

## TR News November-December 2007: Highway Design and Construction: A 2020 Vision

### DETAILS

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# TR NEWS

NUMBER 253

NOVEMBER-DECEMBER 2007

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The aging highway infrastructure, increased traffic congestion, jeopardized safety, a dwindling highway workforce, the scarcity of high-quality materials, environmental issues, and inadequate funding—design and construction professionals view these not as roadblocks but as challenges and are working to provide a highway system acceptable to the traveling public in 2020 and beyond.

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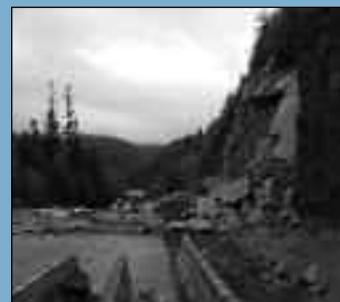
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COVER: The state of the art in highway design and construction carries ready links to future practice, solutions, and developments. Follow the icons for a guided tour.

# TR NEWS

features articles on innovative and timely research and development activities in all modes of transportation. Brief news items of interest to the transportation community are also included, along with profiles of transportation professionals, meeting announcements, summaries of new publications, and news of Transportation Research Board activities.

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# DESIGN & CONSTRUCTION 2020 AND BEYOND



## INTRODUCTION A 2020 VISION FOR HIGHWAY DESIGN AND CONSTRUCTION

L. DAVID SUITS

*The author is Executive Director, North American Geosynthetics Society, Albany, New York, and Chair, TRB Design and Construction Group.*

THE MOTORING PUBLIC KNOWS THAT OUR NATION'S HIGHWAY INFRASTRUCTURE IS AGING AND DECAYING. The recent collapse of the Interstate 35 West bridge in Minnesota has highlighted the problem. Increases in traffic congestion are inconveniencing all highway users and jeopardizing their safety. Less evident to the general public is the dwindling of our trained and experienced highway workforce. Moreover, high-quality materials are becoming scarce or inaccessible.

In addition, environmental issues dominate all aspects and phases of transportation projects. Natural forces, including earthquakes and hurricanes, have caused significant damage to the transportation infrastructure, and with global warming, the potential for increases in such events is alarming.

Yet the funding to provide a renewed and sustainable highway infrastructure is inadequate. Most of these issues were not even considered by those who embarked on construction of the Interstate Highway System 50 years ago. Today all professionals and managers in the highway industry face these issues daily, as they answer the challenge of providing a safe, reliable, and long-lasting highway system.

To highway design and construction professionals, the situation is what it is. Instead of looking at the issues as problems or roadblocks, they accept them as challenges. In dealing with these issues, which will continue into the near future, design and construction professionals remain committed to providing a highway system acceptable to the traveling public in 2020 and beyond.

In this special issue of *TR News*, authors representing the sections of the Design and Construction Group of the TRB Technical Activities Division look into the crystal ball at the future of their fields of expertise. The articles explore the design, materials, pavements, structures, construction, and preservation of tomorrow's highway infrastructure. Although the articles concentrate on highways, other modes of transportation face many similar situations, and the parallels are instructive.

EDITOR'S NOTE: Appreciation is expressed to TRB Senior Program Officers Frederick D. Hejl and G. P. Jayaprakash for their contributions in developing this issue of *TR News*.



# SUSTAINABLE SOLUTIONS THROUGH CREATIVE ENGINEERING

## TRANSPORTATION DESIGN FOR THE MOBILITY AND SAFETY OF ALL

ELIZABETH HILTON

*The author is Director, Plan Development, in the Design Division of the Texas Department of Transportation, Austin, and chairs the TRB Design Section.*

**T**ransportation design encompasses a range of disciplines, and practitioners must work cooperatively not only with other professionals but with many stakeholders in the development of transportation projects. The successful development of the transportation infrastructure for 2020 and beyond requires the recognition that the highway system is part of a larger whole. Designers must seek comprehensive infrastructure improvements that meet public demand for mobility, safety, and choice of mode.

### Mobility and Safety

The aging U.S. transportation system cannot keep pace with the demands for maintenance, modernization, and expansion to serve multimodal uses. Design solutions therefore must consider, adapt to, and integrate all users—that is, more than users of automobiles and trucks—to meet a range of needs within the constrained natural and human environments.

Paved and unpaved low-volume roads comprise the greatest length of road networks worldwide. Many public and private entities—often with extremely limited funding—are responsible for keeping these roads in good condition. Technical concerns of practitioners and researchers include minimizing the environmental impacts of maintenance, assessing the environmental effects of dust suppressants, and obtaining accurate traffic and crash data, as well as reliable information about the value of road assets.

Roadway congestion is a major challenge in urban areas. Adding lanes to an already strained urban system is not a sustainable solution. Transportation professionals must take the lead in focusing on the movement of people—not just of vehicles—as well as on the movement of goods. Transportation agencies must work with metropolitan planning organizations to develop systemwide plans to address congestion. The trend of tolling users for additional capacity will continue, as agencies grapple with funding shortfalls. Congestion pricing strategies increasingly will influence consumer choice of travel schedule and mode.

### Safety Evaluation

Transportation solutions will be evaluated in part by the level of safety provided to all users. Professionals designing the infrastructure will have to understand the relationship between users and facilities, including the ways that changes in various road features and element dimensions may affect quality of service and safety performance. Quantitatively estimating the safe performance of alternative designs is the goal of the *Highway Safety Manual*, now in development under the guidance of a TRB task force, applying research conducted under the National Cooperative Highway Research Program.<sup>1</sup>

<sup>1</sup> Related NCHRP project information and publications are available online: [www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=436](http://www.trb.org/TRBNet/ProjectDisplay.asp?ProjectID=436); [http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_rrd\\_286.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rrd_286.pdf); [http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp\\_w62.pdf](http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_w62.pdf).



The roadside environment—the area between the outside edge of the shoulder and the right-of-way limits—is critical to the safety of a highway facility. But because research on roadside features is conducted mostly in a laboratory environment, under conditions intended to represent worst cases, the full range of conditions that may occur in the field may not be adequately represented. Therefore an ongoing effort is needed to collect real-world data for evaluating highway and utility roadside features, identifying areas of needed research or improvement, and assessing the effectiveness of solutions. The Road Safety Audit (RSA) is a proven tool for identifying safety problems (see box, below).

**Crash Data and Testing**

Effort should focus on detailed crash data, in-service performance evaluation of roadside features, and improvements in roadside hardware inventories. With these kinds of data, researchers can explore the relationships between the driver, the vehicle, the roadway, and the roadside features during various run-off-road crashes. Improved communication is needed between automobile manufacturers and the roadside safety community, so that researchers can



PHOTO: CALIFORNIA PATH

Loop detectors in highway pavement can generate data on traffic conditions and travel time.

determine the effects of changes in vehicle design on the interaction of the vehicle with roadside hardware.

Because the costs of full-scale crash testing are increasing, designers will have to rely on finite element

**Road Safety Audit**

*Benefiting Any Roadway,  
Any Time*

ANTHONY R. GIANCOLA  
AND RONALD ECK

**A** Road Safety Audit (RSA) is a formal examination of the safety performance of a current or future road or intersection by an independent, multidisciplinary team. The audit qualitatively estimates and reports on potential road safety issues and identifies opportunities for improvements in safety for all road users. The Federal Highway Administration works with state and local jurisdictions and with tribal governments to integrate RSAs into the project development process for new roads and intersections and encourages RSAs on existing roads and intersections.

The aim of an RSA is to answer the following questions:

- ◆ What elements of the road may present a safety concern, to what extent, to which road users, and under what circumstances?
- ◆ What are the opportunities to eliminate or mitigate the safety concerns identified?



*A road safety audit identified a crosswalk (left) not visible to approaching motorists. A sign was installed to indicate the location of the crosswalk clearly (right) and to enhance pedestrian safety.*

RSAs are applicable in any phase of project development, from planning and preliminary engineering to design and construction, and for projects of any size, from minor intersection and roadway retrofits to megaprojects. For more information on RSAs, including training, visit [http://safety.fhwa.dot.gov/state\\_program/rsa/index.htm](http://safety.fhwa.dot.gov/state_program/rsa/index.htm) or contact your Local Technical Assistance Program or Tribal Technical Assistance Program center.

*Giancola is Executive Director, National Association of County Engineers, Washington, D.C., and Eck is Professor, Department of Civil and Environmental Engineering, West Virginia University, Morgantown, and Director, West Virginia Local Technical Assistance Program.*

analysis or computer simulation in developing roadside features (see box, below). In the past decade, computer simulation has become an invaluable tool for predicting test results and for supporting design or policy decisions. Through computer simulations, researchers will be able to optimize the design of hardware systems, reduce development costs with fewer crash tests, explore design configurations that would be prohibitively time consuming and costly with physical dynamic tests, and simulate many different scenarios at a fraction of the cost of full-scale testing.

### Project Development

The primary changes to the geometric design process in the past century have been in the area of design tools and computer applications. Future design professionals will apply an interactive, adaptive, and integrated design approach to understand external influences, environmental elements, and contexts. A single pass through the design process will not be sufficient—instead, an iterative approach will balance project issues more efficiently.

Although providing design consistency and uniformity, code-based design and applications will



Photo: California PATH

On-board safety monitoring system in a truck cabin.

decrease in importance, yielding to performance-based design. Project sponsors will apply analytical procedures to quantify or estimate the possible trade-offs and to consider changes and variations in physical dimensions. Design visualization tools will allow designers to verify the accuracy of a design before construction begins. Experimental evaluations in virtual reality may allow the quick and cost-effective assessment of a range of design solutions.

## Advanced Crash Analysis

### Computer Simulation Models Lead to Safety Improvements

KENNETH OPIELA

Computer simulation for analyzing highway crashes has advanced significantly in the past decade. The tools and techniques, which originated in defense analyses more than 40 years ago, can represent vehicles, the roadway and roadside features, and even the vehicle occupants, as finite element models for crash simulations.

The models represent an entity as a collection of many smaller parts—that is, finite elements—each characterized by shape, material, material properties, and the connections or interfaces with other elements. Vehicle and hardware models often are built through reverse engineering—a process that involves the systematic tear-down or disassembly of all parts and the creation of a computerized description of each element.

The resulting models are then subjected to crash events, using powerful software that alters each individual model element over small increments of time, to replicate the forces experienced in a crash. The software documents the incremental changes to each element as a result of the forces; it also tracks the changes in velocity, acceleration, deformation, and other factors, to allow an evaluation of safety performance in a crash.



Advanced crash analysis has produced realistic representations of crashes, contributing to the effective development and refinement of vehicle and hardware designs through incremental changes to the model or parameters and repeated crash simulations. The approach has been applied to design and evaluate roadside barriers and security hardware; determine the compatibility of vehicles in various types of crashes; analyze test procedures; and translate crash forces to the occupants, to predict the risk of injury.

Full-scale crash tests have shown high levels of correlation between real and simulated crashes. The supporting computer software allows detailed animation of a crash; generates multiple quantitative measures of performance, as well as multiple and isolated views of the event and specific parts; and assesses the influence of external conditions. These advanced techniques have reduced the time needed to improve vehicle and hardware designs, increasing the safety of the transportation system.

*The author is Leader of the Roadside Safety Team Office, Office of Safety Research and Development, Turner-Fairbank Highway Research Center, Federal Highway Administration, McLean, Virginia.*

The effects of the transportation system on water resources will remain a concern, particularly stormwater runoff from impervious surfaces and construction and maintenance activities. The effective implementation of best management practices during and after construction will be a focus.

The number and frequency of extreme events affecting transportation facilities have increased in recent years. Compounding the problem is the increased development in coastal areas, requiring a reevaluation of design, construction, and maintenance practices.

### **Emerging Technologies**

Larger-scale solutions will be needed as transportation systems expand. The introduction of intelligent transportation systems (ITS) and other new technologies will support and improve the driver's perceptive capabilities and decision processes. Interdisciplinary research into the new technology and the interaction between the road, the vehicle, and the driver is a fundamental need.

Design processes and applications will integrate emerging technologies, including

- ◆ Smart roads, with sensors generating data on the environment and traffic flow;
- ◆ Safe roads, incorporating collision avoidance and improved design criteria;
- ◆ Smart cars, with proximity sensors, intervehicular exchanges of data, and autocorrection;
- ◆ Self-generated and integrated performance data on crashes, speed and flow consistency, and vehicle dynamics; and
- ◆ Three-dimensional (3-D) georeferenced data—produced by the fusion of computer-aided design and geographic information systems—enhancing repositories of engineering design data, real-time data exchange, and the integration of electronic document management systems.

Funding to deploy emerging technologies, however, will be a struggle for federal, state, and local agencies.

Geospatial technologies for design and construction will complete their migration from today's 2-D processes into the realm of 3-D. Integrating new data from the new technologies with legacy information, however, will pose a challenge. Design, asset management, construction machine control, and ITS will depend on the quality and quantity of the data.

Higher-quality mapping to leverage this technology will require new technical expertise. Remote sensors and geospatial requirements are evolving to provide checks and balances to ensure data integrity. Cities, counties, and states already are cooperating with real-



Photo: Virginia Tech

time Global Positioning System networks.

Data will need to be universally compatible to function and to benefit transportation facilities for a full life cycle. Digital workflows in near real-time to facilitate decision making will be possible only with common standards, specifications, and criteria. Traditional paper or film products will yield to digital media.

### **Accommodating Utilities**

Expediting project delivery will demand increased cooperation, coordination, and communication between the owners of the projects and the utilities that jointly occupy a right-of-way. Critical to avoiding project delays from utility conflicts include information on the presence and location of subsurface utilities; avoidance of utility conflicts by designers; the design of necessary relocations by utility companies; communication and teamwork by contractors with designers and utilities; the timely acquisition of rights-of-way and easements; and the creative financing of utility relocations.

The Federal Highway Administration (FHWA), the American Association of State Highway and Transportation Officials, and the American Society of Civil Engineers (ASCE) have developed guidance on two methods to streamline the utility process—Coordination, Cooperation, and Communication (CCC) and Subsurface Utility Engineering (SUE). These methods encourage highway agencies to take readily available measures to reduce utility-related project delays (see box, next page).

Innovative research, however, will be needed to improve the utility relocation process to reduce delays and expenses. The findings will be critical, because of

Intersection collision avoidance system undergoes testing by Virginia Tech Transportation Institute.



the accelerated rate of change in the utility industry. A strategic utility-related research program should examine methods to locate and characterize deep-buried utilities; procedures and systems for electronic permitting; techniques to optimize the placement of utilities in transportation corridors; and techniques to mitigate or eliminate the effects of open cuts on pavements.

Research also is needed on the interdependency of transportation and utility infrastructure, utility data modeling, geophysical methods for underground utility mapping, the environmental impacts of the aging of the underground utility infrastructure, and integrating utility relocation into project development.

### Context-Sensitive Solutions

A continual, collaborative, and interdisciplinary approach designed to understand the needs of all users will streamline the development of infrastructure in the future. This approach will involve design and construction engineers collaborating with landscape architects; urban and environmental planners; safety experts and engineers; natural and social scientists; user groups—such as pedestrians, bicyclists, and transit riders; community representatives; property owners; representatives of industry groups—such as the American Automobile Association and freight, construction, utility companies; and international part-

ners. Integrating the transportation facility into the local context and across modes will be essential to success.

Broadly informed, participatory processes that effectively stimulate meaningful involvement by stakeholders, as well as the building of relationships, will expand, leading to more integrated, comprehensive, cost-effective, and sustainable transportation solutions. A key to success will be strategic research to develop a seamless transportation system that is an asset to—and integral to—every community. Success will be elusive, however, until the problems are framed within common values and concerns, such as improving quality of life, health, and economic vitality.

### Acknowledgments

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## Avoiding Utilities-Related Project Delays

C. PAUL SCOTT

**T**he Coordination, Cooperation, and Communication (CCC) initiative, promoted by the Federal Highway Administration (FHWA), aims at developing good working relationships in the transportation and utility community. Sometimes the effort requires a fourth C, for commitment.

Highway and utility professionals know that good working relationships are essential for solving problems and enhancing the process of utility relocation; yet achieving those relationships can be difficult. FHWA has provided guidance in a report, *Avoiding Utility Relocations*, and in a video, “CCC: Making the Effort Works!” In response, several states have developed utility coordination committees that provide opportunities for highway and utility representatives to meet and to discuss common problems.<sup>a</sup>

Another strategy, Subsurface Utility Engineering (SUE), is an effective, nondestructive engineering process that combines civil engineering, surveying, and geophysics with geophysical methods, nondestructive vacuum excavation, and computer

technologies to collect and depict information about subsurface utilities. An American Society of Civil Engineers document, *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data*, presents the SUE process, routinely followed by many highway agencies and design consultants in the early development of projects.

Studies at Purdue University and the University of Toronto have confirmed the cost-effectiveness of SUE.<sup>b</sup> Nonetheless, although stakeholders recognize the need for accurate and comprehensive information about subsurface utilities, many do not want to pay for SUE, do not understand the process, or are not convinced that SUE will yield what they need. More attention must be given to educating stakeholders about SUE and its proven advantages.

<sup>a</sup> [www.fhwa.dot.gov/construction/fs02048.cfm](http://www.fhwa.dot.gov/construction/fs02048.cfm).

<sup>b</sup> Purdue University Department of Building Construction Management. *Cost Savings on Highway Projects Utilizing Subsurface Utility Engineering*. Federal Highway Administration, Washington, D.C., December 1999, [www.fhwa.dot.gov/programadmin/pus.cfm](http://www.fhwa.dot.gov/programadmin/pus.cfm).

*The author is a consultant based in Montclair, Virginia.*



# MANAGING PAVEMENT ASSETS FOR THE 21ST CENTURY

## CHALLENGES AND OPPORTUNITIES

THOMAS J. KAZMIEROWSKI

*The author is Manager, Materials Engineering and Research Office, Ontario Ministry of Transportation, Toronto, Canada, and Chair of the TRB Pavement Management Section.*

**I**ncreases in traffic and loading, combined with environmental effects, are accelerating the deterioration of pavements and bridges. Infrastructure in poor condition requires constant maintenance, which increases congestion and user delays—with an adverse impact on the nation's economy and quality of life.

