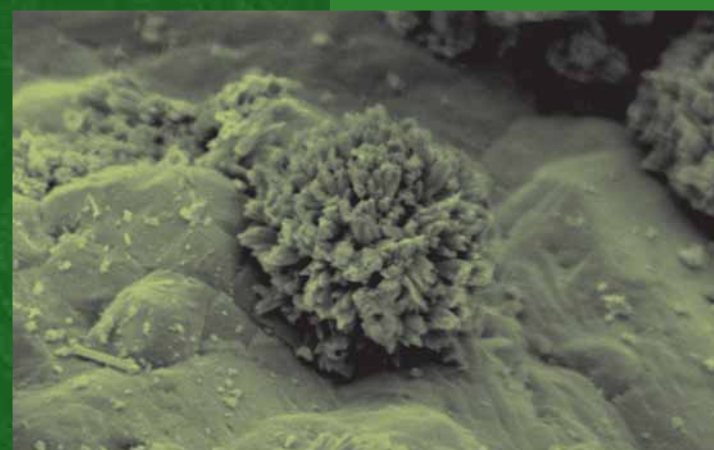
EXPLORATORY ADVANCED RESEARCH

Exploratory Advanced Research Program

Research Associates Program 2016



U.S. Department of Transportation
Federal Highway Administration

Notice

Quality Assurance Statement

Cover photos

Left: Photo of a masonry-faced geosynthetic-reinforced soil (GRS) column, part of a series of large-scale performance tests that helped quantify the durability and serviceability of GRS structural components of bridge foundations under everyday loads (see page 4).

Right: Image showing the nucleation of ettringite mineral in the interfacial transition zone, part of a research objective to develop inorganic curing compounds for addressing the shortcomings of current organic membrane-forming curing compounds in pavement construction (see page 5).

Contents

The Research Associateship Program

Since 1954, the National Research Council (NRC) has conducted the Research Associateship Program (RAP) in cooperation with sponsoring Federal laboratories and other approved participating research organizations. RAP provides highly skilled and exceedingly promising postdoctoral and senior scientists and engineers with opportunities to research problems that are compatible with the interests of sponsoring laboratories. RAP offers recent doctoral graduates opportunities for concentrated research with selected members of permanent, professional, laboratory staff and allows them to contribute to the overall efforts of the laboratories.

The Federal Highway Administration (FHWA) has participated in RAP since 1992. To supplement the expertise of permanent staff, FHWA's Turner–Fairbank Highway Research Center (TFHRC), through its Exploratory Advanced Research (EAR) Program, invites researchers with appropriate backgrounds to investigate specific problems on a short-term basis across a wide range of topics and disciplines.

NRC provides a process for selecting candidates on a competitive merit basis and, subsequently, for administration of the resident fellows during their tenures at FHWA. The process begins with a prospective FHWA adviser developing a proposed research opportunity. The adviser then coordinates with FHWA leadership to approve the opportunity and forward the proposed research to NRC. All research opportunities require an abstract that relates to exploratory advanced research and is of specific relevance to the FHWA research program. One of the significant benefits of this process is that it encourages interaction between government researchers and new researchers who are using cutting-edge approaches and research tools in their work.

RAP provides opportunities for FHWA's EAR Program to advance research methods used at TFHRC. Over the years, associates have researched topics as diverse as nano-additives for concrete and asphalt, alternative intersection and interchange design, and modeling to predict collisions based on driver behavior and environmental conditions.

The following pages contain summary descriptions of some of the research projects that the resident fellows have been involved in during their respective tenures at FHWA.

The EAR Program addresses the need for longer term, higher risk research with the potential for long-term improvements to transportation systems—improvements in planning, building, renewing, and operating safe, congestion-free, and environmentally sound transportation facilities. The EAR Program seeks to leverage advances in science and engineering that could lead to breakthroughs for critical, current, and emerging issues in highway transportation—where there is a community of experts from different disciplines who likely have the talent and interest in researching solutions and who likely would not do so without EAR Program funding.

PROJECT: **Performance of Geosynthetic-Reinforced Soils at the Service Limit State**

ASSOCIATE: Danial Esmaili

SCHOOL: University of Oklahoma

PERIOD: December 2014–October 2015

OBJECTIVE: To analyze large-scale performance test results to evaluate the effect of tensile strength, vertical reinforcement spacing, facing elements, and backfill properties on deformations of geosynthetic-reinforced soil under typical bridge support service pressures.

ADVISER: **Jennifer E. Nicks,** FHWA Office of Infrastructure Research and Development

SUMMARY: Geosynthetic-reinforced soil (GRS) technology consists of closely spaced layers of geosynthetic reinforcement and compacted granular fill material. This method of using geosynthetics to reinforce foundations is a proven alternative to the construction of deep foundations, depending on the site conditions. GRS is widely used for a variety of earthwork projects, particularly in GRS-integrated bridge system (IBS) applications. GRS-IBSs are economical and easy to design; they can be built in a variety of weather conditions and can be modified to accommodate characteristics of varying site conditions. An important geotechnical feature of any bridge foundation, including GRS bridge elements, is the service limit state (SLS), which ensures the durability and serviceability of a bridge and its structural components under everyday loads for the design life.

The SLS for GRS abutments primarily includes vertical settlement, lateral deformation, and reinforcement strain. Notwithstanding their widespread use in construction, the SLSs of GRS abutments have not been well defined.

Danial Esmaili's research project involved analyzing the results of a series of 13 large-scale column experiments (also called performance tests or minipier tests) conducted to help quantify both the SLS and ultimate limit state for GRS. The experiments were conducted on GRS piers consisting of different backfill materials, geosynthetic reinforcement strengths, and reinforcement spacing (the thickness of backfill between reinforcement layers). Some test piers were constructed with concrete masonry facing; others had no facing. All GRS configurations were tested to failure, with the focus of this study on the performance at loads of 200 kPa (recommended allowable GRS bearing pressure) and 400 kPa (to test performance at extreme service loading). Key research findings of these experiments are that:

- GRS piers built with higher strength backfill undergo less lateral and vertical deformation.
- Settlement and lateral displacement at 200 kPa, depending on composition of test columns, ranged from 8.3 mm to 33.9 mm and 3.0 mm to 10.1 mm, respectively.
- Reinforcement spacing plays a larger role than does reinforcement strength in lateral and vertical deformation.
- Lateral movement of pier walls is greatest in the top third of the composite.
- Limiting-bearing pressure to 10 percent of the estimated bearing resistance of the GRS abutment will limit axial strains to within 0.5 percent of the abutment.

IMPACT: Data gathered through these experiments will help engineers more reliably design GRS-IBS projects without having to conduct complex and expensive laboratory testing.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined below.

