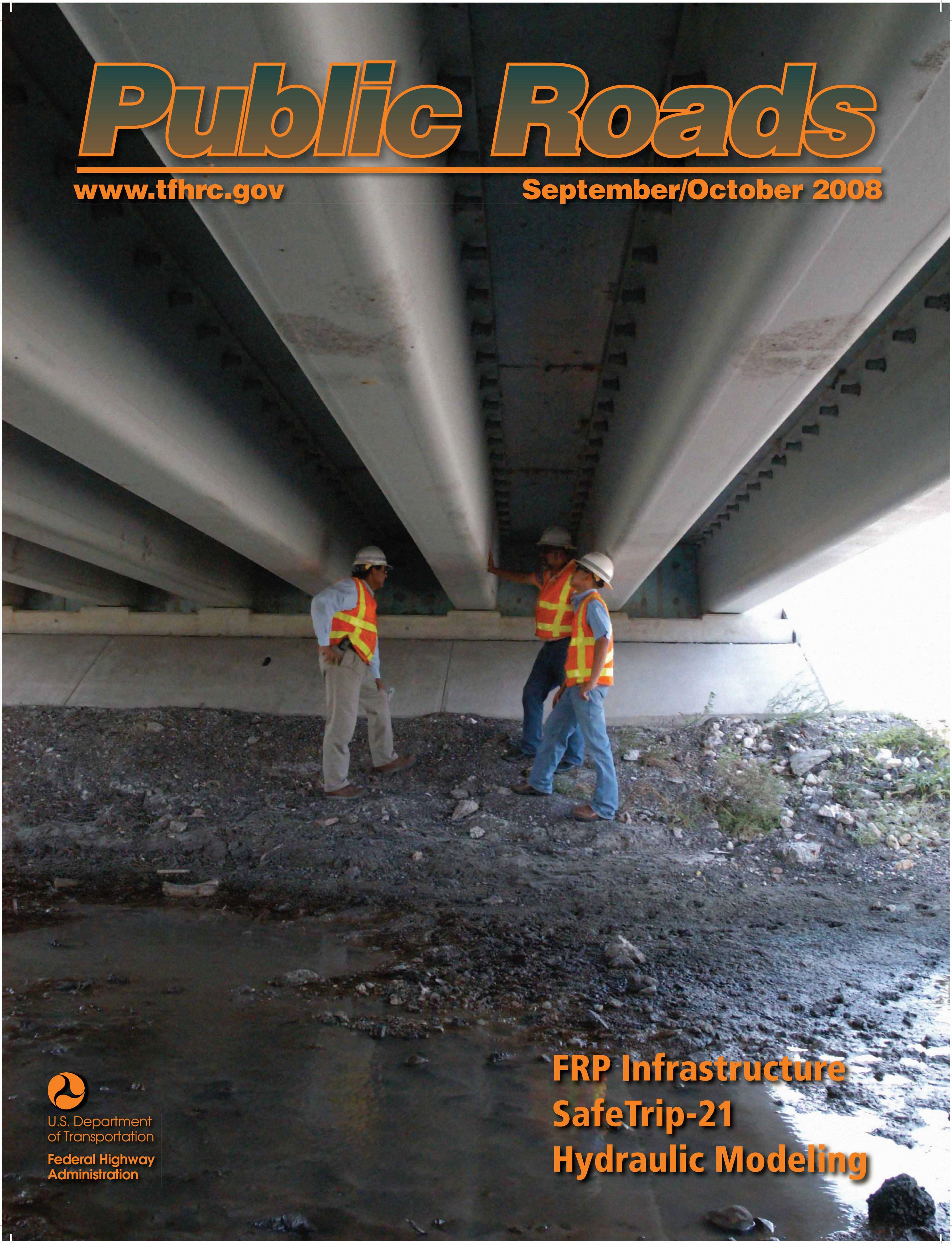

FRP Infrastructure
SafeTrip-21
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U.S. Department of Transportation
Federal Highway Administration

Public Roads

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—featuring developments in Federal highway policies, programs, and research and technology—

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Front cover—In conjunction with ongoing research on new structural technologies, the Texas Department of Transportation (TxDOT) used custom-manufactured, fiber-reinforced polymer (FRP) composite beams for a new bridge in Refugio County, TX. Here, TxDOT officials inspect the beam depth and composite structure's optimal deflection under traffic loading. For more on this project, see "The Ongoing Evolution of FRP Bridges" on page 16 in this issue of PUBLIC ROADS. *Photo: TxDOT.*

Back cover—FHWA's Office of Federal Lands Highway oversaw reconstruction of this roadway in Yellowstone National Park. The project took place on the Grand Loop Road between Madison Junction and Norris Junction along the Gibbon River. The 16-kilometer (10-mile) project consisted of roadway reconstruction including retaining walls, two new bridges, and one bridge rehabilitation. The wall (at right) is simulated stone (concrete) stained to match area rocks. *Photo: Craig Dewey, Western Federal Lands Highway Division.*

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The Secretary of Transportation has determined that the publication of this periodical is necessary in the transaction of the public business required by law of this department.

Guest Editorial

Infrastructure—The Backbone of America's Mobility

Over the past century, innovations have enabled transportation professionals to construct safer and better roads that last longer. This is no accident. The Federal Highway Administration (FHWA) and its partners in the transportation community use long- and short-term strategic planning and the development and deployment of new technologies to make improvements to the safety, operation, and construction of the highway system. Pavements and materials are two of the chief components that form the backbone of America's mobility—literally and figuratively.

The mission of the FHWA pavement and materials program is to provide for a safe and durable pavement network to support the Nation's need for mobility. To carry out this mission, FHWA concentrates on ensuring that the health of the Nation's highway infrastructure remains sound while the system is maintained, rebuilt, and expanded. FHWA is working to plan and deliver a national program that will provide for an infrastructure network that is safe, long lasting, cost effective, sustainable, and maintained effectively with minimal impact on the public.

To plan and deliver the national program, FHWA assesses the current state of the practice, recognizes best practices for advancement, identifies gaps where improved technologies or methods are needed, and defines and evaluates existing risks that need to be mitigated. From this assessment, FHWA develops strategies—including research and development (R&D), implementation, technology transfer, policy, and regulatory actions—to achieve performance objectives for the Nation's pavement network. Throughout this process, FHWA works closely with States, local highway agencies, industry, and academia to deliver the pavement and materials program.

The program focuses on providing innovative solutions that include implementing new, performance-based methodologies for pavement design, using new or alternative materials to achieve longer lasting solutions, developing tools to evaluate the economic benefits of different design solutions, developing advanced tools to better manage the quality of pavement materials, and increasing use of recycled materials in pavements. Deploying these solutions will help address existing gaps that may be jeopardizing the short- and long-term health of the Nation's pavement infrastructure.


Gary L. Henderson


Peter J. Stephanos

This issue of PUBLIC ROADS contains two articles on fiber-reinforced polymers (FRP). One article, "Steel Versus GFRP Rebars?" (page 2) discusses FRP used in a concrete pavement test section in West Virginia. The other article, "The Ongoing Evolution of FRP Bridges" (page 16) reports on a Texas research project that explored the viability of custom FRP beams. Both approaches are innovative in that FRP technologies address corrosion of these highway elements and thus could extend the life of pavements or bridges. A third article, "Applying AQS in the Highway Industry" (page 20), discusses total quality management and highlights quality assurance and corresponding measurements.

The need to test and deploy new solutions to managing the pavement network is increasingly critical as highway agencies are challenged today, more than ever, by funding limitations, rising material costs, material shortages, increasing congestion levels, and reductions in a qualified workforce.

Gary L. Henderson
Director
Office of Infrastructure R&D

Peter J. Stephanos, PE
Director
Office of Pavement Technology

Field studies show that glass fiber-reinforced polymer offers a low life-cycle cost option for reinforcement in concrete pavements.

by Roger H. L. Chen, Jeong-Hoon Choi, Hota V. GangaRao, and Peter A. Kopac

Steel Versus GFRP Rebars?

Glass fiber-reinforced polymer rebar is one of the new products on the market that could offer a number of benefits to the transportation industry. Because it is lightweight and free of corrosion, construction costs should be lower and pavements should last longer. However, laboratory studies offer limited help in determining the real-world performance of glass fiber-reinforced polymer (GFRP) reinforcing bars in continuously reinforced concrete pavements (CRCPs). The reasons: the difficulties in modeling field boundary conditions, such as friction from the subbase and restraints from the shoulders or adjoining pavements; environmental changes; traffic loads; and possible variations in construction work. To overcome these limitations and gain a better understanding of GFRP-CRCP behavior, researchers turned to field investigations.

With support and cooperation from the Federal Highway Administration (FHWA), the West Virginia Department of Transportation (WVDOT), and contractors, West Virginia University (WVU) researchers recently completed the Nation's first GFRP-CRCP test section, along with a steel-CRCP test segment, to study the performance of the two rebar materials. The GFRP and steel test segments are located on Route 9 in Martinsburg, in the northeastern corner of West Virginia.

"The use of GFRP reinforcing bars in lieu of conventional steel reinforcement in CRCP, as demonstrated last fall [2007] in West Virginia, offers some interesting performance considerations," says Sam Tyson, concrete pavement engineer, FHWA. "First, the corrosion resistance of GFRP bars makes them attractive for obvious reasons, particularly in a State where winter conditions require frequent applications of deicer chemicals. In addition, the high tensile strength and low unit weight of GFRP, its matching thermal and matching stiffness characteristics, provide for a unique approach to the design and construction of CRCP. Finally, because GFRP is not magnetic, its use in concrete pavements where various traffic- and toll-monitoring devices are to be installed could be advantageous."

(Above) This truck is traveling on the Nation's first GFRP-CRCP test section, constructed on a segment of Route 9 in West Virginia. The research team took this photograph while conducting a field observation on January 31, 2008. *Photo: WVU.*

These qualities are clear advantages of GFRP, but the WVU study has not reached a conclusion regarding performance, including corrosion resistance, because not enough time has passed to obtain sufficient results. However, the study did show that GFRP-reinforced CRCPs can be constructed at low cost and without added construction time.

Overview of the Study

WVDOT allocated a 610-meter (2,000-foot)-long, two-lane section on Route 9 as the testing ground for the study. The experimental design incorporated two CRCP sections for comparison. The GFRP- and the steel-reinforced segments are both 305 meters (1,000 feet) long and 25 centimeters (10 inches) thick. WVU specified that both segments were to be constructed of concrete containing limestone coarse aggregate placed on a cement-stabilized subbase.

The contractor constructed the two experimental CRCP sections on September 25, 2007, and WVU monitored them continuously during the first 3 days to investigate the early-age cracking behavior. As the concrete cured during this period, WVU researchers recorded changes in concrete strain, reinforcement strain, and temperature. WVU researchers located, counted, and measured early-age cracks to estimate the spacing and width. The research team then analyzed and compared the data, along with additional crack data obtained about 1 month and 4 months after construction.

Design Details

Each CRCP section consists of two travel lanes with asphalt shoulders. A layer of subgrade, consisting of cement-treated aggregate, provides uniform support to the CRCP sections. On top of the subgrade, an open-graded, free-draining base course with #57 aggregate serves as a subbase. The contractor stabilized the subbase with Type 1 portland cement to obtain erosion-resistant stabilized support below both sections.

For the GFRP-reinforced section, the design called for #7 GFRP longitudinal rebars. For the steel-reinforced section, the design specified #6 steel longitudinal rebars. In both test segments, the contractor placed the longitudinal rebars at the middepth of the slab.

For the transverse reinforcement that supports the longitudinal reinforcement, the contractor placed #6 GFRP and #5 transverse black steel rebars at 1.2-meter (4-foot) spacing. The contractor placed the transverse reinforcement on plastic chairs for the GFRP rebars and steel chairs for the steel rebars. Chairs are supports to keep rebars in their proper position during the placement of concrete.

Ensuring that adequate bond strength develops in the lapped splices of the longitudinal reinforcing rebars is important to prevent crack widening and subsequent structural failures. Therefore, a minimum splice length of 40 times the rebar diameter for GFRP and 25 to 30 times for steel is required, with at least three secure ties for each lap splice. Regular steel tie wires were used for the steel rebars and plastic zip ties for the GFRP. The contractor also staggered the lapped splices across the pavement to prevent localized strains in the slab.

The contractor used three wide-flange beam terminal joints between the two test sections and the abutting conventional jointed plain concrete pavement (JPCP) lanes on Route 9. A wide-flange beam joint is designed to accommodate rather than restrain movement of the free end of a CRCP slab. In a wide-flange beam joint system, the bottom of the beam is partially embedded in a reinforced concrete sleeper slab, the large horizontal slab that supports the ends of abutting pavements. The sleeper slab beneath the joint provides a large bearing area and additional support for the free ends. The steel flange helps protect the corners against spalling and aids in load transfer across the joint.

Concrete Mixes and Reinforcement Properties

For both test sections, the contractor used the same concrete mix design in accordance with Section 601 of the West Virginia Division of Highways Standard Specifications and Materials Procedure MP 711.03.23 for portland cement concrete. The contractor used Type I portland cement in the concrete mix along with Class F flyash. The coarse aggregate was #57 limestone, and the fine aggregate was natural sand. The contractor also included an air-entraining admixture and a water-reducing admixture. The water-to-cement ratio was 0.42. The WVU designers specified that the concrete mix have a relatively high concrete strength to avoid excessively narrow crack spacings.

Members of the contractor's team are placing the subgrade layer during construction of the test segments.

WVDOT


WVDOT

This photo shows the continuous reinforcement assemblies with GFRP rebars.


WVU

Shown here are the continuous reinforcement assemblies with steel rebars.

The GFRP rebar properties, provided by the FRP manufacturer, include a longitudinal elastic modulus (a measure of how rebar deforms) of 40.8 gigapascals, GPa (5.92 by 10^6 pounds per square inch, psi), and tensile strengths of 620.6 megapascals, MPa (90 kips per square inch, ksi) for #6 rebar and 586.1 MPa (85 ksi) for #7 rebar. The GFRP rebars are composed of calcium aluminosilicate glass fibers and a urethane-modified vinylester resin matrix with 70 percent minimum fiber content by weight. The contractor used typical grade 60 steel deformed rebars for the steel-CRCP section.

Construction

Concrete placement for the steel-CRCP section began at about 9:00 a.m. in an ambient temperature of about 20 degrees Celsius, °C (68 degrees Fahrenheit, °F). The contractor completed the steel-CRCP section at about 12:30 p.m. and then began concrete placement for the GFRP-CRCP section.

As the placement continued, the temperature of the subbase surface increased due to continuous sun exposure. The contractor measured the subbase surface temperature as about 39 °C (103 °F) at 1:30 p.m. To avoid temperature-related impairment of workability due to dry subbase aggregates absorbing water from the concrete mix and undesirable cracking from accelerated rates of moisture loss, the contractor sprayed water on the subbase from a sprinkler truck before placing the concrete. Workers completed both CRCP sections at about 6:30 p.m., when the ambient temperature was about 29 °C (85 °F).

The construction crews placed the CRCP sections using a slip-form paving machine. The machine was able to accommodate the entire width of the pavement. Agitator trucks delivered the concrete, and a conveyor belt distributed it to the center of the pavement lane. The crews finished the surface of the pavement slab immediately after the paving machine had passed.

Following the paving machine, a texturing/curing machine conducted two additional operations. The machine dragged burlap fabric to create microtextures on the finished surface and then tined the surface to obtain macrotextures to provide adequate friction for dry and wet weather. The

Properties of the Test Sections

Item	Steel-Reinforced CRCP	GFRP-Reinforced CRCP
Slab Width	7.32 meters (24 feet): two 3.66-meter (12-foot) travel lanes	7.32 meters (24 feet): two 3.66-meter (12-foot) travel lanes
Asphalt Shoulder Width	3.05 meters (10 feet) wide next to the right lane; 1.22 meters (4 feet) wide next to the passing lane	3.05 meters (10 feet) wide next to the right lane; 1.22 meters (4 feet) wide next to the passing lane
Longitudinal Reinforcement	#6 rebar at 15.24-centimeter (6-inch) spacing	#7 rebar at 15.24-centimeter (6-inch) spacing
Diameter of Longitudinal Rebars	1.91 centimeters (0.75 inch)	2.22 centimeters (0.875 inch)
Subbase	10.16-centimeter (4-inch)-thick open graded free draining base course stabilized with cement content of 90±2 kilograms per cubic meter, kg/m^3 (150±5 pounds per cubic yard, lb/yd^3)	10.16-centimeter (4-inch)-thick open graded free draining base course stabilized with cement content of 90±2 kg/m^3 (150±5 lb/yd^3)
Subgrade	27.31-centimeter (10.75-inch)-thick cement-treated aggregate subgrade	27.31-centimeter (10.75-inch)-thick cement-treated aggregate subgrade
Required Concrete Compressive Strength	40.7 megapascals, MPa (5,900 pounds per square inch, psi)	40.7 MPa (5,900 psi)
Longitudinal Coefficient of Thermal Expansion	11.88 microstrain per degree Celsius, με/°C (6.6 microstrain per degree Fahrenheit, με/°F)	6.58 με/°C (3.66 με/°F)

This first in a series of four photos shows the reinforcement layout of a sleeper slab during construction of a wide-flange beam terminal joint. *Photo: WVU.*

Here, the wide-flange beam is partially embedded in the sleeper slab. *Photo: WVU.*

This third photo shows continuous steel (left) and GFRP (right) reinforcement assemblies placed on the sleeper slab. *Photo: WVU.*

This fourth photo shows the completed wide-flange beam terminal joint system connecting the steel-CRCP and GFRP-CRCP sections. *Photo: WVU.*

texturing/curing machine then sprayed a curing compound on the textured surface to slow water evaporation from the concrete.

Experimental Instrumentation and Monitoring

The WVU researchers and the contractors tested the concrete mix to measure its properties in both fresh and hardened states. The contractors took concrete samples from the field and immediately measured the temperature, slump, and air content. At the same time, the WVU researchers cast 30 cylindrical concrete specimens for testing of compressive strength, tensile splitting strength, and elastic modulus at various ages, while casting three prismatic specimens for a drying shrinkage test.

WVDOT engineers also took cores about 4 months after construction; the average core compressive strength was almost 40 percent higher than that of the 28-day sample for both the steel-CRCP section (two core samples) and the GFRP-CRCP section (three core samples), although the GFRP compressive strength was slightly higher than that of the steel.

At about midlength of both CRCP sections, the researchers installed thermocouples and strain gages to investigate the first 3-day behaviors of each CRCP in terms of concrete temperature, concrete strain, and reinforcement strain. To set up a reference point and measure the strains in the longitudinal direction, the researchers created an artificial known transverse crack location. The WVU researchers placed a crack-inducer across each CRCP lane at a location where a set of thermocouples and strain gages was installed. The researchers attached an inverse T-shaped plastic crack-inducer on the subbase surface.

For the in situ temperature measurements, the WVU team installed 18 thermocouples at various depths and longitudinal locations. A thermocouple set consisted of three thermocouples and a metal stand. The researchers tied the thermocouples vertically to the stand, enabling temperature measurements to be made at 5, 13, and 20 centimeters (2, 5, and 8 inches) from the top of the pavement slab and glued the four legs of the metal stand to the subbase surface.

The research team placed five of the thermocouple sets at various

The slip-form paving machine. *Photo: WVU.*

longitudinal locations in the GFRP-CRCP section and one set in the steel-CRCP section. The researchers monitored the ambient temperature (with a standard thermometer), the surface (with an infrared thermometer), and interior temperatures (with thermocouples) of the concrete every 2 to 4 hours to attain a comprehensive understanding of the temperature variations at different locations over time under the influence of concrete hydration and ambient temperature.

The researchers installed eight concrete embedment strain gages to measure the concrete strain changes over time. The sensing grid of embedment gages, encased in polymer concrete, has an active gage length of about 10 centimeters (4 inches). A set of embedment gages included two gages and a metal stand tied together to measure the strains at two vertical locations: 5 centimeters (2 inches) from the top and bottom of the pavement slab.

To avoid any effects from the slab edge, the researchers placed all the gage sets about 1.2 meters (4 feet) from the edge of the slab. Two data acquisition systems were used, one for the steel-CRCP section and the other for the GFRP-CRCP section, to collect the concrete strain data every 10 minutes throughout the first 3 days after the concrete placement.

The researchers attached a total of 10 general-purpose resistance strain gages to the reinforcements for measuring the longitudinal reinforcement strains in the steel- and GFRP-CRCP sections. The strain gages were self-temperature-compensated with respect to steel or GFRP rebar materials, so that the undesirable thermal outputs resulting from the mismatch in thermal expansion between the strain gage and the rebar material could be minimized. In each section, to avoid potential loss of field data because of gage malfunction, the researchers installed three reinforcement strain gages at the induced transverse crack location where the maximum reinforcement stress developed. The researchers also installed two gages at 25 centimeters (10 inches) and 0.9 meter (3 feet) longitudinally from the induced transverse crack location.

To protect the wires from the paving machine track, the researchers gathered them into an electrical conduit and embedded the conduit in a trench dug into the subbase. The conduit led the wires into electrical enclosures connecting to a data acquisition station. The thermocouple wires from two additional locations near the main data acquisition station in the GFRP section also were gathered into small electrical enclosures, which were embedded in the shoulder subbase. When the wire connectors were not in use, the researchers kept them inside the enclosures.

The researchers conducted visual surveys for transverse crack spacing and width over the first 3 days and then 1 month after the concrete placement. The team monitored a 122-meter (400-foot) midsection length and a 55-meter (180-foot) end-section (joint-section) in each CRCP section. They classified all cracks

Here, workers distribute the concrete on the subbase. *Photo: WVU.*

within the survey areas according to the location and date of their occurrence.

The researchers observed the cracks at the smooth face of the pavement edge, which had much clearer crack appearances. They measured the crack widths particularly from the upper corner of the pavement edge, which provides overestimated (or conservative) values compared to those from the driving surface. The largest concrete volume changes usually occurred at the upper corner of the pavement edge, where there was less restraint from reinforcement and subbase friction. The changes in crack width at this location should be larger than if measured at other locations.

To measure the crack width, the researchers used a magnifying glass and a crack comparator, which is a transparent ruler printed with graduations at different widths. A GFRP-CRCP crack observed on the third day and again 125 days later showed the maximum crack width in the GFRP-CRCP test section as 0.058 centimeter (0.023 inch) on the third day and 0.086 centimeter (0.034 inch) on the 125th day.

