National Concrete Pavement Technology Center

Performance-Engineered Concrete Paving Mixtures

tech transfer summary

This Performance-Engineered Concrete Paving Mixtures Transportation Pooled Fund—TPF-5(368)—brought newer concrete pavement technologies to state agencies and assisted states in the adoption of specifications and test methods that will help them deliver on the promise of concrete durability.

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RESEARCH PROJECT TITLE
Performance-Engineered Concrete Paving Mixtures (PEM)

SPONSORS
Iowa Department of Transportation (InTrans Project 17-629)
Federal Highway Administration
Transportation Pooled Fund TPF-5(368)

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MORE INFORMATION
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The mission of the National Concrete Pavement Technology Center (CP Tech Center) at Iowa State University is to unite key transportation stakeholders around the central goal of developing and implementing innovative technology and best practices for sustainable concrete pavement construction and maintenance.

IOWA STATE UNIVERSITY
Institute for Transportation

Problem Statement and Project Justification

State transportation agencies and concrete pavement professionals have traditionally accepted concrete based on measurements like strength, slump, and air content. These measurements have had very limited correlation to future performance. However, recent developments in concrete testing technologies have yielded methods that are better predictors of long-term performance.

Pooled Fund Background

The Federal Highway Administration (FHWA) had been working with the National Concrete Pavement Technology Center (CP Tech Center) and other concrete paving experts to identify the specification approach and key testing technologies that are needed for concrete pavements to have reliable performance.

The testing technologies had been developed by Peter Taylor at Iowa State University, Tyler Ley at Oklahoma State University, and Jason Weiss at Purdue University (now Oregon State University). The next critical activities were deployment of the new testing technologies and development of practical specifications and quality assurance/quality control (QA/QC) recommendations.

The FHWA, 19 state transportation agencies, 7 state paving chapters (in Minnesota, Pennsylvania, Michigan, Wisconsin, Iowa, Oklahoma, and the Southeast region), and 4 national associations (Portland Cement Association, American Concrete Pavement Association, Slag Cement Association, and RMC Research & Education Foundation [now Concrete Advancement Foundation]) came together to fund this project. This coalition of federal, state, and industry leaders was dedicated to maximizing pavement performance. Figure 1 shows the locations of the 19 pooled fund member states.

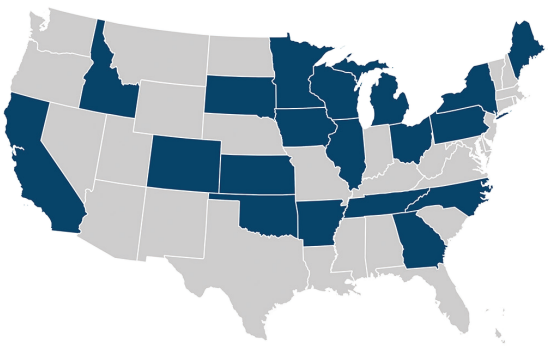

Figure 1. PEM pooled fund member states

Project Objective, Focus, and Methods

The objective of this project was to focus on the deployment of performance-engineered mixtures (PEM). This involved building off the foundational work that the FHWA and the PEM champion states had done, with emphasis on implementation, education and training, adoption of specification language to increase the likelihood of achieving durable pavement performance in the field, and continued development relating early-age concrete properties to pavement performance.

Pooled Fund Project Description/ Summary and Scope

The PEM pooled fund project was broken down into the following tasks:

- **Implementing what is known:** Support study participants with implementation of improved specifications for mixtures within their states through education, training, and project-level assistance.
- **Performance monitoring and specification refinement**: Provide field performance data for use in making decisions on specification limits for strength, shrinkage, freeze-thaw durability, transport, aggregate stability, and workability.
- **Measuring and relating early-age concrete properties to performance:** Build on the foundational work in available measurement technologies in order to design and control concrete pavement mixtures around key engineering properties and address improved testing methods for increased accuracy and reduced cost.

The focus of the work was to address the mixture up to the point of leaving the batch plant.

Accomplishments

Implementation

During the implementation task, PEM technology transfer activities included presentations at various workshops and webinars, specification support, and test support, in addition to shadow project support. The project also resulted in considerable discussion and activity in a number of spheres:

- State implementation
- Industry implementation
- Transportation Research Board (TRB) committee interest
- Federal Aviation Administration (FAA) research project funding

Website

A PEM website was developed at **www.cptechcenter.org/pem** to provide quick access to the following information:

- PEM program information
- Interactive map of shadow project and testing locations
- Instructional videos on test methods and test method summaries
- PEM newsletters
- PEM shadow project reports from state agencies and the FHWA
- State specification review table
- Technical advisory committee (TAC) meeting notes
- Reginal state-industry meeting notes
- Sponsor information

Workshops and Webinars

During the five-year pooled fund, technology transfer for PEM was provided at 82 workshops, meetings, and webinars across the country. The presentations were provided by the CP Tech Center and members of the PEM research team. Figure 2 is an image from one of the PEM workshops.

