U.S. Department of Transportation
Federal Highway Administration

Accelerated Implementation and Deployment of Pavement Technologies

2017–18 Annual Report

Turning Best Practices into Everyday Practices

The mission of the Federal Highway Administration (FHWA) is to improve mobility on the Nation's highways. We strive for roads that are safe, smooth, and free of significant delays, and that provide a great traveling experience for motorists and other users.

The Accelerated Implementation and Deployment of Pavement Technologies program advances the latest and best practices and technologies for constructing and maintaining high-quality, long-lasting pavements. This program is vital to support FHWA's mission.

As we reflect on our progress this year, we want to highlight various technology transfer and outreach efforts, which are central to the program. These activities deliver critical insights, experience, and practices to the pavement community through meaningful and cost-effective strategies, ranging from preparation of webinars, demonstrations, and videos to development of guidance documents.

This year a number of technologies are being implemented in new program areas, which is having significant impacts on highway practices. For example:

- The Back to Basics series of 12 webinars on asphalt pavement reached participants across the country, giving government employees, contractors, and other attendees a greater understanding of innovations.
- The four "Concrete Clips" videos on the YouTube platform gave users unlimited 24-hour access for on-demand information on concrete technology topics. A total of 17 videos are planned for completion by the end of 2019.
- Twenty-one State highway agencies are participating in a pooled fund study to develop a new standard for the automated measurement of faulting of joints and cracks on concrete pavements.
- New technical guidance on the design of porous asphalt pavements was issued and is increasing the use of these sustainable structures in communities across the United States.

In addition, work continues to be done in promoting more performance-engineered mixes for both concrete and asphalt pavement structures to improve the overall sustainability of pavement systems and to increase the use of recycled products.

We continue to enable our stakeholders to effectively manage their pavement assets and improve the condition of the highway system through our strong partnership with highway agencies, industry, academia, the consulting community, and more.

I'm pleased to share these highlights from our ongoing activities, and I look forward to sharing more successes as we continue to develop and deploy innovations on the Nation's roadways together.

Sincerely,

Thomas D. Everett

Thomas D. Everett
FHWA Associate Administrator for Infrastructure

About the Program

Congress established the Accelerated Implementation and Deployment of Pavement Technologies (AID-PT) program in 2012 under the Moving Ahead for Progress in the 21st Century Act (MAP-21). The program's purpose is to document, demonstrate, and deploy innovative pavement technologies—including their applications, performance, and benefits.

In 2015, Congress continued the program in the Fixing America's Surface Transportation (FAST) Act, with funding available through fiscal year 2020. Through strategic partnerships with highway agencies and others across the paving community, FHWA is leveraging Federal investments to maximize the impact of the program, effectively amplifying the benefits to the traveling public.

The AID-PT program focuses on promoting, implementing, and deploying proven technologies and demonstrated practices. Specifically, the program encourages highway agencies to adopt and implement new technologies that have been shown to save money, enhance safety, improve performance, increase efficiency, and reduce delay.

This annual report documents FHWA's approach to achieve the six overarching goals Congress set for the program (see page 2).

The FAST Act Section 6003 calls for "a report on the cost and benefits from deployment of new technology and innovations that substantially and directly resulted from the program." The report may include the analysis of Federal, State, and local cost savings; improvements in project delivery time; reduced fatalities; and minimized impacts of congestion.

Due to the broad scope of the Federal-aid program and wide spectrum of Federal, State, and local stakeholders involved, it is difficult to quantify the overarching impact of the program and the costs and benefits directly attributable to it. Therefore, this report highlights case studies that discuss the anticipated long-term improvements in cost savings, project delivery time, congestion relief, enhanced safety, and pavement performance due to the program.

"The Sustainable Pavements Program is a coordinated effort led by FHWA to advance the knowledge and practice in pavement-related areas. The working group's meetings provide valuable opportunities to stay current and gain knowledge, perspective, and information from the exchange of ideas and interaction with attendees from other DOTs, industry, academia, and FHWA."

— Bouzid Choubane, Florida Department of Transportation

The case studies in the following pages offer a snapshot of the exciting work that FHWA and its partners are doing to accelerate implementation and deployment of cutting-edge pavement technologies and practices.

FHWA is engaged in a variety of efforts to improve paving materials and deliver guidance to help highway agencies design and construct both asphalt and concrete pavements more effectively. These efforts range from focused technology transfer activities featuring webinars and on-demand YouTube videos to practical guide documents on various asphalt and concrete pavement technologies. In addition, they range from stakeholder-based initiatives to promote the overall sustainability of pavement systems to field demonstration and construction projects supported by the agency's mobile testing trailers.

The AID-PT program is an outstanding example of FHWA operating under a shared vision with its teaming partners to implement and deploy critically needed products and technologies. With strong stakeholder support, the program is providing benefits ranging from shorter project delivery times and less congestion to cost savings and fewer roadway fatalities.

Image: Chirachai Phitayachamrat/Shutterstock

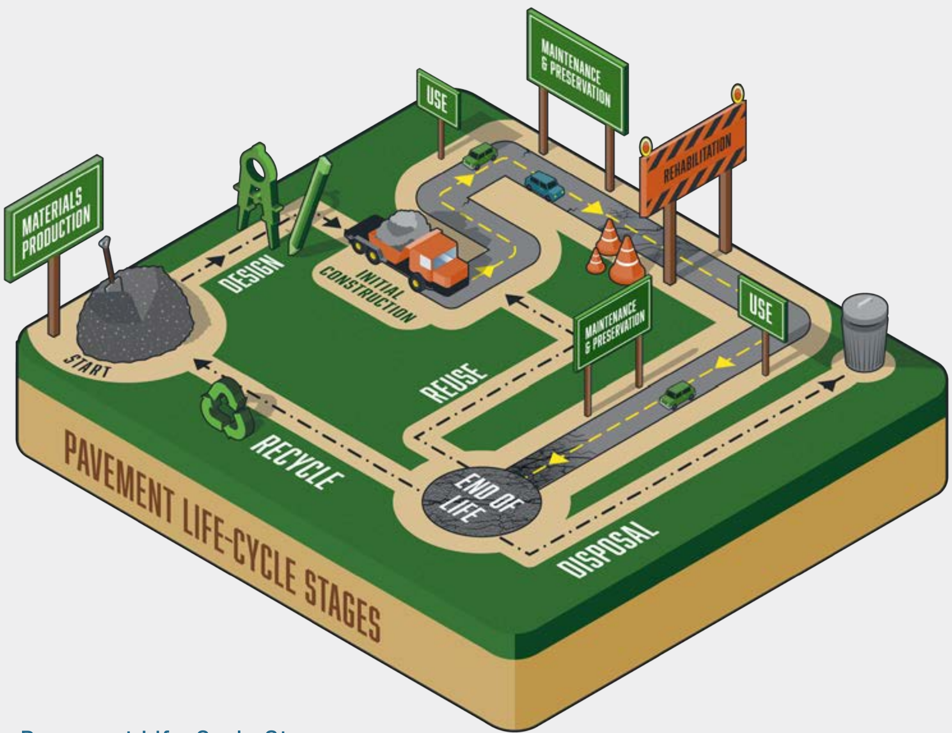
Summary of How Recent FHWA Deployment Efforts Support the Goals of the AID-PT Program

AID-PT Goals [Title 23, United States Code, Section 503(c)(3)]	**Selected FHWA Deployment Efforts**								
	Sustainable Pavements	**Concrete Clips Video Series**	**Back to Basics Webinar Series**	**RAP-RAS-GTR**	**Recycled Concrete Aggregate**	**Performance-Engineered Asphalt Mixes**	**Automated Data Collection Standards**	**Performance-Engineered Concrete Mixes**	**Porous Asphalt Pavements**
1. The deployment of new, cost-effective designs, materials, recycled materials, and practices to extend the pavement life and performance and to improve user satisfaction.	●			●	●	●		●	●
2. The reduction of initial costs and life-cycle costs of pavements, including the costs of new construction, replacement, maintenance, and rehabilitation.	●	●	●	●	●	●	●	●	
3. The deployment of accelerated construction techniques to increase safety and reduce construction time and traffic disruption and congestion.	●	●	●			●			
4. The deployment of engineering design criteria and specifications for new and efficient practices, products, and materials for use in highway pavements.				●	●	●	●	●	●
5. The deployment of new nondestructive and real-time pavement evaluation technologies and construction techniques.		●	●			●	●	●	
6. Effective technology transfer and information dissemination to accelerate implementation of new technologies and to improve life, performance, cost-effectiveness, safety, and user satisfaction.	●	●	●	●	●	●		●	●
See Page	**3**	**6**	**9**	**12**	**15**	**18**	**21**	**24**	**27**

Continuing the Sustainability Journey

FHWA's Sustainable Pavements Program continues to evolve as it supports highway agencies in addressing environmental, social, and economic needs through pavement structures.

The highway community's understanding of sustainability has grown considerably in recent years. For example, at one time recycling was regarded perhaps as the primary means of being "sustainable," but today the pavement community recognizes that sustainability considerations go beyond that. In fact, opportunities to influence the sustainability of a pavement structure occur at every stage of the pavement life cycle. FHWA's Sustainable Pavements Program recognizes this ever-changing landscape and continues to evolve in order to better support the needs of the highway pavement community.



Pavement Life-Cycle Stages

Opportunities to improve sustainability exist at each stage of the pavement life cycle—materials production, design, construction (including maintenance, preservation, and rehabilitation), use, and end-of-life stages. *Source: APTech.*

To date, the program has developed a number of products for use by highway engineers and pavement practitioners. First and foremost is FHWA's hallmark reference document on recommended practices for sustainable pavements, *Towards Sustainable Pavement Systems: A Reference Document* (FHWA-HIF-15-002). Another publication is a framework document that outlines the process for performing a life-cycle assessment, *Pavement Life-Cycle Assessment Framework* (FHWA-HIF-16-014). A third is the *Sustainable Pavements Program Road Map* (FHWA-HIF-17-029), which outlines the short- and long-term needs to be addressed in the area of pavement sustainability.

In addition, the program has undertaken a number of new initiatives to address these needs while working to keep stakeholders engaged through a variety of mechanisms. Here is a look at some of the program's current activities.

Engaging Stakeholders

At the heart of the program is the Sustainable Pavements Technical Working Group. With 20 members representing Federal, State, and local transportation agencies, as well as industry and academia partners, and more than 300 "friends," the working group provides overall guidance for the program and helps raise awareness of sustainability issues. The group meets twice a year to share information through technical presentations, reviews of technical documents, and breakout and roundtable discussions. Recent meetings have covered topics such as life-cycle assessment, economic considerations, pavement technology innovations, and sustainability rating systems.

"The Sustainable Pavements Program is a coordinated effort led by FHWA to advance the knowledge and practice in pavement-related areas," says Bouzid Choubane, State pavement materials engineer with the Florida Department of Transportation. "The working group's meetings provide valuable opportunities to stay current and gain knowledge, perspective, and information from the exchange of ideas and interaction with attendees from other DOTs, industry, academia, and FHWA."

Assessing Impacts

Life-cycle assessment (LCA) provides a structured and methodical way to measure the environmental aspects of sustainability. Initially, agencies can employ LCA to determine where they are in their sustainability journey, and subsequently they can use it to help investigate areas where they could make improvements.

