

FOCUS

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Innovations and Best Practices for Roadway Tunnels

From technology advances to accelerated construction techniques, a domestic scan team sponsored by the National Cooperative Highway Research Program (NCHRP), American Association of State Highway and Transportation Officials (AASHTO), and Federal Highway Administration (FHWA) traveled the country investigating innovations and best practices for roadway tunnel design, construction, maintenance, inspection, and operations.

Team members included representatives from State departments of transportation, academia, and FHWA. The team visited California, Colorado, Maryland, Massachusetts, New Jersey, New York, Virginia, and Washington in August and September 2009. Web conferences were also held with representatives from the Alaska Department of Transportation, District of Columbia Department of Transportation, and Pennsylvania Department of Transportation.

The scan focused on highway tunnel inventory criteria; design and construction standards; maintenance and inspection practices; operations, including safety; and specialized tunnel technologies. Also considered were fire suppression, traffic management, incident detection and management, and repairs of existing tunnels.

“We had the opportunity to learn about best practices and innovations that States are using, so that these can be shared with other States,” said scan cochair Jesus Rohena of FHWA. “We also observed the challenges that tunnel owners are facing throughout the country as tunnels get older.”

Among the innovations being used to accelerate tunnel construction are prefabricated elements. These can include steel and precast concrete submersed tubes, prefinished manufactured steel ceiling panels, precast concrete floors, and precast concrete

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Sign Up Now to Receive Email Notification for the Online Version of *Focus*

The Federal Highway Administration (FHWA) wants you to receive the latest information on highway infrastructure innovations as quickly as possible. *Focus* is typically posted online up to 2 weeks before the printed copy reaches you in the mail. Please go to the *Focus* Web site at www.fhwa.dot.gov/publications/focus/index.cfm to sign up to receive an email notification when each issue of *Focus* is posted online. The email notification will include a short description and a link for each article. It will not include any cumbersome attachments.

FHWA is considering moving the *Focus* newsletter to an online-only distribution. This change would get information to readers faster, reduce costs, and help the environment. An online-only version would continue to provide a printable version for subscribers who prefer to read *Focus* in the traditional eight-page, three-column format.

www.fhwa.dot.gov/publications/focus/index.cfm



U.S. Department of Transportation

Federal Highway Administration

Best Practices for Roadway Tunnels,

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Above: The Eisenhower/Johnson Memorial Tunnel on I-70 in Colorado.
Right: A tunnel inspection is conducted.



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ceiling panels with tiles. Innovations to improve tunnel operations include specialized lighting technologies that control light intensity levels and prevent the “tunnel effect,” which can affect vision when motorists drive into the portal area. Technologies to prevent water leakage include vacuum injection of water seepage cracks and membrane-based waterproofing systems. Tunnel inspection is also being improved through the use of technologies such as laser surveys and multibeam sonar.

Tunnels visited during the scan tour include the Eisenhower/Johnson Memorial Tunnel in Colorado, which carries I-70 traffic under the Continental Divide. At 3,353 m (11,000 ft), the 2.7-km (1.7-mi) tunnel is at the highest elevation for a vehicular tunnel in the world. Also visited in Colorado was the Hanging Lake Tunnel (HLT) on I-70 at the midpoint of Glenwood Canyon. The 1,219-m (4,000-ft) HLT is one of the most technologically advanced tunnel systems in the country, with a traffic control and information center that tracks each vehicle traveling through the tunnel using a system of sensors and closed circuit television cameras. A fleet of emergency vehicles is stationed in the middle of the tunnel around the

clock and emergency refuge areas are located throughout the HLT.

In Virginia, team members observed the Chesapeake Bay Bridge-Tunnel (CBBT), which connects southeastern Virginia and the Delmarva Peninsula (Delaware and the Eastern Shore counties in Maryland and Virginia). The CBBT consists of more than 19 km (12 mi) of low level trestle, two 1.6-km (1-mi) tunnels, two bridges, almost 3.2 km (2 mi) of causeway, and four man-made islands, totaling 28.3 km (17.6 mi) from shore to shore, plus 8.8 km (5.5 mi) of approach roads. Also observed was the Hampton Roads Bridge-Tunnel (HRBT), which includes bridges, trestles, manmade islands, and tunnels connecting Norfolk and Hampton in southeastern Virginia. During the summer approximately 100,000 vehicles cross the HRBT daily.