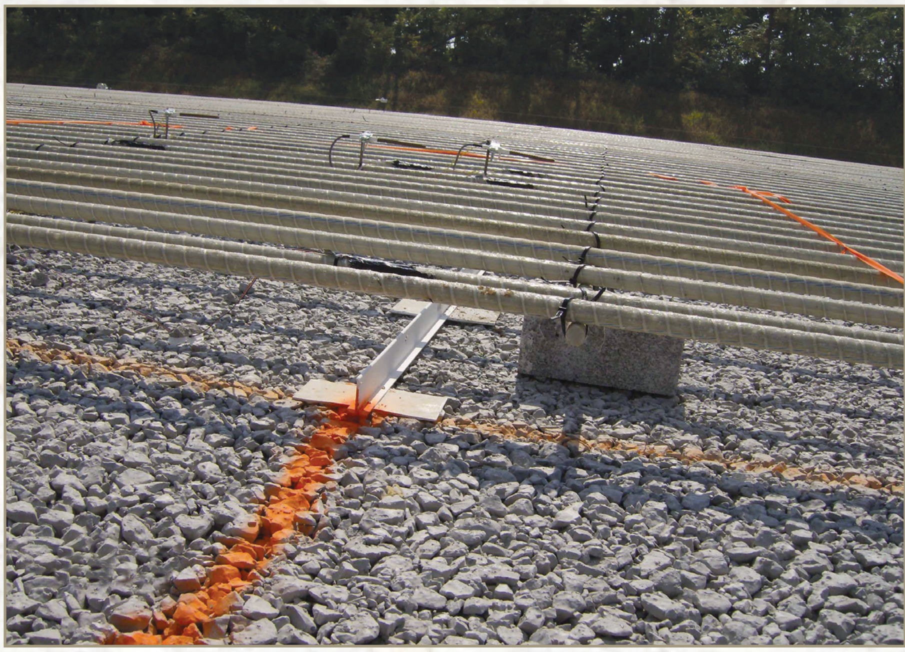
Experimental Results at 7, 28, and 38 Days, and 4 Months

Test	Steel-Reinforced CRCP	GFRP-Reinforced CRCP
Average Compressive Strength at 7 Days (tested at WVU)	19.7 MPa (2,850 psi)	19.7 MPa (2,850 psi)
Average Compressive Strength at 28 Days (tested at WVU)	26.9 MPa (3,900 psi)	26.9 MPa (3,900 psi)
Average Compressive Strength at 4 Months (tested at WVDOT and WVU)	37.6 MPa (5,450 psi)	37.9 MPa (5,500 psi)
Midsection Cracks at 3 Days	45	19
Midsection Cracks at 38 Days	75	40
Midsection Average Crack Spacing at 3 Days	2.88 meters (9.44 feet)	6.91 meters (22.67 feet)
Midsection Average Crack Spacing at 38 Days	1.71 meters (5.61 feet)	3.31 meters (10.86 feet)
Midsection Average Crack Width at 3 Days	0.025 centimeter (0.01 inch)	0.043 centimeter (0.017 inch)
Midsection Average Crack Width at 38 Days	0.028 centimeter (0.011 inch)	0.053 centimeter (0.021 inch)
Maximum Crack Width on January 31, 2008	0.058 centimeter (0.023 inch)	0.086 centimeter (0.034 inch)

Observation of Crack Spacing and Width at Early Age

All of the cracks in the concrete were transverse, with no longitudinal cracks observed. The anticipated absence of longitudinal cracks is due to designing for a longitudinal joint that limits the lane width to 3.7 meters (12 feet) and thus reduces the likelihood of cracking in that direction. The researchers evaluated maximum, average, and minimum values of transverse crack spacing and crack width for each CRCP section for each date when a measurement was made. After the construction, the team traced the width of each crack at four different ages in order to observe the changes in crack width over time.

A drastic decrease in the average crack spacing occurred between the first and second days because a number of cracks were generated due to a combination of a large change in the concrete volume and low concrete strength, which are both inherent at this early age. The crack spacing for the GFRP-CRCP section was larger than that for the steel-CRCP section, due to the lower stiffness of the GFRP reinforcement. Using GFRP rebars as reinforcement can reduce undesirable stress development in concrete caused by mismatches in stiffness and thermal expansion between steel reinforcement and the concrete. Steel stiffness is about six times larger than concrete or GFRP. The improved compatibility can be beneficial depending on other CRCP-design factors to control the crack width



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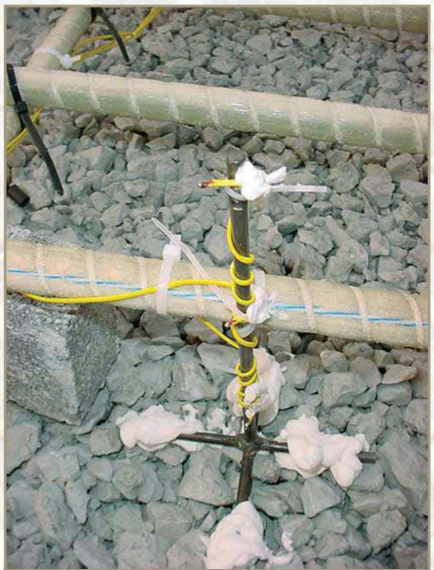
WVU researchers installed a crack-inducer and strain gages in the GFRP-CRCP section, as shown here.

The researchers placed this embedment strain gage set directly above a crack-inducer in the steel-reinforced CRCP section. *Photo: WVU.*



The thermocouple set shown here is installed in a GFRP-CRCP section. *Photo: WVU.*

and spacing, such as reduction of stresses surrounding the reinforcement at a crack location that may cause spalling or punchout failure in CRCP. As expected with the terminal joints, which allow movement of the free end of the CRCP slab, the average crack spacing at the joint-section was larger than at the midsection.

As for the crack width, the researchers observed mixed results. The widths remained unchanged or even became smaller during the second day and then started increasing. The cracks found on the first day generally had the larger widths, while additional cracks found at later ages had smaller widths due to less change in the concrete volume. "We believe that the restraining stress in the concrete was probably released when the additional cracks occurred, narrowing the widths of the existing cracks," says William "Bill" Shanklin, area construction engineer, West Virginia Division of Highways.

The researchers found more new cracks on the second day than on the later days. From the third day and beyond, crack width started slowly increasing due to continuous, yet less drastic, concrete shrinkage. Even though the crack width for the GFRP-CRCP section was larger due to the larger crack spacing and lower stiffness of reinforcement, it still meets the American Association of State Highway and Transportation Officials' (AASHTO) limiting criterion for crack width—≤0.1 centimeter (0.04 inch)—which is of utmost importance in providing adequate aggregate interlock and ensuring the integrity of the pavement. In addition, the crack widths in the joint-section appear to be smaller than those in the midsection, due to the lower restraining stresses developed in the joint-section.

The researchers placed these three embedment strain gage sets in the GFRP-CRCP section. *Photo: WVU.*

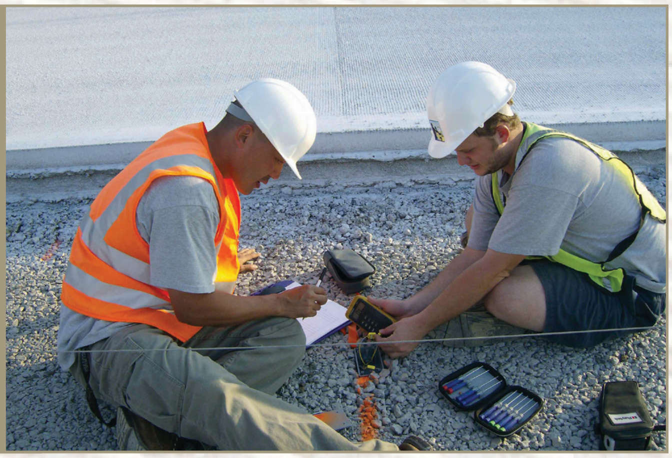
Currently, both CRCP sections are open to traffic. According to field observation on January 31, 2008, the maximum crack width for the GFRP-CRCP section and the steel-CRCP section met the current AASHTO limiting criterion, even though the guideline was based on experience and understanding gained from steel-reinforced CRCP. Limiting criteria, such as crack spacing, crack width, and reinforcement stress level for GFRP-reinforced CRCP still need to be developed.

Suggestions for Future Research

Additional studies on the performance of GFRP-reinforced CRCP in response to traffic loading are needed. The lessons taken from this short-term field study suggest that future research is needed to make further improvement of the design for GFRP-reinforced CRCP, if such improvement proves necessary after long-term traffic loading. Periodic observations of the load transfer efficiency at cracks, crack spacing and width under traffic loading, a crack width profile throughout the slab depth under loading, and pavement distresses are essential to obtain a comprehensive understanding of the overall performance of GFRP-reinforced CRCP. This understanding eventually will assist in developing standard design guidelines for future GFRP-reinforced CRCP.

In terms of CRCP life-cycle costs, the current expectation is that GFRP section costs will be substantially lower than those of steel sections. The long-term maintenance cost would be lower for the GFRP-CRCP than the steel-CRCP because there will be no structural distresses caused by reinforcement corrosion.

The data on early-age performance from the GFRP-CRCP field test section compares favorably with those from the steel-CRCP section. With additional construction experience using GFRP-reinforced CRCP and improvements in GFRP-CRCP design, even better performance should be achievable.



Two WVU researchers are measuring the temperature recorded by a small electrical conduit embedded in the shoulder subbase. *Photo: WVU.*

Roger H. L. Chen, Ph.D., is a professor of civil engineering at West Virginia University (WVU), Morgantown. He has been involved extensively with research in structural dynamics, nondestructive evaluation (NDE), dynamic soil-structure interaction, and material characterization of concrete, composites, and timber and ceramic materials for about 25 years and has ongoing research projects in GFRP-reinforced CRCP, self-consolidating concrete, evaluation of bridges for transporting coal, and diagnostics of thermal barrier coatings. He serves on several technical committees for the American Concrete Institute, American Society of Civil Engineers, and American Society for Nondestructive Testing (ASNT) related to concrete, NDE, FRP, dynamics, and experimental analysis. He received his Ph.D. from Northwestern University and is a fellow of ASNT.

Jeong-Hoon Choi is a graduate research assistant in the Department of Civil and Environmental Engineering at WVU. He received his undergraduate degree in civil engineering from Hanyang University, Republic of Korea, and a master's degree in civil engineering from WVU. His Ph.D. research is related to the design and application of GFRP-CRCP.

Hota V. GangaRao is a professor of civil engineering and director of the Constructed Facilities Center at WVU. He is a fellow of ASCE and serves on many technical committees of professional societies.

Peter A. Kopac is a senior research highway engineer on the Pavement Design and Performance Modeling team of FHWA's Office of Infrastructure Research and Development. He has almost 40 years of highway-related experience, including 31 years with FHWA. Kopac has managed, monitored, and contributed to numerous research studies dealing with concrete and concrete pavements.

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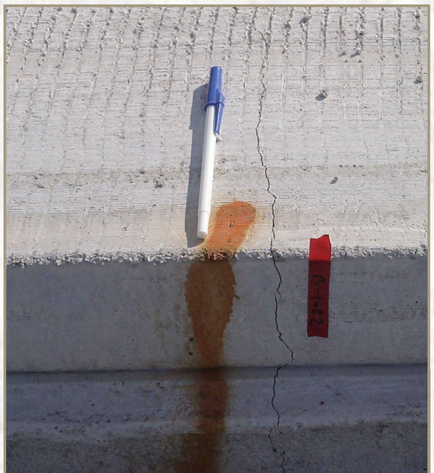
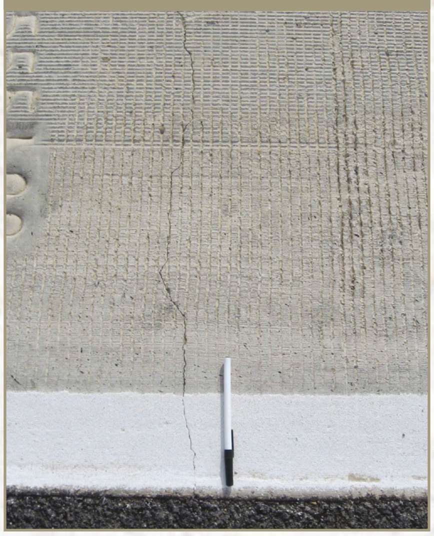


WVU

The researchers placed a ballpoint pen on the GFRP-CRCP section to show the scale of this crack width of 0.058 centimeter (0.023 inch) on the third day (September 28, 2007) after concrete placement. The rusty-orange paint beneath the pen marks the location of each crack found on the first day after concrete placement, and an identification number is written on the red tape.

The GFRP-CRCP section showed a crack width of 0.086 centimeter (0.034 inch) 128 days after placement (January 31, 2008). This crack is the same one pictured in the previous photo. When the shoulder was placed, the contractor removed all the paint and tapes, but the locations were recorded by construction station number.



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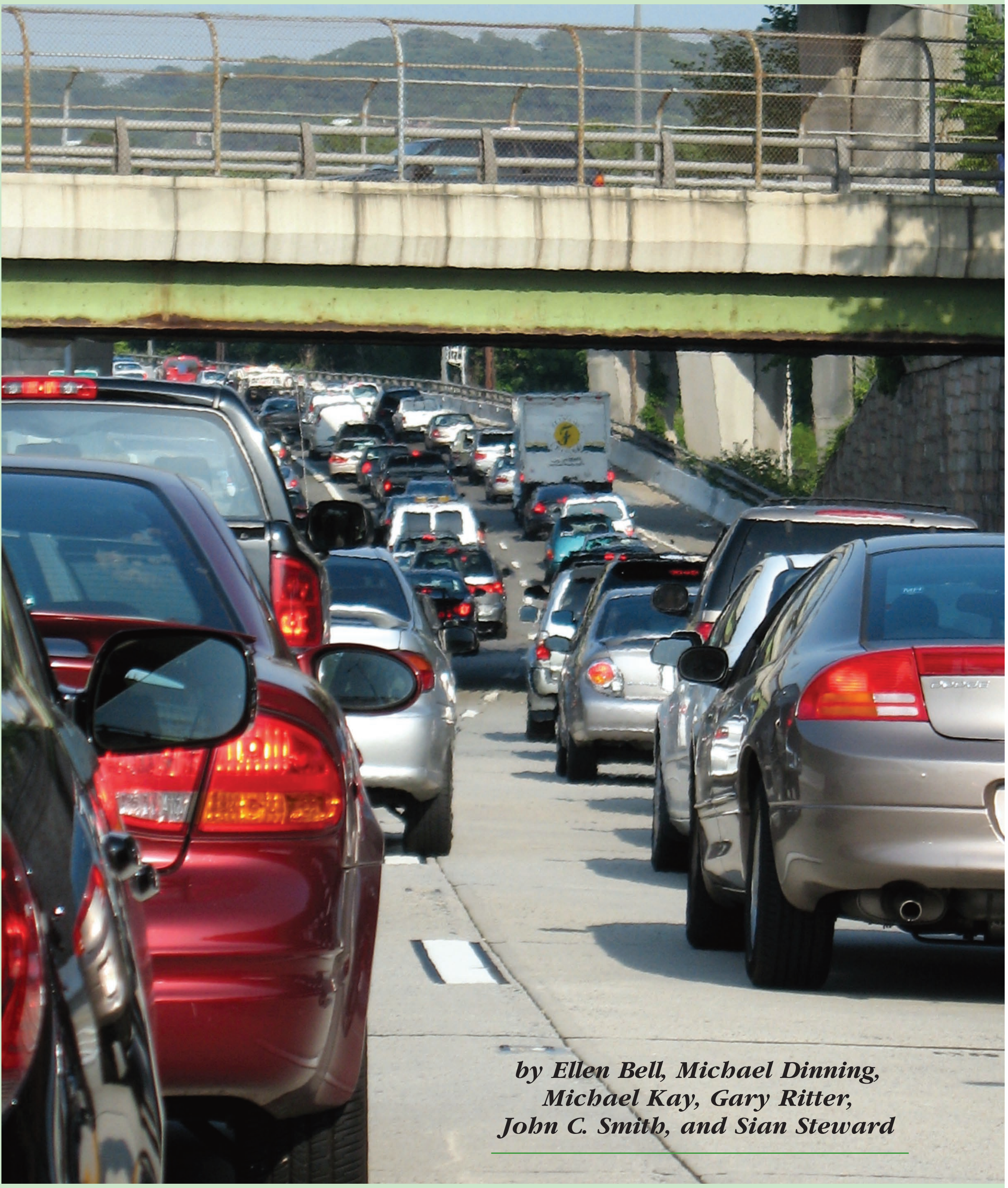
Gearing Up for SafeTrip-21

RITA is promoting technology solutions for improving transportation safety and reducing congestion.



by Ellen Bell, Michael Dinning, Michael Kay, Gary Ritter, John C. Smith, and Sian Steward

(Above) SafeTrip-21 seeks to spur deployment of the latest and best technologies to help reduce congestion, such as the backed up cars and trucks shown here. *Photo: John J. Sullivan IV for FHWA.*

According to the *Urban Mobility Report* by the Texas Transportation Institute, urban congestion in the United States in 2007 resulted in 4.2 billion hours of travel delay, 2.9 billion gallons of wasted fuel, and a net cost of $78 billion. In addition, highway vehicle travel today accounts for 81 percent of total U.S. transportation energy consumption. These costs and delays have increased steadily in recent decades and are likely to worsen over time.

In 2006 nearly six million crashes occurred on U.S. roadways, injuring 2.6 million people, according to the National Highway Traffic Safety Administration (NHTSA). That year, the total equates to a crash happening every 5 seconds. Motor vehicle crashes represent more than 90 percent of transportation-related deaths and are the leading cause of death for people between the ages of 2 and 34. In its "Fiscal Year 2009 Budget In Brief," the U.S. Department of Transportation (USDOT) estimated the economic cost of these crashes at more than $230 billion annually.

To find and deploy solutions to reduce traffic congestion and motor vehicle crashes, deaths, and injuries, USDOT's Research and Innovative Technology Administration (RITA) has launched a bold, new intelligent transportation systems (ITS) initiative that will catapult the United States to the forefront of ITS applications. Dubbed SafeTrip-21, for Safe and Efficient Travel through Innovation and Partnerships for the 21st Century, the program will leverage the Internet and an array of advanced communication, information, and navigation technologies. Specifically, SafeTrip-21 seeks to demonstrate the near-term safety and mobility benefits of improved situational awareness; real-time traffic, parking, and transit information; data collected by vehicle probes; and the ease of electronic payment.

Through SafeTrip-21, USDOT will build upon its Vehicle Infrastructure Integration (VII) research and the success of ITS assets already in place, such as variable message signs and traffic and transit monitoring. SafeTrip-21 embodies not only the largest multimodal ITS test in the world but also one of the largest tests of traffic probe data ever undertaken.

What Is SafeTrip-21?

SafeTrip-21 is a near-term component of the USDOT/RITA VII program, which explores the application of ITS technologies that transfer information on traffic and travel options to and from vehicles to reduce congestion and increase safety, mobility, efficiency, and convenience. RITA is partnering with transportation agencies, ITS technology suppliers, and the university research community to conduct field operational tests of VII concepts to obtain user feedback that will help USDOT better focus on longer term VII research and development (R&D). This effort holds significant implications in terms of generating practical solutions for traffic management organizations seeking cost-effective innovations to mitigate traffic risks while maximizing operational efficiencies.

In addition to the traditional VII focus on automobile travel, SafeTrip-21 seeks to assess ITS technologies that can make public transit a more convenient option. SafeTrip-21 will assess both the viability and performance of advanced traveler information technologies. And, given the growing interest in road-pricing policies to alleviate congestion, another goal is to facilitate convenient electronic payment options. These measures increasingly will benefit individual travelers, including commuters and businesses, as well as boost the performance of the national transportation system.

A key component of SafeTrip-21 is providing motorists and other travelers with the information they need to arrive at their destinations safely and with minimal delay. This includes information—about traffic congestion ahead, roadwork zones, weather conditions due to precipitation and fog, sharp curves in the road, and merging traffic—that will make travel safer and improve mobility.

SafeTrip-21 seeks to accelerate implementation of ITS technologies that contribute toward transportation goals expressed in *Transportation Vision for 2030* (www.rita.dot.gov/publications/transportation_vision_2030/pdf/entire.pdf), USDOT's long-term vision for the Nation's transportation system. The program therefore seeks to expose the public, decisionmakers, and stakeholders to the benefits of VII concepts in real-world travel settings.

The Vehicle Infrastructure Integration (VII) Program

USDOT's VII program is a collaborative R&D partnership with State and local departments of transportation, automobile manufacturers, and others. A key initiative within USDOT's ITS program, VII research focuses on enabling wireless communication among motor vehicles and between motor vehicles and roadway infrastructure. By facilitating secure real-time communication with motor vehicles, these new services will enhance transportation safety, mobility, and commerce.

For comprehensive, up-to-date information on the VII initiative, go to www.vehicle-infrastructure.org and click on Program Information.

By bringing innovative technologies into an operational setting, SafeTrip-21 will enable travelers to not only experience the initial benefits of VII today but also glimpse what is in store for the future. In addition, USDOT can use the results of these near-term activities to modify systems that the Department will introduce over the long term.

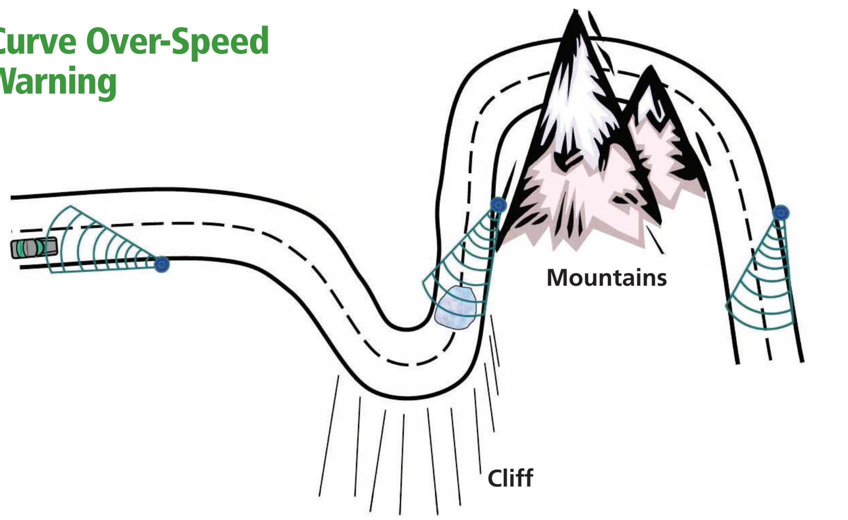
Putting the Wheels In Motion

SafeTrip-21 took root when RITA Administrator Paul R. Brubaker turned to the John A. Volpe National Transportation Systems Center in Cambridge, MA, part of RITA, to explore ITS best practices and methods to accelerate adoption of VII concepts in the United States. The program officially began in late 2007 with an extensive national and international technology scanning effort aimed at gathering information on ITS deployment efforts to date. The team interviewed ITS practitioners and university researchers and established a baseline of all the available technologies.

The impetus for SafeTrip-21 stems in part from successful ITS technology deployments in other countries. Information gathered from Belgium, France, Germany, Italy, and Japan indicates that these systems have the potential to improve safety in the vicinity of 70 percent and mobility by up to 20 percent. Although these impressive safety improvements might not be replicable in the United States where roadway geometrics are more forgiving, SafeTrip-21 intends to assess opportunities for improved safety. Furthermore, these systems can reduce fuel consumption and air emissions by 10 to 20 percent.