Nicks, J. E., Esmaili1, D., & Adams, M. T. (2016). Deformations of geosynthetic reinforced soil under bridge service loads. *Geotextiles and Geomembranes, 44*(4), 641–653.

Adams, M. T., Ooi, P. S. K., Nicks, J. E. (2014). Mini-pier testing to estimate performance of full-scale geosynthetic reinforced soil bridge abutments. *Geotechnical Testing Journal, 37*(5).

Minipier tests helped quantify SLS for GRS with (upper photo) and without (lower photo) concrete masonry facing.

PROJECT: **Use of Inorganic Coatings as Curing Compounds**

ASSOCIATE: **Jessica Silva**

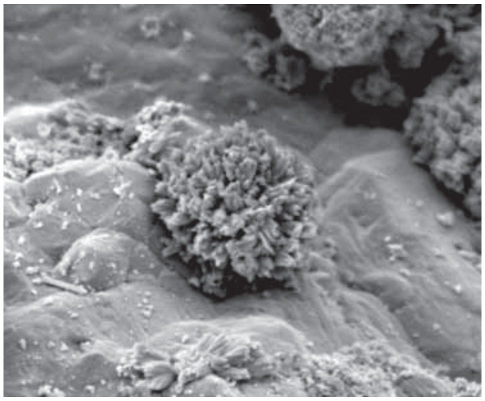
SCHOOL: University of Wisconsin–Madison

PERIOD: September 2012–December 2013

OBJECTIVE: To develop inorganic curing compounds to address the shortcomings of current organic membrane-forming curing compounds.

ADVISER: **Jack S. Youtcheff,** FHWA Office of Infrastructure Research and Development

SUMMARY: Proper curing is a vital post-treatment process when constructing durable concrete pavements. This is because water loss by evaporation through exposed surfaces can result in mechanical or chemical deficiencies in the final surface of the concrete product. Existing membrane-forming curing compounds are widely used to form a physical barrier to prevent the migration of water during the first few hours of concrete placement; however, these membranes do not always form a continuous coating, may degrade after environmental exposure, and provide little protection of the concrete section at later stages of the pavement's service life. Jessica Silva's research project examined the use of inorganic curing compounds to address the shortcomings of current organic compounds. These inorganic curing compounds, prepared from metal-oxide materials, can react with the concrete surface to form durable coatings and hydration products. The compounds may also impart beneficial characteristics to the roadway and provide improvements to the pavement long after traditional membranes. Silva examined changes occurring to the air and mortar and mortar and aggregate interface, in addition to the porosity, density, and chemical makeup of the cement paste. Silva also ensured that the inorganic curing compounds under development would not adversely affect the concrete material. As part of this research project, Silva used a traceable element to better understand the effect of the compound as it penetrates the concrete.



Nucleation of ettringite mineral in the interfacial transition zone.

IMPACT: This research could represent a paradigm shift in the world of curing compounds. In addition, if the material developed as a result of this research is not ultimately useful as a curing compound, it may still prove useful to enhance general concrete characteristics.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined below.

Silva, J. M. S., Youtcheff, J., & Arnold, T. (2013). Utilizing sol-gel nanoparticles in concrete curing to improve surfaces. *National Research Council Research Associateship Programs Newsletter,* 14–16.

Munoz, J. F., Silva J. M. S., Perry L., Youtcheff, Y., & Sobolev K. (2014). Interaction of amorphous nano-aluminosilicates with cement pore solution and the effect on the early hydration reaction of portland cement. Proceedings of the *Fifth International Symposium on Nanotechnology in Construction.*

PROJECT: **Developing New Vehicle–Tire and Contact Friction Models**

ASSOCIATE: Emmanuel Bolarinwa

SCHOOL: University of Birmingham

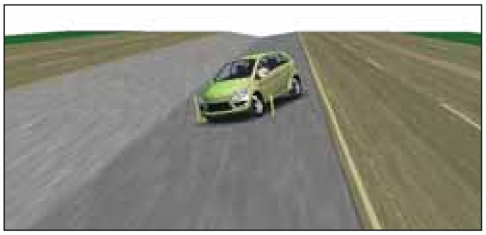
PERIOD: September 2010–September 2015

OBJECTIVE: To use a model-based approach for investigating the effect of tire–pavement contact friction on the safety performance of vehicles.

ADVISER: **James A. Sherwood,** FHWA Office of Infrastructure Research and Development

SUMMARY: The effective management of critical pavement surface characteristics, such as friction and texture, has been shown to help prevent or reduce the consequences of rear-end and run-off-the-road crashes. Although high-friction surfaces can lead to increased numbers of dry pavement rollovers, they also lead to fewer wet pavement run-off-the-road crashes and tend to have fewer crashes involving fatalities and serious injuries. For his research project, Emmanuel Bolarinwa implemented a model-based approach to investigate the effect of variations in vehicle– and tire–pavement friction on vehicle safety performance, such as stopping distances during braking. He considered the interactions among key crash causative factors and predicted vehicle performance and stability metrics. Bolarinwa examined a vehicle simulation package containing various values for pavement friction and texture inputs. For model verification, Bolarinwa obtained vehicle data and crash information from the Highway Safety Information System (HSIS) and the second Strategic Highway Research Program's naturalistic driving study. He then used the model to develop theoretical thresholds for pavement friction and texture inputs (i.e., the minimum values when crash rates have been found to increase at a significantly higher rate). Bolarinwa analyzed results from the simulation to extract vehicle performance and safety metrics as possible indicators of the onset of vehicle crashes for different vehicle types and a variety of road sections and geometries.

IMPACT: This research should lead to enhanced road safety, ensuring significant savings in cost and human lives by managing pavement friction. The research directly contributes to FHWA's strategic safety improvement program by predicting friction threshold values to determine conditions when a pavement should be investigated for maintenance intervention. Bolarinwa's research will lead to better characterization of the effects of a broad range of human, vehicle, and environmental factors on crash outcomes. It will also provide a basis for evaluating practices related to pavement surface material parameters and roadway geometry. FHWA will ultimately use the results of this research to develop new vehicle crash models, which will be of value to safety engineers working on state highway safety improvement programs. In addition, the results could be used to change pavement design standards to select the best pavements in terms of safety.



A simulation model for investigating vehicle behavior on a sloped terrain surface.

ONGOING RESEARCH: Bolarinwa will continue research into the development of theoretical threshold values for pavement friction and develop procedures for predicting stopping distances based on the friction of the pavement surface. The long-term goal is to reduce fatal and severe (incapacitating injury) crashes, by prescribing levels of pavement friction and macrotexture.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined below.

Uzunsoy, E., Bolarinwa, E., Olatunbosun, O., & He, R. (2014). *Investigating vehicle behavior on a sloped terrain surface.* SAE Technical Paper 2014-01-0857.