The HRBT tunnels consist of two parallel single tubes built using the immersed sunken tube method. Prefabricated tunnel elements were placed using barges and then joined together in a trench dredged at the bottom of the harbor and backfilled with earth. State-of-the-art automated traffic control and video monitoring systems are used for traffic management and air quality is constantly monitored.

Based on the information gathered during the tour, the scan team has made eight recommendations:

1. *Develop standards, guidance, and best practices for roadway tunnels.* These standards should include, for example, design criteria for performance-based construction specifications; extreme events and tunnel security; vertical clearance, horizontal clearance, and sight distance; tunnel design life and future maintenance for structural, mechanical, electrical, and electronic systems; and fire and life-safety systems.
2. *Develop an emergency response system plan unique to each facility that takes into account human behavior, facility ventilation, and fire mitigation.* A fire ventilation study should be performed and a fire ventilation plan developed and adopted for each facility. Many facilities also need to improve their procedures for directing the public to safety during an emergency.
3. *Develop and share inspection practices among tunnel owners.* The team recommends that tunnel inspection programs

be as similar as possible to bridge inspection programs. Those components of the tunnel that carry or affect traffic, such as roadway slabs and floor systems that carry traffic, should be load rated in accordance with the AASHTO Manual for Bridge Evaluation to the extent possible. Recommended practices for inspection frequencies, minimum code requirements, and a Federal coding manual also need to be developed.

4. *Consider inspection and maintenance operations during the design stage.* The team found that inviting all disciplines to provide their input during the design phase results in a better product.
5. *Develop site-specific plans for the safe and efficient operation of roadway tunnels.* Agencies should develop a concise site-specific tunnel operations manual, as well as an incident response manual.
6. *Building a tunnel means a long-term commitment to provide funding for preventive maintenance, system upgrades and replacements, and operator training and retention.* The decision to build a tunnel represents a long-term commitment by the owner. Agencies should develop an operational financial plan that addresses the need for future preventive maintenance, system upgrades

and replacements, and operator training and retention.

7. *Share existing technical knowledge within the industry to design a tunnel.* This knowledge base could include domestic and international tunnel scan information, past project designs, construction practices, emergency response best practices, and information on subject matter experts. To protect security, details and best practices should be shared without identifying the specific facilities where they are used.
8. *Provide education and training in tunnel design and construction.* Since many agencies do not have in-house expertise on tunneling, providing access to education and training is vital.

AASHTO will work in conjunction with FHWA and the Transportation Research Board, as well as the National Fire Protection Association and other tunnel-related organizations, to implement the recommendations. Work already underway includes an NCHRP project to develop Load and Resistance Factor Design specifications and guidance for new and existing tunnels. “Developing design guidance is the biggest issue for tunnels, as right now there aren’t standards as there are for bridges,” said scan cochair Kevin Thompson

of Arora and Associates and former State Bridge Engineer for the California Department of Transportation.

To download the scan report, *Best Practices for Roadway Tunnel Design, Construction, Maintenance, Inspection, and Operations*, visit [http://bridges.transportation.org/Documents/NCHRP20-68A_09-05%20\(1\).pdf](http://bridges.transportation.org/Documents/NCHRP20-68A_09-05%20(1).pdf). For more information on the scan tour, contact Jesus Rohena at FHWA, 202-366-4593 (email: jesus.rohena@dot.gov). ✨

A 2005 international scanning team tour sponsored by FHWA, AASHTO, and NCHRP brought back innovations and best practices in designing, building, and operating tunnel systems in Europe. The scan focused on tunnel operations, including incident detection and deterrent technology and incident response and recovery planning. Also studied were tunnel systems and designs that provide fire protection, blast protection, and areas of refuge or evacuation passages for motorists. To download the scan team report, *Underground Transportation Systems in Europe: Safety, Operations, and Emergency Response* (Pub. No. FHWA-PL-06-016), visit www.international.fhwa.dot.gov/uts.



Above: The Mount Baker Ridge Tunnel carries I-90 in Seattle, WA.
Right: The Chesapeake Bay Bridge-Tunnel connects southeastern Virginia and the Delmarva Peninsula.