The scanning efforts included a fact-finding visit to Japan, which is a leading nation in ITS deployment, with extensive ITS infrastructure in place throughout its national roadway network. The Smartway 2007 exposition on the Metropolitan Expressway in Tokyo showcased many ITS technologies that facilitate the exchange of a wide range of information among drivers, their cars, and pedestrians, thus creating a

Curve Over-Speed Warning



Excessive vehicle speed at roadway curves can lead to lane departure, collision, loss of vehicle control, or road departure, any of which can result in a crash. A curve speed warning system, diagrammed here, could help drivers negotiate curves at safe speeds. *Source: NHTSA.*

Volpe Center

This in-vehicle alert system from Japan notifies the driver of an upcoming intersection.

platform for ITS deployment. These technologies include the integration of infrared, microwave, and FM radio transmission technologies. Japan already has a proven Vehicle Information and Communication System across the country that provides drivers with information on road conditions and alternative routes to avoid congestion.

In December 2007, the Volpe Center solicited information from transportation technology companies and researchers worldwide regarding concepts for applicable and viable approaches to mitigating congestion and improving safety through the application of new and existing technologies. The number and quality of the responses indicated significant interest among the broader transportation community in rapidly advancing ITS technologies in the United States and aggressively pursuing world-class field operational tests.

The Technologies

Many opportunities exist to introduce technologies that can produce immediate benefits without extensive public investment in VII infrastructure. These include adding portable navigational devices and smart phones with navigation capabilities to the range of tools that travelers use. Although the navigational tools of today's GPS devices are powerful, current innovations in the technology are bringing a new generation of capabilities that provide dynamic, real-time information to travelers instantaneously and cost effectively. SafeTrip-21 provides an opportunity to assess the ability of these increasingly popular mobile devices to deliver safety and mobility information to travelers safely and effectively. The initiative might point to the need for additional research, particularly with respect to the human interface and options for incorporating data from vehicle-based systems.

Importantly, GPS navigation devices increasingly are incorporating two-way wireless communications capabilities so information on current travel conditions can be shared with transportation facility operators and travelers. These advances enable novel safety functionalities such as proactively and instantaneously providing travelers with timely alerts about slow or stopped traffic ahead, icy bridges, wet curves, and temporary speed reductions. Safety alerts might also warn drivers about imminent stop sign violations, potential pedestrian conflicts, road hazards, and construction work zones. (Researchers at the Federal Highway Administration's Turner-Fairbank Highway Research Center are using a "smart intersection" to study cooperative intersection collision avoidance systems and infrastructure-vehicle communications, in addition to other innovations and technologies.)

Near-term mobility applications include better and timelier information on traffic, travel and weather conditions, transit connections and schedules, and parking. Travelers will be able to obtain travel advisories including congestion information and corresponding options, such as alternative routes, modes, destinations, and time of travel to avoid being stuck in traffic. As more accurate, real-time information becomes widely available, navigation devices will help travelers make informed travel choices to save time, conserve fuel, minimize their environmental footprints, and possibly even reduce risk of injury.

Most ITS technologies and applications involve sharing data, so protecting the privacy of travelers is of utmost importance. SafeTrip-21 will use established principles for maintaining privacy to ensure anonymity.

Field Testing: San Francisco Bay Area

To transition research findings to real-world operational environments more rapidly, the Volpe Center solicited proposals for field test sites

These equipment cabinets are part of FHWA's Intelligent Intersection Traffic Control Laboratory, which conducts research on traffic engineering, pedestrian safety, collision avoidance, and other topics related to the SafeTrip-21 effort. The lab is equipped with advanced ITS technologies including a comprehensive traffic signal control system, a dedicated short-range communication system, a vehicle and pedestrian detection system, and a fiber-optic communication network.

Volpe Center

This highway sign in Tokyo not only displays real-time traveling speeds on roadways ahead but also highlights areas of congestion in color. This type of information can help motorists decide whether to seek alternative routes. (Clearly, any U.S. signage featuring real-time information will need to comply with the requirements of the *Manual on Uniform Traffic Control Devices*.)

and ITS applications. The field testing component of SafeTrip-21 will help identify and promote integrated information, navigation, and communications technologies to advance national transportation goals. Applicants included a cross section of the transportation community, including State DOTs, academia, ITS technology providers, and automakers.

The Volpe Center recently entered into a cooperative agreement with the California Department of Transportation (Caltrans) to establish the inaugural SafeTrip-21 field test site in the San Francisco Bay area. Specifically, the site encompasses I–880 from Oakland to San Jose on the east bay and from San Jose to just south of the San Francisco International Airport, along U.S. 101 and California State Route (SR) 82. The site includes the SR–84 Dumbarton Bridge toll crossing, which links I–880 and U.S. 101.

Caltrans's partners include the Metropolitan Transportation Commission, the University of California–Berkeley's California Partners for Advanced Transit and Highways, the California Center for Innovative Transportation, Nokia, Inc., NAVTEQ, Santa Clara Valley Transportation Authority, and Nissan. The cost of the $12.4 million field test is funded by the private and public sector partners, including the USDOT contribution, equally.

Based on 2005 data, the San Francisco Bay area is among the five most congested metropolitan regions in the United States and has a complex transportation network. Its highly congested I–880 freeway alone sustains 10 to 15 incidents per day, and the region is home to three major airports, a seaport, and extensive heavy rail, commuter rail, and bus transit systems. The bay area is a leader in multiagency, integrated electronic transit fare payment technologies. The region has electronic tolling on its major bridges and has high-occupancy tolling (HOT) authority to convert high-occupancy vehicle (HOV) lanes to HOT lanes at four locations.

The SafeTrip-21 field test will feature a bay area application that involves using GPS-equipped mobile devices to enable drivers to share and receive vital roadway and safety information. It will provide real-time traffic data for highways and arterials that travelers can access through a variety of means, including the Internet, cell phones, and other devices in their vehicles.

Another ITS technology will provide an interface between mobile devices and the roadside infrastructure to make possible a host of VII safety and mobility functions. Through wireless distribution of digital data and routing information, drivers with mobile devices in specially equipped vehicles can be alerted when approaching slow-moving or halted traffic, red lights, grade crossings, stop signs, and other "connected" vehicles. Transit riders will be able to plan trips based on current transit operating conditions (rather than published schedules). Future test elements will incorporate the ability to pay for fares and even locate, reserve, and pay for parking at a transit station—all electronically. Travelers in general will be able to choose a mode, route, and time of travel based on the shortest distance, quickest travel time, most predictable arrival time, or lowest environmental footprint. SafeTrip-21 seeks to evaluate the effects of providing individualized traveler information, choices, and convenience.

SafeTrip-21 at the ITS World Congress and Beyond

USDOT will showcase the selected technology applications at the 15th World Congress on ITS in New York City in November 2008, where ITS leaders, policymakers, and other industry professionals from more than 70 countries will gather. Attendees will have the opportunity

Maciej Korzekwa, iStockphoto

SafeTrip-21 seeks to harness new wireless technologies, such as this dashboard-mounted GPS device, to transfer vital transportation information directly to travelers in real-time. Eventually, any handheld device with wireless capabilities will be able to synch in to this growing network of integrated communications.

Caltrans

Caltrans

Caltrans District 4, in the San Francisco Bay area, is integrating transit information onto variable message signs (left) to entice drivers to switch modes. In addition to the departure time of the next train, these signs can relay information on parking availability at transit stations (right).

to see SafeTrip-21 technologies in an interactive setting that demonstrates operational capabilities.

The formal SafeTrip-21 field tests and evaluations will take place from December 2008 to December 2009. The testing will focus on assessing and measuring the abilities of these technologies to yield near-term safety and efficiency benefits, as well as to contribute to solving long-term transportation problems. The field tests will provide an opportunity to see which applications work and which require further R&D.

The tests also will provide an opportunity to inform transportation decisionmakers about how the technologies work in the field and what safety and mobility benefits DOTs might derive by providing the traveling public with improved traffic and transit information.

Viable Business Models

USDOT predicated the initial VII vision on deployment of a national infrastructure of an estimated 252,000 to 400,000 roadside transponders to communicate information to and from motor vehicles. This approach requires significant investment by the public sector or a public-private partnership in terms of deploying, operating, and maintaining roadside units. SafeTrip-21, however, is assessing near-term possibilities that do not require extensive infrastructure, as well as business models that can support widespread deployment of VII infrastructure to enable collision avoidance and other safety-critical concepts that require roadside units.

The Volpe Center issued a request for information in spring 2008 to gain input from industry and State and local governments about potential partnerships. Based on responses and other analyses, the SafeTrip-21 team identified and will test alternative business models that allow for public-private partnerships for cost sharing and market development.

Tangible Benefits

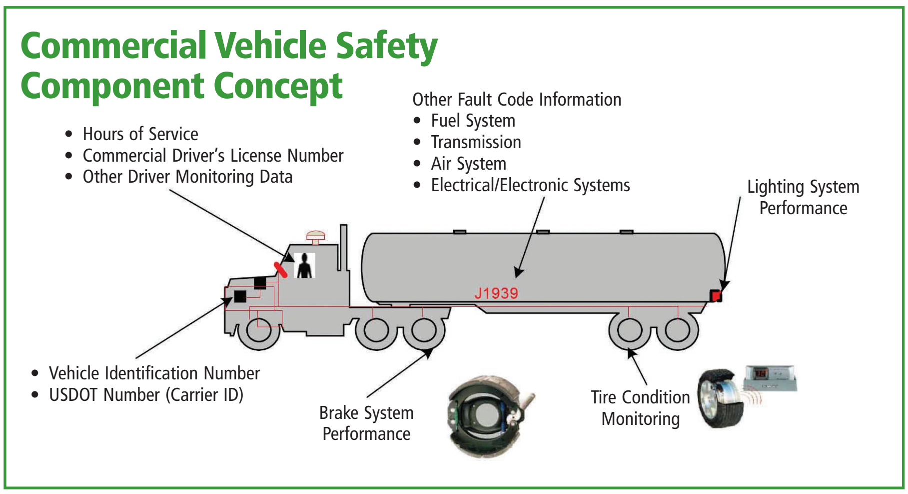
A series of hypothetical scenarios can illustrate how the public might benefit from SafeTrip-21.

Scenario 1: A businesswoman is driving to a business meeting in a major metropolitan area 322 kilometers (200 miles) from home. She drives onto a freeway, but soon the vehicle's traveler information system warns of a severe crash 8 kilometers (5 miles) ahead. The traveler information system in her vehicle shows two alternative routes to reach her destination but estimates that either one will add an hour to her drive.

The woman's business meeting is in 4 hours, and she is concerned about arriving in time. The traveler information system then provides information about air and rail options. The woman chooses the train, which leaves in 45 minutes and will arrive in time for the meeting. Her vehicle's onboard system informs her that a parking spot is available at the train station, and she can make a reservation from her car. Her electronic toll tag, regional transportation smart card, and bank-issued contactless credit card all are accepted for payment at the station's parking garage, and each allows her the flexibility to touch and go without delay.

When the woman reaches her destination city, her smart card enables her to take the subway and bus right to the door of her appointment. She makes the meeting and closes a business deal. As a result of taking transit during her trip, she receives a day's worth of "green credits" payable to her integrated mobility account (smart card). Such seamless, multimodal travel is a key goal of SafeTrip-21.

Scenario 2: A long-haul truck driver is carrying hazardous material. His job has become easier in recent years with the introduction of onboard safety systems and communication links that warn of potential hazards. The driver remains vigilant but has less stress knowing he will be alerted to unusual highway conditions (weather and traffic alerts, severe curves in the road, and construction ahead). His truck already is outfitted with onboard safety systems that signal when he strays from a lane, detect



In trucks equipped with ITS, real-time data on the driver and vehicle can be transmitted to enforcement agencies for a "virtual" inspection, increasing compliance, saving time and manpower, and improving safety and mobility. *Source: FMCSA.*

More widespread use of communications technology can enable timely and strategic deployment of snowplows such as this one and other road maintenance equipment.

AAA Foundation for Traffic Safety

truck stability or impending rollover, and sense whether he is too close to a vehicle ahead of him.

Due to sensors transmitting up-to-the-minute information (on the driver and the truck) that deemed him "safe," the driver was permitted to bypass an inspection station during rush hour, and he is now ahead of schedule. This virtual, wireless inspection also communicates the truck's location and status to the fleet manager, who is not only satisfying Federal regulations and bolstering the driver's operating record but is planning the driver's next trip more efficiently. The driver also gets a bonus from his employer for minimum fuel usage due to economical braking and acceleration.

At the end of the driver's workday, he approaches a city. The truck's onboard system finds a place to park, reserves the spot, and gives the driver directions, including which routes are appropriate for the hazardous material he is carrying. The onboard technologies and their links to infrastructure systems improve the driver's workday, maximize his productivity, and help keep him and his fellow travelers safe.

Scenario 3: A road maintenance official is responsible for keeping certain roads safe in winter. He needs to know as soon as possible whether the roads are icy or if a crash has occurred. Newer technologies make it easier for the official to obtain and use the information he needs. Vehicles traveling on the throughways are equipped with sensors that provide location information, surface temperature, icing conditions, and road surface salinity in real time. Onboard systems send this information to the official, enabling him to send message alerts to other vehicles on the road, and he can activate countermeasures quickly, such as sanding and salting.

Many of the technologies and investment strategies of the SafeTrip-21 program are in the early phases of evaluation. Currently, the program is appraising a multitude of leading technologies to determine the most cost-effective means of supplying next-generation safety and mobility information solutions. All of the technologies under consideration require minimal investments in infrastructure by State transportation agencies. SafeTrip-21 uses current cellular technology and flexible transceiver device tools. The technologies involved are currently available, highly mobile, compact, and inexpensive.

SafeTrip-21 supplies the tools and methods for State and local transportation agencies to collect and disseminate traffic and safety information in a multimodal environment. States will benefit with real-time information that will empower them to make better decisions to reduce congestion, pollution, gridlock, and transportation-related injuries and fatalities.

SafeTrip-21 Future Milestones

As the SafeTrip-21 program evolves, USDOT may include and evaluate other test sites to incorporate additional traffic influencers such as severe winter weather. Throughout 2009, as preliminary results from the field tests become available, the SafeTrip-21 team will share interim findings with the transportation community and issue a summary briefing in early 2010.

Combining the Internet with the latest ITS technologies provides myriad opportunities for travelers to be directly linked to one another and to central information databases in ways never before seen. SafeTrip-21 is poised to be the springboard for a new direction that is paved with features leading to a better-integrated, safer, and more reliable national transportation system.

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This article was a collaborative effort by the Volpe Center's SafeTrip-21 team. For more information and to keep informed about this initiative, please visit the RITA Web site at www.rita.dot.gov or contact Gary Ritter at 617–494–2716 or gary.t.ritter@volpe.dot.gov.

The Ongoing Evolution of FRP Bridges

by Jim Williams

In a research project on new hybrid structural construction, Texas explored the viability of custom fiber-reinforced polymer beams.

Refugio County near the southeastern Texas coast has a humid, subtropical climate with an average of 94 centimeters (37 inches) of rain annually. Given the humidity and proximity to the coast, brackish water in streams and drainage ditches corrodes the county's highway bridges and increases maintenance costs. To address the corrosion issue, the Texas Department of Transportation (TxDOT) specified customized, fiber-reinforced polymer (FRP) composite beams when it replaced a drainage ditch bridge (FM-1684) in Refugio County in 2007.

Although FRP beams are more costly upfront, TxDOT selected them to research the long-term corrosion and structural performance benefits of this material versus traditional steel or concrete beams. The Refugio County Bridge, which is 56 kilometers (35 miles) from Corpus Christi, is the State's second FRP hybrid bridge project. The first was the successful construction of the San Patricio County Bridge in 2005.

The new Refugio County Bridge replaces a single-span girder bridge that was 15 meters (50 feet) long by 10 meters (32 feet) wide. The new bridge has eight customized FRP flanged U-shaped beams and a concrete deck. The beams are 15 meters (50 feet) long by 76 centimeters (30 inches) high, with a composite structure that provides optimal deflection under load. The new beams weigh approximately 2,270 kilograms (5,000 pounds) each and sit on abutments.

"The [Refugio] project began in late 2006 and was completed in the fall of 2007," says Rich LaFountain, the manu facturer's business unit leader for open molding. "The project's goal was to take the lessons learned from the previous bridge project so that the current customization and production processes could evolve in hopes of optimizing performance and cost variables for future projects."

The Innovative Bridge Research & Construction Program helped fund the Refugio project by contributing $462,500.

The Forming Process

In the first lesson learned from the previous project, the manufacturer fabricated the beams using a vacuum infusion process (VIP) rather than the hand layup used on the San Patricio bridge. In a typical hand layup, the manufacturer lays reinforcements into a mold and manually wets down and melts the resin using brushes or rollers. The typical hand layup usually results in excess resin, and resin is very brittle, so any excess actually will weaken the part.

The VIP process, on the other hand, uses a vacuum bag to suck out excess resin from the laminate.

(Above) The Refugio County Bridge is shown here with the FRP beams in place on 1.2-meter (4-foot) centers with plywood formwork between the beams. *Photo: Haas-Anderson Construction.*

Vacuum bagging greatly improves the fiber-to-resin ratio, eliminating all air voids in the laminate and resulting in a stronger and lighter product. VIP is still not ideal and can lead to configuration issues because curved products or those with intricate angles will not work as well in the bag. Vacuum infusion does provide a number of additional benefits, however, including consistent fiber-to-resin ratio, less wasted resin, no limit on setup time, and much lower acoustic emissions.

Using VIP on the Refugio County Bridge project, the manufacturer produced a male mold to the beam design and then laid dry sheets of stitched glass fabric and chopped strand mat over the U-shaped mold in a series of layers to achieve the appropriate 3.8-centimeter (1.5-inch) beam thickness. The next step involved laying a plastic film on top to serve as the vacuum bag. Once a complete vacuum was achieved, the manufacturer then introduced liquid resin into the laminate. The vacuum drew the resin through the fibers, filling all the voids and eliminating any remaining air.

According to LaFountain, "The trick is to get the bag to draw down correctly so that wrinkles don't develop in the individual layers of fabric, which could affect the ultimate strength of the composite."

After the manufacturer fabricated the beams, Robert Sarcinella, materials branch manager for the TxDOT Construction Division, and his staff inspected them. Sarcinella notes, "Using the vacuum process, [the manufacturer] fabricated the beams more quickly and with better quality than on the other project."

Assembly and Installation

Once the beams were completed, the manufacturer cured, trimmed, and assembled them with shear transfer members (brace bars) installed into inserts placed into a 5-centimeter (2-inch) hole drilled into the vertical sides at 41-centimeter (16-inch) centers over the entire length. The inserts were installed to enable the brace bars to make a more positive connection with the composite beams.

After delivery to the site, the contractor placed the beams at 1.2-meter (4-foot) center-to-center spacing and then poured the

Lessons Learned

For the first research project—the San Patricio County Bridge—the manufacturer intended to fabricate the FRP beams using VIP, according to TxDOT's Robert Sarcinella. The manufacturing plant selected was not well-versed in that process, however, so the manufacturer used hand layup instead. Under load testing, the FRP beams manufactured with hand layup resulted in little to no deflection—although more than the FRP beams used on the Refugio bridge, manufactured using VIP.

The San Patricio project required 24 beams, which the contractor unloaded and placed in 7 hours. "Compared to the setting of concrete beams, that's pretty fast," says Sarcinella. The structure on the San Patricio project would have required a cast-in-place design because of the structure's short length.

Compared with traditional methods, the cost per square foot of structure for FRP was around 4 to 4.5 times higher, according to Sarcinella. "Weighing each situation to see if we could afford the additional cost to avoid shutting down a road for a longer time may make sense," he adds. "The major cost benefit is long term, because FRP beams do not corrode over time."

The research projects on the San Patricio and Refugio bridges showed the potential for FRP beams if the cost of materials can become competitive. "FRP beams will be viable if the cost can be driven down by manufacturers producing them as an off-the-shelf product in standard lengths," says Sarcinella. "We need to determine whether the long-term value of the strength and noncorrosive benefit of FRP is worth the upfront cost versus traditional concrete or steel beams."

TxDOT has used FRP in other projects, such as FRP bars used where sensors at toll plazas needed to be isolated from metal reinforcing and FRP wrap used around deteriorating concrete columns to strengthen and protect them against corrosion.

The number of applications for FRP beams is limited to projects where corrosion could be a problem. Sarcinella concludes, "We learned a lot from these two projects—if we did another project, we would design better, specify better, and test better, based on what we learned from these projects."

The use of FRP beams appears to be limited to smaller secondary bridges and culverts because of the relatively short span lengths that FRP can reach. Prestressed concrete beams become limited around 43 meters (140 feet) in length. Steel beam structures span even farther. The maximum FRP beam length for bridge projects is 15 meters (50 feet) due to design limitations.

Federal Highway Administration (FHWA) Division Bridge Engineer Peter Chang adds, "Because the San Patricio and Refugio bridges were research projects, time will be required to determine the effectiveness of FRP for use in future Texas projects."

Other States that are involved in FRP include California (deck panels), Florida (deck panels), Georgia, Hawaii and Illinois (deck panels), Kansas (beams), Kentucky and Louisiana (rebar), Maine (cable stays), Missouri (bonded reinforcement), New York and North Carolina (rebar), Ohio (deck panel and beams), Pennsylvania (bonded reinforcement), Virginia (deck panels), and West Virginia.

For example, Ohio has a 10-year history of using FRP materials for various bridge applications: bonded reinforcement, post tensioning, concrete reinforcement, deck replacements, and complete spans. The Ohio Department of Transportation does not normally use FRP materials due to high costs and technical issues. Counties in Ohio have remained active in using FRP materials, largely due to funding from subsidized programs. There are currently more than a dozen FRP decks in Ohio.

Haas-Anderson Construction

The San Patricio County Bridge, shown with the beams in place with foam to fill the void up to the steel bar level.

reinforced concrete deck. The contractor tied the deck to the beams with horizontal pipe 6.6 centimeters (2.6 inches) deep by 5.8 centimeters (2.3 inches) wide close to the top of the beams. The concrete deck pour was deep enough to engage the brace pipe for optimal strength to tie the beams to the deck. The goal was to achieve composite action, so that the bridge would be able to flex while creating a solid connection between the deck and beams.

Acoustic Emission Testing

In April 2007, before installation of the beams, Guillermo Ramirez, P.E., Ph.D., of The University of Texas at Arlington, and Paul Ziehl, Ph.D., of the University of South Carolina, performed an acoustic emission (AE) evaluation test on two of the beams. This method of nondestructive testing uses mechanical waves moving through materials. When researchers load a structure, subjecting it to external force (or stress), a defect such as a crack or a welding flaw is activated and generates waves that spread at a certain speed. The researchers listen through headphones, and when the loading makes the structure flex, emissions of a certain decibel indicate a beam's stiffness and ability to sustain service loads.

For the tests on the Refugio beams, Ramirez and Ziehl monitored AE during the background check prior to loading, during load holds, and during the background check after completion of loading. The test threshold was 40 decibels (dB), and the evaluation threshold was 48 dB. The thresholds are an indication of how strong a signal has to be in order for the system to consider it valid for recording (converting to digital information and storing). The evaluation threshold is the point at which recorded data is used in the analysis, eliminating anything under that level of energy.