Specification Support

The pooled fund member states were contacted by the research team in 2019 to gain an understanding of their current pavement specifications relating to PEM. A table was developed on how their specifications addressed the six PEM properties: strength, transport, shrinkage, freeze-thaw resistance, aggregate stability, and workability. This table is available at this link: **https://intrans.iastate.edu/app/uploads/sites/7/2020/07/PEM-State-Spec_Reviews-Table-2020-07-02.pdf**

Figure 2. PEM workshop at the Georgia Department of Transportation (DOT)

In 2021, the research team again reached out to member states to see if they had made changes or were considering changes to their specifications based on what they had learned from the PEM program. In many cases, shadow testing, open house demonstrations, workshops, and other forms of technical transfer led to improvements within their specifications.

Test Support

Members of the PEM research team from Iowa State University, Oklahoma State University, and Oregon State University offered test support for the new PEM tests including the Vibrating Kelly Ball (VKelly), Box test, super air meter (SAM), resistivity and formation factor, and Phoenix. Formal test training was provided in 12 of the 19 pooled fund member states. Other forms of test support included webinars, workshop presentations, and guidance documents.

Shadow Project Support

To encourage the use of PEM, the FHWA offered various levels of incentive funding to state agencies to help offset the costs of additional shadow testing, data collection, and reporting. Seven of the 19 pooled fund states accepted incentive funding, and members of the research team coordinated shadow projects with state agencies.

The intent of the shadow projects was to give state agencies exposure to PEM and new testing methods. When possible, open houses were held during shadow projects to provide education on the PEM program and demonstrate new PEM tests. Figure 3 shows participants from one of the PEM open houses.

Data were collected by state agencies, members of the research team, and, in some cases, the FHWA's Mobile Concrete Technology Center (MCTC). Reports are available online with links to them in an appendix of the final report for this TPF. Figure 4 illustrates the locations of PEM projects during the PEM pooled fund.

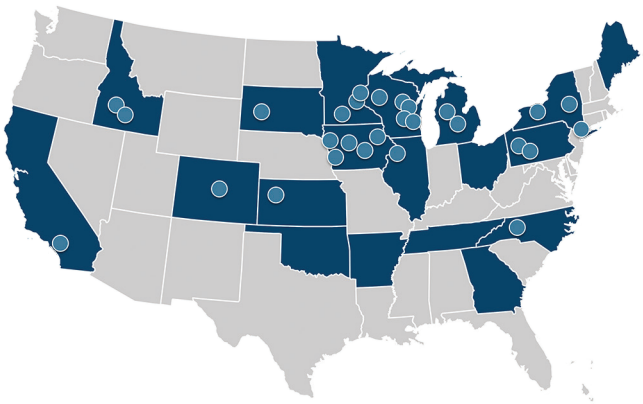

Figure 4. PEM projects that took place during the pooled fund

Virtual Regional State Agency–Industry Meetings

The PEM research team organized virtual regional meetings with state agency members and industry. The focus of the meetings was to get feedback from the state agencies regarding their implementation of PEM and to also include industry as part of the discussions.

Monitoring

The monitoring phase included the development and management of the PEM database. This included data received from state agencies from the shadow test projects. Monitoring also included sampling and testing of cores from the Long-Term Pavement Performance (LTPP) SPS-2 test sites that have been in service for years. Finally, the annual update of AASHTO PP 84, now AASHTO R 101, was provided.

Test Refinement

Water Content

Under this project, the research team at Oklahoma State University worked with the Minnesota DOT (MnDOT) and the FHWA Mobile Concrete Lab to use the Phoenix device in the field and gather feedback. Figure 5 shows the Phoenix device during field testing.

Jagan M Gudimettla, ATI Inc. for the FHWA Mobile Concrete Technology Center

Figure 3. PEM Open House

Figure 5. Phoenix testing device

Based on the feedback, the team made a number of changes to the test, and a test method was developed to use the Phoenix device to measure the moisture content of aggregate, expanding the usefulness of the test method. Finally, a standard test method was developed for the Phoenix device to be used to measure the water content of fresh concrete.

These test methods were shared, and several changes were made. The current test methods are being published by MnDOT as a state test method. This will allow other organizations to use the test methods in the future and provide a stable version to take to larger state agencies.

Thermodynamic Modeling

Under this project, the research team at Oregon State University used a previously developed modeling framework to predict the properties of concrete samples obtained from states and LTPP sites. The model is very useful for predicting performance as well as the carbon footprint and sustainability as it relates to service life.

VKelly

The purpose of the VKelly test is to indicate how a mixture will respond to vibration, providing more information than the yield stress reported by the slump test. Figure 6 shows the VKelly during field testing.