Yang, X., Olatunbosun, O., Ramos, D. G. P., & Bolarinwa, E. (2013). Experimental investigation of tire dynamic strain characteristics for developing strain-based intelligent tire system. *SAE International Journal of Passenger Cars–Mechanical Systems, 6*(1), 97–108.

Bolarinwa, E. O., Mahadevaiah, U., Marzougui, D., & Opiela, K. S. (2012). The development of an enhanced finite element tire model for roadside safety hardware assessment. *Proceedings of the Institution of Mechanical Engineers, Part K: Journal of Multi-Body Dynamics, 226*(3), 206–219.

Bolarinwa, E. O. (2014). *Material and geometrical characterization for FE tire modeling and simulation.* Paper presented at the 2014 Tire Technology Expo Conference, Cologne, Germany.

Bolarinwa, E. O. (2013). *Development of an FE tire model for vehicle crash simulations.* Paper presented at the 2013 Tire Technology Expo Conference, Cologne, Germany.

Bolarinwa, E. O. (2013). *Experimental investigation of vehicle behavior on a sloped-terrain surface.* Paper presented during the SAE 2013 World Congress and Exhibition, Detroit, MI.

Bolarinwa, E. O. (2012). *Role of tire testing in efforts to develop improved finite element models to support crash simulation.* Workshop on Improving the Modeling of Tire, Steering and Suspension Systems in Angular Crashes, FHWA Turner–Fairbank Highway Research Center, McLean, VA.

Bolarinwa, E. O. (2011). *The development of an enhanced finite element tire model for vehicle crash simulations.* Paper presented at the 30th Annual Conference on Tire Science and Technology, Akron, OH.

Bolarinwa, E. O. (2011). *Role of tire testing in efforts to develop improved finite element vehicle models to support crash simulations.* Paper presented at the 2011 Tire Technology Expo Conference, Cologne, Germany.

PROJECT: **Comprehension and Development of Nano-Additives to Judicially Improve the Interfacial Region in Concrete and Asphalt**

ASSOCIATE: Jose Muñoz

SCHOOL: University of Wisconsin–Madison

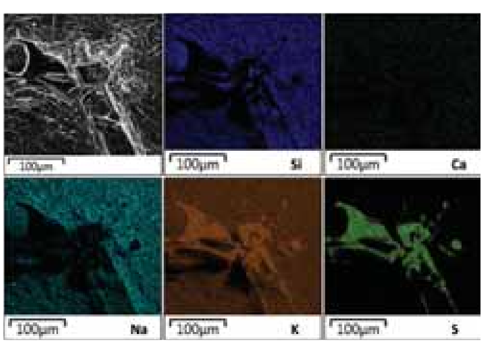
PERIOD: April 2010–March 2013

OBJECTIVE: To investigate how judicially applied coatings on the surface of the aggregates of different nano-additives can improve the interfacial region in concrete and asphalt.

ADVISER: **Jack S. Youtcheff,** FHWA Office of Infrastructure Research and Development

SUMMARY: Jose Muñoz examined a method to enhance the area of contact between cement-paste aggregates and asphalt aggregates, known as the *interfacial region*. This is one of the most vulnerable areas of concrete and asphalt, potentially affecting the overall performance of pavement. The durability of concrete is highly influenced by its pore structure, specifically a highly porous area known as the *interfacial transition zone* (ITZ). Large fractions of the microcracks occurring in concrete are associated with the ITZ; therefore, improving the strength of the ITZ could significantly improve concrete durability. Traditional approaches to the problem, involving the successive addition of different silicon or aluminum-based materials, have been inefficient and costly. Muñoz based his research on the theory that nanoparticles added as nanoporous films, and when judiciously placed on the aggregate surface, can greatly improve the ITZ and thereby the performance of the concrete. He investigated changes triggered by nanoporous thin films in the chemistry and morphology of the hydration products located at the aggregate–cement-paste interface. Muñoz developed a model to determine two-dimensional spatial distribution of cement hydration phases and to study the aggregate–cement-paste interface in concrete. In addition, Muñoz developed a new sol-gel synthesis (a method for producing solid materials from small molecules) to produce "nano-aluminosilicate" gels with a controlled silicon-to-aluminum ratio. Muñoz also studied the effect of these nano-aluminosilicate gels with different silicon-to-aluminum ratios on the hydration reaction of portland cement.

IMPACT: The development of new nano-additives, together with a new method for applying them in concrete, is expected to help create materials with less water and chloride penetrability and higher mechanical strength and resistance to cracking. This is expected to lead to the creation of construction materials with improved characteristics and less energy demand for maintenance operations. The application of nanoparticles in concrete and asphalt, using dip- or spray-coating methods, offers several advantages when compared with the traditional addition of nanoparticles as powder additives. It is an easier and safer application method—fewer additives are required, which reduces costs—and the technology is already available. In addition, this technology can have a positive impact in locations with limited or marginal-quality aggregate sources. For example, these nano-additives can be used to improve performance of currently marginal aggregates, such as natural aggregate with significant contents of clay minerals strongly adhered to their surface.



Backscattered electron images of a potassium sulfate crystal formed inside of a silica gel in the interfacial transition zone.

ONGOING RESEARCH: Muñoz continues to study the effect of the nanoparticles in concrete pore solution at early stages of hydration. In addition, he also performed research with the U.S. Army Engineer Research and Development Center to characterize the ITZ modified with nanoparticles.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined below.

Muñoz, J. F., Meininger, R. C., & Youtcheff, J. (2010). New possibilities and future pathways of nanoporous thin film technology to improve concrete performance. *Transportation Research Record, Journal of the Transportation Research Board, 2142,* 34–41.

Muñoz, J. F., Yao, Y., Youtcheff, J., & Arnold, T. (2011). Nanotechnology to improve aggregate performance. *National Research Council, Research Associateship Program Newsletter.*

Muñoz, J. F., Yao, Y., Arnold, T., & Youtcheff, J. (2013). Mixtures of silicon and aluminum oxides to optimize the performance of nanoporous thin films in concrete. *Cement and Concrete Composites, 48.*

Munoz, J. F., Silva, J. M. S., Perry, L., Youtcheff, Y., & Sobolev, K. (2014). Interaction of amorphous nano-aluminosilicates with cement pore solution and the effect on the early hydration reaction of Portland cement. Proceedings of the *Fifth International Symposium on Nanotechnology in Construction.*

Balachandran, C., Muñoz, J. F., Arnold, T., & Youtcheff, J. (2014). Potential application of surface enhanced Raman spectroscopy as a tool to study cementitious materials. Proceedings of the *Fifth International Symposium on Nanotechnology in Construction.*

PROJECT: **Integrating Driving Simulation and Other Behavioral Data: Assessment of Driver Behavior and Performance**

ASSOCIATE: Alicia Romo

SCHOOL: The University of Texas at El Paso

PERIOD: September 2013–August 2015

OBJECTIVE: To develop methods that will use data from various sources, such as driving simulator experiments, crash databases, and naturalistic driving studies, to gain comprehensive understanding about road-user behaviors.