As highway agencies gain a more complete understanding of LCA concepts, they need a tangible product to help them investigate the environmental impacts of pavement materials and design decisions. To address this need, FHWA is developing a simple, user-friendly, Microsoft® Excel-based tool to aid agencies in assessing, benchmarking, and communicating the environmental impacts of pavement mixtures and designs used in new construction, reconstruction, maintenance, and rehabilitation. The tool will report impacts for a range of environmental sustainability indicators such as emissions, energy use, and recycled materials content, among others.

To guide the process of developing the tool and ensure that it meets the needs of State highway agencies, FHWA has assembled a Pavement Life-Cycle Thinking Task Group. The task group, made up of representatives from State highway agencies, will be consulted throughout the entire process of developing the tool. In addition to helping define its goal and scope, the group has provided input to develop the user interface and proposed content, and will perform beta testing and review of the tool's overall documentation.

Heather Dylla, FHWA sustainable pavement engineer and manager of the Sustainable Pavements Program, says, "This is a huge step in the adoption of sustainability performance metrics rather than prescriptive sustainability requirements. Since sustainability is context-specific, it is important to have a tool like this to help engineers identify the tradeoffs in order to make more informed decisions."

Warm-mix asphalt can reduce 20 percent of the energy required to produce asphalt mixtures and increase the compatibility of the mixture, which improves the overall performance. *Source: APTech.*

To produce a safe and quiet surface texture, Next Generation Concrete Surface (NGCS) employs conventional diamond grinding equipment and blades in a different configuration than traditionally used. *Source: APTech.*

Sharing Success Stories

To help highlight some of the technologies featured in the program's reference document, FHWA is developing reports on 10 case studies. The case studies focus on sustainable pavement practices, techniques, and innovations used on specific projects by transportation agencies. The primary objective is to showcase the tangible, positive sustainability impacts that highway agencies have realized, as demonstrated through lower life-cycle costs, reduced environmental impacts, or improved social consequences.

Revamped Website

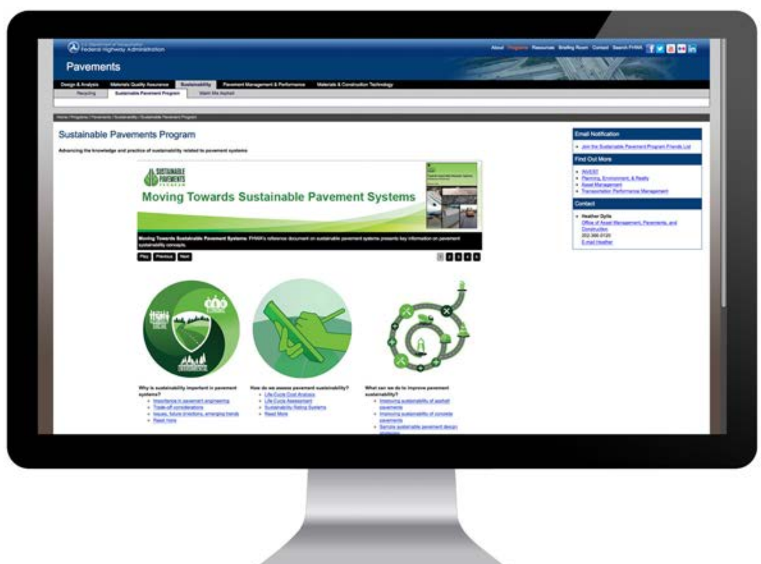
The "Sustainable Pavements Program" website has been completely revamped, offering a sleek, aesthetic design with improved visibility and accessibility to the various products developed under this program. The information on topics related to pavement sustainability are organized under three main areas: importance of sustainability, techniques to assess sustainability, and ways to improve the sustainability of pavement systems. Future updates will include improved integration with mobile devices and social media platforms.

Looking Ahead

The Sustainable Pavements Program will continue to support highway agencies as they incorporate sustainability considerations in their day-to-day operations. On the horizon, FHWA plans to produce additional guidance documents, provide a series of presentations and Tech Briefs on hot topics related to pavement sustainability, conduct outreach activities, and launch a new project focused on incorporating resiliency into pavement considerations.

For more information, visit www.fhwa.dot.gov/pavement/sustainability.

This screenshot shows the updated home page of the "Sustainable Pavements Program" website. *Source: FHWA.*



"The Sustainable Pavements Program is a coordinated effort led by FHWA to advance the knowledge and practice in pavement-related areas."

— Bouzid Choubane, State Pavement Materials Engineer, Florida Department of Transportation

Transferring Technology through YouTube

A pioneering series of videos provides practitioners with valuable information on concrete pavement materials and technologies.

Videographers work with staff from the FHWA Mobile Concrete Trailer to collect footage for use in a future concrete clips video. *Source: Shreenath Rao, Applied Research Associates, Inc.*

In today's high-tech world, pavement innovations are continually under development. These innovative technologies can range from new materials and testing procedures to design and construction improvements. The need to share those technologies and communicate about them effectively is ongoing within the highway community. At the same time, being able to disseminate information on established best practices to a new generation of highway agency personnel remains a continuing challenge.

To help meet this need, FHWA has embarked on a project to share information on concrete technology topics through YouTube, the popular provider of video content. An FHWA team is developing and posting a series of "Concrete Clips" videos on the YouTube platform, effectively reaching a broad audience while providing users with unlimited 24-hour access for on-demand viewings.

In a Nutshell

What are Concrete Clips? They are short (10- to 12-minute) videos that provide information on selected topics about concrete pavement. Targeted at State highway agency personnel and other engineers and developed in a format compatible with YouTube, the videos are structured to provide a high-level overview of information on each topic.

Tom Yu, FHWA's project manager to develop the Concrete Clips, says, "Concrete Clips are a quick and easy way to provide a good overview of a topic and to convey key points to the audience. The visuals help generate interest among viewers, and those interests can be further pursued through sources provided in the videos."

New outreach technologies are expected to lead to improved concrete pavement design, construction, and performance. *Source: APTech.*

Range of Technology Topics

A team of subject matter experts and videographers work together to develop the script and video for each Concrete Clip. The clips cover a variety of concrete pavement technologies. Currently, the FHWA team has identified 15 candidate topics, representing a mix of new technologies and established practices. They fall under broad application categories addressing materials, design, construction, and technology transfer and deployment. The topics selected or being considered for video development include the following:

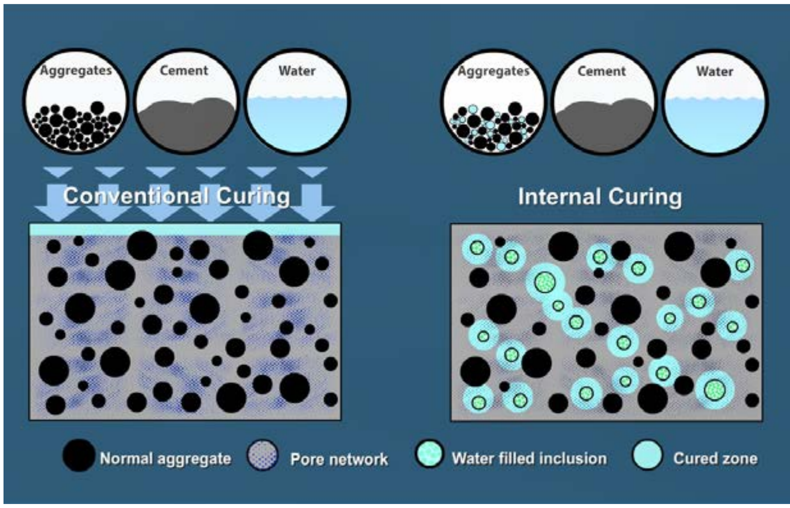
- **Materials**
  - » Cement Manufacturing
  - » Blended Cements
  - » Supplemental Cementitious Materials
  - » Aggregates for Concrete Paving Mixtures
  - » Alkali-Silica Reactivity
  - » Freeze-Thaw Durability
- **Design**
  - » Optimized Mixture Design
  - » AASHTO Pavement ME Design
- **Construction**
  - » Internal Curing
  - » Air Entrainment and Super Air Meter Test
  - » Workability
  - » Permeability and Surface Resistivity Test
  - » Real-Time Smoothness
- **Technology Transfer and Deployment**
  - » FHWA Mobile Concrete Trailer
  - » National Concrete Consortium

Pilot Videos

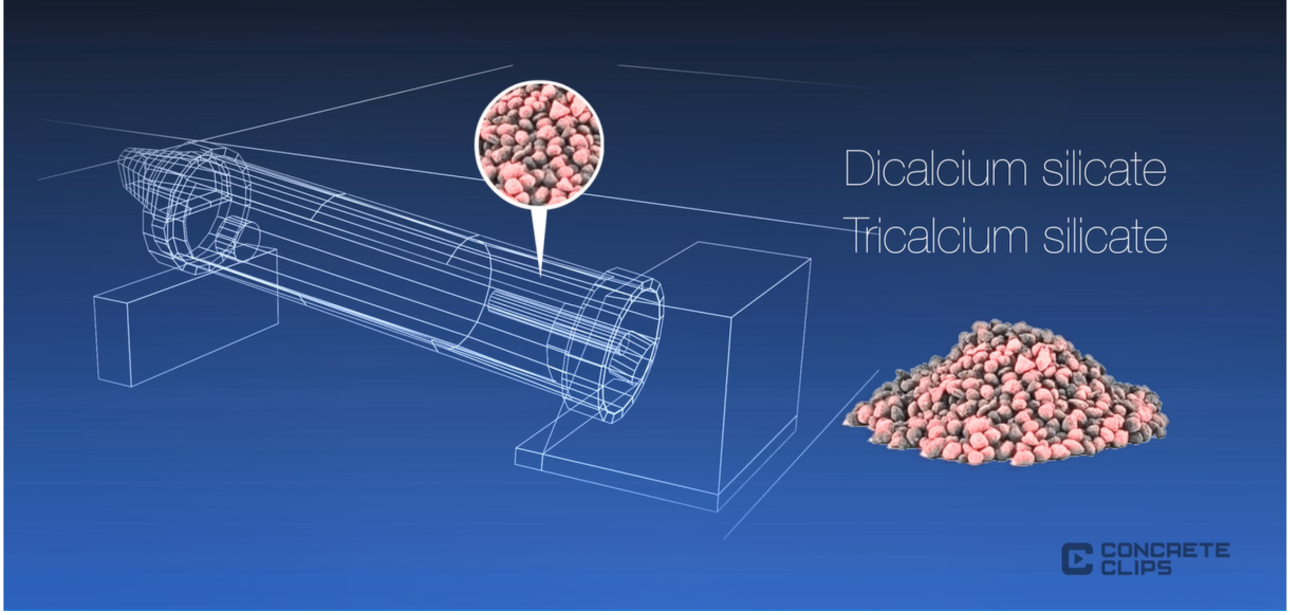
FHWA has completed the first two videos in the series, one on Internal Curing and one on Cement Manufacturing.

Shreenath Rao, project manager for Applied Research Associates, Inc., the contractor responsible for developing the videos, says, "The videos are designed to grab the attention of stakeholders and encourage them to learn more about these technologies. We worked closely with FHWA to ensure these goals are met, and FHWA staff were actively involved in the review and final approval of each script and video."