A Guide to Today's Orthotropic Steel Deck Bridges

First developed in the 1930s, the orthotropic steel deck (OSD) system for bridges continues to offer tremendous potential for building efficient and cost-effective modern structures with extended service life.

The Federal Highway Administration's (FHWA) new *Manual for Design, Construction, and Maintenance of Orthotropic Steel Deck Bridges* (Pub. No. FHWA-IF-12-027) presents a comprehensive guide to OSD technology based on worldwide practice and modern analytical techniques. Included are discussion of the many aspects of orthotropic bridge engineering, including analysis, design, detailing, fabrication, testing, inspection, evaluation, and repair. The manual supplements and updates the 1963 *Design Manual for Orthotropic Steel Plate Deck Bridges* published by the American Institute of Steel Construction. It is based on the recently issued Sixth Edition of the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications.

"Orthotropic steel decks provide a modular, prefabricated design solution that has proven effective in new construction where speed and extended service life are desired, and in rehabilitation of existing bridges where reducing weight is one of the primary goals," said Myint Lwin, Director of FHWA's Office of Bridge Technology.

Originally developed in Germany, the OSD system generally consists of a flat,

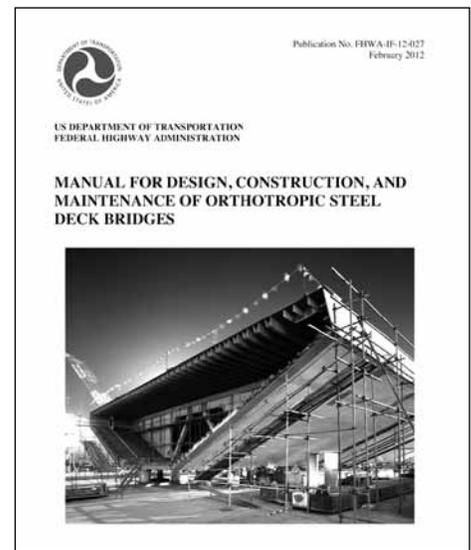
thin steel plate that is stiffened by a series of closely spaced longitudinal ribs and transverse floor beams. As noted in the manual, "the defining characteristic of the OSD bridge is that it results in a nearly all steel superstructure which has the potential (with minimal maintenance) to provide extended service life and standardized modular design, as compared to more conventional bridge construction." Since most of the components are prefabricated and lightweight, OSD bridges can be built quickly. OSD construction also provides a smooth continuous riding surface that has minimal joints, preventing leakage and protecting the other bridge components. Another potential advantage is lower life-cycle costs.

OSD design can provide a cost-effective solution for many different conditions and types of bridges, including:

- Long-span bridges.
- Moveable bridges.
- Bridges in seismic zones.
- Bridges where rapid construction is required.
- Bridges where extended service life is required.
- Cold weather conditions where it is difficult to use cast-in-place concrete.

The OSD system has been used in thousands of bridges worldwide, particularly in Europe, Asia, and South America.

"Orthotropic steel decks provide a modular, prefabricated design solution that has proven effective in new construction where speed and extended service life are desired."



It has not been as widely employed in the United States to date, with an estimated 100 OSD bridges in service across the country. The system has most commonly been used in the United States for particular design conditions, such as for long-span structures where it is paramount to minimize dead load. One example of this design is the new Tacoma Narrows Bridge in Washington. Another use in the United States is for box girder bridges containing slender compressive plate elements that require stiffening, such as the Alfred Zampa Memorial Bridge in California. It has also been used for redecking of major bridges on urban arterials where rapid construction is vital, including the Bronx-Whitestone Bridge in New York City.

OSD bridges present unique design challenges, which has contributed to their more limited use in the United States. For example, the design of critical details is controlled less by dead load or ultimate strength but more by live load, meaning that fatigue is the dominant limit state. Early analytical tools were limited in their ability to quantify the stress states at these details, and data was limited on fatigue resistance. After extensive research efforts in recent decades, however, there is better understanding of OSD performance and proper design. And while wearing surfaces applied to OSDs have experienced some problems in the past, including cracking

NHI Training in Action 2012

and rutting, recent research and development and general design improvements have addressed the causes of many of these problems. As the manual notes, “current design concepts have proven successful in many modern OSD bridges in the United States and abroad.”