In the past 50 years, the U.S. national highway system has fostered unprecedented economic growth and personal mobility. By 2020, however, the aging highway pavements will shoulder a 65 percent increase in highway freight tonnage and a 50 percent increase in total vehicle miles traveled (1,2). In the next 20 years, the United States faces a major challenge in maintaining the competitive edge provided by the national highway system.

Sources of raw materials are limited, so that engineers must maximize the reuse of in-place materials—with or without modification—to provide rehabilitated and reconstructed pavements that are long-lasting, eco-

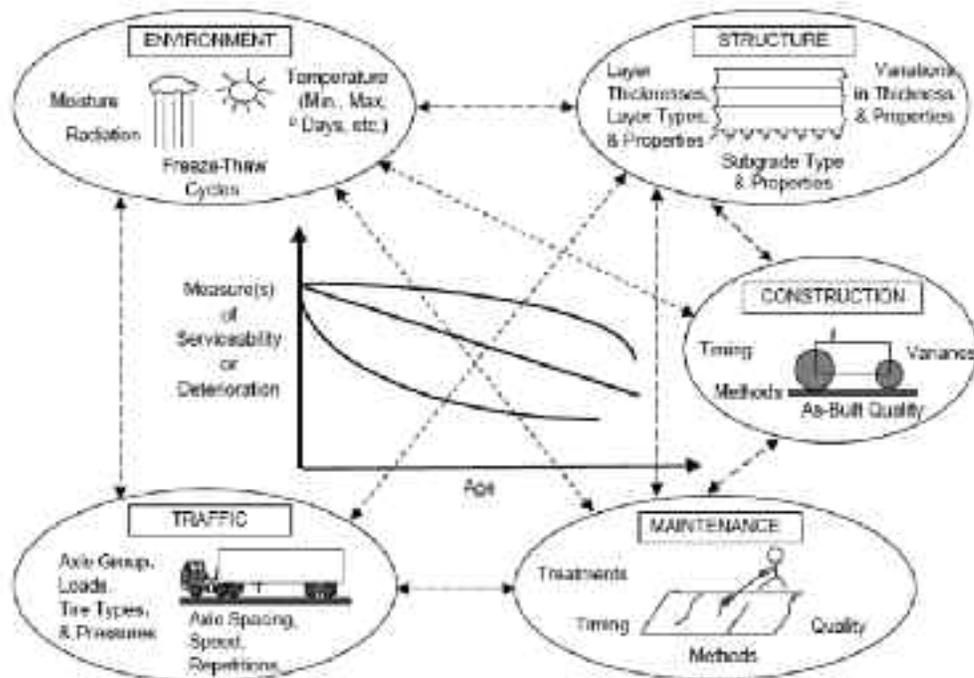
nomical, and sustainable. The pavement analysis, design, and management techniques must be in place to evaluate the current pavement and material condition, the projected loading, the environmental effects, the material properties, and all other interrelated influences on pavement performance.

The context for addressing these technical challenges has evolved substantially in the past several decades, and continued evolution is expected. Concerns about the environment and sustainability will increase in the next 20 years, possibly leading to restrictions on the production of construction materials and to stricter controls on pavement construction. Design-build contracting, public-private partnerships, and other innovative contracting and financing approaches are changing the ways that highway agencies are meeting the needs and interests of the public.

Transportation agency professionals are shifting their focus from specific materials and methods to



FIGURE 1 Factors Affecting Pavement Performance (3)



combined system performance. The performance of a transportation facility depends on the interaction of the traveled surface with its users. This interaction can be described in terms of the functional characteristics that affect comfort, safety, environmental impact, and the preservation of the structure (Figure 1).

Effective application of technological advances and new tools, such as the *Mechanistic-Empirical Pavement Design Guide* (MEPDG) recently adopted by the American Association of State Highway and Transportation Officials, are essential for addressing these evolving needs, challenges, and constraints.

### Design and Performance Prediction Models

Pavement design practice today is largely empirical but is moving toward more mechanistic approaches, particularly with the release of the MEPDG. The goal is to provide technology for long-life pavements that meet user needs for safety, comfort, and economy. Increasing the durability of pavement and reducing the life-cycle cost would enhance productivity and would optimize performance. The goals of mobility and environmental stewardship require reducing congestion, improving road conditions, and creating pave-



Accelerated pavement testing simulates the effects of long-term loading under in-service conditions.

ment surfaces that are safe and quiet.

To accomplish this, pavement designs must be reliable, economical, constructable, and maintainable throughout the service period, while meeting the needs of the traveling public, taxpayers, and highway agencies. Advanced pavement technology must exhibit reliability and innovation and must be applicable to all classes of streets, low-volume roads, highways, and special applications. This requires the application of fundamental engineering principles to enhance design features, to reduce life-cycle costs, and to reduce lane closures during the design life. Finally, advanced technology must integrate pavement designs

with the materials, the traffic loading, the climate, and the methods of preservation and rehabilitation to produce reliable, economical, and user-friendly designs.

Research in the past decade has led to the development of new, more accurate pavement performance models to predict deterioration from a range of causes. Although the mechanistic-empirical approach has incorporated many of these models, more work is needed. Data from the Long-Term Pavement Performance program and from agency pavement management databases are available to validate current models and to improve previously developed models. Large-scale and long-term studies of in-service pavements

## Paving Materials and the Urban Climate

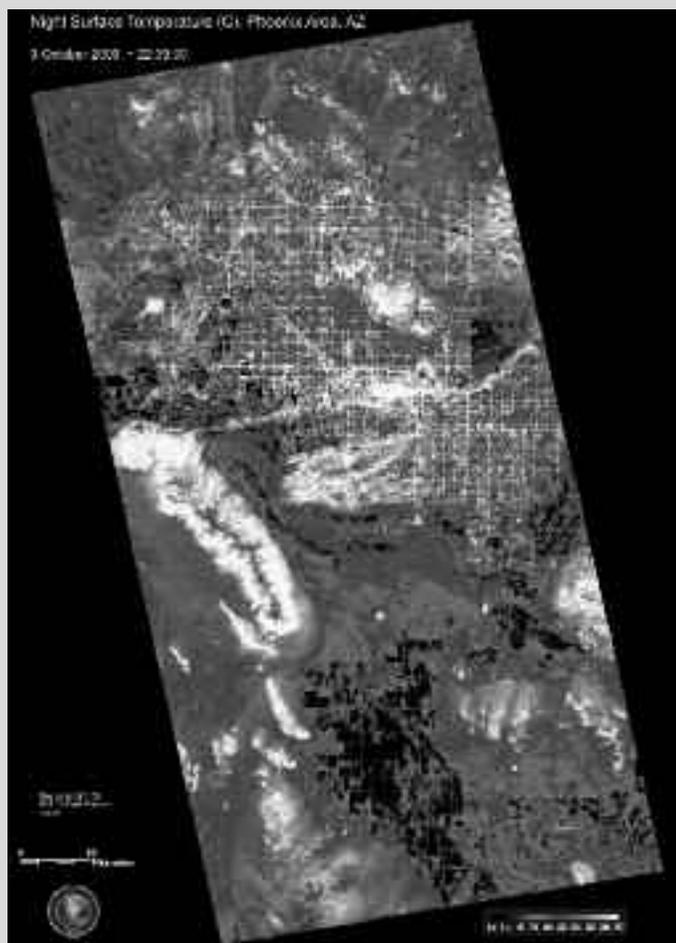
KAMIL E. KALOUSH

**B**ecause the built environment absorbs and stores solar energy, the temperature in cities can be several degrees higher than in adjacent rural areas. This is known as the urban heat island (UHI) effect. Pavements typically comprise 30 to 45 percent of the land area in major cities and contribute significantly to the UHI, through low reflection of solar radiation and high levels of thermal storage.

During the summer, the elevated surface and air temperatures in urban areas can have undesirable effects on public health, the environment, and the economy, through heat-related illnesses, elevated levels of air pollution, and increased energy costs. Policy makers therefore are evaluating incentives and regulations to mitigate the contributions of pavements to the urban climate. Technological initiatives include increasing pavement reflectivity, modifying its thermal properties, developing porous pavement structures, and creating unbound surfaces, such as turf pavements.

The TRB Design and Construction Group has established a Paving Materials and the Urban Climate Subcommittee to address the influence of pavements in the formation and mitigation of the UHI and to examine the relationship of pavements to broader climate concerns. The subcommittee's scope includes modeling, design practices, testing, standards development, and planning and policy considerations. The subcommittee will inaugurate its activities at the 2008 TRB Annual Meeting with a session on interdisciplinary topics addressing environmental concerns related to flexible and rigid pavements.

*The author is Associate Professor, Department of Civil and Environmental Engineering, Arizona State University, Tempe.*



*ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) imagery of surface temperatures in the Phoenix, Arizona, region on October 3, 2003, at 10:39 p.m. The brightest white areas represent the highest surface temperatures.*

IMAGE COURTESY OF NASA-HOUSTON

Multipurpose survey vehicle (MPSV) used by Florida DOT for automated surveys of pavement at highway speed. The MPSV is equipped with an inertial profiler including three laser sensors, two accelerometers, and a distance-measuring instrument; a navigation system; and imaging systems including right-of-way, sign-view, and pavement cameras. A new model MPSV has added a laser rut measurement system and a laser road imaging system.



could provide high-quality data on the performance of new materials and construction technologies.

Improvements in the testing and analysis of paving materials should be accompanied by improvements in the material modeling methods for pavement design. Research is needed to incorporate new modeling techniques for current and future materials into the pavement design processes to maximize the benefits.

### Accelerated Performance Testing

Accelerated pavement testing (APT) can produce early, reliable, and beneficial results while improving pavement technology and the prediction of pavement system performance. APT is the controlled application of realistic wheel loading to a pavement system, simulating long-term, in-service loading conditions.

APT monitors the pavement system's performance under an accumulation of damage, providing valuable information on the effective construction and preservation. APT also can be useful in evaluating new and improved pavement materials, structural designs, and construction techniques, as well as the impacts of increased truck tire loads and tire pressures.

APT users therefore must work together to correlate the APT test results with field performance and to maximize the effectiveness of APT facilities. Sharing the implementation of the findings will stimulate interest in the value of APT as a research tool.



PHOTO: VIRGINIA TECH

Ground-penetrating radar is tested on Virginia's Smart Road for measuring pavement layer thickness and monitoring pavement performance.

### Rapid Rehabilitation

Rapid construction methods for pavement rehabilitation are required to meet current and future traffic demands. Research must continue into innovative paving methods and the development of repair materials that can carry truck traffic within a few hours after placement. Continued development is needed for pre-fabricated systems—such as precast panels—that allow modular repairs.

In addition, future design guides must integrate developments in rehabilitation strategies, producing a more comprehensive approach. For example, the MEPDG should incorporate emerging simulation software such as CA4PRS (Construction Analysis for Pavement Rehabilitation Strategies). The implementation of technologies requires education, training, and assistance. Support from federal, state, and local governments, and from academia and industry will assure that innovative ideas are developed, tested, implemented, monitored, and refined.

### Pavement Management Horizons

The adoption and implementation of the MEPDG will facilitate the integration of highway design with pavement management. Application of the guide with pavement management system data will link long-term performance of highway pavements to materials, design, and construction, making possible the comprehensive and systematic planning of pavement maintenance and rehabilitation.

The MEPDG applies detailed traffic, pavement, and subgrade soil and environmental properties to design pavement structures that will deliver adequate levels of service and performance. Pavement management systems track the actual performance of highway pavements and derive needs for maintenance and rehabilitation. By integrating these systems, engineers will be able to design sustainable pavements that will last longer, require minimal maintenance, and cost less than pavements designed and produced with conventional methods. Information about the pavement system will be available to field and office staff in real time, from compiled electronic reports or displays on tablet computers.

Trade-offs between investments in pavements and in other transportation assets must be considered and optimized to manage the highway infrastructure effectively. Pavement management systems will integrate models for user delay, user inconvenience, vehicle operation costs, and environmental benefits to support an agency's decision making. Mobility management and sustainable throughput will gain emphasis in critical highway corridors.

Public-private partnerships can provide a framework for success by establishing expectations for the



performance of highway facilities. Performance specifications can define the information needed and the procedures for collecting the data, so that the private entities that design and operate the equipment for pavement data collection can serve their public clients at lower cost, with greater efficiency and reliability.

Another area for emphasis is the combination of pavement performance data with data from construction, traffic, safety, maintenance, and other related sources to explain a facility's performance. The sharing of observations among design, construction, and maintenance personnel about the effects of changes in procedures, policies, and practices is necessary to recognize improvements and realize progress in pavement performance.

### Measurement Systems

Accurate assessments of the bearing capacity and the structural characteristics of existing pavements are central to the effective management of pavement assets. This information supports sound decisions about preservation, rehabilitation, and reconstruction and is key for accurately assessing the performance implications of changes in traffic loading from new truck axle configurations and of changes in allowable

axle load limits.

The falling weight deflectometer (FWD)—the de facto standard for pavement structural evaluation—has been in use for more than 25 years. Ever-increasing traffic volumes, however, have reduced the viability of the FWD and other nondestructive test devices that cannot operate at highway speeds. In addition, the sophisticated designs of truck tires and suspensions and the analytical methods for modeling pavement performance demand a more sophisticated measuring device.

Next-generation testing devices must operate at highway speeds and must duplicate moving wheel loads more closely. The new devices must be accompanied by analytical procedures that accurately model the dynamic nature of the test in near real-time.

As the nation moves into the next decade of maintaining, operating, and augmenting the transportation infrastructure, performance standards will reflect the functional characteristics of pavements. Pavement professionals will continue to partner with experts in vehicle dynamics to answer the question, "How smooth is smooth enough?"

Work also will continue to identify traveled surface characteristics that promote lower rolling resistance

Falling weight deflectometers are the current de facto standard for pavement structural evaluation.



The rolling wheel deflectometer is a prototype device that measures pavement response to an actual moving wheel load.



## Pavement Management for 2020 and Beyond

- ◆ The next generation of pavement design improvements will integrate design with materials and construction, enabling designers to address changes to multiple inputs, while ensuring reduced life-cycle costs, enhanced reliability, and sustainability.
- ◆ The implementation of the mechanistic–empirical approach will require engineers to develop and incorporate performance models from field and laboratory data, making it possible to assess the economic impact of flexible and rigid pavement designs.
- ◆ Accelerated pavement testing will evaluate environment-friendly pavements such as warm-mix asphalt concrete, recycled materials, drainable and pervious pavements, and reduced-noise pavements.
- ◆ Research will continue on high-performance materials that offer higher early strengths and longer-term durability.
- ◆ In situ rehabilitation techniques—such as rubblization, cold in-place recycling, and full-depth reclamation—will be refined.
- ◆ Pavement management systems will be integrated into other strategic management systems to maintain safety, reliability, and efficiency in the transport of goods and services.
- ◆ Public agencies will adopt asset management tools to measure the conditions of their pavement assets and to define needs and expectations.
- ◆ Advances will be made in nondestructive testing for pavement evaluation and in the analytical tools and models for interpreting the data.
- ◆ The study of the interaction between surface properties and vehicles will combine system operations with infrastructure design, construction, and maintenance.

without jeopardizing safety or creating unnecessary tire–pavement noise. The implementation of the International Friction Index (IFI) is an important step in equipping pavement engineers with information to strengthen friction management programs.

The development of measurement systems will bring many of these ideas together through high-speed devices that measure grade, cross-slope, and curvature, while applying scanning lasers and continuous texture- and friction-measuring systems to characterize the traveled surface comprehensively. Data from these systems will contribute to comprehensive performance criteria and ensure that the criteria are met systemwide.

### The Pavement Core

An effective transportation system is essential for economic vitality, and pavement assets are the core of the system. Pavements provide the efficient and effective means for goods to move from the producer to the end user.

Yet the challenge of maintaining a serviceable pavement infrastructure for 2020 and beyond includes an array of complexities and challenges—economic, environmental, and political. Innovative research, new materials, changes in vehicle technology, and increases in traffic volumes make pavement management a dynamic field. Research is under way to produce the next generation of long-life pavements.

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# TRANSPORTATION STRUCTURES OVER, UNDER, AND ACROSS TO 2020 AND BEYOND

## TARGETING A SERVICE LIFE OF 100 YEARS

MARY LOU RALLS

*The author is Principal, Ralls Newman, LLC, Austin, Texas, and chair of the TRB Structures Section.*

The Interstate Highway System celebrated its 50th anniversary in 2006. The oldest Interstate bridges in service are approaching the end of their theoretical design life—the average age of these bridges is 42 years. In 2005, approximately one quarter of the nation's 595,000 publicly owned vehicular bridges were classified as structurally deficient or functionally obsolete,<sup>1</sup> despite efforts to repair or replace them. Although these efforts had reduced the number of nonsufficient bridges by 13 percent—from 167,321 in 1999 to 145,996 in 2005

(1)—much work remains. As more bridges reach the end of their theoretical design life, bridge owners must increase repair and replacement.

Critical assets in the economic and environmental success of the U.S. transportation infrastructure are the millions of units of culverts buried under highways and urban streets. Much of the nation's culvert inventory will require rehabilitation or replacement by the year 2020. Cost-effective, nondisruptive technologies are required to accomplish this with minimal impact on traffic.

<sup>1</sup> The Federal Highway Administration uses two terms to summarize bridge deficiencies: “Structural deficiencies are characterized by deteriorated conditions of significant bridge elements and reduced load-carrying capacity. Functional obsolescence is a function of the geometrics of the bridge not meeting current design standards. Neither type of deficiency indicates that a bridge is unsafe.” ([www.fhwa.dot.gov/policy/2006cpr](http://www.fhwa.dot.gov/policy/2006cpr).)

Photo: Scott M. Kozel,  
[www.roadstoneroute.com](http://www.roadstoneroute.com)



Construction of the new Woodrow Wilson Bridge on I-95 and I-495 across the Potomac River near Washington, D.C., proceeded as traffic continued on the old bridge (*left*) and on the completed span (*right*).



Minimizing traffic disruptions and maintaining work zone safety during necessary bridge repairs calls for innovative strategies.

Strain gauges, accelerated monitoring equipment, and finite element modeling were combined for major design retrofit of fatigue-cracked arch ties on the FAI 24 Bridge crossing the Ohio River between Illinois and Kentucky.



## Identifying the Challenges

These needs far exceed funding levels—the nation will face shortfalls in bridge replacement and rehabilitation funding as 2020 approaches. For example, approximately 70 percent of the bridge inventory was constructed before the adoption of modern seismic codes, and only a small fraction has been retrofitted.