CONCRETE MIXES: CONVENTIONAL VERSUS INTERNAL CURING



In the conventional curing process, water is applied at the surface of the concrete and only partly penetrates into the concrete pavement. In the internal curing process, the water stored in the voids of the lightweight aggregate is released and distributed throughout the concrete pavement, resulting in more uniform curing. *Source: Shreenath Rao, Applied Research Associates, Inc.*



Blended raw materials (limestone, clay, sand, etc.) are fed into a rotary kiln and heated to elevated temperatures (>1,400°C) to produce the resulting clinker material that later is ground with gypsum to yield portland cement. *Source: Shreenath Rao, Applied Research Associates, Inc.*

In the Internal Curing video, viewers learn how concrete can be cured from the inside out using prewetted lightweight aggregate as a substitute for a portion of the normal-weight fine aggregates typically used in the mix. Following placement of the concrete and hardening of the cement paste, the water stored in the voids of the lightweight aggregate (for example, expanded shale, clay, slate, and slag) is released into the concrete, which leads to more complete cement hydration. This, in turn, can result in a number of potential performance benefits, including improved durability, reduced shrinkage and curling, and improved fatigue resistance.

The Cement Manufacturing clip provides an illustrative overview of the manufacturing process for portland cement, the primary binding agent used in concrete mixes. The video takes viewers through limestone mining and crushing operations, grinding and mixing with natural materials (clay, shale, sand, etc.) to create raw mix, rotary kiln heating to drive the calcination chemical reactions and clinker production, and final grinding with gypsum to produce cement powder. Methods of controlling the reactivity of the cement throughout the production process also are discussed.

In its first 5 months since its posting on FHWA's YouTube channel on November 13, 2017, the Internal Curing video received more than 1,250 views. And, in its first month since its posting on March 28, 2018, the Cement Manufacturing video received over 500 views.

Video Schedule

Work continues on the development and production of the remaining Concrete Clip videos, which are expected to be released on a regular basis through the fall of 2019. As each new video becomes available, FHWA will announce its release to the agency's division offices and various industry organizations.

To access the Concrete Clips, go to https://www.youtube.com/playlist?list=PL5_sm9g9d4T1ND5YlNt0OuL6g2T_NbGdR.

> **"Concrete Clips are a quick and easy way to provide a good overview of a topic and to convey key points to the audience."**
>
> — Tom Yu, FHWA

Common Ground Builds Better Pavements

A Back to Basics Webinar Series provides asphalt pavement practitioners with the knowledge, information, and shared context that they need to build long-lasting roads.

As the asphalt engineering community has developed and adopted innovations, a common finding is that new staff and experienced practitioners alike need information resources to help them master production and construction of asphalt pavement to ensure good performance. In recognition of this need, FHWA and the National Asphalt Pavement Association (NAPA) have partnered on a number of initiatives to conduct research and develop improved guidance for practitioners.

One initiative pursued through this partnership is the Back to Basics Webinar Series, a collection of 12 instructional webinars that not only cover the engineering fundamentals on asphalt production and construction but also introduce new asphalt technologies and advancements. Delivered by a team of academic and industry experts with years of experience in the asphalt pavement field, the webinars cover standard topics from basic material components to pavement maintenance and rehabilitation. Delivering the material through Web-hosted conferences minimized the production costs of the courses, eliminated the need for participant travel, and permitted contact with a larger audience.

Although the title of the series suggests that the "basics" are covered throughout the webinars, new practices and concepts are emphasized as well. For example, most practitioners in the asphalt community are aware that a proper mixture design is necessary before production and placement, but in addition to covering that topic, the fourth webinar discusses the science behind designing mixes according to Superpave criteria.

WEBINAR AND TOPICS

1 **Asphalt Binder:** The glue that holds a mixture together is the binder.

2 **Aggregate:** The stone that provides the majority of strength and stability in an asphalt mixture is the aggregate.

3 **Volumetrics:** This topic is important to understanding how an asphalt mixture will perform.

4 **Mix Design:** Proportioning mixture components provides optimal performance.

5 **HMA Plants:** The components of an asphalt mix production facility are described, as well as the differences between batch and drum plants, and what can be done to ensure mix quality.

6 **Paving:** Placing a smooth, uniform asphalt pavement begins with proper setup and operation of the paving machine.

7 **Compaction:** Rollers are used to achieve the density a pavement needs to ensure performance and longevity, as well as to create a well-finished surface.

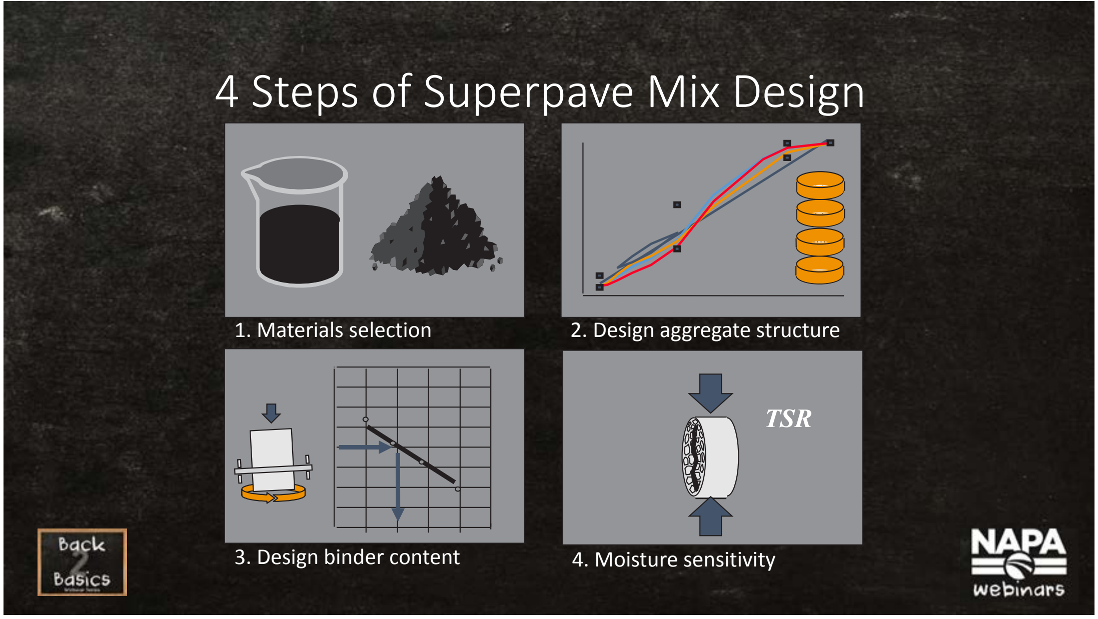
8 **Quality Assurance:** Basic inspection and testing is required for accepting asphalt pavement, and some common mistakes can influence QA results.

9 **Tack Coats:** A good tack coat enables two independent pavement layers to act as a single unit.

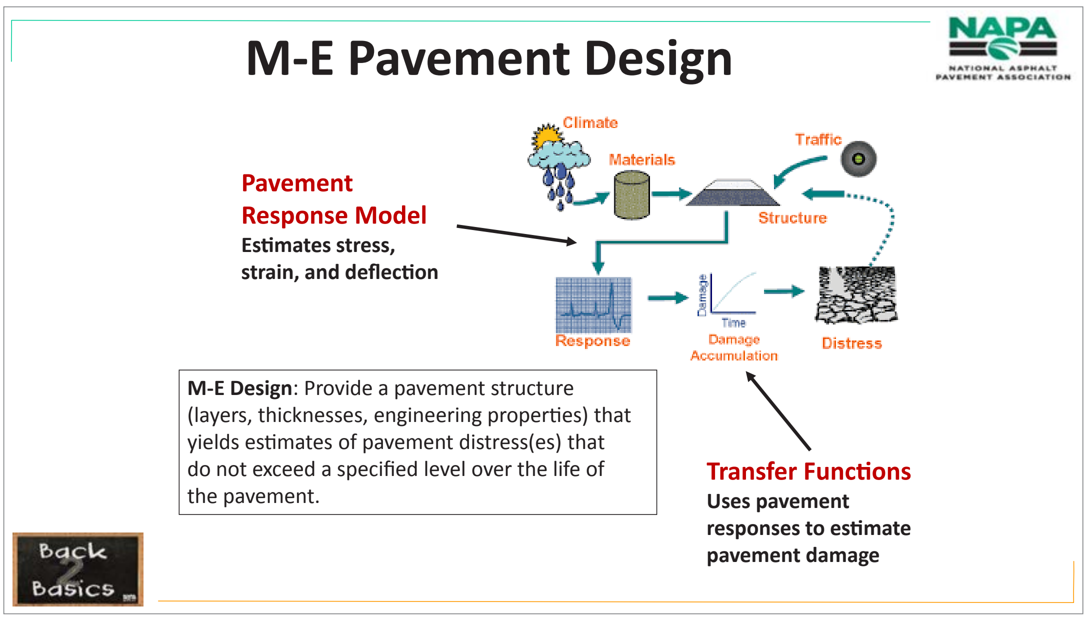
10 **Pavement Design:** Flexible design of pavement thickness has undergone numerous changes over the past half-century.

11 **Forensics:** Learning to recognize different types and severities of pavement distresses and conduct pavement forensic analyses enables practitioners to determine the reasons that pavement distresses have occurred and correct them.

12 **Maintenance and Rehabilitation:** Smart, effective, and economic strategies for pavement preservation and maintenance deployed at the right time can add years of life to an aging pavement.



The Mix Design webinar includes discussion of the four steps involved in designing Superpave mixes. *Source: NAPA.*



Webinar topics include innovative advancements in addition to the engineering fundamentals for asphalt pavements. *Source: NAPA.*

Considerable time is spent on new technologies, material testing, and quality assurance, including contractor quality control and agency acceptance. Examples of showcasing new technologies include teaching the mechanistic-empirical pavement design process that uses environmental factors and pavement performance parameters to predict critical distresses during the pavement life.

Uncovering the Building Blocks

The FHWA and NAPA team delivered the live webinars sequentially, with the first occurring in February 2017 and the last in December 2017. Targeting both industry and public agency audiences, the 12 webinars registered a total of 1,080 sites from locations around the United States. The largest participant group consisted of government employees (including Federal, State, and local agencies), who represented more than 37 percent of those registered. Consistent with another key audience targeted by the webinar team, contractors made up the second highest attendee group (32 percent).

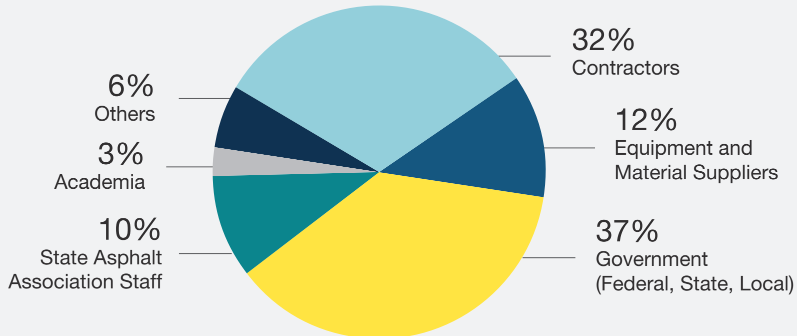
The team recorded the sessions and have made them available for use as a resource by practitioners who were unable to participate in the live webinars or by new staff just beginning their careers in the asphalt pavement industry. Attendees are eligible for professional development hours for completing webinars and subsequent learning assessment tests.

Participants who complete all 12 webinars achieve a professional development certificate of accomplishment. NAPA also offers specialty certificates for those completing webinar subsets related to each specialty area.