The manual examines OSD applications, including use of the system for plate girder bridges, box girder bridges, and suspended span bridges. Typical bridge sections and orthotropic panel details are then discussed, as well as structural behavior and analysis. A section on design covers a general design approach and then offers details on such items as permanent loads, live loads, fatigue resistance, and rib-to-deck welds. The section on construction offers instruction on the fabrication process, welding, erection, and inspection and testing.

Also covered are inspection, evaluation, and repair, including load rating, limit states, and rehabilitation strategies, as well as wearing surfaces and maintenance and repair techniques. Discussion of testing encompasses experimental testing of decks, fatigue testing of orthotropic steel connection details, and testing of wearing surfaces. The manual culminates with two design examples, showcasing the use of the new AASHTO LRFD Specifications in refined analysis for a multiple girder continuous bridge and a cable-stayed bridge.

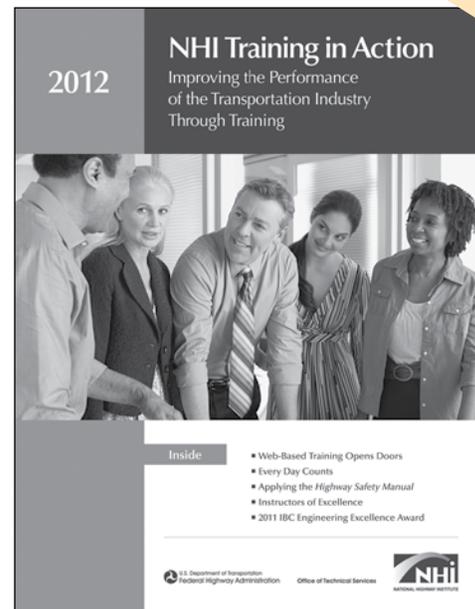
To download a copy of the manual, visit www.fhwa.dot.gov/bridge/pubs/if12027/if12027.pdf. For more information on OSD bridges, contact Brian M. Kozy in FHWA’s Office of Bridge Technology, 202-493-0341 (email: brian.kozy@dot.gov). *

Find out how training available from the Federal Highway Administration’s (FHWA) National Highway Institute (NHI) can help you accelerate innovation and open new doors in your career with the 2012 edition of *NHI Training in Action*.

The magazine spotlights how NHI courses and Webinars support the goals of FHWA’s Every Day Counts (EDC) initiative, including shortening project delivery, enhancing roadway safety, and protecting the environment. The EDC initiative is designed to speed deployment of proven solutions and technologies.

Courses available include NHI Training 131137, Special Mixture Design Considerations and Methods for Warm Mix Asphalt. One of the EDC priority innovations, warm mix asphalt (WMA) encompasses a variety of technologies that allow asphalt to be produced and then placed on the road at lower temperatures than the conventional hot mix asphalt (HMA) method. The lower temperatures may result in cost savings and reduced greenhouse gas emissions because less fuel is required. Other benefits include improved pavement performance, reduced energy usage, and increased worker comfort. The free 2-hour online training highlights key differences in WMA and HMA design procedures (see December 2011 *Focus*). Participants also have the opportunity to convert HMA mixtures into WMA mixtures.

Another course that complements the EDC initiative is NHI Training 142060, Practical Conflict Management Skills for Environmental Issues. This 3-day training equips transportation professionals and their counterparts from local government, tribal entities, and environmental organizations with critical interpersonal skills and the ability to work efficiently and effectively with all stakeholders in the arena of transportation planning and project devel-



opment. The course contributes to EDC’s goal of reducing the environmental footprint of transportation projects.

NHI Training in Action also looks at how Web-based training opens doors. NHI now offers more than 100 Web-based courses, most of which are free to participants. One course participant credits the online training with helping him obtain his current position with the Utah Department of Transportation (UDOT). “The Web-based training component makes 24/7 accessibility a reality, which is another great benefit for today’s busy professionals,” said Rod McDaniels, program manager for outdoor advertising control at UDOT.

Additional features report on how NHI courses are helping practitioners use the American Association of State Highway and Transportation Officials *Highway Safety Manual*, as well as the International Bridge Conference Engineering Excellence Award received by FHWA for the new NHI reference manual, *Analysis and Design of Skewed and Curved Steel Bridges with Load and Resistance Factor Design*. Also included is a list of NHI courses launched in 2011.