Maintaining traffic flow during repairs and replacements to the transportation infrastructure is another challenge. Rehabilitating structures while minimizing traffic disruption and improving work zone safety on congested highways has become a priority that requires a new way of doing business.

All types of structures must be designed to be built quickly and to last longer. New technologies to accelerate methods of construction and apply materials with advanced properties are needed to meet the demands of current and future traffic during reconstruction and new construction of the infrastructure.

Increases in traffic volumes and weights require stronger and more resilient structures. The continued development of high-performance materials is addressing this need.

Environmental issues are also a challenge. Wetlands, air quality, noise levels, and protection of endangered species and historic structures are just a few of the environmental issues that bridge owners must consider.

Although fiber-reinforced polymer (FRP) composites have become more common in civil engineering, use has imitated that of conventional construction materials. Only recently have technologies developed to take effective advantage of the unique and beneficial

characteristics of FRP materials.

The development of new and better design, construction, maintenance, and inspection methods and materials for transportation structures can ensure the safe, effective, and efficient movement of people, goods, and services in 2020 and beyond.

## General Structures

By 2020, owners, practitioners, and researchers will have become more familiar with the various determinants of the physical behavior, service life, economy, appearance, safety, and security of bridges and other transportation structures. The demands on these structures are increasing at unpredicted rates, with new developments in the social and political scene, globalization, and the advent of new technologies. The design and analysis of structures must respond to these demands in a unified fashion to understand and achieve consistency in safety, constructability, and durability at the least cost for the projected service life.

Designs must allow for heavier and less predictable vehicular and environmental loadings and for expected and multiple hazards, to achieve consistent safety and improved performance at the lowest life-cycle cost. Other research and development needs include optimized systems for accelerated bridge construction; nondestructive methods for the reliable, quantitative evaluation of infrastructure, such as steel and precast concrete structures and concrete bridge decks; just-in-time maintenance and other operations relying on smart structures and automated analyses; enhanced ability to address economic considerations, including optimization; the automation of designs and fabrication; the development of improved devices and methods to accommodate structural movement; and appropriate aesthetic guidelines for bridges.

## Steel Bridges

By 2020, the high-performance structural steel produced today will provide the strength and toughness to maintain and expand the highway system and to support the high-precision structures for innovative transportation systems, such as high-speed rail. Improved understanding of the behavior of steel structures under traffic loads and environmental conditions, coupled with improved analysis tools, will allow more accurate prediction of performance. Improved design tools will enable practitioners to develop designs using steel more effectively.

Modern steel construction methods minimize the effects on the human environment. An international collaboration among engineers, researchers, and constructors will continue to share experience, standards, and innovative ideas to take advantage of this benefit and implement new ideas.

Realizing this vision, however, requires advances and improvements in the following areas:

- ◆ Analysis tools for predicting the response of bridges to traffic, construction staging, and environmental effects—particularly for complex bridges, such as curved and skewed bridges and high-speed rail bridges;
- ◆ Design tools that enable all bridge designers to execute effective steel designs and detailing; and
- ◆ Practical design standards and usable codes that respond to the demand for system reliability.

Other efforts should aim at improving the resistance of steel structures to corrosion, fatigue, and fracture; advancing methods of construction and erection to reduce costs and environmental effects; accelerating the design, fabrication, and construction cycle; integrating design, detailing, and construction with the prefabrication of bridge components; and improving maintenance, including the evaluation, monitoring, repair, and protection of steel structures.

## Concrete Bridges

Concrete bridge technology by 2020 will continue to focus on producing structures that are extremely durable and rapidly constructed with materials and techniques that ensure long-term performance, require minimal maintenance, and are easily modified to accommodate changing demands. More structures will have efficient, aesthetically pleasing, and innovative forms.

Achieving this requires the development of prefabricated elements and systems that accommodate modular repair and that ensure adequate transfer forces—particularly for extreme events—while maintaining durability and innovative erection procedures for accelerated construction. Additional areas for development include the following:

- ◆ High-performance materials to provide concretes with lower permeability, higher strength, higher modulus of elasticity, and improved ductility and abrasion;
- ◆ Higher-strength, corrosion-resistant, reinforcing steels and emerging materials, such as FRP;
- ◆ Stressing tendons with greater strengths and larger diameters—and with improved corrosion resistance—to take advantage of higher-strength concretes;
- ◆ A rational method to predict the service life for the maintenance and replacement of structures; and
- ◆ Standard shapes that are aesthetically pleasing and context-sensitive yet meet structural demands.



Load tests have improved understanding of structural integrity and are allowing engineers to extend the useful life of aging structures.

## Dynamics and Field Testing of Bridges

Advances in assessment technologies are needed to meet the challenge of designing, constructing, and preserving the nation's bridge inventory through 2020 and beyond. These new technologies will improve probabilistic and quantitative systems for bridge management, enabling owners to determine the maintenance, preservation, and replacement needs of their bridge inventories, while balancing shortfalls in funding for bridge replacement and rehabilitation. Bridge owners expect to maximize the useful life of bridges through advances in design, innovative materials, and techniques for preservation and rehabilitation.

These advances require addressing problems with bridge components that historically have underperformed—such as bearings, expansion joints, and fatigue-prone details. Also needed are improved understandings of the exposure conditions and the performance of critical details, along with the development of new designs and preservation strategies to reach the target of 100 years of service life.

Other criteria include the following:

Instrumentation once commonplace in the laboratory is finding new use in structural health monitoring, advancing knowledge about how bridges perform.



I-40 crossing the Mississippi River at Memphis, Tennessee, was economically retrofitted for seismic loads in 2001 with a combination of friction-pendulum and lead-rubber elastomeric isolators.



- ◆ Field testing and nondestructive methods to develop assessment technologies that capture performance measures;
- ◆ Applying performance measures to develop probabilistic service-life design criteria that maximize the life of critical bridge details;
- ◆ Field testing and nondestructive methods to optimize material performance and durability, structural performance, and construction practices, leading to longer and more predictable service-life estimates; and
- ◆ Bridge testing and nondestructive methods to generate data for managing bridge inventories with dwindling funds.

### Seismic Design and Performance of Bridges

Highway and rail systems in the United States in 2020 will be capable of withstanding extreme natural events—earthquakes, in particular—without loss of life and with minimal disruption to service. The road map to this vision requires the following measures:

- ◆ Reducing the vulnerability of new bridges in areas with earthquake and geotechnical hazards that are not well understood, such as in the central and eastern United States;

Innovative and environmentally friendly open-bottom culvert on Whitehall Road over Euclid Creek in Ohio rises 11 feet and spans 42 feet.



PHOTO: CONTECH

- ◆ Avoiding forms of construction that have few precedents in bearing extreme loads; and
- ◆ Adapting and developing new technologies to predict seismic loads in high seismic regions and to accommodate the loads with a variety of structures.

In addition, cost-effective and appropriate seismic retrofit methods must be developed for existing bridges, and the performance of highway and rail systems during extreme events must be improved. Complex systems are more resilient than their individual components, and this principle should be applied to highway and rail systems. Research is required to quantify, understand, and construct resilient highway and rail systems.

### Tunnels and Underground Structures

By 2020 the need for underground transportation facilities will have increased. Moving people and goods through urban areas will require more highway capacity in combination with other modes of transportation, such as trains and ferries. Underground space will gain importance in the design of future transportation systems.

Achieving this vision will require improvements in planning and design, to identify efficient routes, including tunnel alternatives in an urban environment. Routing highway traffic underground will open the surface for local, low-traffic roads, pedestrian and bicycle routes, and park settings.

The initial cost of a tunnel will be high, but the benefits to development in the surrounding area include increased property values and higher quality of life. Designs must accommodate incident management strategies. Methods must be developed to evacuate people if a fire occurs and to reduce vulnerability to an attack by terrorists. Public perceptions of the dangers of long tunnels must be addressed and considered in project design.

Consideration also must be given to construction and operations. Constructing below-ground highways requires communities to cope with temporary disruption and inconvenience. A major design issue is ventilation—the exhaust gases at tunnel portals and vent buildings must be mitigated. Improved design and construction techniques and systems will provide additional safety redundancies and enhanced inspection and health monitoring capabilities. As construction techniques improve, tunnels will become more competitive with surface solutions.

### Culverts and Hydraulic Structures

Transportation agencies in 2020 will apply asset management to track culvert conditions, will employ

improved materials and procedures to rehabilitate culverts, and will apply state-of-the-art specifications to optimize the use of innovative materials.

To meet this vision, new materials, methods, and tools must improve to ensure economies of scope and scale. Viscoelastic, composite, high-yield, and matrix-reinforced materials will allow innovative span and geometry arrangements. Trenchless methods that avoid traffic disruption will develop and improve. These innovations in materials and construction techniques promise great rewards once the applications can be analyzed, codified, and disseminated.

Because of the distributed and ancillary function of culverts, the nation's culvert inventory consists of a disorganized collection within and among state departments of transportation, cities, and counties. Assembling and organizing the available information into a comprehensive and usable database will require new technologies in data collection, storage, and manipulation.

### Structural FRP

By 2020, many new concepts and innovative technologies—for example, temporary bridges—will have developed with the use of FRP materials. The light weight of composites allows for rapid placement and for the development of economical short-to-medium span bridges with integral substructures and superstructures. This type of bridge can be manufactured in sections under controlled conditions, transported to the site, and placed with a minimum amount of disruption.

Use of FRP will expand with the verification of performance under seismic loading and the demonstration of the environmental durability of composite column wrapping. The use of FRP in noncorroding precast, prestressed concrete subdeck panels, pretensioned with composite tendons, will allow rapid concrete bridge deck replacement.

For steel bridges, research is needed in the following areas:

- ◆ Strengthening deteriorated, underdesigned, or damaged steel superstructures and substructures with bonded FRP composites, a technique already in use for concrete bridge rehabilitation;
- ◆ Replacing fatigue- and corrosion-prone details on steel superstructures with FRP composite elements, using durable, high-strength adhesives, designed to be fully removable; and
- ◆ Retrofitting suspension and through-arch bridges with lightweight, noncorroding composite hangers.

In addition, composite materials will offer a large

## What's Next for Structures?

◆ Bridge spans prefabricated adjacent to the site are being installed in minutes, positioned with self-propelled modular transporters. Installing multiple-span prefabricated bridges complete with substructures will further reduce traffic disruption.



*Graves Avenue span over I-4, northeast of Orlando, Florida, was installed in minutes with self-propelled modular transporters.*

◆ Bridges in good condition frequently become

functionally obsolete because of increased traffic volumes. Future designs will facilitate reuse of bridges to accommodate changing traffic patterns more efficiently, while conserving resources.

◆ Research is urgently required to quantify, understand, and construct transportation systems that are resilient to natural and manmade disasters. The first step in achieving this goal is the development of the resilient bridge.

damping capacity, improving the bridge's wind resistance.

### Solutions Through Collaboration

In 2020 the Interstate Highway System, along with its aging structures, will be preparing to celebrate its 70th anniversary. The vision for transportation structures in 2020 and the road map to reach that vision clearly show the need to focus on solutions to the many challenges to reliable and sustained performance. Collaboration within the structures community is essential to achieve this vision.

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# ASPHALT MIXTURE INNOVATIONS

## STATE OF THE PRACTICE AND VISION FOR 2020 AND BEYOND

JAMES S. MOULTHROP, REBECCA McDANIEL, ROBERT McGENNIS,  
LOUAY MOHAMMAD, AND ROBERT O. KLUTTZ

*Moulthrop is Senior Consultant, Fugro Consultants, Inc., Austin, Texas; McDaniel is Technical Director, North Central Superpave Center, Purdue University, West Lafayette, Indiana; McGennis is Technical Manager, Holly Asphalt Company, Peoria, Arizona; Mohammad is Professor, Louisiana State University, Baton Rouge; and Kluttz is Research Chemist, Kraton Polymers, Houston, Texas.*

Asphalt pavements have an excellent history of performance, but determining performance characteristics has been complicated by issues such as environment, traffic, and construction. Most tests have been empirical and may not be appropriate in every situation. The recent development of tests to measure the engineering properties of asphalt mixtures has improved the fundamental understanding of performance characteristics, and strides have been made in performance modeling.

The asphalt paving industry faces several challenges that are expected to intensify:

- ◆ The costs and availability of component mix materials;
- ◆ The increases in traffic volume and loads;
- ◆ Demands for longer-lasting pavements that delay the need for resurfacing and that reduce user delays;
- ◆ The use of recycled materials; and

◆ Environmental issues associated with new sources of materials and the location of production facilities.

Some of these challenges are beyond the industry's control. Addressing these issues demands thorough research and innovation.

### State of the Practice

#### Asphalt Binders

Binders always have been an ingredient in asphalt pavements. The specifications for asphalt cement—or binder—have evolved since the early 1900s, when penetration-graded binders were in vogue. Viscosity-graded binders were introduced in midcentury, and today performance-graded binders—developed under the first Strategic Highway Research Program (SHRP)—are prevalent, although not universal. Innovations in test methods historically have facilitated changes in specifications.

Superpave® uses a liquid asphalt grading system, known as the performance grading (PG) system, which specifies performance-related properties and test methods that correspond to in-service pavement conditions. The system also accounts for the likelihood that the climatic conditions may be more severe than those assumed in the design from the historical climate data.

The engineering parameters for grading the PG binders are related to the most critical failure mechanisms—rutting, fatigue cracking, and thermal cracking. At the high temperatures for asphalt mixture production, asphalt binders are fluid, and the PG system also includes a limit on viscosity to ensure proper handling during pumping and mixing. In the PG system, each of the main pavement failure criteria has its own test.

#### Asphalt Mixtures

Mixture criteria have evolved in much the same way as the binder requirements. Early practitioners used spe-



Asphalt mix is applied to a roadway; developments are sought in materials and techniques to increase service life and cost-effectiveness, as well as environmental compatibility.

cialized laboratory tests—such as the Hubbard Field, Hveem, and Marshall test methods—to identify the quality characteristics for acceptable performance, based on empirical observations.

The American Association of State Highway Officials (AASHTO) Road Test, conducted in the late 1950s, generated voluminous data on mixtures and performance. More recently, the volumetric properties of laboratory-prepared mixture specimens have been used to determine the acceptability of mixtures. Research under SHRP built on the earlier work, and the findings are used extensively today.

The Superpave system involves the compaction of mixtures with the Superpave gyratory compactor and the analysis of the volumetric properties of the mixes. The compactor applies a gyratory and kneading action to the hot-mix asphalt (HMA) sample to simulate the action of rollers and traffic. The compaction of the HMA samples is specified in numbers of gyrations, based on the design traffic volume.

The mix design involves the selection of the aggregate gradation and the volumetric properties of the compacted mixes, such as voids in the mineral aggregate, voids in the total mix (VTM), and voids filled with asphalt. Specified values of VTM are established for samples compacted to the design gyration level and also at gyrations lower and higher than the design gyrations, to avoid producing tender and rut-susceptible mixes.

### **Perpetual Pavements**

The concept of perpetual pavements is gaining acceptance in the United States and other countries, including the United Kingdom, France, the Netherlands, Israel, and China. The goal is to extend the service life of flexible pavements by limiting critical stresses or strains in the pavement structure to prevent the formation of cracks. Although asphalt pavements historically have been designed for a 20-year life, perpetual pavements are expected to perform for 35 years or more with only minimal restoration of the surface.

The surface and intermediate layers of a perpetual pavement are designed to be rut-resistant, and the base layer is durable and fatigue-resistant. The surface course can be milled and replaced quickly and economically to restore smoothness, friction, or other properties. Use of this design concept is expanding, with pavements designed and constructed for extended life under heavy traffic loads.

### **Pavement Preservation**

Transportation agencies traditionally have allowed asphalt pavements to deteriorate to fair or poor condition before taking measures to return the pavement to

good-to-excellent condition. The ride quality and the type and level of pavement distress conditions generally are measured. Waiting until rehabilitation is required means spending more money and time to return the pavement to an acceptable condition, as well as interrupting the flow of traffic and inconveniencing the traveling public and businesses.

Some agencies have discovered that the earlier application of a low-cost treatment to a pavement can save money and increase the service life. The gains are a higher-quality pavement with longer life, a happier traveling public, and judicious use of taxpayer funds. Figure 1 (next page) plots pavement condition versus time, indicating the benefits of applying a treatment early in the life of a pavement.

## **Visions for 2020 and Beyond**

### **Innovation**

The Transportation Research Board (TRB) has identified nine critical issues in transportation, including “human and intellectual capital: inadequate investment in innovation” (1). According to the TRB document, transportation and health care account for similar proportions of the gross domestic product, yet federal spending on health care research is 10 times greater than that on transportation research, and it is “unlikely that private funding will fill the research and development gap.” Yet by 2020, a significant, working mechanism must be in place to promote and implement private research and development in the asphalt pavement engineering community.

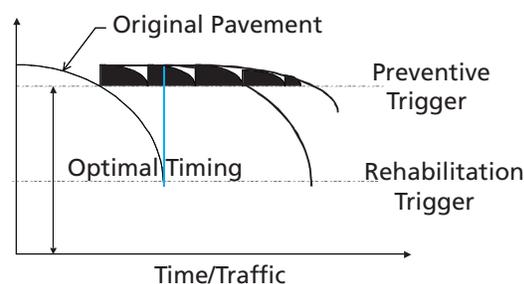


Superpave gyratory compactor, which prepares loose HMA mixtures for a variety of laboratory tests.

Perpetual pavement is installed on I-77 in Ohio. Perpetual pavements can provide service for more than 35 years with minimal maintenance.



FIGURE 1 The Pavement Preservation Concept



Even after spending approximately \$100 billion each year on roadway infrastructure, 33 percent of U.S. roads remain in poor condition. An additional \$150 billion per year would be needed to restore all roads to good condition.

This funding shortfall may reflect a lack of innovation. For example, advances in wireless communications have made commonplace a technology once reserved for only the wealthiest, changing our society. Similarly, innovation in asphalt materials and construction can overcome the chronic roadway infrastructure-funding shortfall—but the innovation must come from the private sector, as well as from the public sector.

Revolutionary innovation, however, is not occurring within the pavements and materials sector despite the skills and talents within the community. Stimulating and encouraging creativity and innovation may require a different public works engineering model by 2020. Just as alternative project delivery methods are revolutionizing the construction of public works facilities, the creative, capitalistic forces within the private sector must work to develop new and innovative pavement materials for 2020 and beyond.