The main sensors used were type R15I, resonant in the range of 150 kilohertz (kHz). The two researchers monitored activity from the R15I sensors and recorded it with a 24-channel transportation instrument—an AE data acquisition system that captures information from resonant frequency sensors and extracts statistical values from the signal. For supplemental analysis of the data, Ramirez and Ziehl used broadband high-fidelity sensors that enabled them to digitize the waves for later analysis.

According to Ramirez, "The test verified the performance of the beams under the load criteria set forth by the project specifications. The beams selected by TxDOT performed well during load testing—passing the major criteria selected for the acoustic emission test. In fact, the beams' stiffness tested better than expected, substantiating their ability to sustain the inservice loads." TxDOT's Sarcinella agrees that deflection was almost nonexistent.

Ramirez adds that the beams had no visible flaws. "The method of fabrication resulted in a very good product," he says, and again Sarcinella agrees.

MFG-CP

This cross section slice of an FRP beam shows a 5-centimeter (2-inch)-diameter brace bar at the top for reinforcement.

Haas-Anderson Construction

The Refugio County Bridge is shown almost ready for the pouring of a conventional reinforced concrete deck. Wood strips hold the beams in place.

The Test Procedures

The Ramirez and Ziehl report, *San Refugio County FRP Bridge Beams (Acoustic Emission Evaluation—Beam Nos. 1 and 2)*, provided to TxDOT in July 2007, summarizes the AE evaluation of the two beams that the researchers performed on April 18, 2007. Ramirez and Ziehl originally loaded beam numbers 1 and 2, using hydraulic rams in an indoor environment, to a total load of 32.0 kips (in increments of 454 kilograms, or 1,000 pounds) on April 17. Because they tested the beams indoors, wind was not present. Background checks prior to and after testing generally were satisfactory, verifying that there were no external sources of AE from those produced by the application of load.

The AE monitoring did not take place on the first loading, but instead the beam was loaded simply to eliminate signals from insignificant sources like bubbles or flaking that does not indicate any kind of permanent damage. The specification did not require monitoring during the first loading, so this caused no departure from the specified testing procedure.

The researchers then allowed the beams to remain in the testing facility unloaded for a minimum period of 12 hours prior to reloading. They reloaded the beams on April 18 to 32.0 kips in accordance with the specifications, at which time the AE testing took place.

Test Results for Beam Number 1

According to the specified evaluation criterion—Article RT-6 of the American Society of Mechanical Engineers (ASME) Section X—no acoustic emission is allowed during the 2-minute evaluation period of the 4-minute load holds, and no emission is allowed during the 28-minute evaluation period of the 30-minute load hold. If strictly applied, beam number 1 would not be in conformance with the specification. However, given that no emissions occurred during the 2-minute evaluation period, and the emissions during the 28-minute evaluation period were of small or medium amplitude, Ramirez and Ziehl concluded that some deviation from the specification might be warranted, and TxDOT concurred with the conclusion.

After they completed the testing, the researchers noticed a drainage hole drilled in the vicinity of sensor R12. Highly localized damage at this drainage location might have been the cause of much of the AE activity recorded by this channel. This observation, they concluded, further supports the case for allowing some deviation from the specification.

Results for Beam Number 2

Beam number 2 had similar emission to beam number 1, but the amount of emission increased in both quantity and amplitude. For this beam the criterion of no emission during the evaluation period of the load holds was not met for the holds at 20, 28, and 32 kips. Again, in most cases the emission was of small or medium amplitude. In one case during the 30-minute load hold, the emission was large in amplitude (81 dB). However, it was only one instance and did not exceed the maximum number of events as specified in the criteria, so TxDOT concurred.

Similar to beam number 1, much of the AE activity was recorded from sensor R12, which was near the drainage hole.

MFG-CP

The FRP beams, shown here from the side, rest on a concrete abutment, as with conventional concrete and steel beams.

Assessments

Roy Tijerina, superintendent with the general contractor Haas-Anderson Construction of Corpus Christi, assesses the short-term benefits of the FRP beams: "[The manufacturer] delivered all the FRP beams in one truck, and handling and installation were easier because of being able to use a small crane or large track hoe versus multiple cranes with steel or concrete options. This meant that minimal equipment and people were required, which equated to built-in time and cost efficiencies on the project."

A postconstruction assessment by FHWA Division Bridge Engineer Peter Chang notes, "The funding to promote the new fiberglass girder technology was allocated by TxDOT as a research project. With the load testing calculated and installation complete, the beams are actually stronger than we anticipated, thus proving the research positive." The structure was load tested during construction to verify the load-carrying capability of the entire unit.

Sarcinella concludes, "Projects of this nature generally start as a research project and then move to an implementation project if they show merit. That was the case for FRP beams. In the implementation project, we found (under loading) that the structure had more stiffness (less deflection downward) than was calculated in the design phase. This is a good thing and could be attributed to several factors (but most likely due to the beams). We have no plans to do any additional load testing unless the structure shows signs of decreasing camber (that is, does not bow upwards)."

The future use of this product with TxDOT will be based largely on cost and flexibility of use.

Benefits of Using FRP

If considering the use of FRP, designers should assess its benefits and weaknesses, such as cost factors, early in the design process.

Corrosion Resistance. FRP does not rust, corrode, or rot, and resists attack from most industrial and household chemicals. This quality has been responsible for its application in corrosive environments where resistance to corrosion can help provide long life and low maintenance.

High Strength, Lightweight. FRP provides high strength-to-weight ratios exceeding those of aluminum or steel.

Dimensional Stability. One of FRP's most useful properties is its high dimensional stability under varying physical, environmental, and thermal stresses.

Parts Consolidation and Tooling Minimization. A single FRP composite molding often replaces an assembly of several metal parts and associated fasteners, reducing assembly and handling time, simplifying inventory, and reducing manufacturing costs.

High Dielectric Strength and Low Moisture Absorption. FRP's excellent electrical insulating properties and low moisture absorption qualify it for use in primary support applications and where low moisture absorption is required.

Minimum Finishing Required. FRP can be pigmented as part of the mixing operation or coated as part of the molding process, often eliminating the need for painting. This is particularly cost effective for large components.

Low to Moderate Tooling Costs. Regardless of the molding method selected, tooling for FRP usually represents a small part of the product cost. For either large-volume mass production or limited runs, tooling cost normally is substantially lower than that of the multiple forming tools required to produce a similar finished part in metal.

Design Flexibility. No other major material system offers the design flexibility of FRP.

Jim Williams started his career in the manufacturing business in 1954 working for Boeing Aircraft, where he was involved in the manufacture of the nose cone for the Boeing 707. In the fiberglass industry for more than 35 years (supporting the construction side for 29 years), Williams served as plant manager for Molded Fiberglass (MFG) Construction Products for 10 years.

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Applying AQS In the Highway Industry

by Alberto Miron, Richard B. Rogers, and Peter A. Kopac

The advanced quality system offers promise for improving pavement quality while helping agencies finish paving projects on time and within budget.

Today more than ever, given current financial and personnel constraints, transportation agencies face the challenges of doing more with less and delivering projects on time. To improve efficiency and cost effectiveness, many agencies are adopting alternative types of contract delivery mechanisms—such as quality assurance (QA) specifications, performance-related specifications (PRS), and warranties—that affect contractors' responsibilities and liabilities.

In this operating environment, an additional tool available to transportation agencies is the advanced quality system (AQS) approach, a total quality management approach that has been proven in other industries and focuses on quality as the top priority. In the highway industry, the target quality level is the one that provides the optimal balance between project cost and a satisfactory level of performance throughout a pavement's life cycle. To help the evolution to a systems approach, transportation agencies can rely on proven quality management methods and concepts that are applicable to all types of organizations, including those dealing with the delivery of highway projects.

"The main goal of any highway agency is to ensure that pavements will maintain an adequate level of performance throughout their designed life," says Brett Haggerty, transportation engineer with the Flexible Pavements Branch of the Texas Department of Transportation (TxDOT) and project director for Research Project 0-5496, Tracking the Performance of HMA Mixtures in Texas. "Hence, it becomes necessary to adopt a system that ensures an acceptable level of quality during the most vital [stages of a project]."

To ensure that contractors understand and meet (or exceed) the requirements contained in project specifications, quality must be managed systematically throughout the process from *quality planning* to *quality control*, to *quality assurance*, and to *quality improvement*. Further, according to the principles of quality management systems, the best way to manage quality is through a system that transforms inputs (requirements, that is to say, specifications) into outputs (products and services) through a chain of value-adding interrelated processes. For example, the design process relates strongly to the specification development and construction processes, and more cost-effective construction can be achieved when the assumed materials properties used in the design are also those specified and those the contractor targets during construction.

For transportation projects, "the use of quality systems is critical for tying together design, construction, and the resulting performance," says Linda Pierce, State pavement engineer for the Washington State Department of Transportation (WSDOT).

Toward that end, the Federal Highway Administration (FHWA) supports the innovative AQS approach, which could help State departments of transportation (DOTs) improve quality in highway paving projects. An AQS seeks early involvement of all stakeholders in an integrated quality

(Above) Adopting AQS approaches could help improve pavements, such as the one being constructed here. *Photo: WSDOT.*

management system that continuously improves its own processes and the quality of the product delivered.

Why AQS?

FHWA introduced the AQS concept to highway professionals attending the Infrastructure Research and Technology Stakeholder Workshop held in 2002 in Chicago, IL. As documented in the FHWA report *Infrastructure Research and Technology Stakeholder Workshop Summary Report: Workshop Proceedings* (FHWA-RD-03-071), the sessions provided the opportunity to solicit input from stakeholders on raising the bar on research and technology, deployment, safety and performance, and extending the life of pavements.

According to the workshop proceedings, one innovation suggested at the workshop is an AQS approach, which could improve the quality of finished pavements by ensuring that contractors meet the specified quality and performance expectations established during project design. By helping guarantee that those specifications are met during construction and that project performance data are used by the planners and designers, an AQS approach provides a closed-loop system.

"It is not our agency's role to prescribe how a contractor performs quality control, but our agency does identify opportunities that might eliminate barriers to innovation," says Tom Harman, team leader for the Pavement and Materials Technical Service Team at the FHWA Resource Center in Baltimore, MD.

Acting on recommendations from the workshop participants, FHWA held a workshop titled Advanced Quality Systems in November 2006 in Alexandria, VA, to discuss quality. The objective of the workshop was to generate discussion about what constitutes an AQS and how to best advance the systems. Individuals from State DOTs, academia, government, and industry shared knowledge and discussed potential solutions for advancing highway construction specifications and establishing an AQS.

What Is an AQS?

During the workshop, attendees settled on a preliminary definition of an AQS and then expanded it to embrace principles outlined in ISO 9001:2000, the set of standardized requirements for a quality management system, maintained by the International Organization for Standardization (ISO). The workshop's expanded definition is as follows: An AQS is an integrated quality management system to fulfill the customer's expectations of pavement performance by making optimum use of the available tools and resources to continuously improve the system processes and the quality of the product delivered while fostering cooperative working relationships among all parties. FHWA used this definition to plan research to be undertaken under a task order-type research contract titled "Advanced Quality Systems."

"An AQS helps fulfill those expectations for pavement performance," adds Harman. "It creates an environment of reduced risk for both the transportation agency and the contractor by ensuring that quality levels are met."

Although FHWA will further refine the workshop's definition, the focus of FHWA's AQS is on the development and use of tools within the integrated system. It is the specific tools, after all, that will distinguish FHWA's concept of AQS from that of other total quality management systems. The tools include nondestructive, rapid test procedures and equipment; analytical evaluation procedures; software programs; guidance manuals; and training courses and workshops (see "Some FHWA-Developed AQS Tools" on page 26). Some of the needed tools have already been developed; others are under development. The development of certain tools (for example, nondestructive evaluation equipment) is a continuous process that will last many years. However, currently there are enough new or

ISO 9000: A Quality Management System

ISO 9000, maintained by the International Organization for Standardization (ISO), offers a series of standards for managing quality systems in almost any type of organization. The ISO 9000 requirements provide the basis for instilling a culture of quality within organizations that embrace eight quality principles: customer focus, leadership, involvement of personnel, process-based approach, systems approach to management, continual improvement, factual approach to decisionmaking, and mutually beneficial relationships with suppliers.

According to ISO 9000, the objective of a quality management system is to help organizations break down communication barriers, change paradigms, and ensure that every department in an organization knows how its work affects other processes or areas in the organization. Aligning a quality management system with the organization's current management system facilitates planning, allocating resources, defining complementary objectives, and evaluating the organization's overall effectiveness.

TxDOT

In this view of a four-lane divided highway, the right two lanes show wear and tear to the pavement, possibly requiring repair as the left two lanes have undergone. Longer lasting pavements are just one product of an AQS.

innovative tools that can positively impact quality such that FHWA can begin promoting them within an integrated system concept.

A description of an AQS, as it might eventually be recommended for application in pavement quality management, follows.

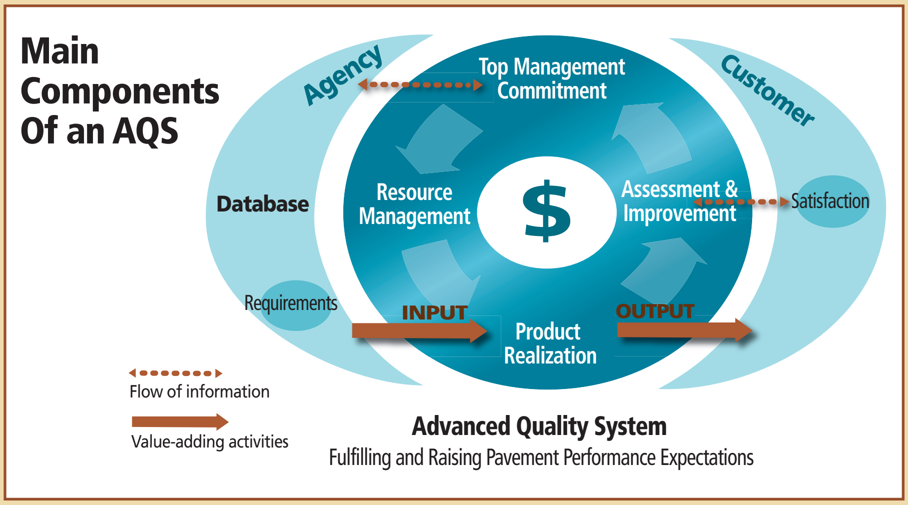
Entities

Customers. To various extents, State DOTs engage stakeholders in the planning phases of transportation projects, but an AQS can help ensure participation by all stakeholders from the beginning, bringing greater efficiency to the overall process. An AQS recognizes the different kinds of customers involved with or affected by a highway paving project: road users, who receive the end result of the product realization process (pavement, for example); internal customers, who take part in the product realization (DOT and contractor personnel); and interested parties or stakeholders (legislators, professional organizations, Federal agencies, State Governments, and more). All these customers have stakes in the end result, and transportation agencies take their requirements into account.

Agency. In an AQS, the transportation agency captures the requirements of all customers in the system and puts them in the form of specifications that communicate to the contractor the level of quality that the pavement's characteristics must have. The agency ensures that the requirements are congruent with the skills of the personnel constructing the pavement. Under an AQS approach, specifications are more comprehensive than is typical, and the agency periodically evaluates the effectiveness of its quality management system in achieving the product and the system's quality objectives, and maintains communication with customers and stakeholders.

Resources and Tools

Database. The construction-quality database is the most important decisionmaking tool within an AQS. The database is not a stand-alone tool but rather is made up of integrated databases (containing data on design, construction, quality testing, cost, condition surveys, and maintenance) with common referencing capabilities and wide accessibility



An AQS ties together activities associated with top management commitment, resource management, product realization, and assessment and improvement. This approach enables an agency to make cost-effective, data-based decisions with the customer in mind. *Source: FHWA.*

to facilitate real-time monitoring of field operations.

Through this integrated database, a DOT can, for example, establish the targets and standard deviations needed to develop specifications,

AQS Elements and Associated Activities

Top Management Commitment

- Identification of customer requirements for the pavement
- Definition of quality and system objectives, quality policy, and the quality plan
- Verification that responsibilities and authorities are defined and communicated throughout the organization
- Verification that improvements are made and actions taken to prevent nonconformities

Resource Management

- Provision of resources (personnel, infrastructure, funds)
- Assignment of personnel
- Verification and development of skills and competencies
- Training
- Assessment of training effectiveness

Product Realization

- Project planning
- Design
- Design verification
- Design adjustment
- Construction
- Construction process control
- Acceptance of constructed product

Assessment and Improvement

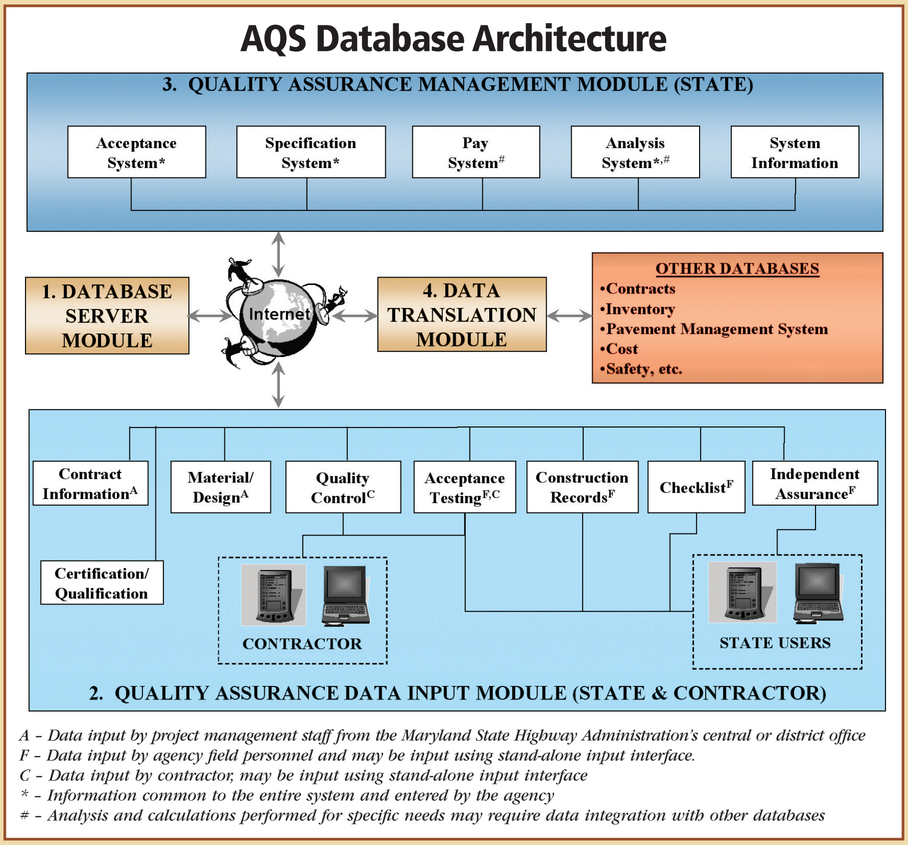
- Monitoring of performance (system and product)
- Assessment and analysis of system and product effectiveness
- Development of improvement plans

trace the costs associated with particular specifications, and verify or revise performance prediction equations. An agency also can use the database to conduct risk analyses for assessing warranty specifications and to evaluate the effectiveness of its AQS. In general, an agency with a well-designed database can perform these and other analyses to help make data-based decisions that gradually improve every AQS element or activity and thereby continuously improve quality.

Funds. Monetary resources are central to an AQS, as they constrain the scope of actions an agency can take for continuous improvement of the system. An AQS underscores the cost of pavement quality and reminds agency officials that they need to make decisions throughout a project's life cycle to ensure delivery of a cost-effective product.

Personnel. Transportation agency and contractor personnel are a key element of the system because through their skills they add value to the chain of processes and activities that lead to the final product.

Infrastructure. More than in standard approaches, an AQS emphasizes the importance of infrastructure—buildings, workspace and associated utilities, process equipment (both hardware and software), and supporting services such as transportation and communications. Modern equipment is key to precise and timely completion of projects, and to maximization of quality.



A well-designed AQS database might consist of four modules: (1) a database server model, which stores system data and connects to the other modules through the Internet; (2) a QA data input module, which provides an interface to record all relevant information on each construction project; (3) a QA management module, which uses data input to analyze construction quality; and (4) a data translation module, which serves as a communication channel with other database systems. *Source: FHWA.*

Top Management Commitment

In an AQS, top management identifies the customer requirements for the pavement, defines quality and system objectives and the organization's quality plan, reviews the effectiveness of the quality system, and assesses customer satisfaction. In addition, managers ensure that staff members from the agency and contractor take action to prevent nonconformities. They also define responsibilities and authorities, and the communication required throughout the product realization, monitoring, assessment, and improvement processes.

Resource Management

The transportation agency ensures that all personnel performing work that affects pavement quality are competent in terms of education, training, skills, and experience. More specifically, the agency educates in-house and contractor personnel about the relevance and importance of their activities and how they contribute to achieving quality. Agency officials maintain and use updated personnel records and evaluate the effectiveness of the various quality-related actions being taken. An AQS especially prizes expertise—and management's awareness of it—and the database is crucial here as it can indicate the personnel or training needed.

Further, the transportation agency determines and provides the infrastructure needed to achieve the pavement requirements. Under an AQS approach, the agency revisits and redefines the role of quality managers so they can, as in any manufacturing process, influence the production decisions without being constrained by workplace hierarchy. The agency ensures that inspectors on the jobsite know what to look for and how to interpret results to make the best decisions on pay adjustments, including pay decreases, and possible corrective actions. In an AQS, there is less need for a dispute resolution board.

Product Realization

Product realization involves all activities before the project starts up through final acceptance of the pavement.

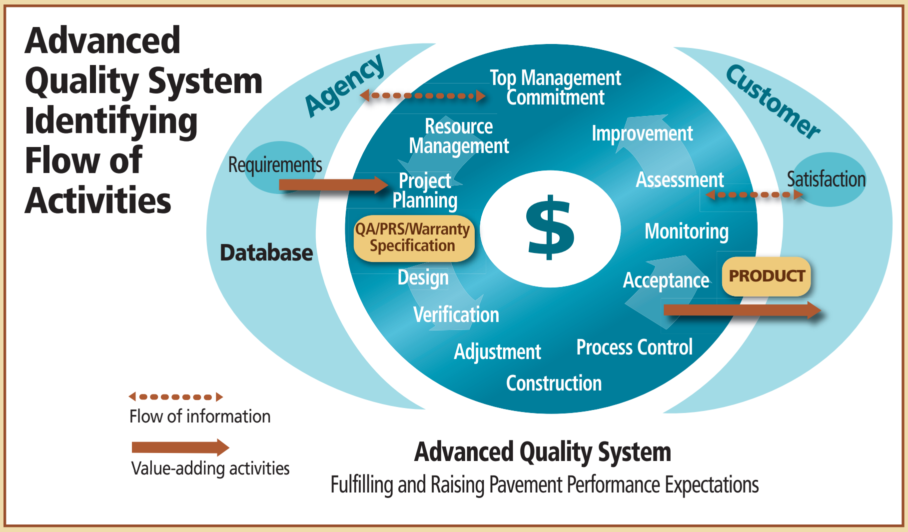
Project planning. During this stage, the transportation agency defines general project requirements that reflect its policies and objectives. The agency might issue requests for proposals at this stage if design is to be a contractor responsibility. Ideally, the level of trust and partnership between the agency and industry are such that public-private partnerships are attractive and feasible.