To download the 2012 *NHI Training in Action* or for more information on NHI training opportunities, visit www.nhi.fhwa.dot.gov. *

Infrastructure Innovation Webinars

This free Webinar provides a quick introduction to the latest infrastructure innovations and technologies.

State-Specific Load and Resistance Factor Rating (LRFR) Load Rating Guidelines

April 19, 2012, 1–3:30 p.m. (eastern daylight time)

The Webinar covers fundamental information, lessons learned, and resources available to address State-specific load rating issues such as the application of State legal loads and load calibration based on weigh-in-motion data. Representatives from the New York State Department of Transportation and Oregon Department of Transportation will share information on their LRFR procedures. The target audience for the Webinar includes bridge and structures staff from local, regional, and State transportation agencies; Federal Highway Administration (FHWA) staff; and consultants. Participants will have the opportunity to download the Webinar presentations.

To register, visit <https://connectdot.connectsolutions.com/statespecificlrfr/event/registration.html>. For more information, contact Lubin Gao at FHWA, 202-366-4604 (email: lubin.gao@dot.gov). *

Join the Context Sensitive Solutions Community

From Maine to New Mexico, agencies are incorporating the principles of context sensitive solutions (CSS) to transform how they plan and develop transportation projects to better meet the needs of users. Visit the Federal Highway Administration (FHWA) CSS Web site (<http://contextsensitivesolutions.org>) to learn how CSS has enabled agencies to design urban thoroughfares that keep neighborhoods walkable, create safer streets that are enjoyable for cyclists and other users, improve rural highways in environmentally sensitive areas, and allow for diverse interests within a community to agree on the purpose, need, scope, and community context for transportation projects.

For visitors to the site, it's all CSS, all the time. Whether you are new to CSS or an experienced practitioner, the recently redesigned site is the place to go for CSS news, research, publications, case studies, and much more.

CSS is a collaborative, multidisciplinary process that involves all stakeholders in planning and developing transportation facilities. This approach preserves and enhances scenic, aesthetic, historic, community, and environmental resources, while improving or maintaining safety, mobility, and infrastructure. The four core principles of a context sensitive approach are:

1. Strive towards a shared stakeholder vision to provide a basis for decisions.
2. Demonstrate a comprehensive understanding of contexts.
3. Foster continuing communication and collaboration to achieve consensus.
4. Exercise flexibility and creativity to shape effective transportation solutions, while preserving and enhancing community and natural environments.



Starting with “What Is CSS,” the site offers resources for a diverse group of practitioners. Visitors new to CSS can learn about the history of CSS, its guiding principles, and the benefits of using the process. “Tools for Applying CSS” includes a more in-depth discussion of the integration of CSS principles in the project development process and in the assessment and decisionmaking that occurs when designing a project. The “Resources” section covers State case studies, successful practices of State and local agencies, publications, and recordings and presentations from CSS Webinars.

A primary feature of the site is the CSS Toolbox, which contains many significant CSS publications, “CSS in the News” and upcoming events, training information, statistics and quotes, a list of industry experts and links to industry resources, FHWA memorandums and other resources, and information on FHWA experts. Users can create their own customized Toolbox by downloading files from the site. Visitors can also join discussion groups or contribute content to the site. Updates on the upcoming CSS National Dialogues will also be available. This program will provide opportunities for CSS

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Highway Technology Calendar

The following events provide opportunities to learn more about products and technologies for accelerating infrastructure innovations.

2012 Design-Build in Transportation Conference April 25–27, 2012, Phoenix, AZ

Join transportation leaders in discussing lessons learned in the use of the design-build project delivery method for transportation projects. Discussions will include choosing the right delivery method, contracting approaches, risk allocation, and performance contracting. The conference is cosponsored by the Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials (AASHTO), and industry groups.

Contact: Jerry Yakowenko at FHWA, 202-366-1562 (email: gerald.yakowenko@dot.gov), or visit www.dbtranspo.com/index.cfm.

2012 International Conference on Winter Maintenance and Surface Transportation Weather

April 30–May 3, 2012, Coralville, IA

Sponsored by the Transportation Research Board, Iowa Department of Transportation, AASHTO, and FHWA, the conference will cover both the state-of-the-art and the state-of-the-practice in improving snow removal and ice control operations. Session highlights include performance measures, road weather and surface condition data collection, innovative equipment and materials, and large-volume snow control.