**Perpetual Pavement**

Perpetual pavement design will increase in use to provide long-lasting pavements for the traveling public. Various developments, such as advances in design methods, will contribute to this trend and to longer ser-

vice lives. Expected improvements include mechanistic pavement design, materials innovations to improve durability and fatigue resistance, and improvements in construction practices and control.

Several issues need to be addressed through research, beginning with the validation of the mechanistic-empirical design values and criteria. The perpetual pavement concept requires maintaining the strains in the pavement below a critical fatigue endurance limit, to prevent the initiation and propagation of fatigue cracks. Although various endurance limits have been proposed, none has been determined and validated for efficient design.

Studies of in-service perpetual pavements are needed to quantify service lives and to assess life-cycle costs. In addition, the materials for perpetual pavement construction—including innovative materials—need to be explored to optimize pavement performance.

**Warm-Mix Asphalt**

Warm-mix asphalt (WMA) is an emerging technology that will gain in use. Originally developed in Europe, WMA mixtures are prepared at temperatures at least 30 percent below typical HMA mixtures but still provide workability at the laydown site to obtain density, as well as proper coating of the aggregate to protect against moisture damage. The reported benefits of WMA mixtures include the following:

- ◆ Improved working conditions,
- ◆ Decreased energy use in manufacturing the mixture, and
- ◆ Reduction in emissions from the WMA plant.

Introduced in the United States in 2002, several WMA technologies have undergone field trials. The Federal Highway Administration (FHWA) and the National Asphalt Pavement Association have formed a technical working group to guide the development of WMA.



Demonstration of warm-mix asphalt paving (*left*). Warm-mix asphalt mixtures can be manufactured at production facilities with reduced emissions and decreased energy use.

### Pavement Preservation

Although preservation relates to both flexible and rigid pavements, significant portions of the treatments include bituminous products. Most of these treatments have been used in the United States and internationally for years, but little research has been conducted to improve the techniques or to identify new and innovative approaches.

FHWA recently sponsored two workshops to identify research needs in pavement preservation, with the goal of identifying the most critical areas for funding. Pavement preservation has not been an active subject for research, but with pavement needs growing faster than the funding available, more cost-effective approaches must be considered to maintain pavements in an acceptable condition. (See sidebar, this page.)

### Recycling

More HMA is recycled than any other material. Nonetheless, HMA materials are not always recycled to take maximum advantage of their properties.

Despite decades of successful recycling, some agencies do not allow the use of reclaimed asphalt pavement (RAP), even at nationally specified limits. But the pressure to use greater quantities of RAP is growing, as urban sprawl makes the opening of new pits and quarries for aggregates more difficult, and high prices—especially for petroleum—and reduced availability of natural resources underscore the economic and environmental advantages of beneficial reuse.

Innovations in processing equipment have made higher RAP content mixes more feasible. Research is needed on the service lives of mixes with a high RAP content, as well as on additional innovations to ensure performance.

### Performance Modeling

By 2020, work now under way on laboratory testing of the fundamental engineering properties of flexible paving mixtures should allow practitioners, harnessing the ever-increasing computational capabilities of computers, to predict flexible pavement performance accurately for a variety of conditions.

### Asphalt Modification

The use of modified asphalts in paving continues to increase. Although the benefits are clear, research is needed to quantify the value. Work is actively under way on refined test methods and models to quantify the improvements in permanent deformation and cracking resistance. The multiple-stress creep and recovery test, for example, appears to correlate with permanent deformation better than the currently used reciprocal shear creep compliance specification.

## Promoting Pavement Preservation

JAMES S. MOULTHROP

◆ Through its Office of Asset Management, the Federal Highway Administration (FHWA) in the past 10 years has encouraged state transportation agencies to develop a robust preservation program. FHWA has published CD-ROMs and pocket guides and has sponsored the Pavement Preservation Expert Task Group.

◆ In addition, with the Foundation for Pavement Preservation, FHWA has advocated the development of regional preservation centers. The National Center for Pavement Preservation (NCP) at Michigan State University is reviewing state DOT preservation programs and serves as the pavement preservation help desk for the American Association of State Highway and Transportation Officials. Other pavement preservation centers have been formed in Texas and California.

◆ Recently the Road Information Program and NCP published a booklet, *At the Crossroads: Preserving Our Highway Investment*, which describes the condition of the nation's highways and presents a compelling message about the importance of an effective preservation program. Copies of the booklet are available from NCP at [www.fp2.org/news/news\\_4.htm](http://www.fp2.org/news/news_4.htm), or send an e-mail to [ncpp@egr.msu.edu](mailto:ncpp@egr.msu.edu).

A shear stress sweep test now in development appears to correlate well with mixture fatigue tests. Several research efforts are focusing on new tests for low-temperature cracking resistance.

More work is needed to translate specification parameters into pavement longevity and then into value for the agency. Research is needed to incorporate new input parameters from these advanced tests into the models for the forthcoming *Mechanistic-Empirical Pavement Design Guide*. Another need is for a disciplined methodology for applying life-cycle cost analysis to modified asphalt pavements.

Finally, understanding the value and impact of modified asphalts in other research areas—such as perpetual pavement design and WMA technology—also requires more attention.

### Vision and Determination

The asphalt paving industry has faced many challenges and has benefited from the work of entrepreneurs with the spirit, vision, and determination to confront and solve the issues for the advancement of the industry. Research and innovation are needed to recognize and resolve the different and more complex issues now emerging.

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# CONCRETE FOR THE TRANSPORTATION INFRASTRUCTURE

## REALIZING THE PROMISES OF HIGH-PERFORMANCE MATERIALS

MOHAMMAD S. KHAN

*The author is Senior Vice President, Professional Service Industries, Inc., Herndon, Virginia.*

Recent improvements in concrete are moving closer to the vision for a material that is crack-free and watertight, requires less construction time, offers a service life of at least 100 years, improves versatility in the infrastructure, and promotes sustainable development. Several recent accomplishments and emerging technologies will assist in achieving this vision.

### High-Performance Concrete

High-performance concrete (HPC) initially was intended to achieve a strength of at least 10,000 psi (69 MPa), along with other desirable durability characteristics. A new generation of concrete, ultra-high-performance concrete (UHPC), is emerging, with compressive strength up to 30,000 psi (207 MPa) and flexural strength up to 7,200 psi (50 MPa).

UHPC provides superior durability in terms of resistance to corrosion, abrasion, and impact. The engineering properties of the material are comparable to those of other high-strength structural materials, such as stainless steel, cast iron, and ceramics.

Ultra-high-performance concrete beam undergoes static testing.



COURTESY OF CELIK OZVULDIRMA, VIRGINIA DOT.

Self-consolidating concrete during placement.

Designers can take advantage of the properties of UHPC to create thinner sections, larger spans, and taller structures. The formulation of the material includes portland cement, silica fume, quartz flour, fine silica sand, high-range water reducer, water, and steel or organic fibers.

### Self-Consolidating Concrete

Self-consolidating concrete (SCC) is a relatively new concrete material that has gained significant momentum in the United States during the past decade. Before introduction in the United States, SCC found extensive use in Japan and Europe in the construction of bridges, buildings, and tunnels.

The material flows into and completely fills intricate and complex forms under its own weight. SCC also can pass through and bond to congested reinforcing steel configurations. In addition, the material offers high resistance to aggregate segregation.

SCC offers a tremendous advantage over conventional concrete and HPC with its workability and ease of placement; the material has exhibited superior performance in reducing shrinkage during drying. Important attributes of SCC include greater efficiencies in design, shorter construction time, and lower life-cycle costs (1).



PHOTO: ULTRACON, GERMANY

Self-lighting concrete pavement in Stockholm, Sweden.

### Self-Lighting Concrete

Advances in fiberoptic technology could eliminate traditional lighting sources for highways and traffic control. Embedded optical fibers, oriented in specific directions, can produce self-lighting concrete. The direction of the light can be controlled by modifying the tips of the fibers. Optical fibers can transmit light efficiently over long distances, allowing large sections of highways to be illuminated from a single, intense light source. A variety of traffic control operations can be completed and managed by switching certain groups of fibers on and off, varying the color of the transmitted light, and pulsing groups of fibers sequentially. In a recent report, *Riding on Light: Optic Technology for Transportation Challenges*, the Joint Advocacy for Optics and Photonics recommends self-lighting concrete for improved highway safety and energy efficiency (2).

### Environment-Friendly Concrete

Sustainable development seeks to avoid the depletion of resources for energy and raw materials and the generation of unacceptable levels of environmental pollution from solid, liquid, and gaseous waste. The concrete industry worldwide annually uses approximately 1.6 billion tons of cement, 10 billion tons of sand and rock, and 1 billion tons of mixing water. Each ton of cement requires approximately 1.5 tons of limestone (raw materials do not convert to the final product in their entirety), and the production is energy-intensive, consuming large amounts of fossil fuel and electrical energy.

Environmental concerns about the production and use of cement and concrete cannot be eliminated but can be minimized to a level acceptable for sustainable development. For example, portland cement can be replaced with supplementary cementitious materials (SCMs), including such industrial byproducts as fly ash, silica fume, and slag. High-quality concrete can be produced even with SCMs replacing up to 50 percent or 60 percent of portland cement (3, 4). Nonspecific

ation fly ash can be used beneficially in allied applications, such as flowable fill, soil stabilization, and base stabilization.

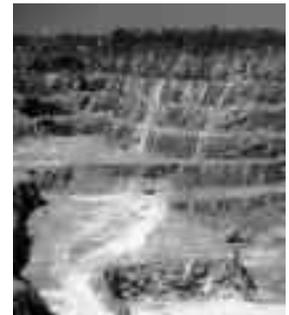
Nevertheless, many potential sources of SCMs, such as coal ash and metallurgical slag, are not used in concrete but are placed in landfills. By more fully utilizing SCMs, the concrete industry can help in minimizing environmental problems associated with other industries. Research should focus on modifying the properties of SCMs to be more acceptable in concrete applications and on developing criteria for appropriate use in concrete.

Aggregates constitute about 75 percent to 80 percent of the volume of concrete, but the supplies of natural rock and sand are not unlimited. Alternative sources of aggregates must be sought. Air-cooled blast furnace slag has been used successfully for many years in concrete transportation infrastructure. Synthetic lightweight aggregates also have met with success in certain applications.

The semimetallic waste from the production of illuminite and titanium oxides can be used to produce concrete with a density higher than that of normal concrete. With a compressive strength of approximately 4,000 psi (28 MPa), this concrete has applications in retaining walls and foundations (5). In Norway, recycled glass from jars and bottles has been used experimentally in concrete as a normal weight aggregate and as a synthetic lightweight aggregate.

Recycling abandoned or demolished concrete infrastructure for aggregates conserves natural resources and solves the problem of disposing of waste concrete. Yet despite successful case histories of such recycling, the applications are limited, particularly in the transportation industry. Recycled water from ready-mixed concrete plants has been used successfully in concrete mixes instead of fresh potable water.

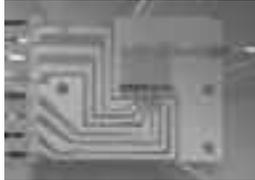
In the past, concrete pavements were designed to



(Above) A quarry for limestone. Manufacturers are seeking to decrease dependence on raw materials such as limestone for the production of high-quality concrete and are turning to alternative and recycled materials for sustainable development.



PHOTO: JIM GROVE, CP TECH CENTER



COURTESY OF NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

Nanotechnology teleportation transfers key properties of one atom to another without a physical link. Nanomodification of concrete can improve key properties, such as strength and ductility.

last 20 years and bridges 50 years. This wastes natural resources in initial construction, during rehabilitation, and finally in replacing the structure within a relatively brief time span.

The current practice of designing and maintaining transportation infrastructure for service lives of 50 to 150 years with preventive maintenance is a major contribution to sustainable development (6). A crack-free and watertight concrete component or system is a key to long service life. The development of cracks, particularly at early ages, and the diffusion of water in concrete initiate most of the deterioration, leading to corrosion of the reinforcing steel, damage from freezing and thawing, alkali-silica reactivity, and sulfate attack.

Cracks at early ages often are associated with the use of large quantities of cement. This can be minimized with SCMs and optimized aggregate gradations (7). In this way, measures that can decrease the environmental impact of concrete also can increase the longevity of the structure. An environment-friendly concrete with a long service life is possible with less portland cement, more SCMs, aggregate alternatives to natural rocks and sand, and recycled water.

Efforts can go beyond conserving natural resources and limiting the carbon dioxide emissions in the production of concrete. Specially prepared concrete surfaces, incorporating nanoparticles of titanium oxide powder with photocatalytic properties, can convert polluting nitrogen oxide ( $\text{NO}_2$ ), generally present in urban areas and in tunnels (8), to harmless  $\text{NO}_3$ , which is washed away easily by rain.

### Self-Healing Concrete

Research is needed for innovative materials and tech-



PHOTO: PORTLAND CEMENT ASSOCIATION

A concrete recycling facility.

nologies that can repair concrete instantaneously when it cracks and deteriorates. For example, at the time of construction, minicapsules filled with crack-repair materials can be embedded and dispersed in the concrete. The development of cracks can trigger the collapse of the capsules, releasing the repair materials.

Intruding moisture, which can initiate deterioration in concrete, could assist instead in healing the concrete. Materials could be developed as part of the concrete mixture but that disperse in the concrete matrix at contact with moisture, counteracting the deleterious effects of alkali-silica reaction and other processes.

### Advanced Monitoring and Inspection

A variety of sensors and techniques for the inspection and monitoring of transportation infrastructure have been introduced in recent decades. The latest high-

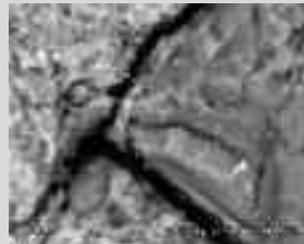
## Nanotechnology-Based Concrete Materials

### A Revolutionary Approach

BJORN BIRGISSON

The mechanical behavior of concrete materials depends on structural elements and phenomena that occur on a micro and a nano scale. As a result,

- ◆ Nanotechnology can modify the molecular structure of concrete material to improve the material's bulk properties.
- ◆ Nanotechnology can improve significantly the mechanical performance, volume stability, durability, and sustainability of concrete.
- ◆ Nanotechnology can have revolutionary effects, allowing the development of cost-



Regular concrete at 2500x magnification, showing distinct interfacial transition zone.

effective, high-performance, and long-lasting products and processes for cement and concrete, within the ideals of sustainable development.

- ◆ Nanoengineering and the modification of concrete materials can lead to unprecedented uses of concrete materials, as well as new classifications of concrete, with extensive applications for the concrete infrastructure of transportation.

The author is a professor at the Royal Institute of Technology, Stockholm, Sweden.

tech sensors include nanoelectromechanical and microelectromechanical sensors, composed of polymers, particles, conductors, computer chips, sensors, and photonic materials ranging in size from 1 nm to 100  $\mu\text{m}$ . Still in development and evaluation, these sensors could measure a variety of parameters for fresh and hardened concrete, including density, viscosity, temperature, moisture, shrinkage strain, pH, chloride ions, carbon dioxide, and relative humidity (9).

A National Science Foundation–sponsored workshop at the University of Florida in August 2006 identified the need for a fundamental multiscale model for concrete that spans from the atomic to the macro level. Such a model would allow the nanomodification of concrete to improve key properties, including higher compressive and tensile strengths, ductility, and volume change characteristics (see box, page 26.)

### Realizing the Promises

Developments, improvements, and applications of high-performance materials, such as ultra-high-performance concrete and self-consolidating concrete, are ongoing. These materials show considerable promise, and the beneficial effects on an economical, safe, and aesthetic transportation infrastructure are yet to be realized.

The research community of the concrete industry will focus on understanding the structure of cement paste at the micro and nano scales, under the heat of hydration and curing regimes, seeking modifications to improve the performance of existing materials and to develop new-generation materials that are crack-free and watertight, and that offer long service life. Nanotechnology will play a key role in the development of sensors for quality assurance management during construction and for monitoring structural health during service life. Advances in computers and analytical tools will revisit some of the models used for predicting the deterioration and the service life of concrete.

Sustainable development will be a major focus of the cement and concrete industry in the coming decades. The synergy and cooperation among academics, researchers, government agencies, manufacturers, and consultants, witnessed in the recent past, will be a key to success. The industry has demonstrated its capabilities for producing concrete that is more environment-friendly and that helps control environmental pollution generated by other industries.

### Acknowledgments

Several TRB Concrete Section and Committee Chairs provided valuable feedback and input for this article: Jamshid M. Armaghani, Florida Concrete and Products Association; Bjorn Birgisson, Royal Institute of Technology, Sweden; Richard A. Miller, University of

## An Aggregation of Initiatives for Concrete

The vision for concrete in the transportation infrastructure of the future can be achieved by

- ◆ Cooperation among various segments of the industry.
- ◆ Building on knowledge and resources.
- ◆ Advancing basic research.
- ◆ Advancing nanotechnologies.
- ◆ Developing high-performance materials.
- ◆ Developing advanced inspection and monitoring techniques.
- ◆ Developing environment-friendly materials.
- ◆ Applying advances in computers and information technology.

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# EQUIPPING THE TRANSPORTATION INFRASTRUCTURE FOR GEOLOGIC AND CLIMATIC CHANGE

JEFFREY R. KEATON, THOMAS C. BADGER,  
AND NANCY M. WHITING

Keaton is Senior Principal Engineering Geologist, MACTEC Engineering and Consulting, Inc., Los Angeles, California; Badger is Assistant Chief Engineering Geologist, Washington State Department of Transportation, Olympia; and Whiting is Research Scientist, Office of Materials, Minnesota Department of Transportation, Maplewood.

Natural disasters, energy and the environment, human and intellectual capital, and infrastructure are the critical issues for engineering geologists and geotechnical engineers serving the needs of U.S. transportation systems through the year 2020.

## Natural Disasters

### Geologic Hazards

Large-scale natural disasters—earthquakes, hurricanes, and flooding—have devastated regions of the

United States many times in the past 30 years, taking a heavy toll on the transportation infrastructure. Collectively, medium- to small-scale natural hazards—such as rock falls, landslides, sinkhole collapses, and swelling and collapsing soils—have caused extensive damage to the nation's highways, as well as deaths and injuries among the traveling public.