The transportation agency also uses a formal risk assessment and allocation that ultimately will lead to aligning the entire project team with customer-oriented performance goals. Further, the governing specifications (QA, PRS, warranty) are determined and become part of the contract documents. In an AQS, the agency might employ database analysis tools not necessarily used in standard approaches—such as FHWA's PaveSpec, SpecRisk, and Prob.O.Prof (Probabilistic Optimization for Profit)—to help write rational, fair, and objective specifications.

Design. Either the transportation agency or the contractor carries out this activity according to project requirements. Management assigns responsibilities and coordinates the communication channels between the different groups involved in design.

Designers can perform their duties using several tools. Traditional pavement design software is abundant; however, performance-related design is the state of the art in an AQS. Accordingly, an agency that has an AQS uses mechanistic-empirical pavement design procedures on new construction, rehabilitation, and maintenance to the extent that the agency will incorporate actual construction test results into validated performance models to determine the contractor's pay adjustment for quality.

Because the design and associated drawings and specifications define what the transportation agency wants, they all need to be



An AQS is a closed-loop system of integrated activities, such that any improvement in any one activity will result in a more cost-effective product and/or greater customer satisfaction. *Source: FHWA.*

consistent. Especially important: The design assumptions used to specify the quality of constructed pavement and predict its performance must be consistent with the quality and performance requirements called for in the specifications.

Verification. The transportation agency or the contractor verifies the design inputs, outputs, and underlying assumptions, including their compliance with input requirements. This process currently is inconsistent, with mixed results, but an AQS can bring precision and consistency by careful verification, which includes performing alternative calculations, comparing new designs with similar proven ones, or undertaking tests and demonstrations. The agency identifies potential problems and proposes solutions. Validation—confirming soundness and thus indicating official sanction—might be part of this process in case the methods and assumptions used are new to the design review and verification team and/or have not been proved elsewhere. The transportation agency maintains records of reviews and verifications.

The designer can use several newly available tools for design verification as well. For instance, High Performance Concrete Paving (HIPERPAV®) software enables a designer (structural design or mix design) to estimate the effect that the design parameters will have on behavior of a pavement under certain environmental, construction, and materials conditions. The conditions become "What if?" scenarios that allow for design optimization.

Adjustment. The transportation agency or the contractor might recommend design changes as a result of design review and verification. Once the changes are made, the agency reviews, verifies, and validates them as appropriate and approves them before implementation. This review includes evaluation of the effect of the changes on the product already delivered (that is, pavement already laid). The agency maintains organized records of changes and any necessary actions. The AQS approach considers and more readily incorporates adjustments that benefit both parties, such as those that improve constructability without compromising performance.

Construction. During this stage, the transportation agency or a contractor performs the actual pavement construction, rehabilitation, or maintenance. A construction QA system is in place, and the level of detail of its related activities is defined depending on the type of governing specification (QA, PRS, warranty).

More than in current practices, AQS approaches use statistically sound and valid specifications that deliver the product quality and performance the DOT wants. Performance specifications (QA, PRS, warranty) are more common than method specifications in AQS approaches.

In an AQS, the agency or contractor pays close attention to detail in preconstruction planning and deployment of the paving operation, and the contractor deploys better equipment and more skilled labor as necessary to achieve the specified goals for quality. Ideally, equipment is mostly automated for highway construction operations, and the builder employs faster construction techniques to minimize traffic disruption.

Process control. Process control refers to the QA actions and considerations necessary to assess and adjust production and construction processes to control the level of quality in the pavement. In an AQS, this is a contractor activity since the contractor is the one capable of modifying its own processes.

Work instructions, use of suitable equipment, use of monitoring and measuring devices, implementation of monitoring and measurement, control of nonconforming product, and release (approval) of conforming product are contained in a quality control (QC) plan. As part of its QC process, the contractor identifies the product status in terms of monitoring, measurement, and acceptance. The controls and related responsibilities and authorities for dealing with nonconforming product are part of the QC plan.

In an AQS, the transportation agency aids in process control by defining criteria for review and approval of the processes, approval of equipment and qualification of personnel, use of specific methods and procedures when they apply, record-keeping protocols, and verification/validation procedures. In addition, during periodic construction quality audits, the agency ensures that any product that does not conform to requirements is identified and corrected to prevent its unintended use or delivery.

A number of tools are available for process control, including preprocess control, that enable contractors to plan their operations by simulating construction scenarios and their effects on pavement behavior. These tools include enhanced HIPERPAV, the Concrete Mixture Performance Analysis System (COMPASS), and Prob.O.Prof software. In an AQS, the contractor also uses statistical process control tools, and the contractor and the

Construction of the pavement, as shown here on this concrete paving project, is the midpoint in an AQS, preceded by planning/design and followed by monitoring and making improvements for future applications.

transportation agency, or an independent party (such as a commercial testing laboratory), use high-speed testing devices to measure quality continuously in the field in a timely fashion through nondestructive techniques, and the results of measurements are reported in real time.

Acceptance. This QA activity consists of sampling and testing, or inspection, to determine the degree of compliance with contract requirements. In QA and PRS projects, the transportation agency monitors and measures the quality characteristics of the pavement at appropriate stages of the product realization process to verify that requirements were met. If the contractor's test results are used for acceptance, the agency validates them by conducting its own tests (at a lesser frequency) and then performing statistical hypothesis tests (t-test to compare the means and f-test to compare the variances). In an AQS, validation becomes less and less necessary because the systems approach (which leads to improvements in quality-related activities such as construction equipment development, construction process control, and technician training) makes construction so precise that there is less need to measure and confirm project features.

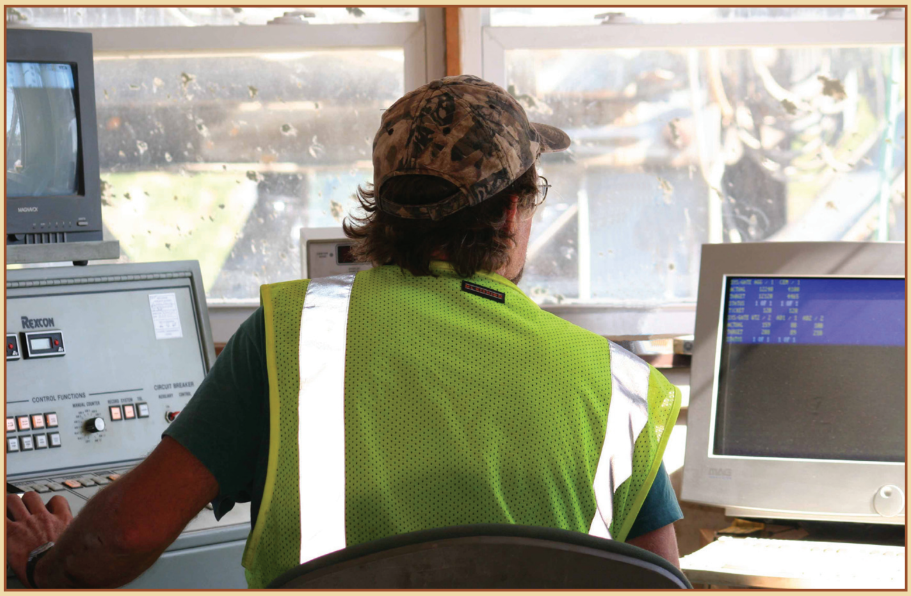
"At least for pavements, knowing how the pavement was constructed—air voids, binder content, density, and so on—can provide insight on how the pavement performs, or for that matter, why it may not have performed as expected," says WSDOT's Pierce. "Having this knowledge provides an agency with the ability to make changes as needed to obtain the desirable quality level."

In warranty projects, DOT inspectors periodically determine payment after monitoring of the inservice pavement and at the end of the warranty period. Inspection consists of measuring compliance of the pavement with the condition indicators set in the contract requirements. During construction, the agency performs quality audits of the contractor's process control and quality management system, keeping records of the audits and data generated in case disputes arise.

In summary, the level of testing and degree of involvement by the transportation agency depend on the type of specification governing the contract. However, the agency's purpose is to provide minimal yet sufficient presence and oversight to record evidence of its commitment to quality.

Assessment and Improvement

Monitoring. This project phase extends to monitoring the quality management system. The transportation agency or contractor applies suitable



Process control, as shown here in the control room of an automated concrete batch plant, is a contractor responsibility. Process control records can be of considerable value to both the contractor and the highway agency.

Some FHWA-Developed AQS Tools

Tool	PP	D	V	Ad	C	PC	Ac	M	As	CI	T
Construction Quality Database, www.fhwa.dot.gov/pavement/concrete/pubs/07019/index.cfm www.fhwa.dot.gov/pavement/concrete/pubs/07020	X	X	X	X	X	X	X	X	X	X	
PaveSpec, www.fhwa.dot.gov/pavement/pccp/pavespec/index.cfm	X	X	X	X	X	X	X				
SpecRisk, Available on CD only; contact Peter Kopac at peter.kopac@dot.gov.	X	X	X	X	X	X	X				
Prob.O.Prof, http://dx.doi.org/10.3141/1946-07 Software currently is being upgraded and expanded.	X	X	X	X	X	X	X				
HIPERPAV, www.hiperpav.com/index.php?q=node/155	X	X	X	X	X	X					
COMPASS, www.pccmix.com	X	X	X	X	X	X					
QA Program Effectiveness, http://dx.doi.org/10.3141/1813-20 Methodology is being upgraded and expanded.								X	X	X	
Percent Within Limits: The Quality Measure of Choice (workshop) For information, contact Dennis Dvorak at dennis.dvorak@dot.gov.											X
Basic Pavement Warranty Workshop For information, contact Victor Gallivan at victor.gallivan@dot.gov.											X
SpecRisk Training (FHWA-NHI-134070) Web-based course currently under development. For information, contact Michael Rafalowski at michael.rafalowski@dot.gov.											X

PP = project planning; D = design; V = design verification; Ad = design adjustment; C = construction; PC = construction process control; Ac = construction acceptance; M = monitoring; As = assessment; CI = continuous improvement; T = Training
Source: FHWA.

methods for monitoring the specified characteristics of the product, including efforts to collect pavement management system (PMS) data, when applicable.

In an AQS approach, agencies use feedback loops from their PMSs to monitor performance. Feedback loops are not used optimally in typical projects today. Agency officials often assume, based on design, that a pavement will last 20 years, for example. But such assumptions are often wrong, and the information on the actual condition of a pavement does not get back to the personnel who need it, or to make specification adjustments affecting future projects.

The monitoring methods demonstrate that the processes and the pavement perform as planned. When expectations are not achieved, the agency or contractor takes corrective actions to ensure conformity. The transportation agency maintains records of conformity with the acceptance criteria.

Assessment. Using a feedback loop, an agency determines, collects, and analyzes data to demonstrate the suitability and effectiveness of its quality management system, and to evaluate where continual improvement of the system can be made. At least one potential objective method is available to assist agencies in determining the effectiveness of, and making improvements to, their quality management systems. This method currently is being refined, expanded, and improved/clarified under an FHWA research contract so that the method can have wider application. Other potential data analyses include surveys of customer satisfaction, evaluation of suppliers, and characteristics of and trends in the product realization processes, where opportunities for preventive action are identified.

On the product side, the transportation agency evaluates performance models and examines correlations among quality, cost, and performance to improve its construction specifications. Note that this process, as well as the previous one, addresses both the pavement and the agency's capability to deliver a quality product.

By conducting self-assessments, the transportation agency can review its activities and results systematically, thus identifying areas requiring improvement and determining priorities.

Continuous improvement. In an AQS, the agency continuously improves the effectiveness of the quality management system and its products through corrective and preventive actions and top management review. The agency takes action to eliminate the causes of nonconformities and prevent recurrence. The agency has procedures to review nonconformities (including customer complaints), determines the causes of nonconformities, evaluates the need for action to ensure that nonconformities do not recur, determines and implements actions needed, and reviews the corrective actions taken. In this manner, the foundation is set for systematic improvement in pavement performance that counts on specifications based on objective information and a commitment to exceeding customer expectations.

The Future of AQSs

New and evolving industry roles that come with adoption of innovative specifications and alternative project delivery methods are changing conventional practices employed by agencies to define, assess, and improve pavement quality. An AQS built

Highway paving projects such as this one in eastern Washington State can be completed faster through an AQS, partly by ensuring that all stakeholders are involved in the early stages.

WSDOT

on ISO 9000 principles can help a transportation agency maximize its resources within a comprehensive quality management plan that integrates value-adding activities to fulfill and raise customer expectations.

Probably the most important improvement an agency can make is to adopt a comprehensive, integrated construction-quality database that allows analysis of design, quality, time, cost, and performance. This kind of database can address funding constraints with analyses to establish the optimal target quality level—the level that provides the best balance between product performance and cost. Also, such a database can provide accurate feedback (both immediate and long term) so top managers and designers can make the necessary refinements in quality-related policies, objectives, and targets.

"Quality management programs make it possible to improve pavement performance and drastically reduce construction and rehabilitation costs," says TxDOT's Haggerty.

FHWA is working to expand these benefits across the Nation. For instance, the agency provides numerous software tools to assist DOTs and contractors with some of the activities that comprise an AQS. The agency already offers rapid, nondestructive testing procedures, such as the Magnetic Imaging Tools (MIT) Scan-2 dowel bar locator and the impact-echo device for measuring slab thickness, to improve process control and acceptance activities. More such developments and new applications of existing technologies are needed, and FHWA is active on these fronts. To assist DOTs in keeping up with new developments and assure proper implementation, FHWA has in recent years offered a number of courses and workshops that deal with individual aspects of AQS.

Alberto Miron is a civil engineer currently managing bid design efforts for highway concession projects in North America for worldwide infrastructure developer Grupo Ferrovial. He previously worked for The Transtec Group, Inc., where he focused on concrete pavement quality and performance and conducted pavement design and assessment of toll road projects. His practical experience in quality management spans implementation of an ISO 9000 quality management system for El Salvador's highway trust fund, field experience that includes highway construction QC/QA, development of a quality database, and development of the first statistics-based pay adjustment factors for highway construction QA specifications in El Salvador.

Richard B. Rogers has been with The Transtec Group, Inc., since 2004. Prior to that, he worked for the Texas Department of Transportation for 25 years. He has performed a variety of supervisory and technical responsibilities in areas such as pavement design, management, and testing and evaluation; specification development; and data collection and analysis.

Peter A. Kopac is a senior research highway engineer on the Pavement Design and Performance Modeling Team in FHWA's Office of Infrastructure Research and Development. He has almost 40 years of highway-related experience, including 31 years with FHWA. His primary research focus has been on QA systems. He has assisted numerous agencies in developing, reviewing, and analyzing their QA programs. He is also an active member of the Transportation Research Board's Committee AFH20, Management of Quality Assurance.

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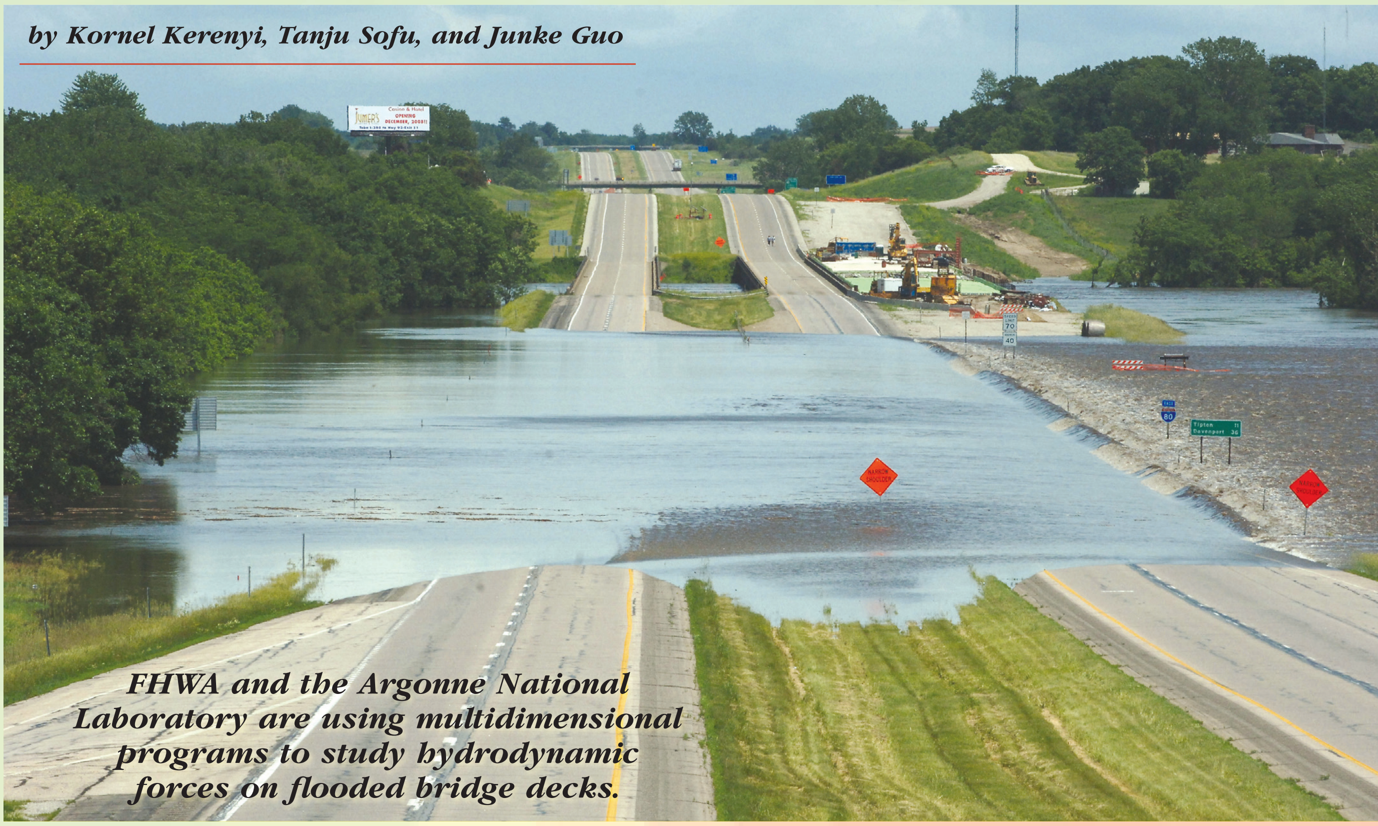
Using Supercomputers to Determine Bridge Loads

by Kornel Kerenyi, Tanju Sofu, and Junke Guo



(Above) Computer modeling can enable engineers to design bridges that are sturdier against floodwaters. This section of I–80 in Iowa was inundated after heavy rains in June 2008, perhaps relieving pressure on the Cedar River bridges in the background. *Photo: Keven Arrowsmith, Iowa Department of Transportation.*

FHWA and the Argonne National Laboratory are using multidimensional programs to study hydrodynamic forces on flooded bridge decks.

Bridges are a vital component of the Nation's transportation network. Evaluating their stability and structural response after flooding is critical to highway safety. When a bridge crossing a waterway is partially or entirely submerged during a flood, the water can exert significant loading on the deck and threaten its integrity. Being able to estimate hydrodynamic loading accurately can help designers and transportation agencies build better, stronger bridges.

Accurately modeling turbulence and sediment transport is essential for estimating the impact of scour on bridges. Researchers typically address problems in science and engineering through two complementary approaches: experimental and analytical (or theoretical). In many applications, such as the fluid mechanics of streams and the impacts on bridges, the governing equations are nonlinear and, except in special circumstances, analytical solutions are not available. In addition, fluid mechanics applications often are multidimensional in nature and time-dependent, which further complicates attempts to understand and model real-life turbulence and scour conditions.

Pursuing a third approach, researchers at the Federal Highway Administration (FHWA) and the new Transportation Research and Analysis Computing Center (TRACC) in West Chicago, IL, a partnership of the U.S. Department of Transportation (USDOT) and the Argonne National Laboratory, are using supercomputers with multidimensional hydraulics programs to closely mimic real-life conditions. The researchers verify the computers' output using flume models at FHWA's Turner-Fairbank Highway Research Center (TFHRC) in McLean, VA, indicating that computers might play an even more valuable role in bridge hydraulics and safety.

"As computer technology improves and the ability to accurately model turbulence and sediment transport becomes more robust, transportation agencies will benefit in both the planning and design of bridges through improved hydraulic and scour estimation," says Kevin Flora, hydraulics branch chief for structure maintenance and investigation at the California Department of Transportation (Caltrans).

The Third Approach

Effective use of prototypic experiments is a key approach to understanding real-life phenomena. For many fluid dynamics applications, such as those associated with bridge hydraulics, full-scale tests are not possible. Researchers use smaller scale, and perhaps simplified, representations of the physical configuration, and they extrapolate the results to apply to actual conditions. Some uncertainty remains in this extrapolation, however, related to the use of simplified experiments to predict the behavior of complex physical systems.

Computational fluid dynamics (CFD) attempts to address these issues and complement the experimental and analytical approaches through numerical solutions. CFD is a branch of fluid mechanics that uses numerical methods and algorithms to analyze and solve problems involving fluid flows, such as water. Researchers use computers to perform the millions of calculations necessary to simulate the interaction of fluids with the complex surfaces involved in engineering. CFD enables scientists and engineers to perform numerical simulations in the laboratory and significantly reduce the amount of experimentation and overall cost. CFD is a highly interdisciplinary research area at the interface of physics, applied mathematics, and computer science.

CFD calculations are numerical solutions to the underlying equations that represent the flow of fluids. As a result, a computational grid—focusing many computers in a network on a single problem—can approximate the true geometry of a given physical condition. In the CFD approach, researchers can include actual observed boundary conditions that might be impossible to represent in a laboratory experiment and perform parametric studies on material properties and physical conditions that might be expensive or time-consuming to perform experimentally.

Although CFD can complement laboratory experiments and theoretical approaches, generating accurate numerical solutions requires establishing fine-mesh computational grids to represent the actual geometry of the problem. Also, in time-dependent cases, the accuracy and numerical stability of the solutions often require small time steps to capture the influence of temporal variations in the flow field.

Computing solutions on these grids can require many calculations, so the use of computers is essential. Development of powerful supercomputers, including massively parallel computers (which contain hundreds of processors sharing a common hardware platform), and adaptation of the CFD techniques for use with these supercomputers in recent years is enabling engineers and scientists to perform these complex CFD calculations.

"By comparing the computed results to some experimental information or to analytical solutions under simplified conditions, analysts can verify and validate the numerical approach," explains TRACC Director David P. Weber. "With verified and validated results, analysts can then feel much more confident in performing calculations on more complex representations of the true physical conditions. Thus, the three approaches of experiment, analysis, and computation are complementary."

Establishing TRACC

The Argonne National Laboratory is leading the initiative to establish a high-performance computing center, TRACC, to pursue transportation research and development (R&D) programs. Argonne analysts provide technical support to researchers at TFHRC on CFD simulations.

