NATIONAL CONCRETE CONSORTIUM

"Moving Advancements into Practice"

MAP Brief Fall 2023

Best practices and promising technologies that can be used now to enhance concrete paving

PEM Evolution: Then and Now

FALL 2023

PROJECT TITLE
PEM Evolution: Then and Now

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Introduction

Performance-Engineered Mixtures (PEM) is an initiative that began several years ago with discussions between the Federal Highway Administration (FHWA), American Concrete Pavement Association (ACPA), and the National Concrete Pavement Technology Center (CP Tech Center). The goal was to advance concrete pavement mixtures toward performance-based specifications with the main challenge of defining effective methods of measuring the performance characteristics of concrete that directly relate to pavement durability and structural longevity. Concluding in 2022, TPF-5(368) focused on materials and mixtures, while, currently, TPF-5(517) focuses on what happens to the mixture after it is delivered to the site. A copy of the final report *Performance-Engineered Concrete Paving Mixtures* can be accessed here: intrans.iastate.edu/app/uploads/2023/04/performance-engineered_concrete_paving_mixtures_w_cvr.pdf.

This document provides the background of PEM; outlines the accomplishments, key findings, and implementation of TPF-5(368); and provides a look at what is current with PEM regarding construction practices (Figure 1).

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.

Todd Hanson, Iowa DOT, used with permission

Figure 1. Paving on US 20 using PEM test procedures

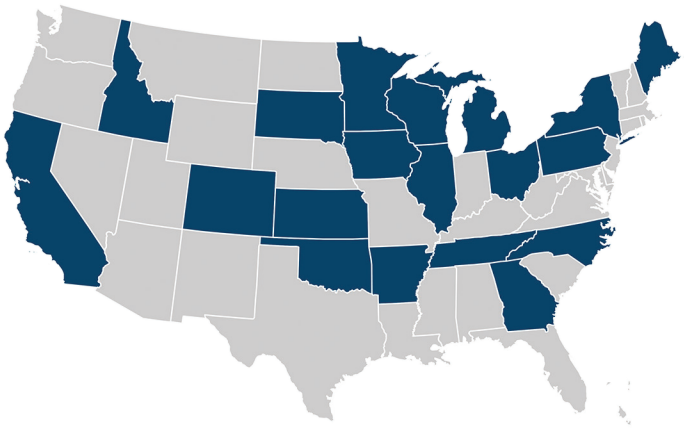

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Figure 2. PEM pooled fund member states

Pooled Fund Background

The FHWA, through a Cooperative Agreement with the CP Tech Center, had been working with 30 member-state transportation agencies through the National Concrete Consortium (NC²) to identify the specification approach and key testing technologies that are needed for concrete pavements to have increased durability.

The FHWA, 19 state transportation agencies, and 4 national associations representing the concrete paving industry came together to fund this project. It was a coalition of federal, state, and industry leaders dedicated to maximizing pavement performance. Figure 2 shows the 19 pooled fund member states.

Project Objective, Focus, and Methods

The objective of this project was to focus on the deployment of 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 performance-engineered paving 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 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, test support, and 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 (Figure 3) 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
- Regional state-industry meeting notes
- Sponsor information

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Figure 3. PEM website

Workshops and Webinars

During the five-year pooled fund project, 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 4 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 related 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: intrans.iastate.edu/app/uploads/sites/7/2020/07/PEM-State-Spec_Reviews-Table-2020-07-02.pdf.

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, super air meter (SAM), resistivity and formation factor, and Phoenix tests. 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 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 5 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 and are linked in an appendix of the final report for this TPF. Figure 6 illustrates the locations of PEM projects during the PEM 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 acquire feedback from the state agencies regarding their implementation of PEM and to include industry as part of the discussions.