In the next decade, engineering geologists must capitalize on recent extensive research to understand the distribution of these geologic processes, as well as the probability and predictability of occurrence at an



## TRB's New State-of-the-Art Report on Rock Fall Characterization and Control

G. P. JAYAPRAKASH

**R**ock falls are an ongoing problem in many states and worldwide, with implications for public safety, the economy, and the liability of transportation design engineers and geologists. In the United States, rock falls have become a concern as the larger slopes along the Interstates constructed 30 to 40 years ago have weathered and become prone to slope failure. New construction in mountainous areas has produced additional slopes and demands for rock fall hazard evaluation and for the design of mitigation systems.

Technology is providing many new approaches to the evaluation and the quantification of rock fall hazards and protections. Researchers have developed new baseline data on rock fall processes and on the functionality of mitigation options, but the results are not yet accessible. A new TRB report, scheduled for publication in 2008, assembles a comprehensive source of information on all aspects of rock falls as a reference for practitioners developing appropriate assessment and design procedures for their localities.

Conceived as a companion volume to TRB Special Report 247, *Landslides Investigation and*

*Mitigation*, the forthcoming *Rock Fall Characterization and Control* focuses only on rock falls and does not cover the entire issue of the design of rock slopes. The volume includes diagrams, tables, references, and other aids documenting the evaluation and control of rock falls, including assessment and design options and considerations.

*Rock Fall Characterization and Control* is intended for a three-fold audience:

- ◆ Transportation engineers responsible for rock fall investigations throughout the world,
- ◆ Students in geoscience and geotechnical fields with an interest in rock falls, and
- ◆ Researchers who need a definitive reference on procedures for rock fall evaluation and control.

Keith Turner of the Colorado School of Mines served as technical coeditor with Robert Schuster of the U.S. Geological Survey, and chaired the task force that produced the report.

*The author is TRB Engineer of Soils, Geology, and Foundations.*

intensity likely to cause severe to catastrophic damage. Engineering geologists and geotechnical engineers will have to work with transportation engineers, structural engineers, and professionals from other disciplines to refine the understanding of the vulnerability and fragility of elements of the transportation infrastructure that are exposed to the range of geologic hazards in the United States.

Probabilistic models of earthquake-induced damage have informed engineering design and the calculation of insurance premiums. Similar probabilistic models are needed for other geologic processes, to describe rock falls, landslides, sinkholes, and expansive and collapsible soils in terms of magnitude and frequency and to prioritize mitigation expenditures.

The localized distribution of some of these hazardous geologic processes has contributed to the lag in the development of probabilistic models; in addition, geologists and engineers seek to model the processes accurately in every detail; finally, local variations in geology are a major challenge for regional models.

The transportation industry and the traveling public may benefit, however, from generalized regional models that yield reasonable results, which then can be fine-tuned with results from deterministic, site-specific studies.

### **Climate Change**

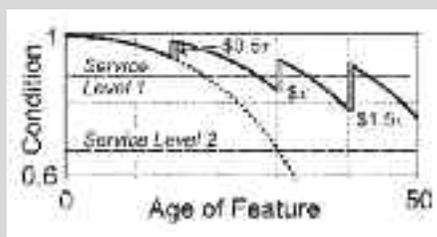
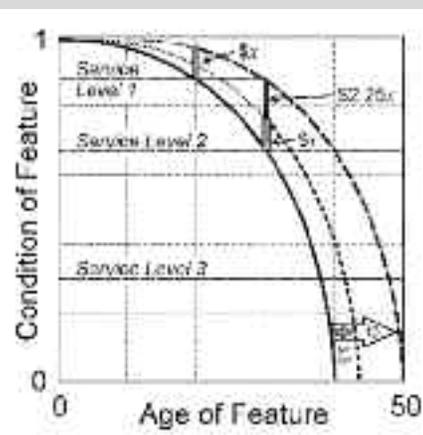
The effects of climate change on the frequency and severity of hazardous geologic processes need to be anticipated and quantified. The controversial causes of climate change must not become a distraction from estimating the ranges and projecting the trends of the probable effects.

According to the report of the Intergovernmental Panel on Climate Change 2007 (IPCC), the intensities of tropical cyclones are likely to increase. Already, between August 25 and September 28, 2004, three hurricanes—Hurricanes Frances, Ivan, and Jeanne—tracked across nearly the same terrain. Such storms, coupled with a predicted rise in the sea level, pose potentially grave consequences in coming decades for

## Conceptual Condition Index and Service Levels for a Hypothetical Feature

In this hypothetical case, maintenance at Service Level 1 in the top diagram extends the service life of the feature 10 years at an expense of  $\$X$ . If maintenance is undertaken at Service Level 2 instead, realizing the same level of service-life extension would cost  $\$2.25X$ . An expenditure of  $\$X$  at Service Level 2 would extend the service life 3.5 years.

The bottom diagram illustrates a maintenance strategy that spends  $\$2X$  over 50 years at 15, 30, and 40 years to maintain the condition approximately at Service Level 1 for 35 years and to keep it from falling to Service Level 2 at 50 years. Effective asset management requires actual feature-condition index curves for all types of infrastructure. Efforts are needed before 2020 to develop relationships for engineered reinforcement and protection elements installed in many remediated slopes along the nation's highway system.



Conceptual condition index curve and service levels (top diagram); maintenance strategy scenario (bottom diagram).

bility in slopes. In humid temperate regions, biotechnical remedial treatments have stabilized slopes, but drought induced by climate change could threaten the sustainability of biotechnical measures.

Trends in geotechnical response to climate changes need to be anticipated, defined, and quantified, so that appropriate remedial treatments can be devised in time to minimize or prevent damage to the transportation infrastructure.

## Recycled and Byproduct Materials

The transportation infrastructure annually uses more than two billion tons of natural, reclaimed, salvaged, and manufactured aggregates—95 percent of all aggregates in construction materials in the United States. The demand for construction aggregates rose quickly in the late 1990s and will continue to rise to support the maintenance and growth of the nation's transportation infrastructure.

To meet this demand, recycled materials and industrial byproducts are becoming economically viable and environmentally attractive as alternatives to natural sand and gravel or to quarried and crushed rock products. The demand is expected to increase for recycled aggregate products, such as crushed concrete, reclaimed asphalt aggregate, glass, and shingles; as well as for industrial byproducts, such as foundry sand, fly ash, and slag.

The depletion of resources, restrictions on mining, environmental concerns, competing land use, permitting difficulties, legal issues, and demands for energy efficiency will spur advances in the use of recycled and byproduct aggregate. These materials have been used to some extent as road surface aggregate; aggregate base course; embankment fill; treatment for wet, weak, or expansive soil; and backfill for utility trenches. The use of recycled materials and industrial byproducts requires significantly less energy than the mining, transporting, and processing of natural aggregates, particularly with increasing haul distances to environmentally acceptable quarries and with rising fuel costs.

## Effective Use

Ongoing research must address questions and concerns about the effective use of recycled and byproduct materials in 2020 and beyond—for example, to develop proper testing and acceptance criteria and to identify mechanical, hydraulic, and leachate characteristics. Tests for the basic physical and chemical properties of aggregate and other construction materials are essential. To optimize designs, to develop performance-based designs, and to facilitate transitions to new design criteria will require an understanding of how these materials react in portland cement and

infrastructure in low-lying regions. Hurricane Katrina demonstrated this in August 2005.

In addition, extended dry periods throughout the western parts of North America have increased the frequency and severity of fires caused by lightning strikes. Hot extremes and heat waves are very likely to increase in this region, according to the IPCC report.

Even modest rises in sea levels threaten transportation facilities in low-lying coastal areas with increased erosion and inundation. Warmer temperatures in regions with extensive permafrost have caused melting and excessive thaw-settlement underneath roads designed and constructed to preserve the frozen soil conditions. Warmer average temperatures in cold regions also increase the freeze-thaw cycles, which can accelerate the deterioration of slopes in degradable rock materials.

In semi-arid regions, climate change can have adverse effects on hydrocompactable soils and can change soil suction conditions that may cause insta-

asphalt–concrete mixes and of how the materials perform as structural components under long-term static and dynamic loads.

The fundamental properties of geologic materials must be developed rapidly. Geologists understand the basic uncertainties in geologic mapping, but these uncertainties have not been well-communicated or integrated into design practice. For example, variability estimates of rock structure and other geologic characteristics of rock masses need to be quantified systematically, so that the geologic description can be used for load and resistance factor design applications. Geology is not a random variable, and geologists are best suited to quantify the variability for engineering use in sensitivity analyses and other characterizations for design.

### Testing and Sensors

Technological advances in many areas of engineering analysis, design, and construction are incorporated into the transportation industry after extensive trial and examination. Sometimes concerns about liability and standards inhibit the adoption of innovations and improvements. Policies and procedures are needed to evaluate new methods and technological developments quickly and to adopt or modify them to realize the benefits. Prescriptive applications of design and main-



A rock fall–prone slope is scanned to determine structural soundness.

## Geotechnology Agenda 2020

- ◆ Engineering geologists and geotechnical engineers need to work with transportation engineers, structural engineers, and professionals from other disciplines to refine the understanding of the vulnerability and fragility of transportation infrastructure elements exposed to the full range of geologic hazards in the United States.
- ◆ Trends in geotechnical response to climate changes need to be anticipated, defined, and quantified so that appropriate remedial treatments can be devised in time to minimize or prevent damage to transportation infrastructure.
- ◆ Proper testing and acceptance criteria must be developed, and mechanical, hydraulic, and leachate characteristics must be identified, so that the use of recycled materials and industrial byproducts may be optimized in transportation infrastructure projects.
- ◆ Prescriptive applications of design and maintenance need to transition to risk-based procedures, to quantify uncertainties and to conserve funds and resources.

tenance need to transition into risk-based procedures to quantify uncertainties and conserve resources.

Investments are needed to improve in situ testing procedures, geophysical methods, and remote-sensing techniques for high-quality and more cost-effective data collection. A few transportation agencies

are using three-dimensional laser scans and terrestrial photogrammetry for virtual geologic mapping and remote documentation of rock structure, with increasing confidence and success. By 2020, this technology will be the standard for documenting surface conditions.

Researchers are developing other sensors for the rapid quantitative characterization of a suite of physical and chemical properties. The rapid remote and quasi-remote sensing will allow investigation and remedial work in live-traffic conditions, with improved safety for designers and contractors.

### Advanced Technologies

State transportation agencies collectively invest tens of millions of dollars every year to acquire geotechnical data that support the design, construction, and maintenance of transportation facilities. With this investment comes the need to archive and retrieve the

information. Challenges to this monumental but critically important effort include institutional will, implementation costs, and the formatting of data in a rapidly evolving field. The benefits, however, are immediate and substantial.

Three-dimensional visualization software and wide-ranging data sources are becoming available for use with geographic information system software to enhance the display, analysis, and communication of geologic and geotechnical data. The enhanced ease of data manipulation and display, however, raises concerns about the abuse and misuse of the data.

Real-time monitoring and deployable remote sensing methods have improved the accuracy of geologic characterization and the assessment of risk from geologic hazards, increasing safety. These methods are being applied to monitor landslides, ground deformations, stream flows, and other processes.

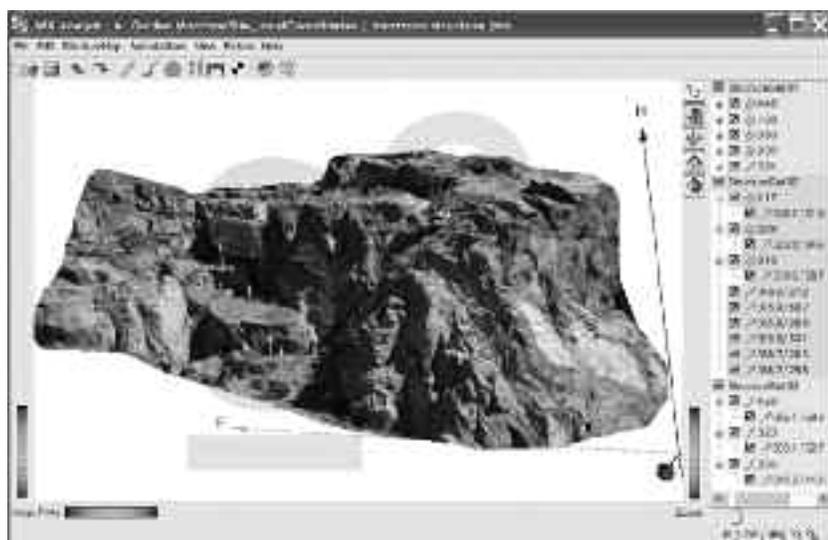
Laser scanning and terrestrial photogrammetry techniques used to characterize rock structure also can detect small-scale slope deformations that can indicate pending slope failures and rock falls. Ground-based radar scanning is a similar technique, applicable in adverse weather conditions and at night, which prevent the use of laser scanning and terrestrial photogrammetry. Such monitoring advances can prove highly valuable in managing risk and in programming mitigation measures.

### Proactive Management

As the infrastructure ages, the demands for maintenance and the likelihood of slope instability increase. The degradation of steeply cut slopes along highways presents an ongoing and increasing rock-fall hazard. In the past 50 years, many rock slopes have been stabilized with steel bolts, creating an urgent need for information about the life-cycle characteristics, the condition of the buried steel elements, and strategies for replacement. Reliable systems, similar to the Pavement Condition Index, are needed to determine the condition of this type of feature; a conceptual approach to a condition index and service levels for a hypothetical feature are shown in the box on page 30.

Improved assessment, characterization, monitoring, and risk-based decision making will make more proactive management possible, promoting more cost-effective strategies to maintain the nation's aging infrastructure and to design and construct improvements. Engineering geologists and geotechnical engineers are bringing together traditional methods and technology-based innovations to improve safety, achieve economic benefits, and exercise environmental sensitivity to design, construct, and preserve the highway infrastructure well beyond 2020.

Rock joint sets are analyzed using a terrestrial photogrammetric system that allows for virtual mapping of geologic structures. Integrated with photos, the wireframe (bottom) represents the actual rock surface as calculated by the software.





# NEW DIRECTIONS IN TRANSPORTATION CONSTRUCTION

## MANAGEMENT, CONTRACTING, TECHNOLOGIES, TRAINING, AND MORE

BY STEVEN D. DeWITT

*The author is Chief Engineer, North Carolina Turnpike Authority, Raleigh, and Chair of the TRB Construction Section.*

A new vision is evolving for the construction and reconstruction of the transportation infrastructure. Not long ago, projects were developed without much public input, environmental considerations were an afterthought, and issues over the effects of projects on communities were viewed more as nuisances than as problems to address during project development, construction, and preservation.

This has changed dramatically—the public is much more attuned to the components and locations of projects, including the traffic issues and the environmental considerations. The consistent demand is for rapid construction without compromising safety, quality, or the environment.

As construction costs increase with high inflation—which has been unabated between 2003 and 2007—a new view of engineering economy is coming into focus. Public transportation organizations will respond to pressures to become more efficient and business-like. Highway infrastructure construction is likely to focus on the reconstruction of the system originally built in the 1960s and 1970s. Public mass transit systems will struggle to balance the vision and needs of the future with the reality of financial constraints. The marriage of mass transit and highway corridors will create oppor-

tunities and challenges, as right-of-way and other related costs escalate in urban areas.

### Managing Construction Projects

In response to public demands, project development must consider how a project is constructed. Construction expertise must be integrated into the planning and design of transportation facilities. Other considerations include contract procurement, contract components, and opportunities to encourage contractor innovation, schedule acceleration, constructability, and value engineering.

By 2020, construction management will start with project scoping, which will consider all these issues. The Construction Management Expert Technical Group (CMETG)—comprising representatives of the American Association of State Highway and Transportation Officials, the Federal Highway Administration, academia, and industry (see box, below)—has drafted the following definition:

**Construction management:** The totality of activities that address the management and technology aspects of highway construction, conducted during the planning, design, construction, and post-construction phases of a project for the purpose of

### Building on Construction Management Insights

As part of the Federal Highway Administration's (FHWA) International Scan program, a group of construction experts representing the American Association of State Highway and Transportation Officials (AASHTO), FHWA, the Associated General Contractors, and the American Road and Transportation Builders Association traveled to Canada and several European countries to view and evaluate construction management techniques. The greatest lesson for the participants was the focus on common goals throughout the project delivery process, concentrating on "setting projects up for success" by ensuring that construction concepts were thoughtfully adopted and adapted in the pre-construction and procurement phases of a project.

As a result of the scan, the expert group developed a new definition of construction management that captures the focus on common goals and the inclusion of a construction mindset throughout the project delivery process. For more information on the Construction Management Expert Technical Group, visit the website, [www.fhwa.dot.gov/programadmin/contracts/cmetg.cfm](http://www.fhwa.dot.gov/programadmin/contracts/cmetg.cfm).



achieving scope, quality level, cost, schedule, and other project performance objectives.

Construction managers still will focus on the physical construction of a project after the award of a contract to ensure that expectations for quality, safety, cost, and schedule performance are met. The breadth and depth of their involvement in the full project delivery cycle, however—including the preservation phases—will become more and more critical.

The traveling public will escalate the pressure to build projects faster and with less inconvenience to users. Accelerated construction programs, techniques, and processes will evolve, but the cost of accelerating projects—such as paying for overtime, multiple crews, and 24-hour-a-day construction—will generate debates in the transportation community. Users may bear more of the costs, but the revenues will not apply to project acceleration, under the argument that user costs are not part of an agency's transportation budget.

Environmental concerns will push transportation projects to reuse construction waste. Hauling waste materials to landfills will come to a close. Restrictions on open burning will change the way vegetative materials must be handled.

The rapidly rising prices of asphalt cement and portland cement will change paving mixes to allow more and more recycled products within the designs for all types of pavements. Pavement mixes will incorporate materials once considered too costly to recycle. In addition, nanotechnology applications will become more prevalent, supplying smart materials and embedded sensors to increase the durability and the performance of pavement materials.

### Contract Procurement

The traditional design-bid-build procurement process will remain predominant. The movement to integrate construction considerations into the design phases of project development—addressing constructability, value engineering, bidability, clarity, and engineering economy—will gain emphasis. This blending—and blurring—of the lines between the traditional functions of design and construction will increase the likelihood of a project's success, addressing issues before they develop into public conflicts during construction.