To date, NAPA has awarded 519 professional development hours. The association plans to maintain the recorded webinar series and provide continuing education. The webinar content should remain current and relevant for a number of years.

Webinar Series Participation

Source: NAPA Data.



Common Ground

A main benefit of conducting training geared to a diverse audience is to gain a common understanding. Conflicts on construction projects often can be avoided or mitigated through proper and appropriate communication between contract administrators and contractors. The webinars promote a greater understanding of specifications and construction practices. This improved knowledge can minimize risk and lead to better performance, while encouraging the adoption of innovations through demonstrated real-world applications and benefits.

Kevin Hall, Ph.D., professor of civil engineering at the University of Arkansas and one of the webinar presenters, says, "The webinar presentations were designed to relate fundamental engineering concepts, balancing state-of-the-art with state-of-the-practice, for both asphalt pavement industry technicians and professionals, with an intent to be technologically current for several years."

SPECIALTY AREA DESIGNATIONS

Mix Design Specialty	Operations Specialty
Asphalt Binder	Asphalt Binder
Aggregate	Aggregate
Volumetrics	HMA Plants
Mix Design	Paving
HMA Plants	Compaction
Quality Assurance	Tack Coats

With broad audience applicability and availability through an Internet platform, the webinar series should serve the industry into the next decade.

Product Well Received

The webinars were successful in meeting the needs of the participants, with 87 percent agreeing or strongly agreeing that the webinars met expectations. Ninety-seven percent agreed they were helpful. As a commitment to keep using the resource, one participant commented, "We will be using this as an introductory explanation for our area managers and our project supervisors. Our lab managers will also be involved."

Other participants offered comments such as the following:

- "I liked how the illustrations were laid out, and the graphics were clear and concise."
- "The 'soup to nuts' progression on design was well done."
- "Very comprehensive information."
- "All of it was very good. This [is] the first time I have viewed such a presentation, and [it] was very well done."

The recorded webinars can be viewed at no cost to the participant by accessing the NAPA website at the following link: http://store.asphaltpavement.org/index.php?categoryID=140.

Resource-Responsible Mixtures Get a Makeover

Agencies around the country will benefit from new how-to guides for incorporating recycled materials into asphalt pavements.

Every year, highway agencies use large amounts of recycled and reclaimed materials in their asphalt pavements. This recycling not only provides initial cost savings, but also can offer a number of other sustainability benefits. Among them are lowered energy consumption, decreased emissions, conservation of natural resources, and reduced waste sent to landfills. These benefits can only be achieved through responsible use of recycled materials to ensure long-term pavement performance that is equal to, or better than, conventional pavements.

Shown here is a double barrel hot mix plant with drum injection ports for baghouse fines and recycled materials (RAP and RAS). The recycled materials are added between the inner and outer barrels to protect them from the intense heat and direct flame located within the inner barrel. *Source: Ray Bonaquist, Advanced Asphalt Technologies, LLC.*

Three products that are commonly recycled in asphalt pavement mixtures are reclaimed asphalt pavement (RAP), reclaimed asphalt shingles (RAS), and ground tire rubber (GTR). The use of RAP is by far the most prominent and well known. A recent survey of U.S. asphalt producers conducted by the National Asphalt Pavement Association (NAPA) showed an estimated 76.9 million tons of RAP used in asphalt mixtures in 2016. The survey also showed an estimated 1.54 million tons of GTR used in the 2016 construction season, and an estimated 1.39 million tons of RAS used during the same period. As reported in the NAPA survey, together, the use of RAP and RAS saved more than $2.1 billion in pavement construction costs in 2016, compared to asphalt made only with virgin materials.

The Fly in the Ointment

Although these resource-responsible asphalt mixtures (R^2AMs) represent a significant and growing portion of the total asphalt mixture production in the United States, limited guidance is available to pavement engineers on how to consider the unique characteristics of R^2AMs during the mixture design phase and in the overall process of pavement design. The use of higher R^2AM percentages does not always provide improved pavement performance. The material properties must be understood and the mixtures engineered to ensure long-term performance, responsible use, and improved life cycle costs. In the design of asphalt rubber mixtures, for example, the presence of rubber particles in the asphalt binder makes certain traditional laboratory binder tests ineffective or meaningless, requiring updated evaluation tools and techniques. And in the case of pavement design, many existing models used to predict pavement performance generally are based on conventional asphalt binders that do not behave or perform the same as the R^2AMs. The end result is that the performance of these R^2AM products may not achieve expectations or can have a detrimental performance impact unless improvements are made in the way the mixtures are engineered and characterized and in how the pavements are designed to ensure responsible use.

The Solution

Having recognized the need for detailed guidance on these topics, FHWA is developing two documents to improve how R^2AMs are evaluated in mixture and pavement structural designs. These guide documents are designed for practicing pavement engineers, lab managers, and technicians who are responsible for testing R^2AM mixtures and for using the results to develop sound pavement structural designs.

"Today, most asphalt mixes include some recycled product, but our test procedures and pavement design guidance are based on virgin mixtures," says Gina Ahlstrom, Team Leader for Pavement Materials in FHWA's Office of Infrastructure. "These guides will provide practicing engineers and technicians with guidance on the best way to design pavements using asphalt mixtures with recycled materials and to measure the engineering properties of these mixtures."

Mixture Design Considerations for R^2AMs

The first guide in the series is called the *Practitioner's Guide to the Performance Testing of R^2AMs*. It will provide recommendations on how to properly characterize the key engineering material properties (such as dynamic modulus, low-temperature creep modulus, and strength) that are required for R^2AM design and pavement structural design. The FHWA team is developing a practitioner's guide based on experience gained between 2014 and 2016 on

The dynamic shear rheometer (DSR) tests the viscous and elastic behavior of asphalt binders and is one of the lab tests that required different tools and sample geometry modification to accurately evaluate GTR materials and other modifiers in the binder. *Source: APTech.*

actual design/construction projects in Florida, Massachusetts, North Carolina, Pennsylvania, and Wisconsin.

Pavement Design Considerations for R^2AMs

The American Association of State Highway and Transportation Officials' (AASHTO) *Mechanistic-Empirical Pavement Design Guide [MEPDG]—A Manual of Practice* and its accompanying software, AASHTOWare Pavement ME Design, are today's tools for the development of pavement structural designs for streets and highways. However, the MEPDG's performance models for fatigue cracking, thermal cracking, and rutting are based on asphalt pavements constructed with conventional asphalt mixtures and not those containing recycled materials. Accordingly, FHWA is developing a second guide document referred to as the *Practitioner's Guide to the Use of Performance Testing of R^2AMs in the AASHTO MEPDG*. It will provide standardized methods and guidance on how to use laboratory test data (obtained in accordance with the new performance testing guide) to calibrate performance prediction models to account for the differences in performance between R^2AMs and conventional asphalt mixtures.

What Are the Expected Benefits?

In addition to helping highway agencies generate engineered performance-driven pavement designs based on the material properties and expected performance of mixes with recycled materials, these practitioner guides offer several other expected benefits:

- Increased reliability in mixture design and pavement structural design for R^2AMs
- Better performance comparisons between conventional mixes and R^2AMs
- More appropriate and responsible, engineering-based use of R^2AMs in the future

Both guides are currently under development and planned for release early in 2019.

Advancing the Cause

In addition to developing the practitioner's guides, FHWA has played a key role in working with industry partners to advance the responsible engineering use of RAP, RAS, and GTR mixes.

Recent Efforts

- Produced a technical brief on *The Use of Recycled Tire Rubber to Modify Asphalt Binder and Mixtures* (FHWA-HIF-14-015).
- Co-sponsored, with the Rubber Manufacturers Association (now the U.S. Tire Manufacturers Association), the 2016 Rubber Modified Asphalt Conference in Ann Arbor, MI.
- Co-sponsored the 8th Shingle Recycling Forum in October 2017 in Cincinnati, OH.

Ongoing Activities

- Working with NAPA to develop a best practices guide for rubber modified asphalt technologies.
- Collaborating with NAPA to develop a *Best Practices for RAP and RAS Management* guide.

Closeup of GTR testing components of the DSR. Rather than testing a flat, thin, circular specimen of asphalt binder, the modified DSR test tools, called concentric cylinders, require that a sample of GTR modified asphalt binder be poured into a small metal cup (outer cylinder) and then tested in shear using one of three different bobs (inner cylinders). *Source: FHWA.*

- Leading efforts related to testing standards for concentric cylinder dynamic shear rheometer (DSR) testing.
- Using the FHWA Mobile Asphalt Testing Trailer (MATT) for field testing and evaluation activities, such as material characterization, replication of mix designs, and Asphalt Mixture Performance Tester (AMPT) equipment-based predictive performance tests.
- Developing more fundamentally based performance prediction models (FlexPAVE™) capable of handling new material types and recycled materials.

These efforts have greatly improved the implementation of recycled materials and are helping to pave the way to a new generation of engineered sustainable asphalt pavements.

For more information on FHWA's current projects and activities, visit www.fhwa.dot.gov/pavement/asphalt/index.cfm.

Breaking Down Barriers

A collection of information from various partners is available to guide highway agencies in using recycled concrete aggregate in their paving projects.

This stockpile of concrete rubble from pavement reconstruction is ready for crushing into recycled aggregate. *Source: APTech.*

Crushing old concrete for use as aggregate in roadway construction has been an established practice for more than 70 years, with an estimated 140 million tons recycled annually in the United States from all sources. The process produces a crushed granular material known as recycled concrete aggregate (RCA). The recycled material can be substituted for virgin aggregate in a range of applications, including concrete pavement mixtures, pavement base and subbase layers, and embankments and shoulders.

At least 44 State highway agencies allow the use of RCA in one or more of the above applications, but a number of barriers currently restrict the more widespread use of this resource. To address these challenges, FHWA is working with highway agencies and industry partners to develop and make available technical guidance on the effective use of RCA in roadway applications.

Why Use RCA?

The two primary reasons are economic and environmental. From the economic perspective, aggregates represent a significant component of construction costs, and using RCA helps reduce those costs by eliminating or minimizing the need for virgin aggregates. RCA can be beneficial particularly in regions where high-quality aggregates are scarce and agencies pay top dollar to purchase and transport those materials to jobsites.

Moreover, contractors can improve construction efficiencies by using RCA and reducing material hauling costs and impacts on traffic. In addition, recycling old pavements eliminates the cost for disposal of the concrete, helping agencies realize time savings and production efficiencies by reusing old materials onsite. As an example, the Illinois

> **"RCA is an engineered material that can be incorporated into a project in a number of ways. To help in that, existing specifications should be reviewed to ensure that RCA materials are not arbitrarily restricted for a specific application."**
>
> — Tom Cackler, CP Tech Center

Closeup of coarse RCA after crushing. *Source: APTech.*

This mobile concrete crusher on a jobsite is used to break down the concrete rubble. *Source: APTech.*

Tollway identified $50 million in savings by using RCA rather than virgin aggregate in pavement base courses, and recycled more than 775,000 tons of concrete in 1 year alone on a major reconstruction of I–90 west of Chicago.

RCA also affords significant environmental benefits, which are important to highway agencies seeking more sustainable construction strategies. The most obvious benefit is that RCA conserves virgin aggregate sources and reduces the energy use and emissions associated with the production and transport of aggregate. Onsite recycling also reduces the fuel consumption associated with hauling the old pavement materials to landfills. For example, concrete recycling on a reconstruction project on U.S. 59 near Worthington, MN, was estimated to have resulted in a 27 percent cost savings and a fuel savings of more than 150,000 gallons.