ADVISER: **C. Y. David Yang,** FHWA Office of Safety Research and Development

SUMMARY: A high percentage of transportation incidents and vehicle crashes are caused by human errors. As a result, it is important to continue investing in research resources to gain a comprehensive understanding of human errors and to try to answer the question, “Why do drivers and travelers do what they do?” A number of different datasets have recently become available to analyze human errors; however, these datasets point in different directions within different areas of interaction. Alicia Romo’s research project is focused on finding methods to combine data from different sources to gain better understanding about road-user behavior. During the first year, Romo conducted a comprehensive literature review and summarized information from more than 100 technical journals and reports about various methods to study road-user behavior and types of available behavioral data. Based on the information from this literature review, Romo has since developed a framework to categorize behavior data from various sources, such as crash databases, driving simulator experiments, field test vehicle studies, and naturalistic driving studies. Romo’s research will show the benefit of using information from multiple data sources to study behavioral issues instead of relying on just one data source.

The relationship between research methods and impacting factors.
Note: There are five empirical factors that can be used to evaluate the quality of data and the analysis performed. The five factors are: driving states, risk, level of control, measurements, and validity. The five factors presented in this figure explain the similarities, differences, advantages, and disadvantages among the different research methods.

IMPACT: This research project is expected to demonstrate one or more methods of using data from various sources to better understand road-user behavior. The concept of combining and using behavioral data from multiple sources is relatively new, and this work will pave the way for others to follow. Results from this project will clearly show many benefits of combining data to better understand behavior issues. Integration of human behavior collected using different methods could lead to faster design and testing of safety countermeasures and new geometric designs, resulting in fewer crashes and potentially saved lives. The integration of different human behavior data also could provide safe and effective methods for studying and testing emerging connected-vehicle and automation technologies.

ONGOING RESEARCH: The second year of Romo’s research will concentrate on demonstrating applicability of fusing data from sources, such as driving simulator experiments and naturalistic driving studies, to gain an indepth understanding about certain behaviors.

RESOURCES: Several publications resulted from this RAP research. They are outlined below.

Romo, A., Mejia, B., & Yang, C. Y. D. (2014). *Utilizing various data sources for surface transportation human factors research: workshop summary report* (Publication No. FHWA-HRT-14-077). FHWA Turner–Fairbank Highway Research Center, McLean, VA. View the report at http://www.fhwa.dot.gov/advancedresearch/pubs/14077/index.cfm.

Romo, A., Yang, C. Y. D. (2015). The science and art of putting drivers under the microscope. *Public Roads, 78*(5). Federal Highway Administration Pub. No. FHWA-HRT-15-003.

PROJECT: **Operational and Safety Analyses of Alternative Intersection/Interchange Designs**

ASSOCIATE: **Nopadon Kronprasert**

SCHOOL: Virginia Polytechnic Institute and State University

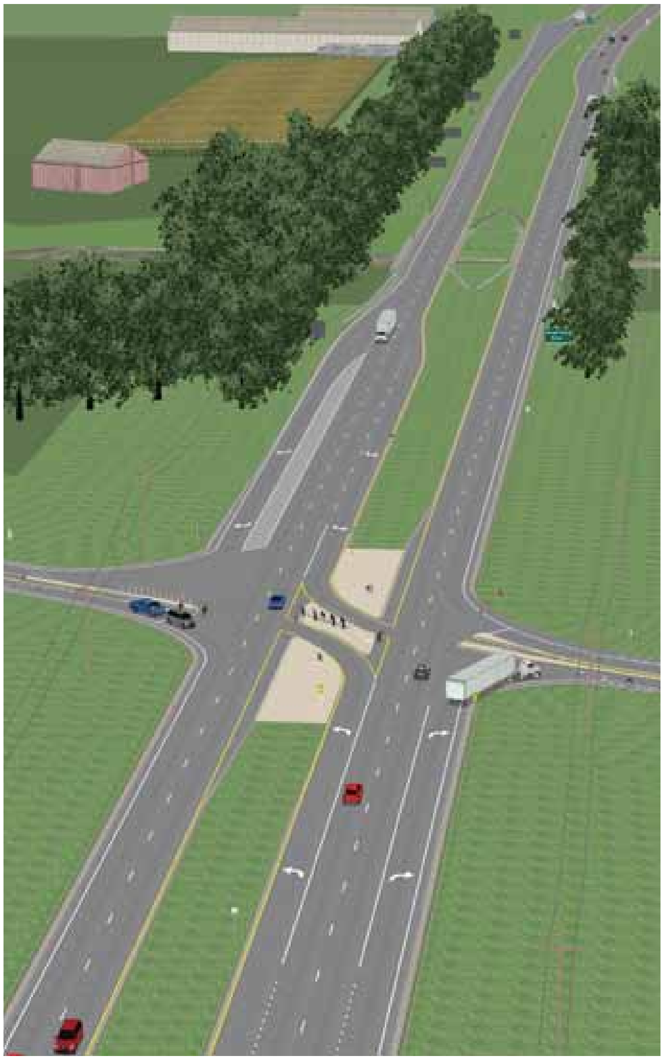
PERIOD: November 2012–April 2014

OBJECTIVE: To evaluate operational and safety impacts when implementing alternative intersection and interchange designs.

ADVISER: **Wei Zhang,** FHWA Office of Safety Research and Development

SUMMARY: Transportation and traffic professionals working on today's highway improvement projects face daunting pressures from the needs of different stakeholders to provide safe, efficient, and cost-effective intersections and interchanges. FHWA recently proposed several alternative intersection and interchange designs to improve the safety- and mobility-related issues across the Nation. These new intersections and interchanges include displaced left-turn, median U-turn, and restricted-crossing U-turn intersections, as well as the double-crossover diamond interchange. It is important to evaluate how efficient the new designs will be and to identify the traffic conditions that will deliver the best cost–benefit performance. In accordance with this objective, Nopadon Kronprasert's research project investigated operational and safety measures and evaluation procedures, analyzed proposed designs at different evaluation sites, and developed mathematical models for evaluating operational and safety measures for different intersection and interchange designs. Kronprasert used microscopic traffic simulation to model characteristics and behaviors of traffic systems and to evaluate the performance of alternative designs. This is a cost-effective method to compare different designs, predict potential impacts, replicate real-world phenomena, and provide valuable insights into the effects on operational and safety performance. Kronprasert conducted his research based on problems derived from real projects. As part of the technical support to State departments of transportation, he performed traffic simulation studies of three double-crossover diamond interchanges, three restricted-crossing U-turn intersections, and six miniroundabout projects.