The use of design-build will increase as the benefits of the approach are proven—the delivery of projects on accelerated schedules, minimal or no-cost increases over traditional procurement mechanisms, and opportunities for increased innovation, flexibility, and accountability for the contracting industry. Many transportation agencies will change over to this approach, achieving the same goals with positive results.

The Missouri Department of Transportation's prac-

## Practical Solutions Within Means

The Missouri Department of Transportation developed the practical design concept in response to the rapidly increasing costs of construction and to the need for designs that focus on “what is really needed” to solve a transportation problem. The practical design approach applies good, solid, engineering guidelines and principles coupled with a financial decision-making approach to ensure efficiency in the use of limited economic resources. This allows for flexibility in project design and challenges the “more is better” philosophy that has gained favor in many transportation agencies. For more information, visit the website, [www.modot.org/business/PracticalDesign.htm](http://www.modot.org/business/PracticalDesign.htm).

tical design concept is an attractive approach for other state transportation agencies coping with the economic realities of the early 2000s (see box, above). As more states adopt the approach, national design guidelines will have to be developed. The design-build concept and process were attempts to move designs in this direction but encountered restrictions. Practical design will lead to practical construction.

The many innovative contracting options developed in the past 20 years will become alternatives—different options to be applied to meet specific or unique project requirements.

The integration of financing, design, and construction through public-private partnerships will create teams with a different outlook on project development. Public-private partnerships and the role of public transportation agencies in construction management and

## Advantages of Early Contractor Involvement

The Highways Agency of the United Kingdom developed the Early Contractor Involvement (ECI) process to counteract the project delays and the increases in contractor claims experienced with traditional low-bid procurement. The ECI process centers on the quality-based selection of a design-builder instead of a hard bid or a more traditional best-value approach. The process relies on an open-book target-pricing approach: [www.highways.gov.uk/business/1175.aspx](http://www.highways.gov.uk/business/1175.aspx).

design are evolving, but allow private companies to take a stronger role in all aspects of project development and implementation.

Contract negotiation will change, with contractors integrally involved at the concept stage instead of at the bidding stage. Contractors will be chosen for complex projects before final plans are complete. On critically important projects, quality-based selection of contractors will follow the way that private engineering firms are chosen today. Several contracting scenarios are likely, each depending on critical paths for completion. The early contractor involvement process used by the Highways Agency of the United Kingdom highlights the advantages of this approach (see box, page 34).

### Specifications and Warranties

As transportation agencies deal with the changing workforce and with limits on the numbers of employees, warranties and performance-based specifications will make contractors directly accountable for a product's longevity. Many transportation agencies advocate contractor accountability and responsibility yet struggle with the specifications and approaches to make this connection fair and appropriate.

By 2020, true performance-based specifications will have been developed and will be implemented in many circumstances. Issues will remain, however, as private industry and public agencies work to find the right balance of risk apportionment, responsibility, flexibility, and accountability.

Warranties will become commonplace, as design responsibility shifts to private industry through design-build approaches. Warranties will specify performance standards and associated measures for identifying the need for maintenance or repair by the contractor. The results of earlier warranties for highway applications will contribute to improvements in the processes.

As the use of warranties increases, so will concerns and debates about litigation. The legal responsibilities for liability will be tested in court cases and will clarify roles and performance requirements.

### Quality Assurance and Control

Staff reductions at public transportation agencies will hamper the regulation and enforcement of quality standards. Many state transportation agencies have gravitated to quality control (QC) instead of focusing on quality assurance (QA).

The definition of QA varies among transportation agencies, and the concept is applied at varying levels. Agencies have struggled to balance their role in QA with the contractor's role in QC. As 2020 approaches, this balance will be more achievable as clearer definitions of QC and QA are developed. The clarifications



PHOTO: MINNESOTA DOT

Minnesota DOT personnel inspect a highway overpass.

will address roles and responsibilities, the core elements of QA programs, and specifications.

Full implementation of agency QA programs is critical to ensure that the traveling public has transportation facilities that are safe, cost-effective, and long-lasting and that can be maintained effectively. Implementation will include statistically valid specifications and pay systems, data storage and analysis, performance-based specifications, warranties, and the early detection of fraud. A renewed and sustained commitment at high levels of transportation organizations will be required to ensure that quality systems are developed and implemented.

### Pay Systems

Comprehensive systems will correlate pay with quality. Statistically based systems will be reliable for evaluating the product and will be valuable for projecting performance. These systems will constitute a critical step in performance specifications and performance contracts. In 2020, the contracting industry will embrace these systems, which will encourage a more consistent and highly productive process, reduce negative pay factors and reworking, and will generate greatly improved products.

These systems will develop appropriate checks and balances to prevent improprieties. QA processes will protect the public trust with robust validation systems, including statistical inference tests to flag projects for which state and contractor test results do not concur.

A key to these pay systems will be construction databases that collect, store, analyze, and monitor material characteristics during the construction of highway elements such as pavements and structures. Similar systems are now in use, but an increased volume of data, enhanced technology, and clear correlations to the many materials—as well as long-term performance measures of these materials in place and under traffic—will contribute to better specifications, better performance measures, and ultimately more appropriate pay adjustment factors for materials that have allowable variations.



A Minnesota DOT employee oversees the placement of prefabricated elements during a construction project.

### Risk Assessment and Allocation

Public transportation agencies will begin to embrace a risk-based approach to construction management. Tools are now available to identify and assess risks, not only in relation to cost and schedule, but in relation to quality, safety, and sustainability. The tools can make risks transparent to agencies, contractors, and project stakeholders, allowing more equitable allocation of the risks to the parties—or team members—who can best manage them to accomplish the project goals.

Agencies will learn to be less risk-averse. When risks are understood and the consequences are measured, agencies can make decisions to allocate risks to minimize costs, promote project goals, and align the project delivery team with the needs and objectives of the traveling public.

### Construction Elements

#### Pavements

Innovations in paving equipment and processes—such as intelligent compaction—will improve the quality of materials, the workmanship, and the products. Portland cement concrete paving operations will open within

hours of the final placement for the day or night. Asphalt and concrete pavements will incorporate a wider range of materials, partly because of a lack of availability of traditional materials and the need to use more marginal materials. This will create new challenges in construction, because these materials and their attributes will affect techniques for lay-down, compaction, and finishing.

Equipment enhancements will allow for safer, smoother, and quieter riding surfaces. Performance-based specifications, which are easier to implement for pavements than for other areas of construction, will be widely adopted, leading to innovations that will reduce construction time and increase job production.

### Bridges and Structures

#### Construction

Construction techniques for bridges and structures will evolve, and methods for the reconstruction of elements may be completely different from those used in the original construction. The focus will be on minimizing the impacts on the public, which will lead to increased reliance on prefabricated structures and on replacement bridges that can be moved into place.

Deck replacement technologies will advance substantially to allow slab and span replacements during traffic or with limited lane closures. Invisible construction will become more common as complete bridges will be replaced with prefabricated elements, causing minimal or no disruption to the public. The work will be performed at night, out of traffic, or during select periods.

In addition, methods of reconstruction will change to maintain uninterrupted traffic flow. Temporary structures may support diverted roadways, for example, allowing reconstruction of the original structure without a reduction in the number of available traffic lanes.

The design and analysis of structures during construction will be a topic for investigation. Findings will ensure safety and stability in operating service conditions different from those considered in the design.

Prefabricated elements will interconnect more easily in construction, and the connections will be more durable. Research will contribute to valuable advances in this area, including the development of new systems for precast, prestressed concrete, as well as for the connectability of steel components.

#### Steel Structures

Advances in the state of the art are expected to improve steel structures by 2020. The most significant improvement will be an increased use of modeling, which will contribute to design accuracy and constructability by facilitating a synergy between the design and fabrication processes, by improving behavior prediction and under-



(Above) A demonstration of hybrid laser arc welding (HLAW) for potential use on rib-to-deck welds on highway bridges. (Below) Denis Dubois, Maine DOT, examines an HLAW weld on a corrugated section similar to panels planned for a Maine DOT bridge deck replacement.



standing during erection, and by facilitating the analysis and load rating of in-service bridges. Technical advances also will improve fabrication speed and cost-effectiveness—for example, with new welding processes such as electroslag and laser welding.

The national program for in-service bridge inspection will continue to serve owners well. The understanding of steel bridge behavior will evolve, creating a more logical approach to fracture-critical inspection. Significant advances will apply to the inspection of metal traffic structures. As logical inspection programs are implemented for susceptible structures, catastrophic fatigue and corrosion failures of traffic structures should be eliminated.

### Emerging Technologies

Technology development will introduce opportunities for advances in the design and construction of transportation facilities. Geographic information systems (GIS) and Global Positioning Systems (GPS) technologies will find new applications in the management and construction of projects.

GIS already is changing the way that projects are screened, that alternatives are chosen, and that final designs are assembled. As projects move into construction, managers will use an array of GIS data to evaluate environmental boundaries such as wetlands and streams and to delineate borrow and waste areas, access to the project during construction, and other efforts.

GPS technology will assist in more advanced and widespread applications of machine guidance, enhancing the quality of projects and the efficiency of construction and will provide accurate as-built plans to facility owners and operators. Electronic design files will translate to three-dimensional formats with direct application to the machine guidance on construction equipment.

Advances in communication technologies will ensure rapid, accurate translation of a variety of vital communications. Handheld devices will be the norm for project record-keeping of all kinds, enhancing the management of projects and the project documentation.

Other advances will include more accurate measurement and surveying devices; wireless computing and communication; microelectronic mechanical systems; robotics; remote sensing with lasers and GPS; four-dimensional design; seamless electronic design, construction, and quality control; and radio frequency identification systems.

### Disadvantaged Business Enterprises

Through concerted efforts with the Disadvantaged Business Enterprise (DBE) community—such as innovative business development programs like Mentor Protégé—the availability and capability of DBE firms will increase.

## Charting Road Maps for Pavement Research

FHWA and AASHTO, working with the concrete pavement and asphalt industries, have created pavement road maps for systematic approaches to pavement research. The road maps are intended to assist in the apportionment of funds for research. The research results are expected to provide new processes and approaches that will improve pavements.

For more information on the concrete pavement road map, go to the website, [www.fhwa.dot.gov/pavement/pccp/pubs/05047/](http://www.fhwa.dot.gov/pavement/pccp/pubs/05047/). For more information on the asphalt pavement road map, visit the National Asphalt Pavement Association website, [www.hotmix.org/RFC\\_NAR\\_08\\_2006.php](http://www.hotmix.org/RFC_NAR_08_2006.php).

Efforts will be necessary to promote and enforce equity in the construction community. Small contracting firms will find unique niches in the marketplace, providing services that will be in demand. As more DBE firms achieve success, their principals will advise and assist in the development of other DBE firms.

### Education

The construction community will struggle with declining enrollments in engineering and technical schools. The traditional needs for craftsmen, machine operators, technicians, and engineers will endure, but more advanced skills with computers and related technologies will be sought. The advanced technical elements of projects will call for a new, well-trained pool of contractors, designers, and contract administrators who can handle specialized assignments.

Increased dependence on technology for planning, designing, constructing, managing, and operating transportation systems will require that educational programs change to fill the needs of the transportation professional of 2020. Project management techniques, knowledge of all steps in the entire project development process, communication skills, and various other skills and abilities will be emphasized in much more formal and focused educational programs.

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# Needed—Innovative Methods to Fix Our Nation's Failing Bridges

BART GORDON

Since the tragic collapse of the Interstate 35 West (I-35W) bridge over the Mississippi River in Minneapolis, Minnesota, on August 1, we have learned that structural problems plague a significant portion of bridges in the United States. A bridge has a life expectancy—just as humans do. If our personal health is in jeopardy, we take action. The same should be true of our infrastructure.

A national bridge inventory in 2006 classified 73,764 bridges (12.4 percent) as “structurally deficient,” including the bridge that collapsed in Minneapolis. In its 2005 Report Card for America’s Infrastructure, the American Society of Civil Engineers gave the nation’s bridge infrastructure a grade of C because of the large number of deficient bridges.

Is this acceptable to Congress? Absolutely not.

## Centralized System

I am frustrated that the federal government does not use a centralized system to classify the structurally deficient bridges that are in dangerous condition. I am frustrated that research and new technologies are underutilized because of cost concerns, lack of training, and lack of awareness.

Because it is financially and logistically infeasible to repair all problematic bridges in the short term, state highway administrations, bridge inspectors, and the public rely on the results of research and technology development to avoid catastrophic and deadly bridge collapses. The transportation research community has identified bridges as a priority and is devoting available resources to short- and long-term research to improve safety. The available resources are slim.

Yet money is never going to solve our bridge infrastructure problem—we never will be able to repair, rehabilitate, or replace all the bridges we need to, because of the sheer lack of time and resources. We need to make a 180-degree shift in our way of thinking. We must approach the problem differently if we’re going to meet the nation’s infrastructure needs successfully in the near and far terms.

## Smart Approach

The smart approach is to invest in high-quality, short- and long-term research, and in good technology transfer programs that get the

*The author is a Member of the U.S. Congress, representing the Sixth District of Tennessee, and is Chairman of the House Committee on Science and Technology. This editorial originally appeared in the St. Cloud Times, October 11, 2007, and is reprinted with permission.*

research results out into the community. We also need to build a technology-savvy and innovative workforce of engineers and inspectors who are comfortable integrating new technology or techniques into their work.

Doing this successfully requires a coordinated effort by federal research and training entities such as the Federal Highway Administration’s (FHWA’s) Turner–Fairbank Highway Research Center and the Research and Innovative Technology Administration’s University Transportation Centers, state departments of transportation (DOTs), industry, and academia. Those groups already are doing a good job of coordinating through the Transportation Research Board, the American Association of State Highway and Transportation Officials, and other organizations, but they especially need congressional support for research projects.

Recently, as chairman of the House Committee on Science and Technology, I convened a hearing to examine the status, feasibility, and affordability of the research and inspection tools we have on hand and in progress. Currently, FHWA, state DOTs, and universities are sponsoring and carrying out research to improve bridge design, maintenance, and inspections. Current research covers a variety of fields, including materials, engineering design, technology development, and modeling.

## The Challenges

Transferring successful technologies to end users, such as state DOTs, is challenging, because of cost concerns and training issues for advanced

technology. In transportation, technology transfer poses a special challenge, because no solution works well for everyone.

Differences in traffic loads, climate, size, shape, and other bridge characteristics mean that new engineering designs, materials, and technologies may work well for a bridge engineer in California but not in New York or Florida. Technology transfer efforts therefore must determine the customer’s unique needs and the appropriate technology.

We must learn a lesson from the I-35W tragedy. Solving the nation’s infrastructure challenge requires a long-term, dedicated effort by all stakeholders. We can take advantage of innovative research and development to design and maintain bridges that will remain stable and safe for generations to come.



Steel-truss bridge on Interstate 35, Minneapolis, Minnesota, after collapse, August 1, 2007.

*POINT OF VIEW presents opinions of contributing authors on transportation issues. The views expressed are not necessarily those of TRB or TR News. Readers are encouraged to comment in a letter to the editor on the issues and opinions presented.*



# Subsurface Site Investigations with Cone Penetration Testing

## Louisiana Develops Cost-Efficient Procedures for Bridge Projects

MURAD ABU-FARSAKH, MARK MORVANT, AND ZHONGJIE ZHANG

Abu-Farsakh is Assistant Professor, Research; Morvant is Associate Director, Research; and Zhang is Pavement and Geotechnical Research Administrator, Louisiana Transportation Research Center, Louisiana State University, Baton Rouge.

Site investigations identify the soil engineering properties that affect the design and construction of transportation infrastructure. A site investigation commonly costs 1 percent to 5 percent of a total project. The Louisiana Department of Transportation and Development (DOTD) spends millions of dollars annually on site investigations that require subsurface exploration. The quality of the subsurface exploration has a direct effect on the quality and efficiency of the design and construction of foundations.

### Problem

Conventional site investigation with soil borings and laboratory testing is expensive and time consuming, and sometimes the procedures require highly skilled and experienced technicians. Therefore, performing tests that yield satisfactory results is not always economical, and some degree of interpretation is required—which often leads to conservative engineering designs.

A 3- to 5-person crew, for example, can complete 5 to 8 soil borings in one week, depending on the depth of the boring. Laboratory testing for cohesive soils typically will take an additional two weeks. The laboratory tests are performed on small, undisturbed, and intact samples extracted from the borings. Yet almost all recovered samples have some degree of disturbance from the sampling, handling, transportation, and test preparation. As a result, the laboratory-derived soil parameters do not accurately represent the in situ conditions.

### Solution

In situ tests such as the cone penetration test (CPT) or piezocone penetration test (PCPT) are an alternative to laboratory testing. Performed under in situ stresses and boundary conditions, the tests can provide rapid, accurate, and reliable results in assessing the engineering properties of soil.

The CPT is a robust, simple, and economical test that can provide continuous soundings of subsurface



FIGURE 1 Cone Penetration Test System

soil with depth. The CPT advances a cylindrical rod with a cone tip into the soil (Figure 1). During penetration, the cone penetrometer measures the cone tip resistance, the sleeve friction, and—when the PCPT is used—the excess pore water pressures. These measurements can be used for detailed soil stratification and to evaluate different soil properties. Because of the soft nature of soil deposits in Louisiana, the CPT and PCPT are excellent tests for subsurface investigation and site characterization.



FIGURE 2 Pile Driving on the I-310/US 61 Interchange near New Orleans

### Research Efforts

Louisiana DOTD began to implement the CPT technology in the mid-1980s. At first, the technology was limited to identifying elevations of dense sand layers for pile foundations. Soil borings were taken during the design phase to estimate pile lengths, and CPTs were conducted during bridge construction to define pile tip elevations for plan lengths (Figure 2).

Since then, the Louisiana Transportation Research Center (LTRC) has conducted several research projects to develop tools and methods for implementing the CPT and mini-CPT technology for other types of Louisiana soils (1, 2). To facilitate the implementation, Louisiana DOTD developed several Visual Basic software tools for use in geotechnical engineering analysis and design.

### Soil Classification

The identification and classification of soil types was one of the earliest applications of the CPT technology. Several soil classification methods were developed by correlating CPT and PCPT data profiles with databases of soil types collected from soil borings.