Overcoming Barriers

Two primary barriers currently hinder the greater use of RCA: (1) limited technical understanding of the properties and behavior of RCA, and (2) rigid specifications that exclude or limit the use of RCA materials. FHWA, through a cooperative partnership with the National Concrete Pavement Technology Center (CP Tech Center), Technology Transfer Concrete Consortium (TTCC), National Concrete Consortium (NCC) member States, and the concrete industry, is working to break down the barriers by providing technical guidance on RCA technologies and demonstrating the effective use of RCA in a range of applications.

FHWA has led the development of a series of resource documents and technology transfer products to help highway agencies, engineers, and contractors take advantage of the economic and environmental benefits of RCA. The products include the following:

- **Webinars.** Four webinars were presented a minimum of three times each and reached an audience of more than 400. The webinars were recorded and are available online for on-demand viewing:
  - Introduction to Concrete Pavement Recycling
  - Construction Considerations in Concrete Pavement Recycling
  - Environmental Considerations in Concrete Pavement Recycling
  - Case Studies in Concrete Pavement Recycling
- **Technical Briefs.** FHWA has developed six technical briefs, which are available online:
  - Introduction to Concrete Pavement Recycling
  - Concrete Pavement Recycling and the Use of Recycled Concrete Aggregate in Concrete Paving Mixtures
  - Quantifying the Sustainability Benefits of Concrete Pavement Recycling
  - Concrete Pavement Recycling—Project Selection and Scoping
  - Protecting Water Quality through Planning and Design Considerations
  - Protecting the Environment During Construction

- *Practitioner's Reference Guide.* This comprehensive document covers key information on concrete recycling, including details on specific uses and applications.
- *Recycled Concrete Aggregate Usage in the U.S.: Summary Report.* This document presents the results of a separate two-part benchmarking survey conducted by the American Concrete Pavement Association of State highway agencies and concrete paving contractors to gain insights about their current recycling practices.

"The benchmarking surveys confirmed that using RCA in the base course is the most predominant application, and this is allowed by almost all States," says Tom Cackler, the CP Tech Center project manager in charge of the concrete recycling program. "And a number of contractors are moving to zero-waste processes in which everything from a project is reused or recycled."

Selecting Projects

Which concrete reconstruction projects are most suitable for recycling? Virtually every project can be a candidate, and most concrete on a project can be recycled if properly matched to the quality level needed for its anticipated reuse. Still, several key considerations come into play, such as specification requirements, production options, regulations, and the cost of virgin materials, among others.

"RCA is an engineered material that can be incorporated into a project in a number of ways," says Cackler. "To help in that, existing specifications should be reviewed to ensure that RCA materials are not arbitrarily restricted for a specific application."

FHWA and its industry partners continue to chip away at existing barriers to the increased use of RCA by providing technical guidance and outreach. The aim is to realize the complete economic and environmental benefits of RCA.

For more information and to access the related resources, visit www.cptechcenter.org/concrete-recycling.

A GENERALIZED APPROACH TO SELECTING AND SCOPING RCA

Identification of the Project

Characterization of the Source Concrete and Use Selection

- Known or unknown source
- Materials characteristics
- Review of agency specifications
- Identification of candidate uses
- Use selection

Production Options for RCA

- Mobile onsite processing (typically for base and fill uses)
  - » Equipment utilized
  - » Space requirements
  - » Cost considerations
- Stationary onsite processing (typically for PCC, base, and fill applications)
  - » Equipment utilized
  - » Space requirements
  - » Cost considerations
- Offsite processing options (for all applications)
  - » Hauling
  - » Other cost considerations

Economics

- Cost of virgin aggregate
- Management of residual materials
- Disposal/beneficial reuse options

Other Factors

- Project staging
- Environmental impacts
- Public perception
- Project duration

Plans and Specifications Developed to Reflect Project Scoping

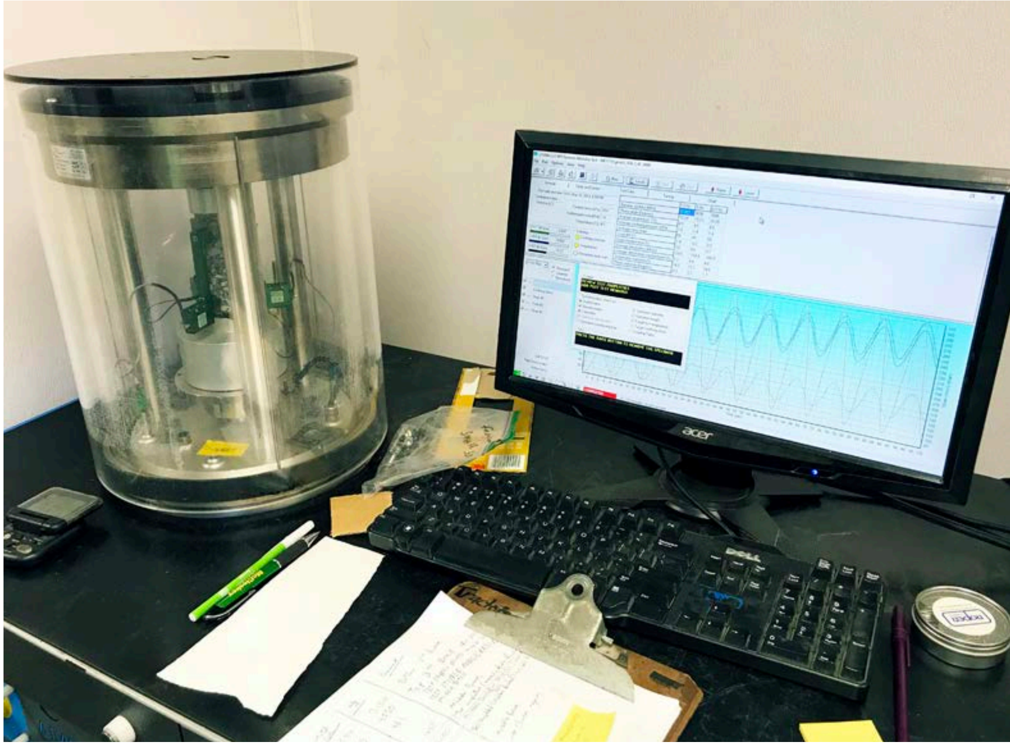
The RCA project selection and scoping process begins with characterizing the source concrete, considering various options for producing RCA, evaluating the economics of RCA, and considering other factors before identifying the appropriate plans and specifications for the project. *Source: CP Tech Center, based on its work for FHWA.*

The Latest on Performance-Engineered Asphalt Mixtures

Innovations lead to greater understanding of long-term resistance to rutting and cracking throughout a pavement's life.

Modifying production specifications for asphalt paving materials to give contractors more control over the final product promotes the development of mixtures that resist cracking and rutting and deliver long-term performance.

"Performance-engineered mix designs consider key asphalt properties and fundamental engineering parameters that are known to contribute to long-term performance," says Shane Buchanan, asphalt performance manager at CRH Americas Materials. "A mix design meeting the performance criteria increases the cost-effectiveness of the pavement, increases user satisfaction, and saves taxpayers' money."



The Asphalt Mixture Performance Tester, also called the AMPT, applies oscillating loads and measures stress and strain responses while load cycles are applied to the samples. *Source: APTech.*

Performance-engineered mixture designs benefit both owner agencies and contractors. Using these designs, agencies are able to share more of the risk with their contractors, thereby benefitting from longer lasting pavements. At the same time, contractors can take advantage of the opportunity to innovate and differentiate themselves in the marketplace by designing, producing, and constructing high-performance mixtures.

Implementing Performance Testing

Performance-engineered mixture designs use specialized testing as part of a performance specification to determine the resistance of asphalt mixtures to rutting and cracking under varying climatic and traffic conditions. FHWA not only endorses the adoption of performance specifications, but also participates in developing, refining, and testing devices that measure fundamental engineering properties related to performance.

Designers can select an optimum blend of materials after measuring engineering properties for multiple combinations of aggregates and asphalt content. The optimum values ensure that the mixture will perform as intended because the engineering properties have been validated through field performance. Although previous design, production, and testing processes and specification requirements have produced asphalt mixtures that resist rutting, they may indirectly allow or encourage decreased resistance to cracking, especially when only considering volumetric properties paired with materials, production, and testing tolerances and variability. Performance-engineered mixture designs seek to provide resistance to multiple failure modes across a wide variety of materials, climates, and traffic conditions.

FHWA and industry partners have shown that a commercially available device, the Asphalt Mixture Performance Tester, and its associated testing and evaluation protocols, can successfully relate engineering properties to pavement performance. The tester measures stiffness, deformation, and cracking resistance as various loads are applied at various temperatures. Values calculated from the test can be entered directly as parameters in a mechanistic-empirical pavement design. Owner agencies also can compare the values to desired limits for rut and crack resistance as a quality check during construction.

To prepare for performance testing, a technician loads asphalt mixture into a compaction mold. The mixture is compacted, and then four small specimens are removed from the sample using a core barrel and drill press. *Source: FHWA.*

Small-diameter specimens for the Asphalt Mixture Performance Tester are affixed in a jig awaiting attachment of deformation sensors. *Source: APTech.*

Improving the Technology

A battery of performance-engineered mixture design tests historically takes approximately 3 days to complete. To improve testing efficiency, FHWA has led efforts to reduce material requirements and the time needed to prepare and test samples. An assessment of specimen sizes revealed that smaller test specimens can be used with statistically equivalent results. After reviewing the assessment, the expert task group recommended the new size: a 38-mm diameter cylinder that is 110 mm long, about a quarter of the previous sample size. The smaller size reduces by 75 percent the quantity of materials and also reduces the overall mixing time required in the laboratory. The smaller specimen size also allows testing and evaluation or forensic investigation of in-service pavements typically constructed with asphalt layers less than 100 mm thick. FHWA also assisted in drafting revised AASHTO testing procedures using the 38-mm specimen.

While testing of the smaller size continues, new testing parameters to model performance even more closely are being evaluated. The Cracking Index Parameter (S_{app}) has been shown to predict resistance to cracking. S_{app} describes the apparent capacity of a mixture to absorb fatigue damage before cracking. Comparing data generated by the Asphalt Mixture Performance Tester to the performance of more than 20 mixture combinations placed on experimental test sections has confirmed the reliability of the new parameter.

FHWA uses the Mobile Asphalt Testing Trailer, pictured here staged adjacent to a highway resurfacing project near Albuquerque, NM, to introduce innovations, new technology, and test methods to pavement engineers across the United States. *Source: APTech.*

Field-Testing the Technology

FHWA continues to use the Mobile Asphalt Testing Trailer to aid State DOTs in evaluating the new testing apparatus and performance-engineered asphalt materials. In 2017, Maine deployed the testing trailer to shadow the DOT acceptance testing during a resurfacing project. Derek Nener-Plante, the Maine DOT State asphalt pavement engineer, says, "We were intrigued with the possibility of comparing testing equipment that could predict pavement performance and evaluating changes in performance parameters associated with material variations that occur during the construction process." Nener-Plante indicates that one way the Maine DOT could currently use performance-related testing is to validate incentive (or disincentive) payments to contractors for consistently meeting (or not meeting) production air voids and targets for voids in mineral aggregates.