IMPACT: As of October 2014, at least one restricted-crossing U-turn and three miniroundabouts Kronprasert worked on have been constructed and opened to traffic. Many of the performance predictions stated in his research are being verified in the field. The results will help analysts understand the relationships between



A screen capture of an intersection based on Nopadon Kronprasert's simulation input.

the features of alternative designs and their operational and safety benefits. The research will ultimately help practitioners to find the best course of action when implementing alternate designs and also will help highway engineers and the public understand the benefits and impacts.

ONGOING RESEARCH: Wei Zhang is continuing to conduct research on alternative intersection and interchange designs, building on Kronprasert's work. Zhang and Kronprasert are also collaborating on at least two more research papers.

A screen capture of the simulation video created by Nopadon Kronprasert.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined below.

Krause, C., Kronpraset, N., Bared, J., & Zhang, W. (2015). Operational advantages of dynamic reversible left-lane control of existing signalized diamond interchanges. *Journal of Transportation Engineering, 141*(5).

Zhang, W., & Kronprasert, N. (2014). The ABCs of Designing RCUTs. *Public Roads, 78*(2), 9–13.

Zhang, W., & Kronprasert, N. (2014). *Unlock DDI's capacity potential by implementing relaxed bowtie, superstreet, and quadrant road design at adjacent signal intersections.* Presented at the Second International Conference on Access Management, Shanghai, China.

Zhang, W., & Kronprasert, N. (2014). *Unlock diverging diamond interchange's capacity potential using relaxed bowtie design at adjacent signalized intersection.* Presented at the Transportation Research Board's Alternative Intersections and Interchanges Symposium, Salt Lake City, UT.

Zhang, W., & Kronprasert, N. (2014). *Crash prediction models for rural restricted crossing U-turn intersections.* Presented at the Transportation Research Board's Alternative Intersections and Interchanges Symposium, Salt Lake City, UT.

Zhang, W., & Kronprasert, N. (2014). *Mini-roundabout case studies.* Presented at the Transportation Research Board's International Roundabout Conference, Seattle, WA.

Zhang, W., Kronprasert, N., & Gustafson, J. (2014). *Unclog local network congestion using high-capacity mini-roundabouts: A feasibility study.* Presented at the Transportation Research Board's 93rd Annual Meeting, Washington, DC.

Lochrane, T., Kronprasert, N., Bared, J., Dailey, D., & Zhang, W. (2014). Determination of mini-roundabout capacity in the United States. *Journal of Transportation Engineering, 140*(10).

Zhang, W., & Kronprasert, N. (2013). *Restricted crossing U-turn intersection design for improving safety and mobility at high-speed stop-controlled intersections.* Presented at the Road Safety and Simulation International Conference, Rome, Italy.

Zhang, W., Kronprasert, N., & Bared, J. G. (2013). *Visualizing the benefits of restricted crossing U-turn intersection design at high-speed two-way stop-controlled intersections.* Presented at the Transportation Research Board's Seventh International Visualization in Transportation Symposium, Irvine, CA.

PROJECT: **Utilizing Naturalistic Driving Data and Highway Safety Information System to Advance Highway Crash Data Modeling Concepts and Methods**

ASSOCIATE: **Kun-Feng Wu**

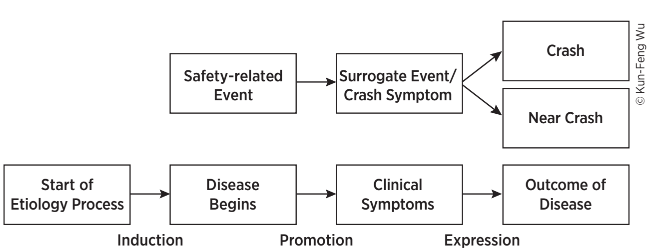
SCHOOL: Pennsylvania State University

PERIOD: July 2012–June 2013

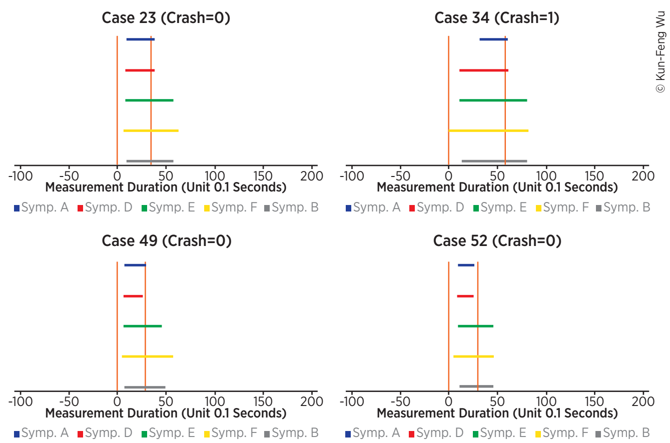
OBJECTIVE: To advance safety analysis using surrogate safety measures and improve the evaluation of intervention effectiveness.

ADVISER: **Craig P. Thor,** FHWA Office of Safety Research and Development

SUMMARY: Kun-Feng Wu's research project builds on 40 years of research concerning the development of crash surrogates for assessing traffic safety. The term *crash surrogate* refers to a crash or near-crash event, defined in this project by a set of driver or event attributes, driving environment, and kinematic variables. Researchers use crash surrogates because crashes are rare events, making it hard to draw statistically valid conclusions about contributing factors. Surrogate event counts can be used to predict the expected number of crashes and identify sites with promise for improvement by knowing the number of surrogate events at each intersection. Wu investigated a sequence of statistical tests with the overall goal of validating surrogate events and facilitating their use in enhanced safety analyses. Wu used raw naturalistic driving data, including vehicle kinematic, video, and location information, to produce sets of specific conditions that identify crashes and near crashes (i.e., surrogate events). Wu tested the procedure on a small, 100-car naturalistic driving study dataset, conducted by the Virginia Tech Transportation Institute, with successful results. A second validation procedure compared these results with the number of crashes observed in HSIS data, a multistate database that contains crash, roadway inventory, and traffic volume data for a select group of States. Wu's research extends research already completed in the joint use of crash events and surrogate events in a structured framework. His research project specifically compared surrogate analyses of countermeasure effectiveness and sites with improvement potential to comparable HSIS studies. Wu applied the same methods to evaluate the Integrated Vehicle-Based Safety System dataset (an initiative designed to develop and field test an integrated safety system on light vehicles and commercial trucks). In addition, Wu expanded the procedures to include diagnostic analytical techniques borrowed from medical science. These statistical methods allow for a more accurate assessment of the presence of surrogate events.



A schematic that relates the crash progression process to the etiological process of disease progression.