Contact: Roemer Alfelor at FHWA, 202-366-9242 (email: roemer.alfelor@dot.gov), or visit www.trb.org/Calendar/Blurbs/2012_International_Conference_on_Winter_Maintenanc_164319.aspx.

FHWA Intelligent Compaction (IC) Workshop

May 3, 2012, Minneapolis, MN

The workshop highlights the fundamentals of IC and discusses the route to successful IC implementation. The training is designed for State agency staff, professionals in the earthwork and paving industries, IC roller vendors, and global positioning system vendors.

Contact: George Chang at The Transtec Group, 512-451-6233, ext. 227 (email: gkchang@thetranstecgroup.com), or Lee Gallivan at FHWA, 317-226-7493 (email: victor.gallivan@dot.gov). Registration information is available at www.IntelligentCompaction.com.

Seventh RILEM International Conference on Cracking in Pavements

June 20–22, 2012, Delft, Netherlands

Conference topics spotlight the detection, prediction, and mitigation of cracking in pavements; laboratory and field model validation; and accelerated pavement testing. Organized by RILEM (the International Union of Laboratories and Experts in Construction Materials, Systems, and Structures), conference partners include FHWA and AASHTO.

Contact: Katherine Petros at FHWA, 202-493-3154 (email: katherine.petros@dot.gov), or visit www.rilem2012.org.

Forty-Ninth Annual Petersen Asphalt Research Conference

July 9–11, 2012, Laramie, WY

Organized by the Western Research Institute (WRI), the conference will present current research aimed at understanding and improving asphalt performance. Topics covered range from fundamental compositional research to applied field engineering. Attendees are also invited to participate in an open mic discussion.

Contact: Steve Salmans at WRI, 307-721-2306 (email: ssalmans@uwyo.edu), or Jack Youtcheff at FHWA, 202-493-3090 (email: jack.youtcheff@dot.gov). Information is also available at www.petersenasphaltconference.org.

2012 Pavement Performance Prediction Symposium

July 12, 2012, Laramie, WY

Presented by WRI in cooperation with FHWA's Turner-Fairbank Highway Research Center, the symposium will take an indepth look at a single asphalt-related topic.

Contact: Steve Salmans at WRI, 307-721-2306 (email: ssalmans@uwyo.edu), or Jack Youtcheff at FHWA, 202-493-3090 (email: jack.youtcheff@dot.gov). More information on the selected topic will be available at www.petersenasphaltconference.org.

International Conference on Long-Life Concrete Pavements

September 18–21, 2012, Seattle, WA

Organized by FHWA, in partnership with the National Concrete Pavement Technology Center, the conference will address concrete pavement design, construction, and materials technologies that result in long-life, sustainable concrete pavement. A mini-symposium on concrete paving durability will be held on the final day of the conference.

Contact: Shiraz Tayabji at Fugro Consultants, Inc., 410-302-0831 (email: stayabji@aol.com), or Sam Tyson at FHWA, 202-366-1326 (email: sam.tyson@dot.gov). Conference information is also available at www.fhwa.dot.gov/pavement/concrete/2012conf.cfm. *

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Its primary mission is twofold: (1) to serve the providers of highway infrastructure with innovations and support to improve the quality, safety, and service of our roads and bridges; and (2) to help promote and market programs and projects of the various offices of FHWA's Office of Infrastructure.

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Context Sensitive Solutions,

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practitioners across the country to exchange best practices, ask questions, and raise awareness of the latest developments in CSS.

FHWA is also exploring the development of an interdisciplinary CSS course with the University of Maryland School of Architecture, Planning, and Preservation. This course is tentatively scheduled to begin in fall 2012. Supplemented with speakers from FHWA, the course will

feature a syllabus developed from CSS research and case studies in conjunction with the University's curriculum.

Start exploring CSS by visiting <http://contextsensitivesolutions.org>. To subscribe to the quarterly CSS newsletter, see the "CSS Newsletter" information on the home page. For more information about CSS, contact Jon Obenberger at FHWA, 202-366-2221 (email: jon.obenberger@dot.gov). *



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www.fhwa.dot.gov/publications/focus/index.cfm