In 2018, New Mexico deployed the Mobile Asphalt Testing Trailer to shadow a DOT resurfacing project near Albuquerque. The main experimental goal for the project was to compare a standard NMDOT Superpave warm-mix asphalt to a finer-gradation Superpave warm-mix asphalt. As with other shadow projects, the cutting-edge testing equipment aboard the testing trailer was key to the testing plan.

Mohiuddin Ahmad, a doctoral degree candidate at the University of New Mexico, says, "The university has an Asphalt Mixture Performance Tester, so it was great to see one in operation so close to our campus. Observing expert technicians preparing the samples and attaching the monitoring gauges will aid us as we begin a mix design research project for NMDOT." The research team will implement the smaller dynamic modulus testing samples to reduce sample preparation times.

FHWA continues to lead implementation of performance-engineered mixture design by collaborating with State DOT and industry experts, developing and refining standards, and demonstrating innovative practices to standardize the tests relating to long-term performance. The technology is currently implementable, so agencies can use it to achieve more cost-effective pavements with longer life.

For more information, visit www.fhwa.dot.gov/pavement/asphalt, www.fhwa.dot.gov/pavement/asphalt/tester.cfm, www.fhwa.dot.gov/pavement/asphalt/trailer/pemd.cfm, and www.fhwa.dot.gov/pavement/asphalt/trailer.

"A mix design meeting the performance criteria increases the cost-effectiveness of the pavement, increases user satisfaction, and saves taxpayers' money."

— Shane Buchanan, CRH Americas Materials

Measuring Faulting on the Fly

An FHWA pooled fund study seeks to establish new standards for automated data collection and measurement of joint and crack faulting on concrete pavements.

Closeup of transverse joint faulting. *Source: APTech.*

Smooth and safe. Those are important attributes of virtually all roadway pavements, and keeping them in that condition is a top priority for owner agencies. To do that, agencies must be able to monitor, record, and correct pavement conditions that could detract from smoothness and safety.

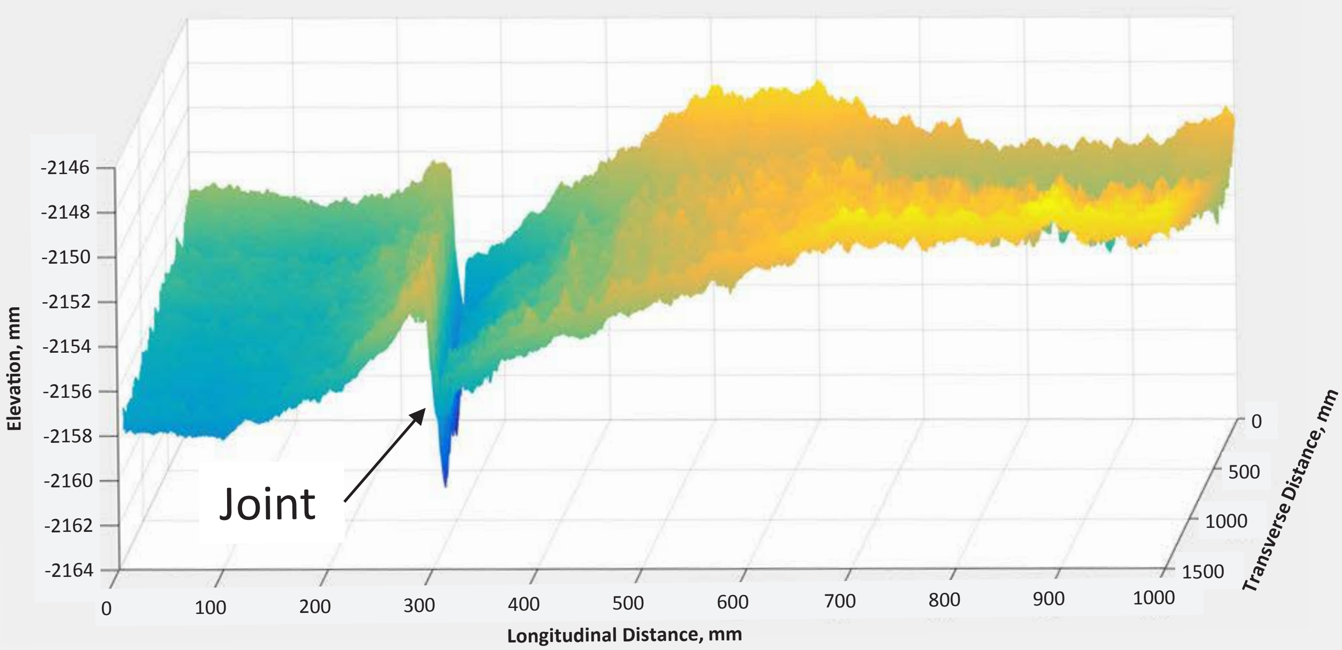
Common pavement conditions that can compromise these attributes are rutting, cracking, and faulting. A critical distress, faulting, is defined as the difference in pavement elevation across a transverse joint or crack. Faulting occurs as the result of several mechanisms, including erosion of base material from beneath the pavement, poor load transfer across the joint/crack, and slab curling or warping. Its development not only contributes to overall roughness, but also may lead to slab cracking and joint deterioration that can further reduce ride quality.

In addition to its effect on performance, faulting can be an important factor in programming projects for their effective preservation and rehabilitation. Furthermore, under the current national transportation legislation, Fixing America's Surface Transportation (FAST) Act, faulting is a key performance metric in assessing the condition of the Nation's roads. Thus, it is important that faulting is measured on an accurate and consistent basis on all concrete pavement projects across the country.

The Evolution of Faulting Measurement Technologies

State highway agencies have long measured and monitored concrete pavement faulting levels on jointed concrete pavements. The test equipment and procedures for measuring faulting have evolved from manual measurements using a straightedge and ruler, to spot measurements made with a hand-held Georgia faultmeter (GFM), to comprehensive automated measurements obtained with high-speed data collection equipment.

The GFM was the standard tool used by State highway agencies for more than two decades and has served as the official measurement tool for FHWA's long-running Long-Term Pavement Performance program. The Georgia Department of Transportation designed, developed, and built the device in 1987 as a way of simplifying and expediting the previous manual methods and improving measurement precision.



Joint faulting analysis using 3-D imagery illustrates how fault measurements can vary depending on different measurement locations away from and along the joint.
Source: Georgene Geary/Georgia Institute of Technology.

The use of high-speed data collection equipment for measuring faulting began in the 1990s. The technology has advanced considerably since then, and today several commercially available inertial profilers and multipurpose survey vehicles can perform automated fault measurements (AFMs). These devices use a variety of highway-speed data collection instruments, such as accelerometers and point or line lasers, to generate pavement profile data, and 2-D or 3-D cameras to acquire digital pavement surface imagery. Onboard computers store the collected data and are equipped with integrated software for data analysis. Some devices use integrated software with algorithms for detecting joints/cracks from the longitudinal profile data, whereas others rely on manual interpretation by human raters. Once the joint/crack is identified, another algorithm then calculates the associated faulting. Compared to manual measurement, high-speed automated methods offer improved worker safety, measurement at every joint/crack, and increased rates of data collection.

The Current AASHTO Standard

The current AASHTO standard for measuring faulting on concrete pavements is presented in R36-17, *Standard Practice for Evaluating Faulting of Concrete Pavements*. It provides three methods for measuring faulting at joints/cracks: a manual method based on a generic faultmeter and two automated methods, designated as methods A and B.

Both of the automated methods follow the same high-speed inertial profiling requirements, recording pavement profile elevations along the length of the roadway at fixed intervals. They differ, however, in the algorithms that are used to analyze the data. In method A, the AFM module within a ProVAL software program is used to identify joint/crack locations and compute faulting, whereas in method B an Excel-based automated fault program tool is used to identify joint/crack locations and calculate the faulting.

Setting a New Standard

Although the current standard (and its predecessors) helped to establish fault measurement protocols, a new standard is needed to address inconsistencies in current faulting measurement methods and to accommodate the arrival of new 3-D technologies. The inconsistencies in faulting measurements are largely the result of the variability in the operational characteristics and AFM processes used by different devices. Furthermore, measurement inconsistencies are compounded by the presence of various pavement features, including both joint characteristics (for example, spacing, orientation, width, condition) and slab characteristics (for example, grade, curling/warping, surface texturing). At the same time, the accuracy and precision of the data collection systems can affect the measured surface profile.

The increased use of laser-based 3-D technologies for automated surveys of pavement condition provides an opportunity to improve the technology behind faulting measurement and reporting. Andy Mergenmeier, senior pavement and materials engineer at the FHWA Resource Center, says, "3-D analysis offers the potential benefits of quicker and more definitive joint/crack detection and more complete accounting of pavement irregularities (for example, spalling, slab curling and warping, surface texturing) in the fault measurement computation."

Once completed, the new standard will provide a universal framework for measuring joint and crack faulting, one that is blind to the data collection/analysis methodology and based on reasonable yet firm requirements for measurement accuracy based on the intended use of the information. The overall result is improved and more consistent measurements of joint and crack faulting.

This van is equipped with high-speed data collection equipment. *Source: APTech.*

Championing the New Standard

The FHWA-administered Transportation Pooled Fund (TPF), TPF-5(299), will focus future efforts to develop the new standard. TPF-5(299) includes the participation of 21 State highway agencies, and representatives from several of these agencies will serve on an oversight panel for a soon-to-be-announced project on faulting measurement. The project will assess the available fault measurement technologies, determine the needed levels of fault measurement precision and accuracy, and develop an improved faulting measurement standard for AASHTO consideration. According to Mergenmeier, "The new standard will provide States with greater confidence in their fault measurements, greater certainty in their programming decisions, and greater assurance of their reported pavement condition."

The pooled fund project is expected to be conducted over a 42-month period, with the new draft standard submitted for AASHTO balloting in the summer of 2022.

"The new standard will provide States with greater confidence in their fault measurements, greater certainty in their programming decisions, and greater assurance of their reported pavement condition."

— Andy Mergenmeier, FHWA Resource Center

The News on Performance-Engineered Concrete Mixes

A new specification provides the tools for highway agencies and contractors to optimize concrete mixture designs for improved longevity, durability, and sustainability.

Concrete pavements are known for their longevity, and their performance hinges on the use of materials and mixtures that are designed for the prevailing load and environmental conditions. The challenge to both highway agencies and contractors is to achieve the specific performance requirements for a given project consistently and reduce the risk of premature failure. Achieving these goals requires that highway agencies be able to communicate their needs through meaningful specifications tied to performance and that contractors be able to meet the specifications while having some flexibility in how that is accomplished.

A new materials specification is expected to improve the durability and longevity of the Nation's concrete pavements. *Source: Jagan Gudimettla/FHWA Mobile Concrete Trailer.*

Inspiring Innovation

Most current specifications for concrete pavement construction include traditional measures such as strength, air content, and slump. Those measures, however, are not strongly related to performance, so just because they are met on a particular project does not necessarily ensure that the pavement will perform as intended. At the same time, many of the existing specifications are largely prescriptive; that is, they provide exact details on the materials and methods used to achieve the results. These types of specifications severely limit the contractor's ability to innovate with new methods or technologies that could improve performance significantly. Notes Jerry Voigt, president and CEO of the American Concrete Pavement Association, "It's the agency's responsibility to allow for innovation. It's the contractor's responsibility to deliver."