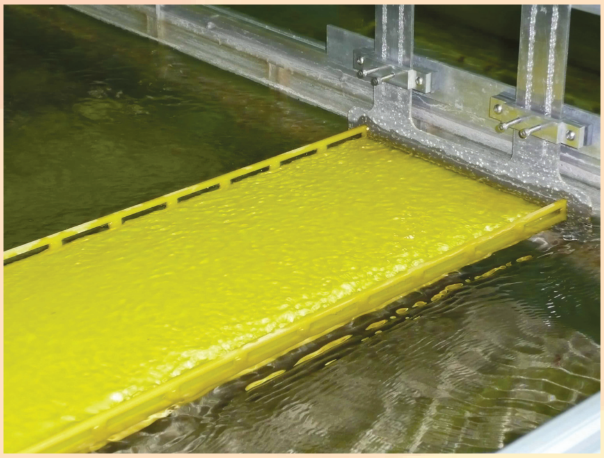
The overall objective of this effort is to establish validated computational practices to address the transportation community's research needs in bridge hydraulics. Traditionally, the bridge hydraulics work relies on scaled experiments to provide measurements for flow field, which is the velocity and turbulence of a fluid as functions of position and time. Now, however, parallel computers and commercially available software provide an opportunity to shift the focus of these evaluations to the CFD domain. After being validated using the data from a limited set of experiments, high-fidelity CFD simulations can be used to expand the range and scope of parametric studies. The CFD simulations also can be used to predict the effects of scaling by studying differences between the reduced-scale experiments and full-scale bridges.

Most recently, reduced-scale experiments conducted at TFHRC's J. Sterling Jones Hydraulics Research Laboratory established the foundations of a CFD-based simulation methodology. Researchers at Argonne and TFHRC worked together to study CFD techniques for simulating open-channel flow around inundated bridges.

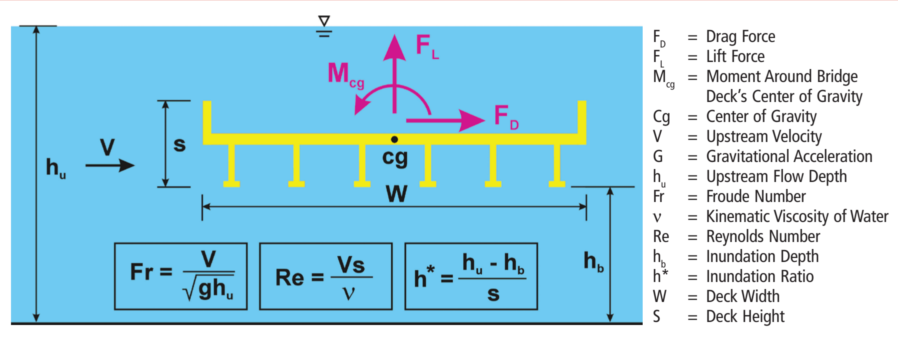
"The use of supercomputers and CFD code can potentially overcome the inherent problems of modeling sediment in the laboratory," says Flora. "Once physically based models of sediment transport and scour are developed, computer simulations will provide engineers with new insights into better design and mitigate for scour at structures."

Research Considerations

The Argonne-TFHRC research included analysis of lift forces (F_L) (or simply lift), forces produced perpendicular to the flow of a fluid; drag forces (F_D), forces exerted on objects in the path of fluids; and moments (M), the tendency to cause rotation about a point or axis, on inundated bridge decks under various flow configurations. The two research teams investigated the applicability of commercial CFD software for predicting flow field and evaluating lift, drag forces, and moments. They compared the results with laboratory data using an ultraprecise force balance (which is



This photo shows an experimental model of a typical U.S. highway bridge deck partially inundated in a tilting flume at FHWA's J. Sterling Jones Hydraulics Research Laboratory.



This definition sketch shows a cross section of the model six-girder bridge deck tested during the study. It defines the direction of the hydrodynamic forces and flow acting on the flooded bridge deck model. The sketch also shows the point of application of forces, that is, where the moments act. The three boxes below the bridge deck define the Froude number, Reynolds number, and the inundation ratio used in the design charts.

a mounting device to measure hydrodynamic forces on scale model bridge decks) to measure lift, drag force, and moments for various inundation ratios and flow rates.

They also used Particle Image Velocimetry (PIV) to study flow fields around submerged model bridge decks. PIV is a noninvasive measurement technique to visualize flow distributions. The technique involves adding microscopically small, highly reflective particles to the flow and using a laser to illuminate a thin layer of the flow, so only the particles in that light sheet reflect the laser's light. Using cameras pointed with different angles toward the light sheet, researchers can capture images and an algorithm based on statistical probability to determine the speed and direction of the moving particles. PIV-related tasks included the following:

- Assessing applicable phenomena for open-channel flow and identifying appropriate models—free surface, two-dimensional (2-D) versus three-dimensional (3-D) to include the effects of channel wall, appropriate flow profile at the inlet, and roughness at the bottom surface
- Studying the sensitivity of the CFD solutions to the grid structure and mesh density (number of computational cells per unit area)
- Identifying the most suitable turbulence model in terms of accuracy and computational requirements

The researchers also adopted numerical simulations using two turbulence models, high-Reynolds number k-(epsilon) model and large eddy simulation (LES), to resolve unsteady turbulent flow. Turbulent flow is an irregular condition in which the flow particles show a random variation with time and space coordinates. The k-(epsilon) model simulates transport of both the turbulent kinetic energy (k) and the turbulent energy dissipation rate (epsilon). The rationale for using LES is to simulate the larger and more easily resolvable scales of the motions while accepting that LES will not represent the smaller scales accurately.

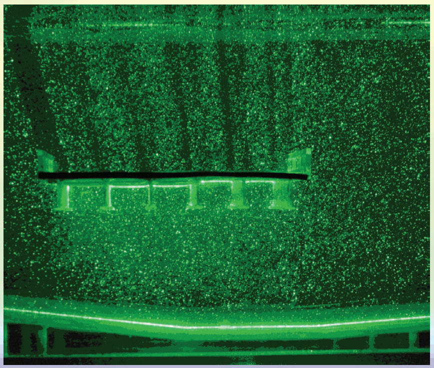
The researchers examined the agreement between experimental data and the results of CFD simulations for a typical U.S. highway girder deck, corresponding to Froude numbers (dimensionless ratio) ranging from 0.12 to 0.40 characterizing the open-channel flow. That is, the Froude number is a ratio comparing inertial and gravitational forces. If the Froude number is less than 1, the flow is subcritical, and if it is greater than 1, the flow is supercritical. The TRACC researchers used STAR-CD (software for modeling fluid dynamics), while the TFHRC team used Fluent, Inc. CFD software in their simulations.

The researchers integrated forces and moments over the surface of the bridge deck along the flow and perpendicular directions, respectively. When calculating the lift over the bridge deck, however, they excluded the component of buoyancy, as they were interested only in hydrodynamic loading, not static loading.

Advances in CFD research provide the basis for modeling the multiphase nature of open-channel flow that consists of air and water separated by a free surface. In multiphase flows, each phase has individually defined physical properties and flow fields. In both the STAR-CD and Fluent approaches, the researchers had three multiphase flow models available. The first was the volume of fluid (VOF) model, which can model two or more nonmixable fluids by solving a single set of continuum equations and tracking the volume fraction of each of the component fluids throughout the domain. Applications of the VOF model include stratified flows, free-surface flows, filling, sloshing, the motion of large bubbles in a liquid, the motion of liquid after a dam break, the prediction of jet breakup (surface tension), and the steady or transient tracking of any liquid-gas interface.

In the VOF model, in addition to the conservation equation for mass and momentum, one has to introduce the volume fraction of phase in computational cell. In each control volume, the volume fraction of all phases sum to unity. The fields for all flow variables are shared by the phases, as they represent volume-averaged values. Thus, the variables and properties in any given cell are representative of one of the phases, or a mixture of phases, depending upon the volume fraction values.

Second was the mixture model, in which the flow consists of a continuous phase and one or more dispersed phases. Although it is computationally efficient, this Lagrangian approach is suitable only for dispersed flows and cannot be used to accurately resolve the stratified nature of free-surface flows. The third was the Eulerian model, which is a multiphase model in which the phases are treated as interpenetrating continua coexisting in the flow domain. The Eulerian model provides a general framework for both dispersed and stratified multiphase flows. However, the free surface calculated with this approach is usually less sharp in comparison with the VOF method, making the latter the preferred model. Therefore, the researchers are testing the VOF computational method with both STAR-CD and Fluent to capture the impact of free surface reasonably accurately and efficiently.



This photo shows a submerged six-girder bridge deck model using PIV, a nonintrusive method to measure flow velocities, to visualize the flow field around the deck. A powerful laser light illuminates PIV tracer particles, and high-speed cameras track their displacements, which then are converted into velocities.

Experimental Setup At TFHRC

The TFHRC researchers conducted the laboratory experiments using a 12.8-meter (42-foot)-long, 0.4-meter (1.3-foot)-wide, and 0.5-meter (1.6-foot)-high Plexiglas® rectangular flume. They set the flume horizontally and controlled the depth of flow with an automatic adjustable tailgate located at the downstream end. The team used a 0.054-cubic-meter (2.0-cubic-feet)-per-second pumping system to supply the flow. They measured the water surface level using ultrasonic sensors at two cross sections along the flume. An electromagnetic flow meter measured the discharge. They used an Acoustic Doppler Velocimeter probe to measure the velocity distribution (speed of the water) of the flow.

The researchers constructed a six-girder bridge deck shape, which is typical of U.S. highways, using yellow Plexiglas and adopting a geometrical reduction scale of 1:40 based on the depths, maximum discharges (flow rate), and inundations (submergence level) available. This scaled bridge deck is optimal to produce values ranging from low to high flows, all at subcritical Froude numbers (less than 1) in the upstream flow.

To measure forces induced by the bridge deck model in the flow direction (drag) and simultaneously perpendicular to the flow direction (lift) using electric strain gauges, the research team constructed an ultraprecise force balance, which can capture even small forces. They mounted the bridge deck model between brackets attached to a measuring platform. To test different submergence ratios, they mounted the platform and model flexibly to allow vertical positioning of the bridge deck. The flexibility was important to perform testing at various submergence levels of the bridge deck.

They conducted the experiments for water approach velocities ranging from 0.25 to 0.50 meter (0.8 foot to 1.6 feet) per second. They kept the flow depth for all experiments constant at 0.25 meter (0.8 foot). They varied the Froude number within a range of 0.16 to 0.32 and the submergence of the bridge deck from slight submergence of the girders to complete overtopping of the bridge deck, inundation ratio, $h^* = 0.29$ to 3.2.

The force balance experiments used the PIV technique to visualize and measure flow fields for the submerged bridge deck model. The PIV technique is an optical flow diagnostic based on the interaction of light refraction and scattering, using nonhomogeneous media. The fluid motion is made visible by tracking the locations of small tracer particles at two instances of time. The researchers then use the particle displacement as a function of time to infer the velocity flow field. They analyzed the data in a format that could be compared with the CFD modeling.

TRACC Computing Facility

TRACC is a general purpose advanced computing and visualization facility available to the transportation community for a broad spectrum of applications. Discussions among staff at USDOT's Research and Innovative Technology Administration and FHWA identified specific initial applications and technologies for assigning the highest priority for research and development (R&D) and user support.

The TRACC components include high-performance computing, visualization, and networking systems. To take advantage of Argonne's extensive experience in acquiring and operating similar facilities, TRACC acquired the system components and then set them up in dedicated facilities at the DuPage National Technology Park near the DuPage Airport in Illinois.

The TRACC computational cluster is a 512-core, customized LS-1 system from Linux Networx that comprises 128 computational nodes, each with two dual-core Advanced Micro Devices, Inc. Opteron™ 2216 central processing units and 4 gigabytes of random access memory; a DataDirect™ Networks storage system consisting of 240 terabytes of shared RAID (Redundant Array of Inexpensive (or Independent) Disks or (Drives)) storage that is expandable to 750 terabytes; a high-bandwidth, low-latency InfiniBand network for internode computations; and a high-bandwidth Gigabit Ethernet management network.

TRACC also provides scientific visualization capabilities through the National Center for Supercomputing Applications' Technology, Research, Education, and Commercialization Center at the same location. TRACC meets the needs for visualization of multidimensional data via a high-performance graphics cluster linked with a 15-panel liquid crystal display (LCD) tiled display and a portal optimized for visual simulation and high-speed broadband connectivity.

Test Results

The researchers conducted the CFD simulations using models of an 8.0-meter (26.2-foot)-long, 0.34-meter

Argonne-TRACC

The TRACC parallel computing system, shown here, provided researchers the visualization capabilities necessary for their experiments. The TRACC computational cluster consists of a 512-core, customized LS-1 system from Linux Networx.

Defining the Terms

As customary, the measured and calculated drag, lift, and moments often are expressed in terms of dimensionless drag, lift, and moment coefficients. Depending on the value of upstream water level, h_u, the drag coefficient, C_D, is defined as

$$C_D = \frac{F_D}{0.5 \times \rho \times V^2 \times s \times L}; \text{ for } h^* > 1 \text{ where } h^* = \frac{h_u - h_b}{s} \quad (1)$$

$$C_D = \frac{F_D}{0.5 \times \rho \times V^2 \times s \times L \times h^*}; \text{ for } h^* < 1 \quad (2)$$

the lift coefficient C_L is defined as

$$C_L = \frac{F_L}{0.5 \times \rho \times V^2 \times W \times L}; \quad (3)$$

and the moment coefficient C_M is defined as

$$C_M = \frac{M}{0.5 \times \rho \times V^2 \times W^2 \times L}. \quad (4)$$

All variables used in the equations above are defined in the following table:

Drag Force	F_D
Lift Force	F_L
Moment	M
Drag Force Coefficient	C_D
Lift Force Coefficient	C_L
Moment Coefficient	C_M
Density of Fluid	ρ
Upstream Velocity	V
Gravitational Acceleration	G
Upstream Flow Depth	h_u
Froude Number	Fr
Inundation Depth	h_b
Inundation Ratio	h*
Deck Width	W
Deck Height	S
Deck Length	L

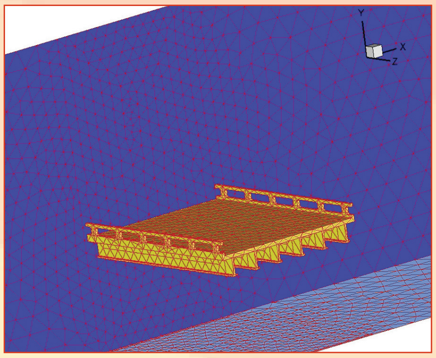
(1.1-foot)-wide, 0.5-meter (1.6-foot)-high rectangular channel. The study simulated both 2-D and 3-D models. The researchers placed the bridge deck 4.4 meters (14.4 feet) downstream of the inlet of the channel to obtain a fully developed flow upstream. They situated the outlet far away from the deck to avoid the influence of the outlet boundary on the flow field around it. The team conducted the simulations using Fluent and STAR-CD for approach velocities ranging from 0.25 meter (0.8 foot) to 0.50 meter (1.6 feet) per second. The Froude number varied within the range of 0.16 to 0.32, and the team ran the simulations for various inundation ratios. The researchers modeled the flow domain using either tetrahedral cells (in Fluent) or hexahedral cells (in STAR-CD), both with gradually refined mesh structure in the vicinity of the bridge deck. (The gradual refinement of mesh in the vicinity of the deck reduced computational time. If the researchers had refined the mesh in the complete domain, it would have increased the number of cells, which would require more computational time.)

This computer visualization shows the meshed geometry of the 3-D bridge deck for the CFD model in Fluent. The bridge deck is in yellow/brown. The portion of the flume wall behind the deck is in dark blue, and the portion below it is in light blue. Both portions are cross-hatched in black lines to indicate the triangular mesh placed in the flow domain, with the lines and triangles denser for the more detailed flow field investigation close to the bridge deck.

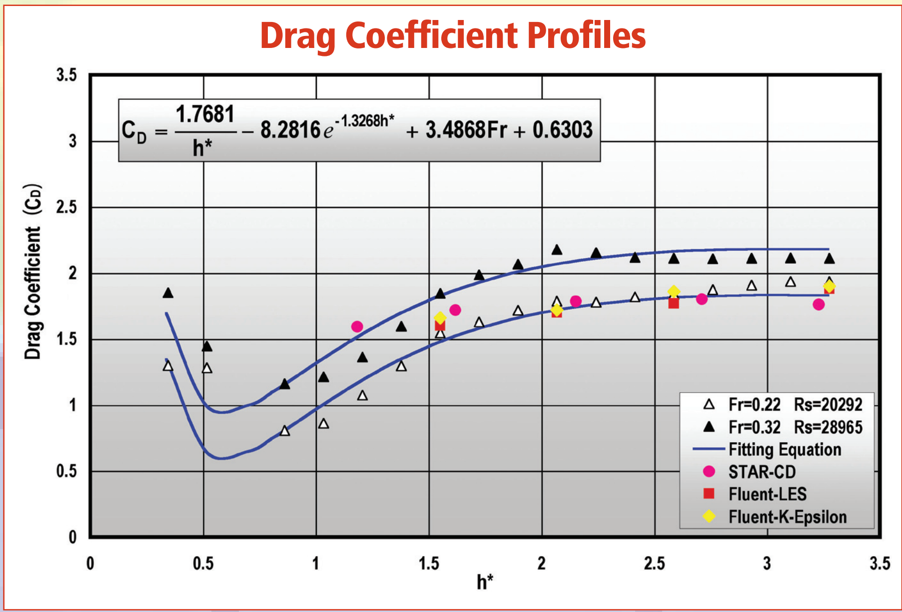
The team presented the experimental and simulation results in dimensionless form for various Froude numbers (which characterize the open-channel flow) and the inundation ratio (which characterizes the flooding height). They presented the measured and simulated forces and moments in terms of dimensionless coefficients as drag, lift, and moment coefficients. They performed the Fluent simulations for 200 seconds using LES as well as the k-(epsilon) turbulence model. Due to fluctuating values of C_D (drag force coefficient), C_L (lift force coefficient), and C_M (moment coefficient) with time, they averaged the final values from 50 to 200 seconds. They checked the velocity distribution along the depth of flow at various locations upstream of the bridge deck, and profiles clearly showed that fully developed flow occurs upstream of the bridge deck.

The experimental data can be compared with the Fluent and STAR-CD simulation results for the drag coefficient as a function of dimensionless inundation ratio, h*, and Froude number, Fr, which characterizes the flow rate. The simulated drag coefficient using Fluent increases as the inundation ratio increases from 1.0 to 1.5, and then tends to level off for the inundated bridge deck. In other words, increasing the water level over the submerged bridge causes C_D to reach its maximum and then stay constant, similar to what the researchers observed in the experiments. Although the simulated data using STAR-CD are slightly above those observed from Fluent, they are generally compatible with each other. In practice, an empirical equation can be used to estimate C_D, including the effects of the inundation ratio and Froude number.

The researchers also looked at the variation of lift coefficient values, C_L,



Argonne-TRACC



The graph shows experimentally determined and computer simulated drag coefficients versus inundation ratio for the six-girder bridge deck model. One blue line roughly tracks with the Froude Number 0.22, Reynolds Number 20292 data points (hollow triangles), and the other roughly tracks with the Froude Number 0.32 and Reynolds Number 28965 data points (black triangles). The plot shows that the drag coefficient is constant for higher inundation ratios. *Source: FHWA.*

versus inundation ratio using Fluent and STAR-CD simulation results along with the experimental data. Like the experiments, the component of buoyancy is excluded from the lift forces calculated with the CFD models. Both the simulated and experimental lift coefficients come out to be negative, indicating that the net hydrodynamic force is directed downward. The lift coefficient value decreases as the inundation ratio decreases (that is, it gets more negative) until h* = 1.0. The maximum (negative) value of C_L is observed between h* = 0.5 and 1.0. Like the drag coefficient, when inundation is very large, the effect of free surface diminishes and C_L tends to a constant. This means that when the bridge deck is immersed well below the water level, the net lift force on the bridge deck does not change.

The researchers also compared the moment results of the drag and lift forces for the simulation data and experimental data. Again, the simulated results from Fluent and STAR-CD were close to the experimental results.

The research team conducted the PIV experiments in a special flume using transparent Plexiglas models. The PIV flow field analysis was necessary to calibrate the CFD models. The researchers observed strong agreement between computer simulation and PIV experiments; comparison of the contracted flow fields under the bridge deck especially showed excellent conformity.

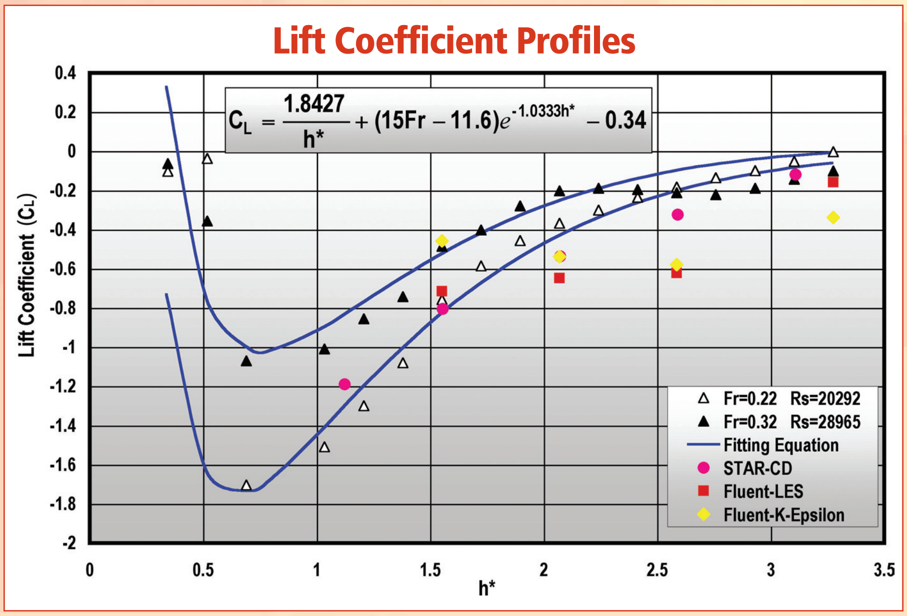
Significant Findings

The k-(epsilon) turbulence model and LES together with the VOF method simulates faithfully the flow past the bridge deck in an open channel. The predictions of drag, lift, and moment coefficients through the numerical modeling show a trend similar to the flume experimental results. Future bridge designers can use the numerical CFD model without much effort to obtain the coefficients on a bridge deck in an open channel for various flow conditions encountered in practice. The Argonne and FHWA researchers are undertaking additional simulations for other shapes of bridge decks to predict the drag, lift, and moments with the help of CFD.