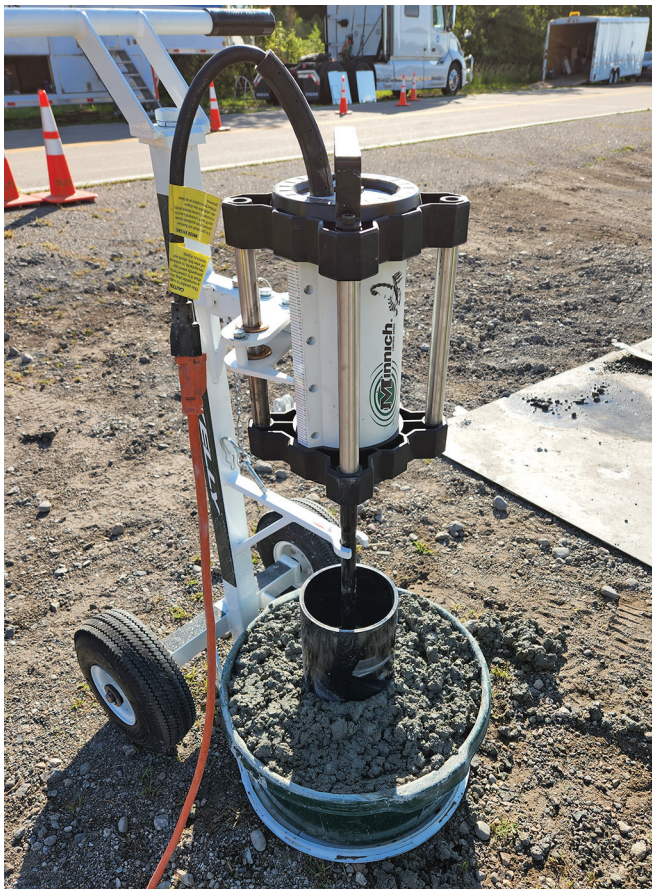

Figure 6. VKelly test

Feedback from some of the states that were provided with VKelly devices was that the system was labor intensive and not user friendly, although in some cases it was felt that the data were valuable. It was reported that a number of operators were using a variety of vibrators and head sizes leading to large variability in the data produced.

During this project, a vibrator manufacturer was able to redesign the system including mounting a speed-controlled motor directly above the ball, thus reducing energy loss and improving the ease of conducting a test. Work is still ongoing to automatically report the rate of penetration to provide an instantaneous readout.

Key Findings and Results

Through the PEM pooled fund, the project team learned the following:

- Each state agency is unique in the way they specify concrete pavements. Table 2 in AASHTO R 101 gives the agency choices on select PEM properties and their standard test methods in the areas of strength, shrinkage, freeze-thaw durability, transport, aggregate stability, and workability.
- Successful PEM shadow projects were the result of coordination and communication between state agencies and industry.
- New test methods require training and practice following standard methods to achieve desired results.
- Contractors involved in shadow projects were supportive and continue to use the tools provided.
- Sustainability is improved when utilizing PEM approaches.
- Additional technology transfer is needed for state and local agencies, industry, and the private sector to increase their exposure to PEM and its benefits.
- The goals of the pooled fund project were achieved including implementation, education and training, adjustment of the specification values, and continued development of tools to relate early-age concrete properties to performance.

Implementation Readiness and Benefits

The PEM pooled fund showed success in the form of improved specifications at the agency level that have been accepted by contractors. Intensive evaluation, demonstration, training, education and implementation efforts have meant that a number of states and contractors have adopted approaches through this TPF and are reporting reduced costs, improved reliability, and improved sustainability.

While the funding from this pooled fund is ending, the need continues to implement the PEM program and to extend the effort to include tests to monitor the impacts of construction activities (such as the addition of water and admixtures, vibration, finishing, and curing of mixtures until concrete pavements are ready for traffic loads).

The story of PEM needs to continue to be told so that more agencies have an opportunity to achieve the benefits that PEM offers. The outcome of PEM implementation is success for all parties involved—from the design engineer to the material producer to the pavement contractor to the agency, and finally, to the users of the transportation facility.

Progress was made, but more work needs to be done. With PEM approaches, concrete pavement should perform better and last longer with a lower environmental impact. This will enable agencies to reduce costs by minimizing maintenance operations, keeping the flow of traffic undisturbed for longer periods of time and increasing safety for the traveling public.

Future Work

To ensure success after a concrete mixture is delivered to the paving site, proper construction operations are needed. These include use of the appropriate amount of vibration for consolidation as well as effective finishing, curing, saw-cutting, and sealing operations. The team recommends concentrating on these construction operations during the next TPF, Performance-Centered Concrete Construction (P3C).

This new TPF project it is intended to follow the model used by the PEM pooled fund project to carry out the following:

- Establish a sound understanding of the workmanship involved in concrete paving and its effects on performance properties
- Develop/select appropriate test methods for evaluation at or behind the paver
- Select pass/fail criteria
- Provide documentation, training, and other resources to encourage agencies and contractors to adopt specifications and practices reflecting these suggestions

The P3C pooled fund will lean on agencies, contractors, machine manufacturers, and researchers to develop a detailed scope of work starting with the determination of which actions need to be taken on the grade to ensure sustainable pavement performance. Test methods and limits will be determined to measure the following:

- Uniformity
- Segregation
- Consolidation
- Air void system
- Durability and strength
- Smoothness
- Cracking

Successful completion of the project will involve the development of specifications and guidance tools for technology transfer, including videos, written documents, and training programs.