FHWA recognized the advantages of moving to performance specifications and also saw the need to reexamine the fundamental material properties of concrete and the effects of those properties on pavement performance. Since 2015, FHWA has been working with highway agencies and industry to develop a new specification for concrete paving mixtures that not only meets today's rigorous performance requirements but also produces more resilient mixtures. The result was the development of AASHTO PP84, *Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures*, which was released in 2017. The new provisional practice covers test methods for concrete pavement mixtures and recommends threshold values required for long-term performance. A separate document serving as a commentary to the specification provides agencies, contractors, and material producers with detailed information on its use, application, and implementation.

Mixture Design Parameters

The new Performance Engineered Mixtures (PEM) specification features a range of key concrete properties, including strength, cracking tendency, freeze-thaw durability, permeability, aggregate stability, and workability. The specification is not solely a performance specification, as it includes both prescriptive and performance criteria. The prescriptive approach provides specific requirements the contractor must follow (for example, w/c<0.45), while the performance approach provides test methods and target values for a series of tests that correlate to field performance. The PEM specification also features a tiered approach, so that highway agencies can impose tighter controls as the level of risk increases.

In many ways, the PEM specification is like a buffet. Agencies can pick and choose the material properties to measure under the various mix design parameters listed earlier. The specification incorporates several new test methods and procedures developed in collaboration with industry and academia partners. These include the Super Air Meter, the box test, the vibrating Kelly ball test, and the formation factor.

Pooled Fund and Incentive Implementation

To move the specification forward, FHWA established a 5-year transportation pooled fund study, with initial funding provided by FHWA, 15 State highway agencies, and several concrete pavement industry and trade associations.

Mike Praul, FHWA program lead for concrete materials, states, "The purpose of this study is to promote the implementation of the PEM specification through an active training and outreach effort featuring webinars, workshops, construction of shadow and demonstration projects, and onsite support from the FHWA Mobile Concrete Trailer and PEM team members."

Praul also notes that the development of emerging test procedures, in addition to refining the existing ones, also will be funded under the pooled fund. The equipment required to conduct some of the tests outlined in the AASHTO PP84 standard are available through FHWA's equipment loan program at www.fhwa.dot.gov/pavement/concrete/trailer/resources/loans.cfm.

PRESCRIPTIVE AND PERFORMANCE APPROACHES FOR ACHIEVING CONCRETE PROPERTIES

Prescriptive Approach	Performance Approach
How the material or product is formulated and constructed is dictated by the agency	Desired characteristics of the material or product are identified by the agency
Based on past experience	How to provide those characteristics is controlled by the contractor
Minimal/uncertain ability to innovate	Maximum ability to innovate
Agency required to have proper manpower and skill set to provide oversight	Reduced oversight burden on the agency

Source: FHWA.

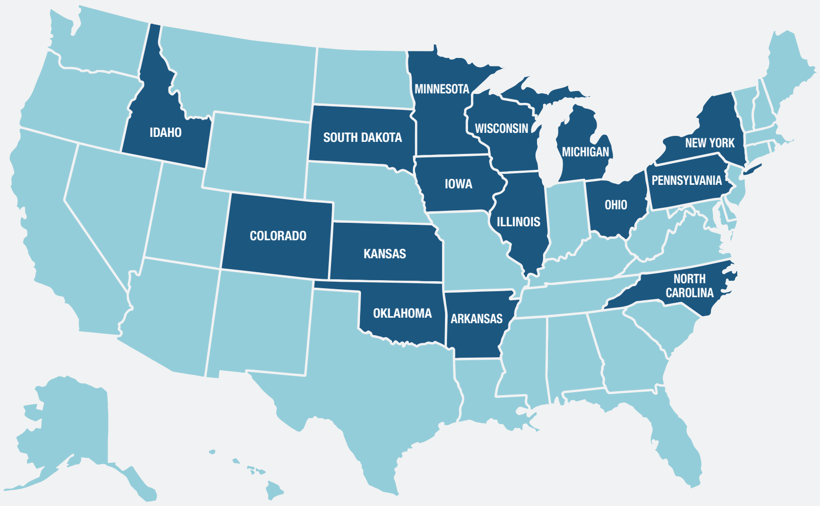
MATERIAL PROPERTIES MEASURED UNDER VARIOUS MIXTURE DESIGN PARAMETERS

Mixture Design Parameter	Material Properties Measured
Strength	• Flexural Strength • Compressive Strength
Shrinkage Cracking Potential	• Volume of Paste • Unrestrained Volume Change • Restrained Shrinkage • Probability of Cracking
Durability of Hydrated Cement Paste for Freeze-Thaw Durability	• Water-to-Cement Ratio • Fresh Air Content (Pressure or Volume Method) • Fresh Air Content Using Super Air Meter • Time of Critical Saturation • Damage due to Deicing Salts • Calcium Oxychloride Limit
Permeability	• Water-to-Cement Ratio • Rapid Chloride Penetration Test Value • Formation (F) Factor/Resistivity • Ionic Penetration, F Factor
Aggregate Stability	• D Cracking • Alkali Aggregate Reactivity
Workability	• Box Test • Modified V-Kelly Test

Source: FHWA.

The 15 original States participating in the PEM pooled fund study.

Source: National Concrete Pavement Technology Center.



FHWA's Mobile Concrete Trailer is being used to provide hands-on training on PEM test procedures. *Source: Jagan Gudimettla/FHWA Mobile Concrete Trailer.*

Responding to the overwhelming popularity of this program, FHWA recently procured additional Super Air Meters, surface resistivity test devices, and other equipment.

In addition to the pooled fund program, FHWA is sponsoring an implementation incentive program for the States participating in the pooled fund for the following activities: (a) pilot testing and shadow testing for the new test procedures in the mix design stage, (b) acceptance testing during construction, (c) development of an enhanced quality control plan, and (d) use of control charts during concrete production. Interest in the incentive program is high, with eight States already approved and another five working on their applications. FHWA will use data from the implementation program, along with feedback from the States and contractors, to further refine the AASHTO PP84 standard.

A Renewed Emphasis on Quality

The AASHTO PP84 standard acknowledges the key role of quality control (QC) in a performance specification and requires the development of an approved QC plan that includes the following: (a) QC testing and control charts, (b) testing targets, frequency, and action limits, and (c) equipment and construction inspection. The fundamental shift in the approach is the transfer of risk and control from the agency to the contractor; however, the agency still retains responsibility and accountability to the taxpayers.

"The New York State Department of Transportation [NYSDOT] has found it very beneficial to move forward with the implementation and integration of the PEM specification into its concrete program," says Don Streeter, group director, Accelerated Delivery and Innovative Deployment–Structural Materials and Research, NYSDOT. "We shouldn't be telling contractors what to do, but rather we should give them the chance to innovate and meet the performance criteria specified by NYSDOT in the most economical and environmentally sustainable manner."

The ultimate vision of the PEM program is this: By implementing the new specification, highway agencies can look forward to faster and better quality assurance tests, optimized mixtures that lead to cost savings, and longer lasting concrete pavements.

For more information, visit www.cptechcenter.org/pem.

Working with Rainfall Instead of Against It

Long the enemy, storm water finds a place to rest in porous asphalt pavements, percolating through slowly to recharge groundwater.

As communities increase in size, natural permeable ground is converted into impermeable surfaces such as roofs, sidewalks, pavements, and parking lots. Rainfall that is not absorbed becomes runoff and must be carried away or stored. To prevent flooding, storm water might have to be contained upstream through either retention or detention structures. Retention structures hold the water so that it then can percolate slowly into the ground, while detention structures contain it for a time, reducing the subsequent downstream peak flow. Both minimize the storm water impact of residential and commercial developments.

Porous pavement is an alternative to traditional retention or detention structure solutions. Designated as a low-impact treatment, porous pavement improves land-use sustainability by combining the storm water management and parking requirements in the same space of a residential or commercial development. The benefits include the following:

- Retaining storm water to prevent increased runoff volumes
- Filtering storm water before releasing it
- Recharging groundwater using storm water runoff

Because of these positive attributes, storm water management agencies, municipalities, and transportation departments are increasing their use of porous pavements.

FHWA, in cooperation with the National Asphalt Pavement Association (NAPA), identified the need to provide design and construction guidance on porous asphalt pavements. Audrey Copeland, Ph.D., PE, NAPA vice president for engineering, research, and technology, says, "The guidance is needed because we were seeing an increased interest in porous pavements from owners and contractors, not just for parking lots and residential applications, but also for urban and higher trafficked roadways. The demand is increasing, but there was little published guidance for designing and constructing porous asphalt pavements. Local municipalities continue to increase their use of porous asphalt pavements as storm water management devices, and it was necessary to compile design, construction, and maintenance guidance into a single source."

Porous pavements have been used extensively in parking lots like this one in Everett, WA. *Source: APTech.*

In response, NAPA and FHWA developed the TechBrief "Porous Asphalt Pavements with Stone Reservoirs" to provide guidance to design engineers and municipalities seeking to install these treatments.

Why Is This New?

Porous layers have been used in pavement structures for decades. They have typically served as lateral drainage layers placed beneath conventional pavements to provide a sound foundation and to prevent water from being trapped in the pavement structure. In addition, transportation agencies have used porous pavements as riding surfaces in the form of open-graded friction courses, also called porous friction courses (PFCs). Placed approximately 1 inch thick, PFCs use a single-sized aggregate coated with liquid asphalt binder. The ability of PFCs to keep standing water away from the tire-pavement interface has improved safety and driver visibility with significantly reduced levels of water splash and spray churned up by vehicles.

In the late 1970s, engineers began designing porous pavements to serve a different function. In the newer use, porous pavements employ the same open-graded structure, but are placed several inches thick, to hold and manage storm water in parking lots, along shoulders, and on low-volume roads. Porous pavements differ from PFCs and drainage layers in that they are designed to be vertically permeable so that water can pass through the pavement and into deeper natural ground layers.

(Above) With impermeable pavements, splash and spray are significant during rainfall events. *Source: APTech.*

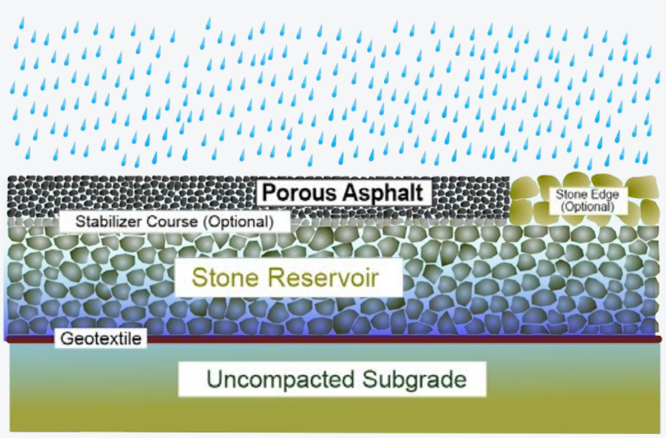
(Right) A porous friction course (PFC) can enhance visibility during rainfall because it keeps standing water away from the pavement-tire interface. *Source: APTech.*

So How Do They Work?

The aggregate structure within the porous asphalt pavement uses a single-sized, cubical aggregate that creates approximately 16 to 22 percent air voids after construction. Because the air voids are widespread and interconnected, the material is highly permeable. The contractor installs an open-graded stone reservoir beneath the porous asphalt layer, with the reservoir thickness determined by the required storage capacity.

This cross section shows a typical porous asphalt pavement with a stone reservoir.

Source: FHWA TechBrief.