The Louisiana Soil Classification by Cone Penetra-

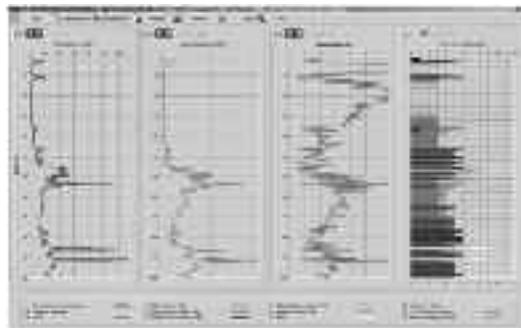


FIGURE 3 LSC-CPT Soil Classification Using Robertson et al. Method

tion Test (LSC-CPT) Program was developed to provide geotechnical engineers with a useful tool for subsurface soil identification. The program includes five different CPT classification systems; Figure 3 shows an example of LSC-CPT soil classification with the Robertson et al. method.

### Prediction of Pile Capacity

Since Louisiana subsoils often are soft, highway bridges and other transportation structures typically are supported with pile foundations. Accurately estimating the load capacity for friction piles is always a challenge. Louisiana DOTD pile design has relied on static analysis from laboratory data and the standard penetration test. Several methods have been proposed to predict pile capacity using the CPT data.

LTRC conducted a research project to identify the most appropriate CPT methods for estimating the ultimate axial load-carrying capacity of driven, precast concrete piles in cohesive soils (3). The ultimate pile capacities predicted from eight CPT methods were evaluated, and three CPT methods were selected for implementation in Louisiana soils: the French Central Bridge and Pavement Laboratory (or LCPC) method, De Ruiter and Beringen, and Schmertmann methods.

To facilitate Louisiana DOTD's implementation of the CPT technology for pile design and analysis, the three methods were coded into a Visual Basic Microsoft Windows program, called Louisiana Pile Design by CPT (LPD-CPT). The program provides the design engineers with ultimate capacity profiles and depths for piles.<sup>1</sup>

The Federal Highway Administration and the American Association of State Highway and Transportation Officials have mandated use of the load and resistance factor design (LRFD) methodology for all new bridges—including substructures—as of October 1, 2007. To implement the CPT technology in the LRFD design of driven piles, LTRC conducted research to calibrate the resistance factors for the CPT design methods in the LPD-CPT.

### Evaluation of Soil Properties

Several methods have been developed to evaluate different soil properties based on correlations between CPT or PCPT data and laboratory test results. Although some of these results may correlate closely, existing models should be calibrated or new models developed from local databases and experience. LTRC therefore conducted three research projects.

One project established a correlation between the 2-cm<sup>2</sup> mini-CPT data and the resilient modulus ( $M_r$ ) of subgrade soil for pavement applications (4). The

<sup>1</sup> The LPD-CPT and other CPT programs are available as free downloads from the LTRC website, [www.ltrc.lsu.edu](http://www.ltrc.lsu.edu).



CPT testing on South Louisiana marsh deposits.

second project evaluated the constrained modulus ( $M$ ) and other consolidation parameters ( $c_v$ , overconsolidation ratio [OCR]) needed for estimating the magnitude and rate of consolidation settlement for embankments on cohesive soils from CPT data (5).

The findings from these two projects are being implemented into software for estimating the magnitude and time rate of consolidation settlement in symmetric and asymmetric embankments. The software also includes an option of profiling with depth the undrained shear strength, constrained modulus, coefficient of consolidation, and OCR of subsurface soils based on established correlations from CPT data.

The third project deals with the calibration of the cone tip factor ( $N_{ik}$ ) for various soil types, to improve the prediction of the undrained shear strength of soils.

### Application and Cost Benefit

Louisiana DOTD has used CPT technology for soil classification and pile design on more than 80 percent of its recent bridge projects, to reduce or supplement standard soil borings. The site investigation for the 18-mile LA-1 elevated bridge currently under construction between Golden Meadow and Port Fourchon required 99 soil borings and 124 CPT soundings. The reduction in the number of standard borings saved more than \$1 million dollars.

CPT technology also is saving time and money on the reconstruction of the I-10 Twin Span Bridge over Lake Pontchartrain, which was ravaged by Hurricane Katrina in August 2005. The dense deposit underlying much of the site can vary up to 16 feet within a single footing area. Multiple CPT probes are being used within the cap footprint to define the bearing layer of sand deposits and to reduce pile cut-offs and buildups.

The cost of the CPT soundings on this project was less than 25 percent of the cost for soil borings. These

savings, plus the savings for pile order lengths and construction time, are estimated at more than \$1 million dollars.

### Future Research

LTRC will continue to conduct research projects to develop, refine, and expand the CPT technology for geotechnical applications. One project scheduled for 2008 will examine the use of PCPT technology for predicting pile setup. Another project will evaluate the spatial variability of soil within a site for reliability analysis, to calibrate corresponding LRFD resistance factors.

In addition, LTRC is planning to upgrade the LPD-CPT software to include steel-driven piles and drilled shafts, plus a new CPT method based on piezocone penetration measurements using effective cone tip resistance ( $q_e$ ).

For more information, contact Mark J. Morvant, Associate Director, Research, Louisiana Transportation Research Center, 4101 Gourrier Avenue, Baton Rouge, LA 70808, telephone 225-767-9124, e-mail [markmorvant@dotd.la.gov](mailto:markmorvant@dotd.la.gov).

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Suggestions for "Research Pays Off" topics are welcome. Contact G. P. Jayaprakash, Transportation Research Board, Keck 488, 500 Fifth Street, NW, Washington, DC 20001 (telephone 202-334-2952, e-mail [gjayaprakash@nas.edu](mailto:gjayaprakash@nas.edu)).

## Jeffrey R. Keaton

*MACTEC Engineering and Consulting, Inc.*

**E**ngineering geologist and consultant Jeffrey Keaton has had a distinguished, 37-year career in managing, conducting, and supervising diverse geologic, seismologic, and geotechnical projects in areas that include energy development and transmission; gas, liquid, and sewer pipelines; fossil-fuel and nuclear power plants; bridges, roads, and highways; mines, quarries, and milling facilities; water supply, power generation, flood control, tailings disposal, and sediment control dams; hospitals, schools, and government buildings; radioactive waste disposal facilities; and communications and document storage facilities.

Keaton began his career as a soils technician observing fill placement and conducting density tests in Southern California during the summers of his undergraduate studies at the Univer-



**“Membership in a variety of technical and professional societies is beneficial when promoting research ideas and disseminating results.”**

sity of Arizona. In 1971, he started work at the Los Angeles offices of Dames & Moore, a global engineering corporation, and pursued a master's degree in engineering at the University of California, Los Angeles. In 1972, with his master's degree completed, Keaton accepted a variety of project assignments—natural gas collection and electric power generation in Iran, as well as domestic projects involving site characterization, landslide hazard mapping, and calculation of earthquake ground motion for design.

In 1979, Keaton transferred to the Salt Lake City, Utah, offices of Dames & Moore, where he worked on projects in coal mine development, highway improvement, and siting and design of government, commercial, and educational facilities. Developing an interest in the formal aspects of engineering geology mapping, Keaton published a paper on a system of mapping symbols and began participating in—and later chairing—the Engineering Geology and the Exploration and Classification of Earth Materials committees at TRB. He currently chairs the Section on Geology and Properties of Earth Materials and serves on the Emerging Technology for Design and Construction Committee, and the Design and Construction Group executive committee. He also served on a National Cooperative Highway Research Program

Project Panel on Development of Portable Scour Monitoring Equipment, and is an emeritus member of the Exploration and Classification of Earth Materials Committee.

In the late winter of 1983, the El Niño storms affecting the western United States provided a unique opportunity for Keaton. As a U.S. Geological Survey external grant researcher, he participated in a series of Utah State University Research Projects to map regional liquefaction hazards in Utah's Wasatch Front.

“As a result of my research, I was asked to participate in a National Academy of Sciences disaster reconnaissance team to identify research opportunities in the landslides, floods, and debris flows occurring in Utah during the 1983 El Niño event,” Keaton recalls. “I was successful in documenting the damaging natural processes and I wrote my doctoral dissertation on one of the debris-flow topics I identified at the time.”

Other notable endeavors in which Keaton has participated include a National Cooperative Highway Research Program project to develop guidelines for scour at bridge foundations on rock; a project to develop earthquake ground motion for the design of a proposed composite steel and concrete bridge at the Hoover Dam, Colorado; earthquake design parameters and foundation requirements for a cable-stayed pipe bridge and a full suspension bridge in the State of the Amazonas, Peru; and directing landslide hazard and risk assessment for suspension bridge foundations at two gas pipeline crossings in northwestern Los Angeles County, California.

Currently a senior principal engineering geologist with MACTEC Engineering and Consulting, Inc., Keaton is active in many professional transportation and engineering organizations and he maintains that “membership in a variety of technical and professional societies is beneficial when promoting research ideas and disseminating results.” He presently chairs the International Association for Engineering Geology and the Environment Commission No. 1 on Engineering Geological Characterization and Visualization. He is also a member of the Technical Coordination Council of the American Society of Civil Engineers' Geo Institute and of the Engineering Accreditation Commission of ABET, Inc. In 2004, he was the Richard H. Jahns Distinguished Lecturer in Engineering Geology, an honor jointly sponsored by the Engineering Geology Division of the Geological Society of America and the Association of Environmental and Engineering Geologists—groups of which Keaton served as chair in 1989 and president in 1992, respectively.

Keaton is a registered professional engineer in Alaska, Arizona, California, and Utah. He received a bachelor's degree in geological engineering from the University of Arizona, Tucson, in 1971; a master's degree in engineering from the University of California, Los Angeles, in 1972; and a doctorate in geology from Texas A&M University in 1988.

## James S. Moulthrop

*Fugro Consultants, Inc.*

A veteran transportation engineer with expertise in asphalt technology and pavement preservation, Jim Moulthrop applies extensive experience to his current position managing pavement research projects and mentoring staff as a senior consultant with Fugro Consultants, Inc., Austin, Texas.

In a diverse, 44-year career, Moulthrop has served as a soils engineer, field materials engineer, and director of highway maintenance for the Pennsylvania Department of Transportation (DOT). As eastern regional director of asphalt modification for the Lubrizol Corporation, he participated in business planning, interacted with state DOTs and the Federal Highway Administration, and implemented modified pavements in West Virginia, Ohio, and Kentucky. He also worked for Exxon Chem-



**“Sponsoring and supporting such research activities [as the Strategic Highway Research Program] is crucial to the future of transportation.”**

ical Americas in business planning and the implementation of a new group of pavement performance-enhancing asphalt modifiers and asphalt mixtures using Polybilt™ polymers.

A career highlight for Moulthrop occurred in 1987, when, as a researcher in the civil engineering department of the University of Texas at Austin, he participated in the Strategic Highway Research Program (SHRP)—a five-year, applied research initiative authorized by the U.S. Congress to develop and evaluate techniques and technologies to counter the deteriorating national highway infrastructure.

“Participation in SHRP provided me with the opportunity not only to be involved with groundbreaking research in asphalt binders and mixtures, but also to interact with world-class scientists and engineers. Research programs like SHRP have been the cornerstone of the transportation system innovations and developments that I’ve participated in and witnessed throughout my career. Sponsoring and supporting such research activities is crucial to the future of transportation.”

Active in TRB for 35 years, Moulthrop chaired and is an

emeritus member of the Committee on Pavement Maintenance and the Committee on Characteristics of Bituminous Aggregate Combinations to Meet Surface Requirements. He chairs the Bituminous Materials Section; cochairs the Roadway Pavement Preservation Task Force; and has served as a member of the Design and Construction Group and of committees on Maintenance and Operations Management and on Management of Quality Assurance.

In addition to his work at TRB, Moulthrop chaired the Federal Highway Administration (FHWA) Pavement Preservation Performance-Related Specification Expert Task Group and the Road and Paving Materials Committee of the American Society for Testing and Materials. He serves as vice president of the Association of Asphalt Paving Technologists; is an ad hoc member of the American Association of State Highway and Transportation Officials’ Subcommittee on Maintenance; has served as a member of the Advisory Board of the National Center for Pavement Preservation at Michigan State University; is a former member of the Steering Committee for the 5th International Conference on Managing Pavements; and has served on the Technical Advisory Group for the International Society of Asphalt Pavements Conference, Copenhagen, Denmark.

A registered professional engineer in Arizona and Pennsylvania, Moulthrop has authored manuals on the quality assurance and materials control of asphalt materials, statistical quality control of highway construction, and the performance of asphalt pavements, as well as papers that have appeared in many scientific journals, periodicals, and proceedings. He has given presentations to audiences at transportation conventions and conferences throughout North America and has taught courses on a variety of topics in highway construction at Pennsylvania DOT and the FHWA National Highway Institute.

Moulthrop has received awards recognizing his achievements, including the 1975 National University Extension Association Creativity Award for a series of 12 continuing education courses on Statistical Quality Control of Highway Construction; inclusion in the 2nd edition of *Who’s Who in Science and Engineering*; the 1999 Association of Asphalt Paving Technologists Award of Recognition; and the 1999 FHWA Partnership in Excellence Award. He received a bachelor’s degree in geology from St. Joseph’s College, Rensselaer, Indiana, in 1960, and a master’s degree in geology from Kansas State University in 1963.

## NEWS BRIEFS



### Incident Information System Works in Real Time

Researchers at the Center for Advanced Transportation Technology Laboratory (CATT), A. James Clark School of Engineering, University of Maryland, have created an automated incident information sharing system that allows traffic controllers and emergency workers to communicate electronically, in real time, reducing the need for phones and other human-initiated systems for sharing traffic-related information.

An initiative of the Metropolitan Area Transportation Operations Coordination Program, the Regional Integrated Transportation Information System is funded by a \$1.9 million federal grant and uses maps, lists, and other graphics to convey real-

time traffic incident, accident, and road weather information to transportation agencies in the Washington, D.C., metropolitan area. The system serves as the foundation for a proposed regional 511 phone system that will provide roadway status information to the traveling public.

*For more information, visit [www.eng.umd.edu](http://www.eng.umd.edu).*

### Boston Harbor Shipping Lanes Redrawn

On July 1, ships transiting in and out of Boston Harbor began traveling on rerouted shipping lanes. The redrawing of the lanes, carried out by the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Coast Guard, added 3.75 nautical miles to the overall distance and 10 to 22 minutes of travel time per one-way trip.

The east-west leg of the lanes moved 12 degrees to the north, and lanes were narrowed from a width of 2 to 1.5 miles. The lane shift will put large-ship traffic farther away from waters containing high concentrations of whales, fishing boats, and other small watercraft—improving safety by reducing the risk of ship-ship and ship-whale collisions.

To determine the potential for collision reduction, NOAA researchers calculated the spatial density of whales in the NOAA Stellwagen Bank National Marine Sanctuary. Possible safety and navigational affects on ship traffic were examined by the U.S. Coast Guard, and data on whale presence were collected by the Provincetown Center for Coastal Studies, the Whale Center of New England, and by individual researchers in the region.

*For more information, visit [www.noaa.gov](http://www.noaa.gov).*

**HIGH-SPEED RAIL AT OLYMPICS**—A next-generation, high-speed train arrives in Southampton, United Kingdom, in preparation for the 2012 Olympic Games. The train, built by Hitachi Europe, is capable of traveling at speeds of 225 km/h and will be joined by 29 additional units, which will operate on Southeastern Railways High Speed 1 line between Ashford, Kent, Southeast England, and London's St. Pancras terminal.



## CALENDAR

## TRB Meetings 2008

## January

- 13–17 TRB 87th Annual Meeting  
Washington, D.C.  
Linda Karson

## March

- 2–5 1st Pan American  
Geosynthetics Conference  
and Exhibition\*  
Cancun, Mexico
- 9–12 GeoCongress 2008:  
The Challenge of Stability in  
the Geoenvironment\*  
New Orleans, Louisiana
- 17–18 Data Sources to Measure the  
Impacts of Goods Movement  
on Air Quality  
Irvine, California

## April

- 1–4 Innovative Instrumentation  
for Quality Control  
Assessments of Ground  
Improvement Projects\*  
Taipei, Taiwan  
G. P. Jayaprakash
- 8–9 Highway Economic  
Requirements Modeling and  
Data Integration Conference  
Irvine, California  
Thomas Palmerlee
- 10–11 Western Traffic Data  
Workshop: Successful  
Strategies in Data Collection  
for Corridors and Planning  
Irvine, California  
Thomas Palmerlee

## May

- 13–14 Open Architectures to  
Support Data Integration  
Peer Exchange (*by invitation*)  
TBD  
Thomas Palmerlee

- 15–16 Aligning Data to Support  
Transportation Decision  
Making (*by invitation*)  
Washington, D.C.  
Thomas Palmerlee
- 18–21 National Roundabout  
Conference  
Kansas City, Missouri
- 19–22 International Conference on  
Heavy Vehicles\*  
Paris, France
- 27–31 10th International  
Conference on Application of  
Advanced Technologies in  
Transportation\*  
Athens, Greece

## June

- 2–4 25th International Bridge  
Conference\*  
Pittsburgh, Pennsylvania
- 16–17 4th National Conference on  
Surface Transportation  
Weather  
Indianapolis, Indiana
- 16–18 6th RILEM International  
Conference on Cracking in  
Pavements\*  
Chicago, Illinois
- 17–19 7th International Symposium  
on Snow Removal and Ice  
Control Technology  
Indianapolis, Indiana
- 23–28 7th International Conference  
on Managing Pavements and  
Other Roadway Assets\*  
Calgary, Alberta, Canada

## July

- 6–9 47th Annual Workshop on  
Transportation Law  
San Diego, California  
James McDaniel

- 13–16 8th National Conference on  
Access Management\*  
Baltimore, Maryland
- 13–17 4th International Conference  
on Bridge Maintenance,  
Safety, and Management\*  
Seoul, Korea
- 27–30 6th National Seismic  
Conference on Bridges and  
Highways\*  
Charleston, South Carolina

## August

- 6–8 North American Travel  
Monitoring Conference  
and Exposition  
(NATMEC 2008)  
Washington, D.C.
- 11–16 6th International Conference  
on Case Histories in  
Geotechnical Engineering\*  
Washington, D.C.
- 17–21 9th International Conference  
on Concrete Pavements\*  
San Francisco, California

## September

- 8–11 International Conference on  
Construction Management\*  
Orlando, Florida  
Frederick Hejl
- 17–19 11th National Conference on  
Transportation Planning for  
Small and Medium-Sized  
Communities: Tools of the  
Trade  
Portland, Oregon
- 22–23 North American Freight  
Transportation Data  
Conference  
Irvine, California  
Thomas Palmerlee

Additional information on TRB meetings, including calls for abstracts, meeting registration, and hotel reservations, is available at [www.TRB.org/calendar](http://www.TRB.org/calendar)). To reach the TRB staff contacts, telephone 202-334-2934, fax 202-334-2003, or e-mail [lkarson@nas.edu](mailto:lkarson@nas.edu). Meetings listed without a TRB staff contact have direct links from the TRB calendar web page.