The crash symptoms (horizontal lines) as they compare to manual identification of a crash-related event (vertical red lines). This exhibits the potential of surrogate measures to predict safety-related events based on kinematic and environmental factors.

IMPACT: Specific conditions for defining surrogate events could be further tested and studied through driving performance assessment and may ultimately lead to improved understanding of inappropriate driving behaviors, driver responses, roadway design, and operational deficiencies. In addition, crash surrogate studies could ultimately reduce the time needed to develop a sufficient sample size for analysis. These studies would enable researchers to develop models with greater prediction precision and understand the factors that contribute to crashes. Decreasing the time and increasing the precision of factors that contribute to crashes allow faster development and implementation of better countermeasures, thereby reducing crashes and potentially saving lives.

RESOURCES: The papers that resulted from this RAP research are outlined below.

Wu, K. F., Thor, C., & Ardiansyah, M. N. (2016). Identify sequence of events likely to result in severe crash outcomes. *Accident; Analysis and Prevention, 96*:198-207.

Wu, K. F., & Thor, C. (2015). Method for the use of naturalistic driving study data to analyze rear-end crash sequences. *Transportation Research Record, Journal of the Transportation Research Board, 2518*(2518):27-36.

PROJECT: **Developing Frameworks of Performance-Based Asphalt Mix Design**

ASSOCIATE: Jong-Sub Lee

SCHOOL: North Carolina State University

PERIOD: September 2015–April 2016

OBJECTIVE: To investigate use of mechanistic models to evaluate voids in mineral aggregate (VMA), design air void content, and in-place air void content as parameters for reliably predicting field performance of various asphalt mix designs.

ADVISER: **Katherine Petros,** FHWA Office of Infrastructure Research and Development

SUMMARY: Performance-related specifications (PRS) will offer engineers, contractors, and funding agencies a way to assess future performance, maintenance requirements, and lifecycle costs for highway construction projects. PRS can be thought of as a set of quality assurance specifications that describe the desired levels of key materials and construction-acceptance quality characteristics that correlate with fundamental engineering properties that predict performance. PRS will rely on models that objectively assess performance based on observed construction-quality characteristics related to fundamental engineering properties and will:

- Utilize testing that focuses on key measureable characteristics related to performance.
- Use pavement design assumptions as a basis for construction performance.
- Incorporate incentives and disincentives based on modeled performance.
- Allow contractors to innovate and be competitive.
- Reduce long-term monitoring and management.

When fully developed, PRS will employ the quantified relationships containing the characteristics to predict as-constructed pavement performance. Thus, PRS will provide the basis for rational acceptance and pay-adjustment decisions related to highway construction projects.

Jong-Sub Lee's research helped develop a testing and modeling framework for performance-based asphalt mix design. The goal was to identify the effect of volumetric mix design targets (design VMA and design air void) and compaction level (in-place air density) on fatigue characteristics and performance. The project investigated asphalt mixtures based on the Superpave® mix design system (developed through the Strategic Highway Research Program) using mechanistic analyses based on the viscoelastic continuum damage (VECD) analyses and mechanistic–empirical pavement analysis using the AASHTOWare Pavement ME Design® program. The analyses included the simplified VECD model at the material level and two structural models: (a) layered viscoelastic analysis and (b) layered viscoelastic pavement analysis for critical distresses.

Key performance-related findings of the research include:

- The damage state at failure is increased (i.e., better fatigue performance) with an increase in the design VMA and a decrease in the in-place air void and design air void content. The design VMA is more sensitive than the others.
- Fatigue life was found to improve when the value of the design VMA was increased and the in-place air void content and design air void content was decreased in rank of sensitivity.
- Superpave® mix design parameter of design VMA was the most sensitive parameter that significantly affected the linear viscoelastic property, damage characteristic, and fatigue life in the mechanistic analysis.
- The effect of the design air void on mechanistic fatigue life was diminished as the pavement thickness increased.
- Increasing the design VMA content caused the least amount of fatigue cracking area at the thin pavement.

IMPACT: Data gathered through this research will contribute to the development of testing and modeling protocols that can be used to develop PRS for asphalt mix design.

RESOURCES: The following reports resulted from this RAP research and are outlined below.

Lee, J-S., Kim, Y. (2014). Performance-based moisture susceptibility evaluation of warm-mix asphalt concrete through laboratory tests. *Transportation Research Record, Journal of the Transportation Research Board*, 2446.

Lee, J., Norouzi, A., and Kim, Y. R. (2016). Determining specimen geometry of cylindrical specimens for direct tension fatigue testing of asphalt concrete. *Journal of Testing and Evaluation, 45*(2).

Lee, J-S., Gibson, N., Kim, Y. R. (2015). Use of mechanistic models to investigate fatigue performance of asphalt mixtures: effects of asphalt mix design targets and compaction. *Transportation Research Record, Journal of the Transportation Research Board*, 2507.

Performance Specifications for Rapid Renewal (R07). AASHTO Strategic Highway Research Program at http://shrp2.transportation.org/Pages/R07 PerformanceSpecificationsforRapidRenewal.aspx

Balis, J., & Platte, K. (n.d.). Performance specifications to speed construction, reduce oversight, and encourage innovative approaches: Performance specifications for rapid renewal (R07). *SHRP2 Solutions.*

The following Web site provides insight on the FHWA UHPC research portfolio: https://www.fhwa.dot.gov/construction/ pssr0402.cfm

PROJECT: **Developing and Implementing Dynamic Junction Control System in the United States**

ASSOCIATE: **Ximiao Jiang**

SCHOOL: University of Tennessee, Knoxville

PERIOD: October 2013–May 2015

OBJECTIVE: To investigate the efficiency of dynamic merge control (DMC) strategy at freeway merge areas.

ADVISER: **Joe Bared,** FHWA Office of Operations Research and Development

SUMMARY: Dynamic merge control (DMC) is a traffic management strategy that can be used to dynamically monitor and control traffic flow at freeway on- or off-ramps or where multiple-lane freeways merge—for example, where a 2-lane freeway merges with a 3-lane freeway into 4 lanes. DMC minimizes disruption that can occur, for example, when traffic volume on an on-ramp is significantly higher than on the freeway. In this case, ramp traffic must find gaps in lower volume freeway traffic, resulting in hesitation and delay and increasing the possibility of rear-end collisions. DMC strategy, now being used in Germany and the Netherlands, assigns priority to the high-volume traffic stream. In the example above, DMC could close the right lane of the main freeway and allow ramp traffic free access at the merge. DMC has not been implemented anywhere in the United States, and knowledge of the strategy is still experimental here.