Drainage structures like this one carry away storm water flow that exceeds the holding capacity of the porous pavement and stone reservoir. *Source: APTech.*

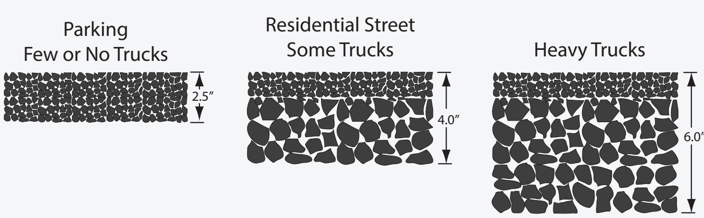
A geotextile fabric lines the bottom of the pavement layer and enables water to flow downward out of the pavement structure, but prevents soil from migrating upward into the layer of porous pavement. Constructing the porous pavement over uncompacted or lightly compacted subgrade maintains the permeability of the soil so that storm water can flow through the pavement and subgrade layers to eventually recharge the groundwater. Overflow pipes are installed along the pavement edges to divert water into other storm water conveyances in the event the flow exceeds the designed retention capacity.

What about the Design?

The hydraulic design for these structures determines the depth and storage volume of the stone reservoir. The required storage volume is established by examining a locally specified rainfall event, and by determining the volume of runoff that occurs due to the impermeable surfaces. The TechBrief provides thickness design parameters that engineers can use to determine the optimum depth of the porous asphalt and the corresponding depth of the reservoir to protect the subgrade from overloading. Minimum thicknesses are also recommended for applications with varying traffic levels.

Shown here are the recommended minimum thicknesses for porous asphalt pavements under various traffic loads.

Source: FHWA TechBrief.



What Maintenance Is Required?

A primary maintenance activity is vacuuming or flushing the pavement to remove debris that is clogging the void structure. This needs to be done on a routine basis to ensure that the pavement does not clog with debris and is able to drain water. As the pavement ages and begins to ravel and pothole, conventional patches may be applied so long as no more than 10 percent of the area is affected. It is important to maintain the permeability or drainability of the pavement and to avoid creating significant barriers to flow across the pavement.

What's Next?

Although porous asphalt pavements have been used primarily on parking lots, FHWA is supporting the development of additional documents to provide information on the use of porous pavements on roadways. Most roadway agencies have little to no experience related to the structural design of porous asphalt pavements, and documented field performance and validation of design procedures are lacking.

Two documents, *Structural Design Guidelines for Porous Asphalt Pavements* and a complementary TechBrief will assist in filling that need. They represent current best judgments based on material characterization data and adaptability to hydrologic conditions at the local level. By offering technical information on the materials and structural design, FHWA continues to provide leadership in the implementation of porous pavements. Despite their limited application, by recognizing the sustainability role that these structures play as low-impact treatments, FHWA is promoting the increased use of the practice in communities across the United States.

The TechBrief "Porous Asphalt Pavements with Stone Reservoirs" can be found at www.fhwa.dot.gov/pavement/asphalt/pubs/hif15009.pdf.

For more information, visit www.fhwa.dot.gov/pavement/asphalt.

Appendix

Related Pavement Technology Development and Deployment Activities Supporting the AID-PT Program

The Center for Accelerating Innovation (CAI) leads five innovation programs to support the accelerated deployment of transformative technologies into practice.

Every Day Counts Innovation Deployment Program

The Every Day Counts (EDC) Program (FAST Act §1444) is a State-based model that identifies and rapidly deploys proven, yet underutilized innovations to shorten project delivery, enhance roadway safety, reduce traffic congestion, and improve environmental sustainability. Proven innovations promoted through EDC facilitate greater efficiency at the State and local levels, saving time, money, and resources that can be used to deliver more projects.

The Every Day Counts program has supported four pavement-related innovations during the first four rounds of the program from 2011 through 2018.

Intelligent Compaction	www.fhwa.dot.gov/innovation/everydaycounts/edc-2/compaction.cfm
Pavement Preservation (When, Where, and How)	www.fhwa.dot.gov/innovation/everydaycounts/edc_4/pavement.cfm
Safety Edge^SM^	www.fhwa.dot.gov/innovation/everydaycounts/edc-1/safetyedge.cfm
Warm Mix Asphalt	www.fhwa.dot.gov/innovation/everydaycounts/edc-1/wma.cfm

Selection of EDC innovations is a stakeholder-engaged process. The AID-PT program directly supports pavement-related innovations advanced under EDC.

State Transportation Innovation Councils

Key components to the success of innovation deployment programs such as EDC are the State-based approach and the State Transportation Innovation Council (STIC) concept. A STIC brings together public and private transportation stakeholders to evaluate innovations and spearhead their deployment in each State. The STIC Incentive program provides resources to help STICs foster a culture of innovation and make innovations standard practice in their States. Through the program, funding up to $100,000 per State per Federal fiscal year is made available to support or offset the costs of standardizing innovative practices in a State transportation agency or other public sector STIC stakeholder.

The STIC Incentive program provides resources to each STIC to advance innovation. Projects are selected at the individual STIC level and advanced through the Federal-aid Division Office and Federal Lands Highway Division for approval. The AID-PT program directly supports pavement-related incentive projects advanced under this program. A listing of all STIC Incentive projects is available here.

Summary of Pavement-Related STIC Incentive Activities (June 2017 to May 2018)

State	Projects
Alaska	Develop and implement a performance specification for acceptance of asphalt paving compaction based on continuous-full-coverage density data collected by ground penetrating radar.
Alabama	Develop and provide training on pavement preservation and management techniques.
Colorado	Implement CDOT's Lean Everyday Ideas for local agencies, including asphalt hotboxes.
Colorado	Host a Local Innovation Implementation Summit to demonstrate and highlight EDC technologies to local government agencies.
Delaware	Purchase and evaluate advanced quality assurance and quality control tools for soil and asphalt compaction.
Delaware	Purchase, use, and evaluate unmanned aerial systems to develop and refine operations procedures for collecting additional field data for efficient bridge and pavement design.
Iowa	Advance virtual reality for transportation projects for improved public outreach and technology transfer purposes.
New Hampshire	Advance SHRP2 R06B program, Techniques to Fingerprint Construction Materials (Keeping up with innovation adding FTIR and XFR capability to the toolbox).
Oklahoma	Develop and implement an outreach plan to accelerate innovation deployment in Oklahoma.
West Virginia	Purchase equipment and provide statewide training to demonstrate how to apply pavement preservation techniques properly, including scrub seals.
Washington	Advance a Low-Volume Pavement Rehabilitation Online Scoping Tool.

Accelerated Innovation Deployment Grant Program

The Accelerated Innovation Deployment AID Demonstration program provides funding as an incentive to accelerate the use of innovation in highway transportation projects. FHWA expects approximately $10 million to be made available for AID Demonstration grants in each of fiscal years 2016 through 2020 from amounts authorized within the Technology and Innovation Deployment Program (TIDP) under the Fixing America's Surface Transportation (FAST) Act.

The AID Demonstration grants program operates under a rolling solicitation. Eligible agencies can submit applications through the Notice of Funding Opportunity (NOFO) published on September 1, 2016. The AID-PT program directly supports pavement-related AID grants. View a list of all AID Demonstration grants here.

Summary of Pavement-Related AID Demonstration Grant Activities (June 2017 to May 2018)

State	Applicant	Projects
Washington	Washington State DOT	Washington State Department of Transportation (WSDOT) – Concrete Pavement Replacement Demonstration Project Using Precast Concrete Panels (PCP)
Illinois	Illinois DOT	Saraville Road Resurfacing Project*

**The Illinois AID Demonstration application is currently pending agency and departmental approval for award.*

Accelerating Market Readiness

The Accelerating Market Readiness (AMR) program is intended to spur the advancement of emerging and transformative innovations in the transportation industry: those that significantly advance conventional practice, address knowledge and technology gaps, significantly advance the state of the art, or constitute a sea change in the development and delivery of transportation projects and programs. The AMR program is structured with an internal and an external component. The external component is managed through a broad agency announcement, while the internal component is managed through CAI with the support of the chief innovation officer and associate administrators for the review and selection of projects.

Increased Federal-Share for Project-Level Innovation

Increased Federal-share for Project-level Innovation, a provision of Section 120(c)(3) of title 23, United States Code, provides the option of an increased Federal share for projects using innovative project delivery methods. Established by the Moving Ahead for Progress in the 21st Century Act (MAP-21) and amended by the FAST Act, this provision builds on the Every Day Counts initiative. The increased Federal share for innovative techniques incentivizes use of innovation to help deliver projects more efficiently and to rapidly deploy proven solutions that make a difference. This program is approved at the Federal-aid division office level.

“More than ever, owners, industry, and academia face a weighty imperative and an unprecedented opportunity to design, rehabilitate, and build pavements that will meet rapidly changing needs. As a starting point, highways must carry ever-increasing traffic volumes and loads, but also they will be expected to do much more. As driverless vehicles, population shifts, dedicated truck corridors, and unforeseen disruptive factors alter transportation, the demands on highways will increase, not decrease. Accelerated Implementation and Deployment of Pavement Technologies (AID-PT) has proven to be a great success in helping agencies and industry implement available technology and prepare for this evolution. Dividends from the AID-PT investments can be seen in technology advancements such as performance-engineered concrete mixtures, which is a program striving to ensure that agencies can specify—and contractors can deliver—durable pavements every time. Practical technology transfer through FHWA’s Mobile Concrete Trailer and equipment/instrument loan programs, concrete overlay implementation program, technical and tech transfer documents, and life-cycle cost analysis guidance also are helping everyone involved produce higher quality and longer lasting roadway and highway pavements. By continuing to build on the momentum of technology implementation, AID-PT is helping position U.S. highway agencies to deliver the Nation’s future surface transportation network today.”

— Gerald F. Voigt, P.E., President and CEO
American Concrete Pavement Association

“The AID-PT program and partnership between FHWA and NAPA continue to successfully speed implementation of innovative technologies that improve pavement performance and highlight advances in the use of impactful practices, such as recycled asphalt pavements. In 2017, FHWA and NAPA hosted the Paving for Performance conference to advance specific design, production, and construction practices that improve pavement performance. Participation included representatives from the asphalt paving industry, FHWA, State departments of transportation, and the Army Corps of Engineers. In the field, NAPA continues to assist FHWA efforts to increase density for improved performance.

This year, under the AID-PT program, NAPA has developed a webinar series for the design and construction of Heavy Duty Pavements, as well as quantified the longer pavement life and performance of Stone Matrix Asphalt (SMA). FHWA and NAPA see SMA as a technology ready for wide-scale implementation. To this end, the AID-PT program is providing resources to educate highway agencies and contractors at the International SMA Conference in November 2018 in Atlanta, GA. The conference also has the support of the Transportation Research Board, the Association of Asphalt Paving Technologists, and other material- and pavement-related organizations.

The AID-PT program continues to advance sustainability, and this year, with FHWA’s help, NAPA is proud to distribute the *Contractor’s Guide to Sustainability*, which will help in putting FHWA’s work to advance sustainable pavements into practice. Finally, FHWA and NAPA are formalizing the process for identifying technologies ready for implementation through the asphalt pavement catalog. This multifaceted approach to advancing performance, innovation, and sustainability with asphalt pavements is possible thanks to the AID-PT program.”

— Mike Acott, President
National Asphalt Pavement Association

Image: Blue Planet Studio/Shutterstock

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