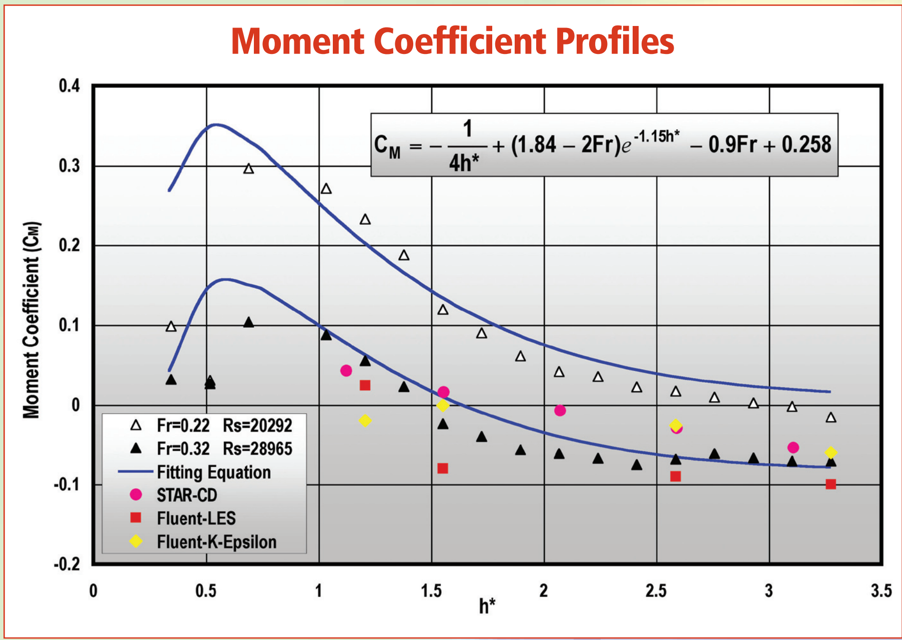
"The validation of the computer modeling gives confidence in the results from computer program analysis of complex hydraulics structures without using physical models," says Michael Fazio, deputy director of research and innovation at the Utah Department of Transportation. "This is a great advancement for hydraulics research."

FHWA's future strategic plan for hydraulics R&D proposes to move away gradually from physical experiments and use more CFD modeling to develop design guidance for practitioners. This successful collaboration between Argonne and FHWA's hydraulics R&D program is the first step toward that vision.

"The use of CFD software on high-speed computers will undoubtedly



The graph shows experimentally determined and computer simulated lift coefficients versus inundation ratio for the six-girder bridge deck model. The lift coefficient is negative for all tested inundation ratios. This observation corresponds to a down-pull force. *Source: FHWA.*



The graph shows experimentally determined and computer simulated moment coefficients versus inundation ratio for the six-girder bridge deck model. The moment coefficients have a maximum when the girders of the bridge deck are inundated. *Source: FHWA.*

play an increasingly important role in the future for understanding scour potential at bridges," says Caltrans's Flora. "Rapid development of various bridge scenarios will be much easier through numeric simulation on supercomputers than through physical modeling in the lab."

Kornel Kerenyi is a hydraulic research program manager in FHWA's Office of Infrastructure R&D. He coordinates FHWA's hydraulic and hydrology research activities with State and local agencies, academia, and various partners and customers, and he manages the Hydraulics Laboratory. He was previously a research engineer for GKY & Associates, Inc. and supervised the support staff in the data collection and analysis for this study. Kerenyi holds a doctorate in fluid mechanics and hydraulic steel structures from the Vienna University of Technology in Austria.

Tanju Sofu manages the Engineering Simulation and Safety Analysis section in the Engineering Analysis Department at Argonne. He specializes in large-scale computational physics and fluid dynamics simulations on high-performance computing platforms and has extensive experience with a wide range of engineering systems analyses involving multidimensional, multiscale, multiphysics phenomena. Sofu holds a doctorate from The University of Tennessee Knoxville.

Junke Guo is an assistant professor in the department of Civil Engineering at the Peter Kiewit Institute at the University of Nebraska-Omaha. He received his doctorate in fluid mechanics and hydraulics from Colorado State University. His research interests include CFD, turbulent boundary layer flows, open-channel turbulence and sediment transport, and environmental fluid mechanics. His current research emphasizes CFD applications in transportation-related flows.

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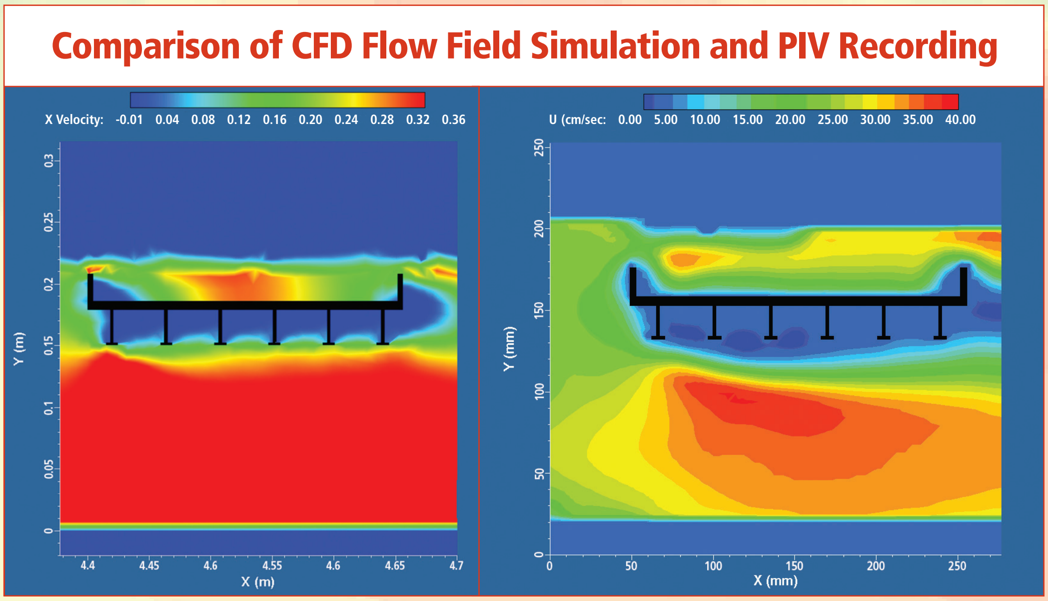


Shown here are the velocity contour plots for the six-girder bridge deck using Fluent CFD code (left) and PIV technology (right). The red area below the bridge deck indicates higher flow velocities, green represents intermediate velocities, and blue indicates areas with negative velocities. The blue region between the girders shows negative velocities where the water is trapped under the bridge deck and the water is flowing backward. The higher velocities are mostly below the bridge deck due to the higher turbulence level, while the regions away from the deck show intermediate velocities due to lower turbulence levels. The negative velocities indicate that the water is flowing in a circular motion creating underpressure between the girders. The underpressure system creates turning moments that are dangerous to the bridge deck. *Source: Argonne-TRACC, FHWA.*

Along the Road

Along the Road is the place to look for information about current and upcoming activities, developments, trends, and items of general interest to the highway community. This information comes from U.S. Department of Transportation (USDOT) sources unless otherwise indicated. Your suggestions and input are welcome. Let's meet along the road.

Policy and Legislation

GAO Reports Progress in Implementing SAFETEA-LU Planning, Environmental Provisions

According to a recent report by the U.S. Government Accountability Office (GAO), some State transportation agencies have shown progress in implementing the streamlined planning and environmental review processes enacted under the Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (SAFETEA-LU). The report, *Highways and Environment: Transportation Agencies Are Acting to Involve Others in Planning and Environmental Decisions*, concludes that it will take several years to determine the full impact of the changes.

The changes facilitate more efficient reviews of transportation projects, allowing them to be completed more quickly without diminishing environmental protections. For example, SAFETEA-LU requires that State departments of transportation (DOTs) and metropolitan planning organizations (MPOs) consult with Federal and State resource agencies when developing long-range transportation plans.

The report focuses on six States and six MPOs selected based on geographic diversity and their varying levels of experience with implementing the new requirements. According to the Federal Highway Administration (FHWA), four of these agencies (two DOTs and two MPOs) have issued long-range plans that comply with the post-SAFETEA-LU planning requirements. The others expect to do so by 2010, in line with their planning cycles.

Researchers gathered data for the report through interviews with Federal, State, and local agency officials responsible for implementing the SAFETEA-LU changes within those States.

To view the report, visit www.gao.gov/new.items/d08512r.pdf.

GAO

Management and Administration

California Kicks Off National Work Zone Awareness Month

In April 2008, the California Department of Transportation (Caltrans) kicked off National Work Zone Awareness Month with a ceremony honoring the 170 Caltrans employees who died in the line of duty since 1924, including three who died in 2007. The ceremony marked the first time that the national event has taken place outside Washington, DC.

As part of this year's event, transportation agencies across the United States are adopting the Caltrans campaign slogan, "Slow for the Cone Zone." The goal is to encourage motorists to slow down when driving in work zones.

The ceremony featured a temporary memorial of 170 orange safety cones arranged into a 13-meter (45-foot)-wide caution sign to signify the ultimate sacrifice made by each fallen Caltrans worker. The event also included a ceremonial dove release and wreath dedication performed by the Caltrans Honor Guard.

Transportation experts and leaders from Federal and State government and industry attended the ceremony. Sponsors included FHWA, the American Traffic Safety Services Association, the American Association of State Highway and Transportation Officials (AASHTO), the American Road & Transportation Builders Association, the Associated General Contractors of America, and the District of Columbia, Maryland, and Virginia DOTs.

Caltrans

Technical News

FHWA Manual on SPMTs Now Available

FHWA, AASHTO, the Transportation Research Board's (TRB) National Cooperative Highway Research Program, and the Florida Department of Transportation recently completed a *Manual on Use of Self-Propelled Modular Transporters to Remove and Replace Bridges* (FHWA-HIF-07-022).

The top recommendation from a 2004 international scan tour on prefabricated bridge elements and systems was adoption of self-propelled modular transporters (SPMTs) for use in moving bridges and bridge components. SPMTs are computer-controlled platform vehicles weighing up to several thousand tons that can move bridge systems with precision to within a fraction of an inch. The prefabrication of bridges offsite under controlled conditions followed by rapid installation onsite can achieve quality installations with traffic impacts of minutes to a few hours compared to the months typically required for conventional onsite construction.

The manual, now available on the FHWA Web site, contains information on the equipment, benefits, costs, project selection criteria, planning, design, contracting issues, and sample contract documents for using SPMTs. The document also includes case studies and lessons learned from previous projects. Bridge owners, construction contractors, suppliers, and other professionals involved in bridge design and construction can use the manual to plan and execute projects using SPMTs to remove or install bridges.

Using this manual in combination with the FHWA decisionmaking framework and analysis of delay-related user costs should provide the guidance that bridge owners and other bridge professionals need to understand the technology, determine whether using SPMTs will benefit a specific project, and develop contract documents that incorporate the technology.

To view the manual, visit www.fhwa.dot.gov/bridge/pubs/07022/hif07022.pdf.

UMTRI

Researchers at the University of Michigan Transportation Research Institute (UMTRI) outfitted these 11 identical sedans with road departure crash warning systems for use in a field operational test.

NHTSA Releases Report on Warning System For Road Departure Crashes

More than 1.2 million road departure crashes occur each year in the United States. Because these crashes often involve rollovers or collisions with fixed objects, they can be particularly severe, and statistics show that they account for a high percentage of fatal crashes. The Volpe National Transportation Systems Center (Volpe Center), in support of the National Highway Traffic Safety Administration (NHTSA), recently completed an independent evaluation of a road departure crash warning system that alerts drivers when they are in danger of departing the road, drifting out of their lanes, or approaching a curve at unsafe speeds. The goal of the study was to determine the safety benefits and driver acceptance of this crash-avoidance system.

Researchers at the University of Michigan outfitted 11 identical sedans with roadway departure crash warning systems and two cameras, extra sensors, and data acquisition systems. The researchers then conducted a field operational test of the system, collecting data from 78 participants who drove more than 130,000 kilometers (80,800 miles) on public roads and completed surveys reporting on their experiences.

The final report, *Evaluation of a Road-Departure Crash Warning System* (DOT HS 810 854), includes a comprehensive analysis of data from the field test and concludes that the system shows positive results in terms of system performance, driver acceptance, and safety benefits.

To access the report, visit www.nhtsa.dot.gov/staticfiles/DOT/NHTSA/NRD/Multimedia/PDFs/Crash%20Avoidance/2007/4638-810_854%20RDCW%20EvalCLTest.pdf.

USDOT and Argonne National Lab Open Research and Computing Center

The USDOT Research and Innovative Technology Administration, in cooperation with the U.S. Department of Energy's Argonne National Laboratory, recently announced the opening of the Transportation Research and Analysis Computing Center (TRACC) in suburban Chicago.

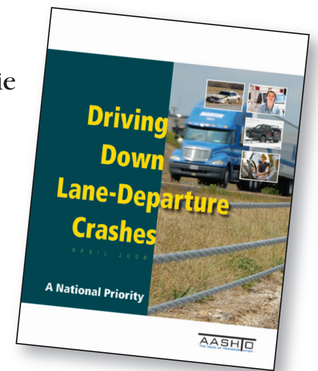
The state-of-the-art modeling, simulation, and high-performance computing center will tackle a host of transportation problems, including traffic congestion in major cities, the effects of stresses on transportation infrastructure, and the crashworthiness of vehicles. Using the simulations generated by TRACC, researchers will be able to study road weather and vehicle performance issues such as aerodynamic drag, fuel-injector spray dynamics, and under-the-hood thermal management. The TRACC simulations will closely resemble actual road conditions.

The models generated by TRACC have the potential to save lives by providing researchers with a better understanding of crash behaviors so they can enhance roadside safety structures. USDOT and the automotive industry already perform computerized crash simulations along with real-world crash tests, but TRACC technology will increase the speed and accuracy of these tests significantly.

For more information, visit www.anl.gov/TRACC or www.transportation.anl.gov/publications/transforum/v8n1/tracc.html.

Argonne National Laboratory

New AASHTO Report Targets Lane-Departure Crashes



AASHTO

Approximately 42,000 people die on the Nation's highways annually, and more than 25,000, almost 60 percent, are killed in crashes caused when their vehicles veer from their lanes. To help improve safety, AASHTO recently released a report detailing low-cost solutions to reduce the number of traffic fatalities in the United States due to lane departures.

The report, *Driving Down Lane-Departure Crashes*, outlines quick-to-implement strategies to identify and remove, or otherwise protect drivers from, roadside safety hazards such as trees and utility poles. The report features examples from States that have dramatically reduced lane-departure crashes and fatalities through successful leadership and systematic implementation of low-cost safety improvements.

For example, the Missouri Department of Transportation reduced fatalities related to lane departure by 25 percent from 2005 to 2007 through countermeasures such as rumble stripes, pavement markings, and cable median barriers. In Washington State, as the miles of divided highway protected by cable median barrier increased, the number of crossover median collisions decreased 74 percent, from 42 crashes per year to just 11 in 2007.

To view the report, visit http://downloads.transportation.org/PLD-1.pdf.

AASHTO

FHWA Reports on International Scan Focused On Warm-Mix Asphalt

In 2007, a team of 13 materials experts from the United States visited Belgium, France, Germany, and Norway to witness and evaluate warm-mix asphalt (WMA) paving technologies. FHWA recently released a report summarizing the results of the international scan tour.

According to the report, *Warm-Mix Asphalt: European Practice* (FHWA-PL-08-007), the benefits of WMA technologies include reduced fuel usage and emissions by the machines used to lay the asphalt when compared to hot-mix asphalt (HMA); improved field compaction, which can facilitate longer haul distances for the WMA and cool weather paving; and better working conditions compared to HMA due to the lower mix temperatures required by WMA that provide a more comfortable working environment.

Although adopting WMA for use in the United States will require modifications to existing materials and production practices, the scan team reported no long-term barriers to using the technology in this country. With additional research and trials, the team expects that State DOTs will adopt WMA as an alternative to HMA.

To view the report, visit http://international.fhwa.dot.gov/pubs/pl08007/pl08007.pdf.

FHWA to Collect Nationwide Data On Highway Bridges

In May 2008, FHWA initiated the Long-Term Bridge Performance (LTBP) program, a 20-year research effort to collect data on bridges nationwide. The LTBP program was designated under SAFETEA-LU in 2005. Researchers will use the data for a variety of purposes, including studying deterioration and durability of bridges and the impacts of maintenance and repair. The program will provide a better understanding of bridge deterioration, including the effects of corrosion, fatigue, environmental conditions, and traffic loading, ultimately leading to better investment decisions.

FHWA awarded a contract worth up to $25.5 million to the Rutgers University Center for Advanced Infrastructure and Transportation (CAIT) to carry out the first phase of the program funded through fiscal year 2012. CAIT will lead and administer the program, with Parsons Brinckerhoff, an infrastructure consulting and engineering firm, as its primary industry partner. Other partners include the Utah Transportation Center at Utah State University; the Institute of Transportation Studies at University of California, Berkeley; Siemens America; Advitam; Bridge Diagnostics, Inc.; and the Virginia Transportation Research Council, which will work closely with the University of Virginia and the Virginia Polytechnic Institute and State University.

For more information, visit www.tfhrc.gov/structur/ltbp.htm.

Public Information and Information Exchange

BTS Releases Pocket Guide to Transportation 2008

The Bureau of Transportation Statistics (BTS), a part of USDOT's Research and Innovative Technology Administration, released the online version of its latest guide to transportation. The *Pocket Guide to Transportation 2008* is a quick reference on changes in the U.S. transportation system since 1970 and how they have affected the Nation's economy, safety, energy use, and the environment.

The guide features the latest available statistics in chapters covering system extent and use (components of transportation network, bridge conditions), safety (transportation fatalities and injuries), security (items intercepted at airport checkpoints, petroleum consumption), mobility (vehicle miles traveled), economy (gross domestic product, trade), environment (vehicle fuel economy, carbon dioxide emissions), and a glossary.

To view the guide, visit www.bts.gov/publications/pocket_guide_to_transportation/2008/pdf/entire.pdf.

USDOT Performance Report Named Best In Government

In May 2008, the Mercatus Center at George Mason University awarded USDOT the top spot on its list of best government agency performance reports for its publication, *U.S. Department of Transportation Performance and Accountability Report for Fiscal Year 2007*. This is the second year in a row that the Mercatus Center has recognized the quality of USDOT's report.

To evaluate the performance reports, Mercatus Center officials look at how an agency informs the public about its successes and failures, how it substantiates any benefits cited in the report, and the degree of leadership exhibited in making improvements based on the results of past reports. A team of experts evaluates each report using 12 criteria (such as whether the agency addresses major management challenges and links goals and results to costs), awarding a score of up to 60 points. USDOT's 2007 report received a record-high 55 points and was "well organized, reader friendly, and consistently substantive," Mercatus Center officials said.

For more information, visit www.mercatus.org/Publications/pubID.4509/pub_detail.asp.

Mercatus Center, George Mason University

CITE and FHWA Introduce Course: Improving Highway Safety With ITS

FHWA and the Consortium for ITS Training and Education (CITE) recently introduced a blended (instructor-led, Web-based) version of the course Improving Highway Safety with ITS. The course aims to increase awareness of the benefits of deploying intelligent transportation systems (ITS) in highway safety applications.

The blended course format combines the best features of instructor-led and Web-based instruction, including live discussions with the instructor through conference calls; convenient, flexible Web-based modules; a specific time schedule during which to complete the course; and the ability to interact with other students through class problems posted on a discussion board.

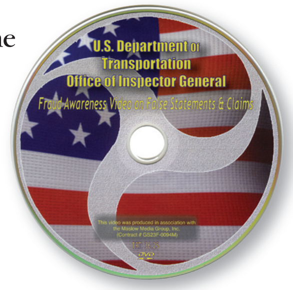
The course provides an overview of safety challenges currently facing transportation engineers, with a particular focus on 10 areas where ITS applications can help mitigate the challenges. Discussion of these applications includes presentations on nine USDOT-supported ITS initiatives and their impacts on safety. Participants learn about real-world applications of ITS technologies to improve safety by reviewing case studies of actual highway projects. Other modules focus on fusing traditional and ITS approaches, developing safety strategic plans, and meeting FHWA requirements regarding implementing ITS projects.

Throughout the training, hands-on activities help participants identify and prioritize highway safety challenges and formulate organization- and individual-level actions to mitigate the challenges.

For more information, visit www.citeconsortium.org/courses/HighwaySafety-blended.html.

CITE

USDOT Offers Video on Fraud Awareness



According to USDOT's *Fiscal Year 2008 Budget in Brief*, each year the department spends approximately $70 billion on transportation-related projects. To help protect this investment, in March 2008, USDOT's Office of Inspector General released a video on fraud awareness to educate government officials, contractors, and the public about common fraud schemes. The purpose of the video is to strengthen collaborative efforts to prevent and detect fraud involving transportation projects and programs.

Using a cable news format, the video presents examples of investigations that resulted in criminal and civil penalties for businesses and individuals who engaged in fraud while working on contracts funded by Federal transportation dollars. The video provides legal perspectives on false statements and claims and highlights red flag indicators to help government employees, contractors, and others in the transportation community know how to identify fraud. The video also instructs viewers on how to report possible fraud, waste, abuse, and other irregularities in USDOT programs to the Office of Inspector General's hotline.

For more information, visit www.oig.dot.gov/Hotline. To request a free copy of the video on DVD, e-mail fraudvideo@oig.dot.gov.

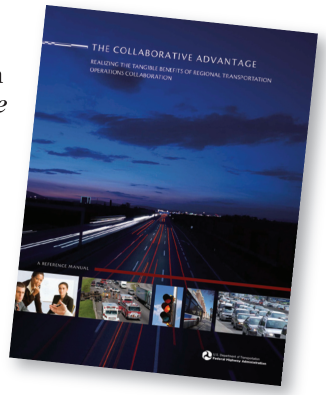
FHWA Issues Report on Creating Safe And Walkable Communities

In April 2008, FHWA released *A Resident's Guide for Creating Safe and Walkable Communities*, a document highlighting examples of communities working to improve pedestrian safety. The guide includes information, ideas, and resources to help community members understand issues that affect walking conditions, identify ways to address or prevent these problems, and promote pedestrian safety.

In addition, the guide features fact sheets, worksheets, and sample materials that communities can adapt and distribute to those working to improve pedestrian safety. For example, one checklist covers the top 10 things that a pedestrian safety organization can do to encourage walking, such as organizing educational seminars and talking to local planning and engineering staff. Another item included in the guide is a template for a letter that can be sent to drivers who are observed disobeying traffic laws.

To download the guide or order a hardcopy, visit http://safety.fhwa.dot.gov/ped_bike/ped/ped_walkguide.

FHWA Publication Highlights Benefits Of Regional Collaboration



According to a new FHWA report, collaboration is more than just the latest buzzword in management. *The Collaborative Advantage: Realizing the Tangible Benefits of Regional Transportation Operations Collaboration—A Reference Manual* (FHWA-HOP-08-001) is designed to help State, regional, and local officials involved with transportation operations and planning to understand the range of benefits associated with participation in multiagency collaborative efforts.

The strategies and benefits highlighted in the manual represent the combined input of more than 50 transportation and public safety professionals from across the United States. Developed by the FHWA Office of Operations and Office of Planning, Environment, and Realty, the manual highlights nine collaborative efforts to illustrate the tangible benefits of multiagency activities, ranging from incident management to transit operations. Among those benefits are access to additional funding and resources, improvement in agency operations and productivity, and assistance in achieving mobility and safety goals.