Ximiao Jiang's research project used an analytical technique called microsimulation to examine the effectiveness of DMC on several road and traffic configurations. Microsimulation can effectively model the behavior of many individual vehicles within specified traffic environments, including merge queuing and congested road networks, to the point of gridlock. Dr. Jiang simulated DMC lane-closing strategy on two traffic configurations: the first, two 2-lane freeways merging into 3 lanes, and the second, a 3-lane freeway merging with a 2-lane freeway into 4 lanes. Simulations included traffic demands ranging from 1,000 vehicles per hour (vph) to 4,600 vph on 3 lanes and 2,500 vph to 6,500 vph on 2 lanes. In the simulations, signals notify drivers of lane closure 2,500 ft upstream of the lane closing and close the lane 1,000 ft upstream of the merge. The simulation assumed that drivers would be 100-percent compliant with lane closure. Fifteen runs were simulated for each scenario. Key findings of the simulations are:

- Implementing DMC strategy produced benefits in vehicle delay and speed at almost all demand combinations.
- When traffic demand on the minor roadway reached 1,900 vph per lane, DMC benefits became statistically and practically significant.
- DMC reduced lane changing in the merge area, thereby increasing capacity and delaying the formation of bottlenecks.

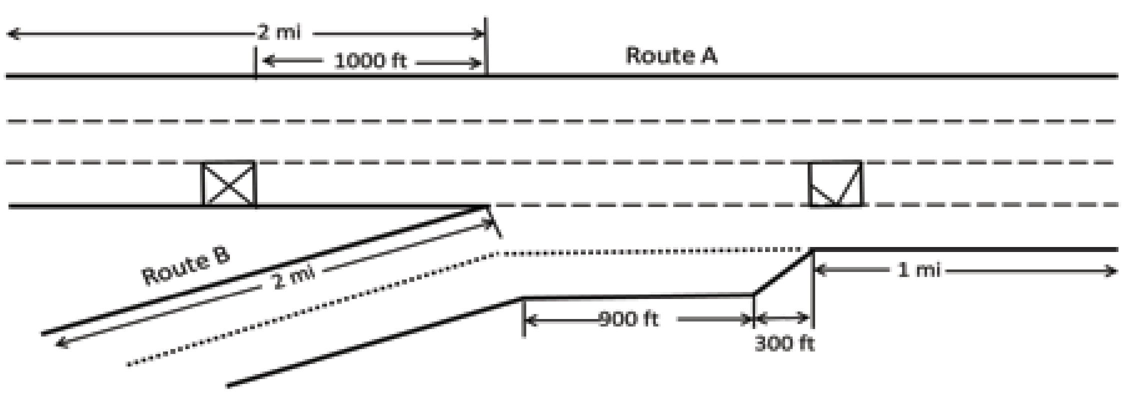
IMPACT: This research represents an important first step in evaluating the DMC strategy as an effective approach to reducing delays and congestion at freeway merge areas.

ONGOING RESEARCH: The next phase of DMC microsimulation will investigate varying closing locations and varying distances at which drivers are warned. The next phase also will investigate various closed-lane compliance ratios.

RESOURCES: Several publications resulted from this RAP research. They are outlined below.

Jiang, X., Gan, Q., Bared, J., Mannes, M., & Hale, D. (2015). Traffic performance analysis of dynamic merge control using micro-simulation. *Transportation Research Record, Journal of the Transportation Research Board*, 2484.

Zhang, Y., Jiang, X., Haghani, A., & Huang, B. (2015). Exploring nonlinear effects of traffic crash determinants using a novel poisson-mixed multivariate adaptive regression splines model. *Transportation Research Record, Journal of the Transportation Research Board*, 2515.



Microsimulation studies evaluated dynamic merge control in configurations such as a 2-lane freeway merging with a 3-lane freeway to form four traffic lanes.

From Jiang, X., J. Bared, M. Maness, and D. Hale. Traffic Performance Analysis of Dynamic Merge Control Using Microsimulation. *Transportation Research Record: Journal of the Transportation Research Board,* No. 2484, Figure 1, p. 24, 2015. Reproduced with permission of the Transportation Research Board.

PROJECT: **Tensile Response of Ultra-High Performance Concrete: Validation of Characterization Methods**

ASSOCIATE: **Luis Felipe Maya Duque**

SCHOOL: Polytechnic University of Madrid

PERIOD: June 2013–April 2016

OBJECTIVE: To critically assess the applicability of a recently proposed tensile-test method for ultra-high performance, fiber-reinforced concrete.

ADVISER: **Ben Graybeal,** FHWA Office of Infrastructure Research and Development

SUMMARY: Concrete is the most widely used construction material and has played a fundamental role in the development of infrastructure since the Romans. Advances in fiber-reinforced concretes over the last 50 years have enabled the development of an entirely new generation of cement-based composite materials. Ultra-high performance concrete (UHPC) represents a class of cement composites with high compressive strength and whose tensile response is characterized by high-strain capacity accompanied by multiple microcracking. To take full advantage of the tensile behavior of these UHPC materials, it is necessary to develop tensile-test methods and guidelines to be incorporated into codes and recommendations. Luis Felipe Maya Duque's research project focused on the assessment of proposed test methods designed to provide a reliable assessment of UHPC tensile behavior, not only in a research environment, but also for quality-control purposes in a production environment. Maya Duque assessed a singular direct tensile-test method that has already been the subject of FHWA research to establish advantages and drawbacks compared with existing methods. Maya Duque also conducted a critical review of the state of the art in tensile-test methods for UHPC. The research project included an extensive experimental campaign to properly assess the performance of the proposed tensile-test method. Furthermore, Maya Duque also considered the suitability of the direct tension test method to accurately reflect the influence of the fiber distribution and orientation in structural elements.

Casting of beam splice connection.

Full-scale flexural test of a beam splice connection made of UHPC.

IMPACT: This research allows for the development and implementation of a quality control test method for UHPC in a production environment. Broader use of UHPC could lead to more durable and longer lasting highway structures, reducing the cost and risks associated with reconstruction.

ONGOING RESEARCH: FHWA conducted over 120 direct tension tests on both mold-cast and sawed specimens to assess the influence of flow conditions, as well as fiber orientation and fiber distribution on the tensile response of UHPC. FHWA also performed flexural tests on UHPC strips and slabs to correlate the results from the material characterization tests with the mechanical response of structural elements. Those results will contribute to assessing the reliability of the current design approaches as well as to improving understanding of the main mechanisms and variables to be considered in the development of design codes and recommendations. Maya Duque continues to complete the assessment of the structural efficiency of fiber reinforcement in UHPC structures through an experimental and analytical validation process at FHWA. FHWA plans to conduct two full-scale beam tests at the TFHRC Structures Laboratory. The results of these tests will provide insight for the development of continuity connection using UHPC as an alternative to increase the span range currently covered by conventional, precast, prestressed concrete girders.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined below.