\*TRB is cosponsor of the meeting.

# TRB HIGHLIGHTS

From *Record* No. 1 (left) to No. 2000 (right), with several intervening cover variations.

## TRB's Journal Passes Milestone

In November, the Transportation Research Board published the 2,000th volume of the Transportation Research Record journal series. The series started in 1963 as the Highway Research Record, changed to the Transportation Research Record in 1974 with No. 480,

and added the subtitle, Journal of the Transportation Research Board in 1999 with No. 1653.

*Transportation Research Record: Journal of the Transportation Research Board, No. 2000* contains 15 papers on Intelligent Transportation Systems and Vehicle-Highway Automation. In the past 25 years, TRB has published more than 16,000 peer-reviewed papers in 17 transportation subject categories. In March 2007, TRB made more than 8,000 papers available online at <http://trb.metapress.com/home/main.mpx>.

The first volume in the series came out in March 1963, consisted of 65 pages with seven papers on Materials Inventories, and cost \$1.40. The publication's size was 7 x 9.75 inches, and changed to 8.5 x 11 inches in 1977 with No. 587. The original masthead listed staff members Fred Burggraf and W. N. Carey, Jr., and Executive Committee members Pyke Johnson and K. B. Woods—all of whom have major TRB annual awards named after them.



## COOPERATIVE RESEARCH PROGRAMS NEWS

### Specifications and Protocols for Fly Ash Acceptance Tests

A byproduct of coal combustion, fly ash is often used as a cementitious and pozzolanic ingredient in hydraulic cement concrete. Although fly ash improves some properties and lowers the cost of concrete, the chemical and physical composition of fly ash influences the constructability, performance, and durability of concrete and may contribute to problems, including concrete cracking and alkali-silica reactivity in pavements, bridge decks, and other highway structures.

Current specifications and test methods do not adequately characterize fly ash properties, address the effects of fly ash characteristics on fresh and hardened concrete, or consider the alkali content of cements. Inadequate characterization of fly ash properties and their effects on concrete pavements may lead to unwarranted restrictions. Research has not dealt with the applicability of current spec-

ifications to the fly ashes that are being produced. Recommendations therefore are needed to improve fly ash specifications and to test protocols to help highway agencies evaluate and use fly ash to provide acceptable structural performance and durability.

Michigan Technological University, Houghton, has been awarded a \$749,125, 36-month contract (National Cooperative Highway Research Program [NCHRP] Project 18-13, FY 2007) to recommend potential improvements to specifications and test protocols for determining the acceptability of fly ash used in highway concrete. Resulting specifications and test methods will be recommended for adoption by the American Association of State Highway and Transportation Officials.

For more information, contact Amir Hanna, TRB, 202-334-1892, [ahanna@nas.edu](mailto:ahanna@nas.edu).

### Advanced Concrete for Bridge Girders and Decks

Many state highway agencies have adopted high-strength, prestressed concrete girders and high-performance decks for use in bridge construction because of their technical and economic benefits. The girders and decks are manufactured with concrete made of natural, normal weight aggregates. Use of manufactured lightweight coarse aggregates—such as expanded shale, slate, and clay—to produce lightweight concrete offers the benefits of reducing superstructure weight; reducing the size of girders, substructures, and foundations; and reducing shipping, handling, and construction or replacement costs of bridge elements.

Because design and construction guidelines are lacking, recent advances in high-performance, high-strength, lightweight concrete have had limited application in bridge construction. There is a need to address the design, constructability, and performance of high-

strength, prestressed concrete bridge girders and high-performance bridge decks, as well as to recommend changes to the American Association of Highway and Transportation Officials' (AASHTO) Load and Resistance Factor Design (LRFD) bridge specifications to facilitate use of lightweight concrete for these applications.

Virginia Polytechnic Institute and State University, Blacksburg, Virginia, has been awarded a \$749,880, 36-month contract (NCHRP Project 18-15, FY 2007) to develop guide specifications for the use of lightweight concrete in high-strength, prestressed girders and in high-performance bridge decks, and to recommend changes to applicable AASHTO LFRD Bridge Design and Construction Specifications.

For more information, contact Amir Hanna, TRB, 202-334-1892, [ahanna@nas.edu](mailto:ahanna@nas.edu).

**Research Round Table 134: Market Access, Trade in Transport Services and Trade Facilitation**

P. Latrille, T. R. Lakshmanan, W. P. Anderson, J. F. Francois, I. Wooton, D. Nikomborirak, P. Demetriades, D. Stoyanov, V. Sarigiannidis, and G. Aifadopoulos. OECD-ECMT, 2007; 235 pp.; \$91; 97-892-8210-1-469.

Taken from the proceedings of a research roundtable hosted by the Hellenic Institute of Transport, Greece, this book presents information on transportation's role in regional economic integration under the multilateral liberalization of trade; the effects of liberalized transportation services on market structure and on national competition policies; and the demand for the coordination of international transportation infrastructure and logistics policies and of transportation security.



Authors of the introductory reports include Pierre Latrille, World Trade Organization; T. R. Lakshmanan and William Anderson, United States; Joseph Francois, Netherlands; Ian Wooton, United Kingdom; Deuden Nikomborirak, Thailand; Panicos Demetriades, United Kingdom; D. Stoyanov, Bulgaria; and Vassilos Sarigiannidis and G. Aifadopoulos, Greece.

**The Asphalt Handbook**

Asphalt Institute, 2007; 770 pp.; \$120; 1-934154-27-X.

A comprehensive manual on the use of asphalt for contractors, engineers, consultants, specifiers, and agencies, the 7th updated edition of the *Asphalt Handbook* features a two-color layout, new graphics and photos, state-of-the-practice illustrations and charts, detailed reference lists, and a new topical and keyword index.



The text shows how to apply the latest paving technologies to address a variety of challenges, including issues in pavement durability, load rating, wear and tear, noise, and more. New topics include Superpave® asphalt binder, Superpave mix design, stone matrix asphalt, open-graded friction courses, quality control and acceptance, pavement management, and rehabilitation of concrete pavements with hot-mix asphalt.

The books in this section are not TRB publications.  
To order, contact the publisher listed.

**TRB PUBLICATIONS****Guidelines for Concrete Mixtures Containing Supplementary Cementitious Materials to Enhance Durability of Bridge Decks**

NCHRP Report 566

Presented are guidelines to facilitate the use of supplementary cementitious materials to increase the durability of concrete for highway construction and bridge decks. Also included is a methodology for selecting optimum concrete mixture proportions to ensure durability and suitability for specific environmental conditions.

2007; 119 pp.; TRB affiliates, \$35.25; nonaffiliates, \$47. Subscriber categories: bridges, other structures, and hydraulics and hydrology (IIC); materials and construction (IIIB).

**TransXML: XML Schemas for Exchange of Transportation Data**

NCHRP Report 576

This report proposes a common framework for the exchange of transportation data in eXtensible markup language or TransXML. The framework can

be used for developing, validating, disseminating, and extending current and future schemas. The potential benefits from the adoption and expansion of TransXML are summarized, and the future efforts needed to ensure success are outlined.

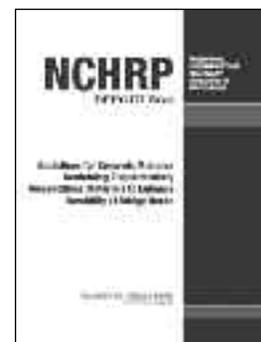
2007; 59 pp.; TRB affiliates, \$28.50; nonaffiliates, \$38. Subscriber categories: planning and administration (IA); design (II); highway operations, capacity, and traffic control (IVA).

**Tribal Transportation Programs**

NCHRP Synthesis 366

Innovations and model practices of tribal transportation programs, including program histories and legal and administrative developments, are examined. Programs are presented in the context of tribal sovereignty and tribal relationships with federal, state, and local governments, as well as with local and regional planning agencies.

2006; 132 pp.; TRB affiliates, \$33; nonaffiliates, \$44. Subscriber categories: planning and administration (IA); energy and environment (IB).



## TRB PUBLICATIONS (continued)

**Smartcard Interoperability Issues for the Transit Industry**

TCRP Report 115

This report presents findings on the interoperability of transit smart cards, identifies information needed by public agencies to implement interoperable smartcard payment systems, examines the necessary flows of information, and outlines a set of functions for a standard public domain application programming interface for developing a uniform application protocol data unit.

2006; 99 pp.; TRB affiliates, \$23.25; nonaffiliates, \$35. Subscriber category: public transit (VI).

**Fixed-Route Transit Ridership Forecasting and Service Planning Methods**

TCRP Synthesis 66

Presented are findings on the state of the practice in fixed-route transit ridership forecasting and service planning. Forecasting methodologies are identified, along with resource requirements, data inputs, and organizational issues. Also included is information about the impacts of service changes and about transit agency assessments of self-implemented improvement programs.

2006; 50 pp.; TRB affiliates, \$23.25; nonaffiliates, \$31. Subscriber category: public transit (VI).

**Innovative Finance and Alternative Sources of Revenue for Airports**

ACRP Synthesis 1

This first volume in the Airport Cooperative Research Program Synthesis series provides an overview of common capital funding sources used by airport operators; a review of capital financing mechanisms used by airports; descriptions of various revenue sources developed by airport operators; and a review of the privatization options available to U.S. airport operators.

2007; 43 pp.; TRB affiliates, \$33; nonaffiliates, \$44. Subscriber categories: planning and administration (IA); aviation (V).

**Impact of Behavior-Based Safety Techniques on Commercial Motor Vehicle Drivers**

CTBSSP Synthesis 11

Identified and described are strategies to increase the safe driving behavior and to decrease the at-risk driving behavior of commercial motor vehicle drivers. An extensive literature review and case study information on innovative and successful behavior-based safety practices in commercial vehicle settings are included.

2007; 67 pp.; TRB affiliates, \$36; nonaffiliates,

\$48. Subscriber categories: operations and safety (IV); freight transportation (VIII).

**Traffic Flow Theory 2006**

Transportation Research Record 1965

This volume is divided into three parts. Part 1: Traffic Flow Theory and Characteristics addresses such topics as an analysis of bottleneck activation on German autobahns and an adaptive approach to short-term traffic flow prediction that accounts for disruptive factors. Part 2: Car-Following Models presents research on an alternative paradigm for traffic dynamics models appropriate for traffic simulation; car-following behavior of individual drivers in traffic; and estimating traffic delays caused by lane-change maneuvers. Part 3: Traffic Simulation, Cell Transmission, and Measurement contains research on the development of credible and valid simulation models of two unconventional traffic circles in New Jersey; a model for studying the impact of traffic camera quantity on the precision of estimated travel times on a road in the French Alps; and more.

2006; 218 pp.; TRB affiliates, \$45; nonaffiliates, \$60. Subscriber category: highway operations, capacity, and traffic control (IVA).

**Freight Analysis, Evaluation, and Modeling: Truck Transportation**

Transportation Research Record 1966

Authors present research findings on the development of a framework for the evaluation of commercial vehicle border preinspection systems; the identification and analysis of current U.S.–Mexico border crossing issues; freight warehouse layout and design problems; a framework for carrier dynamic collaboration using dynamic, incentive-compatible mechanisms; the receptiveness of Manhattan, New York, restaurant industry representatives to policies that foster off-peak hour deliveries to restaurants; enhancing models of rail freight system capacity and capacity flexibility; grain elevator trip generation equations to aid in site pavement design and large truck access; and more.

2006; 132 pp.; TRB affiliates, \$39; nonaffiliates, \$52. Subscriber category: freight transportation (VIII).

To order the TRB titles described in Bookshelf, visit the TRB online Bookstore, at [www.TRB.org/bookstore/](http://www.TRB.org/bookstore/), or contact the Business Office at 202-334-3213.

## INFORMATION FOR CONTRIBUTORS TO

**TR NEWS**

*TR News* welcomes the submission of manuscripts for possible publication in the categories listed below. All manuscripts submitted are subject to review by the Editorial Board and other reviewers to determine suitability for *TR News*; authors will be advised of acceptance of articles with or without revision. All manuscripts accepted for publication are subject to editing for conciseness and appropriate language and style. Authors receive a copy of the edited manuscript for review. Original artwork is returned only on request.

**FEATURES** are timely articles of interest to transportation professionals, including administrators, planners, researchers, and practitioners in government, academia, and industry. Articles are encouraged on innovations and state-of-the-art practices pertaining to transportation research and development in all modes (highways and bridges, public transit, aviation, rail, and others, such as pipelines, bicycles, pedestrians, etc.) and in all subject areas (planning and administration, design, materials and construction, facility maintenance, traffic control, safety, geology, law, environmental concerns, energy, etc.). Manuscripts should be no longer than 3,000 to 4,000 words (12 to 16 double-spaced, typed pages). Authors also should provide appropriate and professionally drawn line drawings, charts, or tables, and glossy, black-and-white, high-quality photographs with corresponding captions. Prospective authors are encouraged to submit a summary or outline of a proposed article for preliminary review.

**RESEARCH PAYS OFF** highlights research projects, studies, demonstrations, and improved methods or processes that provide innovative, cost-effective solutions to important transportation-related problems in all modes, whether they pertain to improved transport of people and goods or provision of better facilities and equipment that permits such transport. Articles should describe cases in which the application of project findings has resulted in benefits to transportation agencies or to the public, or in which substantial benefits are expected. Articles (approximately 750 to 1,000 words) should delineate the problem, research, and benefits, and be accompanied by one or two illustrations that may improve a reader's understanding of the article.

**NEWS BRIEFS** are short (100- to 750-word) items of interest and usually are not attributed to an author. They may be either text or photographs or a combination of both. Line drawings, charts, or tables may be used where appropriate. Articles may be related to construction, administration, planning, design, operations, maintenance, research, legal matters, or applications of special interest. Articles involving brand names or names of manufacturers may be determined to be inappropriate; however, no endorsement by TRB is implied when such information appears. Foreign news articles should describe projects or methods that have universal instead of local application.

**POINT OF VIEW** is an occasional series of authored opinions on current transportation issues. Articles (1,000 to 2,000 words) may be submitted with appropriate, high-quality illustrations, and are subject to review and editing. Readers are also invited to submit comments on published points of view.

**CALENDAR** covers (a) TRB-sponsored conferences, workshops, and symposia, and (b) functions sponsored by other agencies of interest to readers. Notices of meetings should be submitted at least 4 to 6 months before the event.

**BOOKSHELF** announces publications in the transportation field. Abstracts (100 to 200 words) should include title, author, publisher, address at which publication may be obtained, number of pages, price, and ISBN. Publishers are invited to submit copies of new publications for announcement.

**LETTERS** provide readers with the opportunity to comment on the information and views expressed in published articles, TRB activities, or transportation matters in general. All letters must be signed and contain constructive comments. Letters may be edited for style and space considerations.

**SUBMISSION REQUIREMENTS:** Manuscripts submitted for possible publication in *TR News* and any correspondence on editorial matters should be sent to the Director, Publications Office, Transportation Research Board, 500 Fifth Street, NW, Washington, DC 20001, telephone 202-334-2972, or e-mail [jawan@nas.edu](mailto:jawan@nas.edu).

- ◆ All manuscripts should be supplied in 12-point type, double-spaced, in Microsoft Word 6.0 or WordPerfect 6.1 or higher versions, on a diskette or as an e-mail attachment.

- ◆ Submit original artwork if possible. Glossy, high-quality black-and-white photographs, color photographs, and slides are acceptable. Digital continuous-tone images must be submitted as TIFF or JPEG files and must be at least 3 in. by 5 in. with a resolution of 300 dpi or greater. A caption should be supplied for each graphic element.

- ◆ Use the units of measurement from the research described and provide conversions in parentheses, as appropriate. The International System of Units (SI), the updated version of the metric system, is preferred. In the text, the SI units should be followed, when appropriate, by the U.S. customary equivalent units in parentheses. In figures and tables, the base unit conversions should be provided in a footnote.

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# Addressing the Design, Construction, and Preservation of the Nation's Highway Infrastructure

Addressing the design, construction, and preservation of the nation's highway infrastructure is as important today as it was more than 85 years ago, when TRB was established. Since its founding, the exchange of information and research results on highways has been a core TRB mission. The Board's first continuing research management activity, the National Cooperative Highway Research Program, started in 1962; in 2006 the congressionally requested, second Strategic Highway Research Program began work on advancing solutions for highway safety, renewal, reliability, and capacity. Today's TRB—multimodal in mission, services, and outlook—continues to develop and publish extensive information designed to improve the safety, durability, and reliability of the nation's roadways. Recent TRB publications of interest include the following:

## Highway Capacity Manual 2000

- U.S. customary print version (HCM2KE), ISBN 0-309-06746-4, 1,134 pages, binder (2000), \$110
- U.S. customary print version with CD-ROM (HCM2EC), ISBN 0-309-06746-4, 1,134 pages, binder (2000), \$155
- Metric print version (HCM2KM), ISBN 0-309-06681-6, 1,134 pages, binder (2000), \$110
- Metric print version with CD-ROM (HCM2MC), ISBN 0-309-06681-6, 1,134 pages, binder (2000), \$155
- Set of two CD-ROMs: U.S. Customary and metric versions (HCM2KC), 2001, \$100

## Simplified Live-Load Distribution Factor Equations

National Cooperative Highway Research Program (NCHRP) Report 592, ISBN 0-309-09900-4, 127 pages, 8.5 x 11, paperback (2007), \$49

## Soil Mechanics 2006

Transportation Research Record: Journal of the Transportation Research Board (TRR), No. 1975, ISBN 0-309-09984-6, 162 pages, 8.5 x 11, paperback (2006), \$55

## Geometric Design Strategic Research

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