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Figure 4. PEM workshop at the Georgia Department of Transportation (DOT)

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

Figure 5. PEM Open House

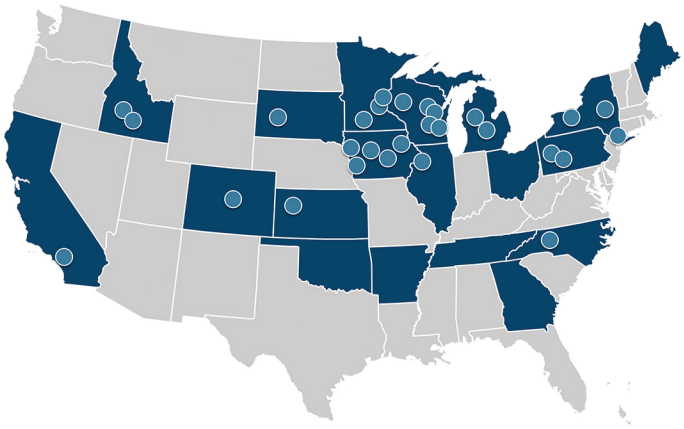

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Figure 6. PEM projects that took place during the pooled fund

Monitoring

The monitoring phase included development and management of the PEM database. This included shadow project test data received from state agencies. Monitoring also included sampling and testing of cores from the Long-Term Pavement Performance (LTPP) SPS2 test sites that had 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 Laboratory to use the Phoenix device in the field and gather feedback. Figure 7 shows the Phoenix device during field testing.

Based on the gathered 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 for measuring the water content of fresh concrete.

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Figure 7. Phoenix testing device

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 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 8 shows the VKelly during field testing.

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.

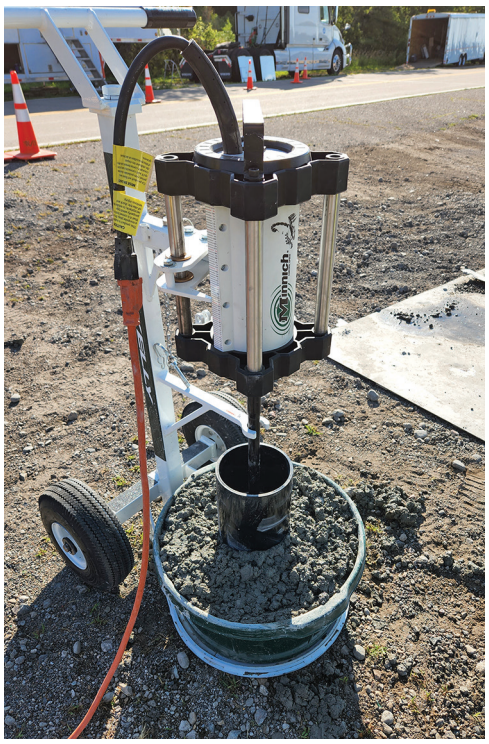

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Figure 8. VKelly test

Key Findings and Results

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

- Each state agency is unique in the way it specifies concrete pavements; Table 2 in AASHTO R 101 gives agencies choices on the selection of PEM properties and 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 provided tools.
- 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

PEM has 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 pooled fund and are reporting reduced costs, improved reliability, and improved sustainability.

While TPF-5(368) has concluded, 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, foremost, 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 optimize costs by maximizing pavement performance, minimizing maintenance operations, keeping the flow of traffic undisturbed for longer periods of time, and increasing safety for the traveling public.

PEM Today (P3C)

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 current PEM pooled fund TPF-5(517) Performance-Centered Concrete Construction (P3C) seeks to develop specifications to address these needs.

TPF-5(517) 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 effect 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 ask agencies, contractors, machine manufacturers, and researchers to prioritize the tasks and suggest test methods to address the following:

- Sufficiency and timing of curing
- Consolidation practices and measurement
- Finishing practices and measurement
- w/cm ratio measurement in the field
- Air void system measurement in the field
- Effect of materials and mixtures on smoothness

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

Currently, the following states have made commitments to TPF-5(517):

- Iowa (lead state)
- Colorado
- Idaho
- Kansas
- Michigan
- Missouri
- North Dakota
- Pennsylvania
- Wisconsin

For more information, please contact Peter Taylor at ptaylor@iastate.edu.