Maya, L. F., Zanuy, C., Albajar, L., Lopez, C., & Portabella, J. (2013). Experimental assessment of connections for precast concrete frames using ultra high performance fibre reinforced concrete. *Construction and Building Materials, 48*(11), 173–186.

Maya, L. F., Ruiz, M., Muttonni, A., & Foster, S. J. (2012). Punching shear strength of steel fibre reinforced concrete slabs. *Engineering Structures, 40,* 83–94.

Graybeal, B., & Baby, F. (2013). Development of a direct tension test method for ultra-high-performance fiber-reinforced concrete. *ACI Materials Journal, 110*(2) 177–186.

The following Web site provides insight on the FHWA UHPC research portfolio: http://www.fhwa.dot.gov/research/resources/uhpc/

PROJECT: **Prediction of Pavement Temperature Profiles Using Surface Temperatures: An Analytical Approach With Model Validation Based on Long-Term Pavement Performance Data**

ASSOCIATE: Dong Wang

SCHOOL: University of Illinois at Urbana–Champaign

PERIOD: June 2011–May 2013

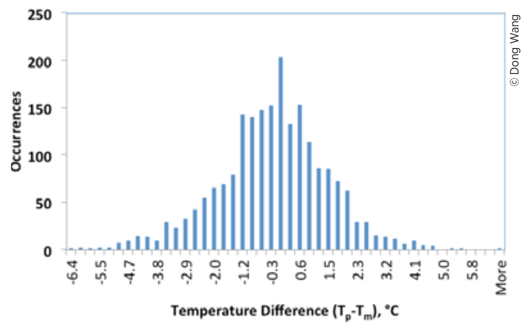
OBJECTIVE: To derive and field-validate an easily implementable algorithm for predicting temperature profiles in paving materials.

ADVISER: **Yan "Jane" Jiang,** FHWA Office of Infrastructure Research and Development

SUMMARY: The mechanical properties of paving materials are usually temperature-dependent, but to accurately back-calculate the elastic moduli of pavement layers (i.e., the pavement's resistance to being deformed elastically when a force is applied to it), time-dependent pavement temperature must be known. Knowing the temperature profile allows researchers to better characterize the properties of paving materials and predict pavement responses under traffic and environmental loadings. Dong Wang's research project investigated a new method for predicting time-dependent pavement temperature profiles with limited inputs. There are currently three main methods for predicting temperature profiles: statistics-based models, numerical, and analytical approaches. These existing methods require large databases of climatic, meteorological, and geographical data and several other inputs to predict temperatures for the algorithms to operate effectively. Current pavement-testing methods do not easily obtain the required climatic data; thus, these algorithms are subsequently limited in their ability to predict pavement temperature profiles. Wang focused his research effort on infrared pavement surface temperature data that can be easily obtained during pavement testing. This improved approach makes it possible to develop an entirely new algorithm for predicting a time-dependent pavement temperature profile that requires very limited inputs when compared with previous algorithms. The only inputs needed for this new method are infrared surface temperatures, initial pavement temperature profile, pavement geometry, and thermal properties of layer materials. Most important, unlike previous methods, no climatic data are required. To validate the new algorithm, when there are so many different types of pavement structures across regions with varied climatic conditions, an extremely large temperature dataset is required. To meet this requirement, Wang used data from the Long-Term Pavement Performance (LTPP) Program database for model validation.

IMPACT: Wang's research is expected to greatly benefit field engineers in characterizing pavement temperature for the purpose of analyzing and interpreting testing data. In addition, it could lead to high savings on pavement evaluation costs.

RESOURCES: Several publications and papers resulted from this RAP research. They are outlined in the following column.



Histogram of asphalt pavement subsurface temperature difference (predicted (T_p)-measured (T_m) temperature difference).

Wang, D. (2013). Prediction of asphalt pavement temperature profile during FWD testing: A simplified analytical solution with model validation based on LTPP data. *Journal of Transportation Engineering, 139*(1), 109–113.

Wang, D. (2012). Analytical approach to predict temperature profile in a multilayered pavement system based on measured surface temperature data. *Journal of Transportation Engineering, 138*(5), 674–679.

Wang, D. (2013). Simplified analytical approach to predict asphalt pavement temperature. *Journal of Materials in Civil Engineering, 27(12)*.

Wang, D. (2013). Prediction of asphalt pavement temperature profile during FWD testing: simplified analytical solution with model validation based on LTPP data. *Journal of Transportation Engineering*, 139(1).

Wang, D. (2012, July 5–7). *Prediction of time-dependent temperature profile in a slab.* Paper presented at the Third Advanced Workshop on Innovations and Modeling for Sustainable and Resilient Concrete Pavements, Quebec, Canada.

Wang, D. (2013, January 13–17). *Assessing BELLS3 equation in predicting asphalt layer temperature profile based on the latest LTPP FWD temperature data.* Paper presented at the 92nd Transportation Research Board Annual Meeting, Washington, DC.

Wang, D. (2013, January 13–17). *Simplified analytical approach to predict temperature profile within a PCC slab during FWD testing.* Paper presented at the 92nd Transportation Research Board Annual Meeting, Washington, DC.

Wang, D. (2012, January 22–26). *Model validation based on LTPP data to predict asphalt temperature profile.* Paper presented at the 91st Transportation Research Board Annual Meeting, Washington, DC.

Wang, D. (2012, January 22–26). *Prediction of temperature profile in a multilayered pavement system using measured surface temperature data: An analytical approach.* Paper presented at the 91st Transportation Research Board Annual Meeting, Washington, DC.

Getting Involved with the EAR Program

To take advantage of a broad variety of scientific and engineering discoveries, the EAR Program involves both traditional stakeholders (State department of transportation researchers, University Transportation Center researchers, and Transportation Research Board committee and panel members) and nontraditional stakeholders (investigators from private industry, related disciplines in academia, and research programs in other countries) throughout the research process.

Learn More

For more information, see the EAR Program Web site at www.fhwa.dot.gov/advanced research. The site features information on research solicitations, updates on ongoing research, links to published materials, summaries of past EAR Program events, and details on upcoming events.

EAR Program Results

The EAR Program strives to develop partnerships with the public and private sectors because the very nature of the EAR Program is to apply ideas across traditional fields of research and stimulate new approaches to problemsolving. The program bridges basic research (e.g., academic work funded by National Science Foundation grants) and applied research (e.g., studies funded by State departments of transportation). In addition to sponsoring EAR Program projects that advance the development of highway infrastructure and operations, the EAR Program is committed to promoting cross-fertilization with other technical fields, furthering promising lines of research, and deepening vital research capacity.

U.S. Department of Transportation
Federal Highway Administration

EXPLORATORY ADVANCED RESEARCH

FHWA-HRT-17-023
HRTM-30/02-17(1M)E