To view the manual, visit www.ops.fhwa.dot.gov/publications/benefits_guide/index.htm.

Missouri DOT Posts Online Video On Dedicated Truck Lanes

The Missouri Department of Transportation (MoDOT) recently posted an online video that demonstrates what truck-only lanes could look like on Interstate 70 (I–70) and how they might operate.

As truck traffic continues to increase, Missourians asked MoDOT to consider separating cars and trucks on the interstate. Therefore, MoDOT is studying truck-only lanes as a way to improve safety and reduce congestion during reconstruction and expansion of I–70. The video helps people understand how the truck-only lane concept works, especially how vehicles get on and off the highway.

The agency also plays a key role in the nationally designated Corridors of the Future program. By conducting this study now, MoDOT will be positioned to move quickly to address I–70's challenges, either by adding more general-use lanes or by building truck-only lanes, if funding for design and construction becomes available.

MoDOT has posted other videos online showing dramatic footage of the Route 19 Missouri River Bridge demolition, testing of guard cable crashes, and an aerial view of ongoing construction of Interstate 64 in St. Louis. Another video helps viewers understand the concept of a shared four-lane highway, which is a highway with additional passing lanes to ease congestion and improve safety.

To view the videos, visit http://youtube.com/user/modotvideo.

MoDOT

Personnel

FHWA Division Chief to Head Minnesota Department of Transportation

In April 2008, Minnesota Governor Tim Pawlenty appointed Thomas K. Sorel commissioner of the Minnesota Department of Transportation (Mn/DOT). Sorel was serving as division administrator for the FHWA Minnesota Division Office in St. Paul.

Throughout his career, Sorel has held various positions within FHWA, including major project team leader at the agency's headquarters in Washington, DC, and director of planning and program development and chief of technology services in Albany, NY. During the 2002 Winter Olympic Games in Salt Lake City, UT, Sorel was the USDOT liaison for Federal transportation issues and led the effort to build the infrastructure for the event.

While at FHWA, Sorel received many performance awards. He received the Presidential honor for leading the Federal transportation response, recovery, and rebuilding efforts in Minnesota in the aftermath of the collapse of the I–35W bridge.

Mn/DOT

Reporting Changes Of Address

PUBLIC ROADS has two categories of subscribers. One includes the organizations and people who receive the magazine without charge; the editorial office of the magazine maintains the mailing list for this group. The other category is the group of people and companies that pay to receive the magazine; the mailing list for this group is maintained by the Superintendent of Documents for the U.S. Government Printing Office.

Free copies are distributed to offices of the Federal Highway Administration, State highway agencies, technology transfer centers, and selected leaders who have responsibility for highway-related issues. Most of these copies are mailed to offices for their internal distribution or to people by position title rather than by name. If any office or individual subscriber in this category has a change of address, please send the complete previous mailing address and the complete new address to our distribution manager, Martha Soneira, via e-mail (martha.soneira@fhwa.dot.gov), telephone (202–493–3468), or mail (Martha Soneira, PUBLIC ROADS Distribution Manager (HRTM), Federal Highway Administration, 6300 Georgetown Pike, McLean, VA, 22101-2296).

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Internet Watch

by Keri A. Woodard

New Blog Keeps Transportation News Moving

Just a few years ago, Merriam-Webster declared "blog" the word of the year, as it received the largest number of user requests by a wide margin on the dictionary's Web site. Since then, blogs, or "Web logs," have appeared all over the Internet as a way to engage, educate, and provide feedback on a host of topics. In spring 2008, the U.S. Department of Transportation (USDOT) joined the blogosphere with *Fast Lane*, accessible at http://fastlane.dot.gov. *Fast Lane* is an online community for those interested in the Nation's transportation system and its future.

USDOT officials underscored two primary goals in launching *Fast Lane*. First, the department will use the blog as a vehicle for communicating news and announcing significant events in the transportation industry. Second, *Fast Lane* serves as an open forum where professionals and the public alike can contribute ideas and highlight innovative transportation activities in their communities. *Fast Lane*, therefore, provides a two-way exchange of information between USDOT and the public.

Diversity of Topics

Because *Fast Lane* is a blog covering USDOT, it highlights transportation topics across all modal administrations. For example, posts have covered topics such as a program to improve safety for teenagers behind the wheel, a rule requiring airlines to report the time that passengers spend on the runway, and an announcement about the opening of a new span of the Woodrow Wilson Bridge connecting Maryland and Virginia.

By covering a diversity of topics, the blog attracts a wide audience. To stay informed about the latest blog postings, readers can sign up to receive e-mail or rich site summary (RSS) updates each time a new posting is added to the site. With these capabilities, *Fast Lane* helps readers stay tuned into USDOT and the transportation industry.

Comments and Suggestions

In the spirit of two-way communication, *Fast Lane* not only provides information for visitors to read, but also offers a place where people can discuss topics by posting comments, questions, suggestions, and recommendations.

For example, when USDOT officials posted information about a grant awarded to Chicago to reduce congestion by funding new rapid transit bus routes and implementing a variable pricing system for onstreet parking, the post drew both questions and comments. Some readers suggested ways to improve the city's public transit system, and others recommended creating more bicycle paths. Such comments underscore the utility of blogs in stakeholder dialogs: By joining the blog, members of the public can communicate their ideas to top government officials. Blogs such as *Fast Lane* help create a collaborative environment in which citizens can offer input on how government can improve projects, programs, legislation, and laws.

Guest Contributors

Although the USDOT Secretary is the most frequent author of *Fast Lane* postings, other senior officials from across the department contribute to the blog. For example, a posting from a top official in the Federal Railroad Administration discussed the National Rail Safety Action Plan, which focuses on reducing train crashes, accelerating research to reinforce tank cars containing hazardous materials, addressing fatigue among train crews, and improving safety at highway-rail grade crossings by forging stronger partnerships with States to address the issue.

Fast Lane also welcomes guest bloggers from government, industry, and the broader transportation community. For example, Virginia Governor Timothy Kaine blogged about his agency's collaboration with USDOT to advance a major transit project in northern Virginia.

In this day and age, news travels fast. With *Fast Lane*, USDOT is helping share transportation news quickly, while simultaneously enabling the public to engage in topics that matter to them as the primary beneficiaries of the Nation highways, seaways, railways, and airways.

To quote a post from one USDOT official, "If [we're] going to insist on 21st century solutions for our transportation system, [we] better communicate in a 21st century way!"

Keri A. Woodard is a contributing editor for PUBLIC ROADS.

To sign up to receive e-mail or RSS updates of new postings, visit http://fastlane.dot.gov and click on the appropriate links under the "Subscribe" heading on the right toolbar.

***Fast Lane*, USDOT's official blog.**

NATIONAL HIGHWAY INSTITUTE

Training Update

by Stacy Stottmeister

TCCC and NHI: Partners In Highway Training

Attrition of the highway construction workforce poses an ongoing challenge for transportations agencies. At the same time, cutting-edge technologies for construction and system preservation demand new skills and highly trained personnel. To provide leadership at the national level in addressing workforce development focused on the frontline of highway construction and maintenance, the Federal Highway Administration (FHWA) partnered with the American Association of State Highway and Transportation Officials and five regional certification groups to create the Transportation Curriculum Coordination Council (TCCC).

The TCCC is a partnership of FHWA, the National Highway Institute (NHI), State departments of transportation (DOTs), and the highway transportation industry. The council's purpose is to build and maintain training resources for the transportation workforce, primarily at the technician level at State, municipal, and county DOTs. Since the council's creation in 2000, it has grown to include hundreds of subject matter experts from across the country and throughout the highway industry.

In the coming year, the TCCC expects to shift focus increasingly toward distance learning. According to Ann Gretter, NHI's liaison to the council, the TCCC and NHI have partnered to develop many courses, and members are working to roll out 13 Web-based trainings (WBTs) and instructor-led courses in 2008, with 4 Web-based courses already released in early 2008. "NHI relies on input from subject matter experts to develop quality training," Gretter says. "The council works with NHI by providing subject matter expertise and funding for course development."

New WBT Courses

The four most recently launched WBTs cover a range of topic areas relevant to highway construction personnel: Basic Materials for Highway and Structure Construction and Maintenance (FHWA-NHI-131117), Ethics Awareness for the Transportation Industry (FHWA-NHI-134069), Basic Construction and Maintenance Documentation—Improving the Daily Diary (FHWA-NHI-134071), and Hardened Concrete Properties—Durability (FHWA-NHI-134075).

"The intent is to give agencies and contractors good, quick training for employees to help them save travel time," says Chris Anderson, technical training coordinator for Iowa DOT, who serves as chair of the TCCC's course development team. "It's a money-saving way to get the skills to the people who need them."

All four courses were developed to review and improve basic highway and structure knowledge applied to construction and maintenance projects. The target audience for these WBTs includes entry- and intermediate-level personnel at State and local agencies and their industry counterparts involved in construction, maintenance, and testing processes for highways and structures.

Other WBTs under development through TCCC and NHI collaboration include Math Module (FHWA-NHI-134072), Bolted Connections (FHWA-NHI-134074), Stormwater (FHWA-NHI-134076), and GPS Technology (FHWA-NHI-134078).

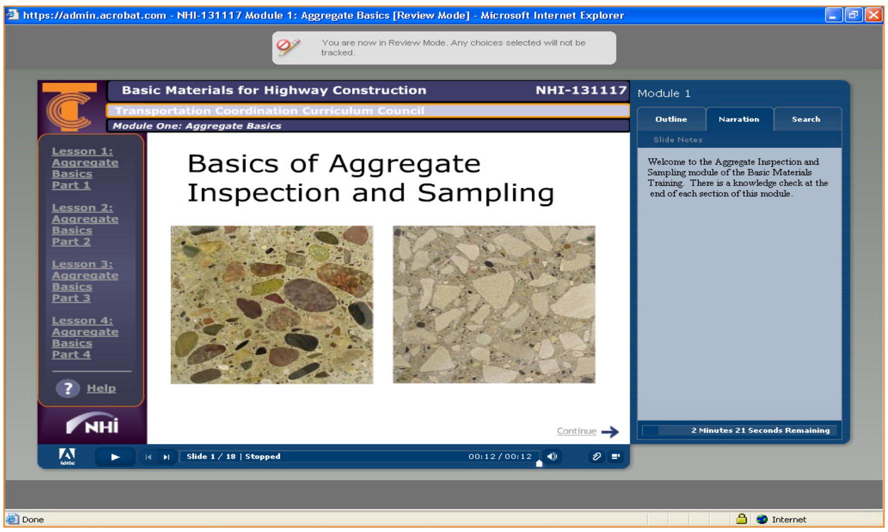
Pooled Fund

The TCCC is committed to providing training materials to State and local transportation agencies and other partners at minimal or no cost. Therefore, FHWA, States, and industry partners are combining resources into a pooled fund to make the best use of limited training dollars. Toward that end, the TCCC recently issued a solicitation for a second 5-year, $5 million pooled fund that will help the partnership continue to develop new WBT and instructor-led courses.

State DOTs and other transportation agencies interested in supporting the TCCC through participation in the pooled fund can visit www.pooledfund.org for more information.

For more information about the TCCC, visit www.nhi.fhwa.dot.gov/tccc or contact Christopher Newman at 202-366-2023 or christopher.newman@fhwa.dot.gov. For complete course descriptions, or to host or enroll in TCCC training, visit www.nhi.fhwa.dot.gov.

Stacy Stottmeister is a contractor for NHI.



A screen shot from the course Basic Materials for Highway and Structure Construction and Maintenance.

Communication Product Updates

Compiled by Zachary Ellis of FHWA's Office of Corporate Research, Technology, and Innovation Management

Below are brief descriptions of communications products recently developed by the Federal Highway Administration's (FHWA) Office of Research, Development, and Technology. All of the reports are or will soon be available from the National Technical Information Service (NTIS). In some cases, limited copies of the communications products are available from FHWA's Research and Technology (R&T) Product Distribution Center.

When ordering from NTIS, include the NTIS publication number (PB number) and the publication title. You also may visit the NTIS Web site at www.ntis.gov to order publications online. Call NTIS for current prices. For customers outside the United States, Canada, and Mexico, the cost is usually double the listed price. Address requests to:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703–605–6000
Toll-free number: 800–553–NTIS (6847)
Web site: www.ntis.gov

Address requests for items available from the R&T Product Distribution Center to:

R&T Product Distribution Center
Federal Highway Administration
9701 Philadelphia Court, Unit Q
Lanham, MD 20706
Telephone: 301–577–0818
Fax: 301–577–1421
E-mail: report.center@fhwa.dot.gov

For more information on R&T communications products available from FHWA, visit FHWA's Web site at www.fhwa.dot.gov, the Turner-Fairbank Highway Research Center's Web site at www.tfhrc.gov, the National Transportation Library's Web site at http://ntl.bts.gov, or the OneDOT information network at http://dotlibrary.dot.gov.

Methods for Maintaining Traffic Sign Retroreflectivity
Publication No. FHWA-HRT-08-026

Signs are essential to communicating regulatory, warning, and guidance information on roadways. A unique form of reflection known as retroreflectivity gives signs the ability to fulfill this role at night. Sign retroreflectivity, however, degrades over time. In response to a congressional directive aimed at ensuring safety, FHWA established minimum retroreflectivity levels for traffic signs and incorporated that information into the *Manual on Uniform Traffic Control Devices* (MUTCD).

One of the concerns expressed by transportation agency personnel responsible for conformance with these required minimum levels is the potential increase in tort exposure. Therefore, FHWA developed retroreflectivity maintenance methods that, when implemented as intended, provide agencies with a flexible means of achieving conformance and offer protection from potential tort claims.

This report describes a variety of methods agencies can use to meet and maintain minimum retroreflectivity requirements for signs. Specifically, the report outlines procedures to systematically identify signs that do not meet the minimum levels, initiate activities to upgrade signs as necessary, monitor the retroreflectivity of in-place signs, and update practices and policies for managing the nighttime visibility of signs. Agencies can use this information to help determine which retroreflectivity maintenance method or combination of methods best suits their needs.

The document is available from NTIS under order number PB2008106478.

March 2008 *Focus* Newsletter
Publication No. FHWA-HRT-08-011

FHWA's *Focus* newsletter has a mission to accelerate infrastructure innovations. Toward that end, the March 2008 issue features articles on the following topics: "Implementing an Accelerated Bridge Construction Program in Utah," "A Composite Solution to Repairing Overhead Sign Structures," "All About Steel Bridges," and "New Training on Cost Estimating for Today's Highway Projects." The newsletter also contains the popular highway technology calendar, which lists upcoming events that provide opportunities to learn more about infrastructure-related products and technologies.

The March issue of the newsletter is available at www.tfhrc.gov/focus/mar08/index.htm.

April 2008 *Focus* Newsletter
Publication No. FHWA-HRT-08-012

The April 2008 issue of *Focus* features articles on the following topics: "Green Highways: Partnering to Build More Environmentally Sustainable Roadways," "The Era of Intelligent Compaction Has Arrived," and "Warm-Mix Asphalt Debuts in Yellowstone National Park." This issue spotlights a peer-to-peer approach to improving work zone safety and mobility and FHWA's Pavement and Materials Environmental Stewardship Team. The newsletter also features a calendar of infrastructure-related events.

The April issue is available at www.tfhrc.gov/focus/apr08/index.htm.

Structures Laboratory Fact Sheet
Publication No. FHWA-HRT-07-060

The Nation's approximately 600,000 bridges, including those on the National Highway System and those maintained and operated by State and local entities, are essential to mobility. The Structures Laboratory at FHWA's Turner-Fairbank Highway Research Center specializes in developing and testing innovative bridge designs, materials, and construction processes that promise more efficient structures for the Nation's highway system.

The lab supports national bridge design specifications to improve the safety, reliability, and cost effectiveness of bridge construction in the United States. It also provides forensic investigation services to determine the causes of bridge structural failures and develops practices and procedures to help avoid these failures in the future. This fact sheet summarizes the lab's capabilities and equipment, as well as its mission, partners, and accomplishments.

The document is available at www.tfhrc.gov/about/struct.htm.

Defining an Advanced Quality System and the Elements That Integrate It
Publication No. FHWA-HRT-07-058

This report summarizes the findings of the Advanced Quality Systems Workshop held in Washington, DC, in November 2006. Sponsored by FHWA, the workshop brought together researchers and practitioners to discuss exactly what constitutes an advanced quality system and how best to advance quality systems at State highway agencies. During the workshop, attendees defined advanced quality systems and noted that advanced quality systems should include quality assurance for both design and construction. The two are part of the same system, and State highway agencies need to be consistent in communicating to the contractor the desired quality and performance of construction. The report concludes that continuous improvement in construction quality occurs best when construction personnel at the State highway agency have a thorough understanding of the design, especially the assumptions regarding quality, and when they provide feedback to the designers on construction quality.

The document is available from NTIS under order number PB2007112617.

Analysis of an Ultra-High Performance Concrete Two-Way Ribbed Bridge Deck Slab
Publication No. FHWA-HRT-07-056

Ultra-high performance concrete (UHPC) is a relatively new material that has demonstrated good durability properties, high compressive strength, and usable tensile resistance. Recent studies on material characterization and structural behavior have shown the average compressive strength to be 193,100 kilopascal, kPa (28 kips per square inch, ksi) while a tensile strength of greater than 10,340 kPa (1.5 ksi) can be maintained throughout a tensile strain of approximately 0.010. Researchers conclude that these desirable mechanical properties make UHPC a worthy material for use on the Nation's highly stressed bridge decks.

Because UHPC exhibits a unique flexural behavior, a design methodology must be developed to distinguish it from that of traditional reinforced concrete. This report details UHPC flexural behavior, offers a design methodology, and presents the analysis of a two-way ribbed precast bridge deck. Without having design specifications for UHPC, the researchers used the 2006 American Association of State Highway and Transportation Officials' (AASHTO) load and resistance factor design (LRFD) specifications where appropriate in designing and analyzing the bridge deck. From the proposed design methodology, mechanics of the materials, and strain compatibility, the researchers analyzed the UHPC deck cross section for positive and negative moment capacities. The analysis revealed that the proposed UHPC deck design is capable of resisting the developed design loads. The researchers recommend further verification through physical testing of a full-scale UHPC two-way ribbed deck slab.

The document is available from NTIS under order number PB2007112112.

Synthesis of Research and Provisions Regarding the Use of Lightweight Concrete In Highway Bridges
Publication No. FHWA-HRT-07-053

Researchers reviewed the *AASHTO LRFD Bridge Design Specifications* and the *AASHTO LRFD Bridge Construction Specifications* to identify provisions that affect the use of lightweight concrete. They also compiled a synthesis of research relevant to those provisions and proposed research problem statements to generate data to update the specifications in areas where gaps exist for lightweight concrete.

This report corresponds to a TechBrief titled *Current Provisions and Needed Research for Lightweight Concrete in Highway Bridges* (FHWA-HRT-07-051). Printed copies of the TechBrief are available from FHWA's Product Distribution Center. The report is available from NTIS under order number PB2007110768.

Quick Response Freight Manual II
Publication No. FHWA-HOP-08-010

Freight transportation requires distinctly different planning from passenger transport. Existing data provide varying levels of detail, rarely offering a complete picture of a region's freight transportation. In many cases, local data collection efforts can provide more accurate and relevant data to support freight demand analysis and planning.

Understanding the strengths and weaknesses of available data sources can help transportation planners decide what data to use in particular situations. The *Quick Response Freight Manual II* explains current data sources and techniques for integrating freight data into planning efforts. Because States, metropolitan planning organizations, and other planning organizations possess varying degrees of knowledge and expertise in freight transportation, the manual offers methodologies for collecting and using data in models at the State and local levels.

The manual is an update to an earlier document developed in 1996. Like its predecessor, the new edition provides background on the U.S. freight transportation system and factors affecting demand. The manual can help planners locate available data and develop forecasts for facilities at a variety of geographic levels. Further, it provides simple techniques and transferable parameters for developing trip tables for freight vehicles.

The document is available at www.ops.fhwa.dot.gov/freight/publications/qrfm2/index.htm.

Conferences/Special Events Calendar

Date	Conference	Sponsors	Location	Contact
November 2–6, 2008	ACI Fall 2008 Convention in St. Louis: The Spirit of Concrete	American Concrete Institute (ACI)	St. Louis, MO	Lauren Mentz 248-848-3795 conventions@concrete.org www.aciconvention.org
November 4–7, 2008	California's Public & Community Transportation Conference & Expo	California Association for Coordinated Transportation and California Transit Association	Monterey, CA	Mary Zavislan 916-446-4656 mzavislan@caltransit.org www.calact.org/conference
November 11–13, 2008	International Conference on Warm-Mix Asphalt	National Asphalt Pavement Association, Federal Highway Administration	Nashville, TN	Tracie Christie 888-468-6499 tcrhistie1@hotmix.org www.hotmix.org
November 12–14, 2008	2008 NYS Public Transit Fall Conference & Expo	New York Public Transit Association	Albany, NY	Cara Grassie 518-434-9060, ext. 112 info@nytransit.org www.nytransit.org
November 17–19, 2008	First ASBI International Symposium 2008	American Segmental Bridge Institute (ASBI)	San Francisco, CA	Cliff Freyermuth 602-997-9964 asbi@earthlink.net www.asbi-assoc.org/news/symposium
December 2–5, 2008	2008 Ground Water Expo and Annual Meeting	National Ground Water Association (NGWA)	Las Vegas, NV	NGWA Customer Service Department 800-551-7379 customerservice@ngwa.org www.ngwa.org
December 3–5, 2008	American Concrete Pavement Association's 45th Annual Meeting	American Concrete Pavement Association (ACPA)	San Antonio, TX	ACPA Meetings & Events 847-966-2272 acpa@pavement.com www.pavement.com
December 7–9, 2008	Transportation Finance Summit	International Bridge, Tunnel and Turnpike Association	Washington, DC	Cheryle Arnold 202-659-4620, ext. 15 carnold@ibtta.org www.ibtta.org

IMPROVING FREIGHT ANALYSIS AND PLANNING

Quick Response Freight Manual II

Now Available

Freight transportation is distinctly different from passenger transport and in most cases requires supplemental considerations for planning. To help State departments of transportation and metropolitan planning organizations develop more accurate freight forecasts, the Federal Highway Administration recently updated its *Quick Response Freight Manual II* (FHWA-HOP-08-010).

A variety of freight-related information is available to assist with regional and local freight planning. However, varying levels of detail and coverage can make it difficult to develop a complete picture of a region's freight transportation. This manual is designed to help planners meet this challenge by offering guidance in several key areas.

Available online, the manual offers the following information:

- Provides background on the U.S. freight transportation system and factors affecting demand.
- Helps planners identify and locate available data and forecasts.
- Explains current data sources and techniques for integrating these data into planning efforts.
- Shows how to apply freight data in developing forecasts for specific facilities.
- Presents straightforward methodologies for collecting data to use as inputs in State and local planning models.

To access the manual, visit www.ops.fhwa.dot.gov /freight/publications/qrfm2/index.htm.

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Federal Highway Administration

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