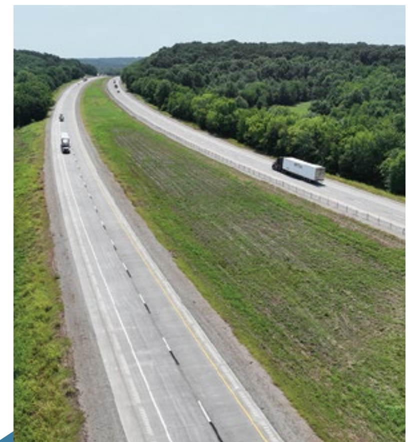
FHWA Cooperative Agreement HIF190010PR (2019–2024)

Summary of Accomplishments

IN SUPPORT OF

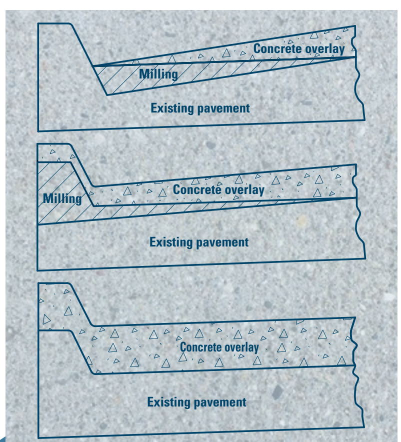
Advancing Concrete Pavement Technology Solutions



1 Extended Life

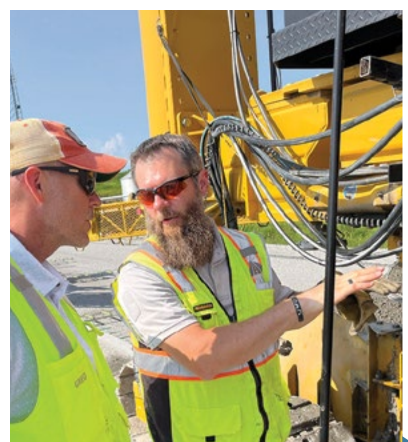
2 Reduced Cost

3 Accelerated Construction



4 Design and Specifications

5 Real-Time Evaluation



6 Technology Transfer

IOWA STATE UNIVERSITY
Institute for Transportation

National Concrete Pavement Technology Center
CP Tech Center

The Accelerated Implementation and Deployment of Pavement Technologies (AID-PT) program was established by Congress in 2012 with the Moving Ahead for Progress in the 21st Century (MAP-21) Act. At its core, the AID-PT program seeks to move the latest technologies and innovations into practice for the benefit of assisting state highway agencies (SHAs) with improvement of the nation's highway infrastructure. Congress continued the program in 2015 as part of the Fixing America's Surface Transportation (FAST) Act (Pub. L. 114-94) and again in 2022 as part of the Infrastructure Investment and Jobs Act (IIJA).

Under the 2019–2024 Advancing Concrete Pavement Technology Solutions cooperative agreement with the Federal Highway Administration (FHWA), the National Concrete Pavement Technology Center (CP Tech Center) undertook the task of bringing the latest innovations, knowledge, and technologies to SHAs in support of the AID-PT goals. Technical support and products were provided to SHAs through this agreement to better equip them to manage their investments in concrete pavements. The cooperative agreement was divided into the following six work areas aligned with the six goal areas of the AID-PT program:

1. Deployment of new, cost-effective designs, materials, recycled materials, and practices to extend pavement life and performance and to improve user satisfaction.
2. Reduction of initial costs and life-cycle costs of pavements, including the costs for concrete pavement rehabilitation and maintenance.
3. Deployment of accelerated construction techniques to increase safety and reduce construction time and traffic disruption and congestion.
4. Deployment of engineering design criteria and specifications for new and efficient practices, products, and materials for use in highway pavements.
5. 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.

This document summarizes the accomplishments resulting from the work performed under the cooperative agreement.

Summary of Accomplishments

The cooperative agreement included the development and publication of 5 guides and manuals, 15 tech briefs, 8 tech summaries, 19 case studies, 11 one-pagers, 5 reports, 3 American Association of State Highway and Transportation Officials (AASHTO) products, 2 white papers, 4 videos, 4 spreadsheets, 11 demonstration project or field reports, and a draft model specification.

Cooperative agreement documents were downloaded from the CP Tech Center's website more than 35,000 times during the contract period. Figure 1 shows a summary of the top 10 most frequently downloaded publications from https://www.cptechcenter.org/ since March 2022.

Many of the publications are interactive to allow the reader to access more expansive information about topics addressed in the publications. Copies of the products developed under the cooperative agreement are available in PDF format on the CP Tech Center website: https://cptechcenter.org/research/in-progress/advancing-concrete-pavement-technology-solutions/.

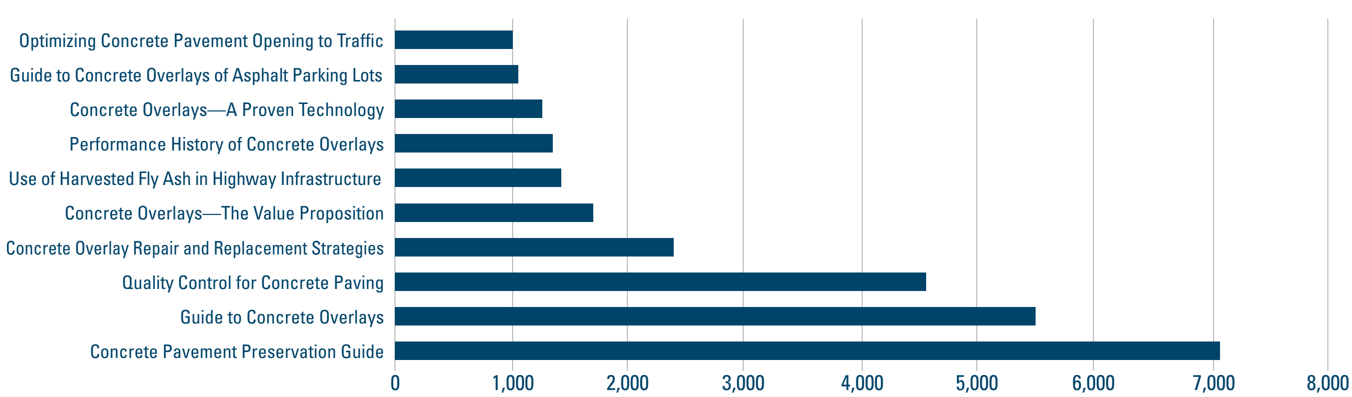


Figure 1. Top 10 most frequently downloaded cooperative agreement publications from https://www.cptechcenter.org/ since March 2022

In a few cases, publications were also printed to help facilitate workshops and to respond to individual requests from some stakeholders. Printed copies of the following publications were produced:

- *Guide for Reducing the Cradle-to-Gate Embodied Carbon Emissions of Paving Concrete*, 250 copies
- *Quality Control for Concrete Paving: A Tool for Agency and Industry*, 200 copies
- *Guide to Concrete Overlays* (4th Edition), 300 copies
- *Concrete Pavement Preservation Guide* (3rd Edition), 100 copies

In addition, the CP Tech Center delivered between 40 and 60 presentations and workshops across the country each year on topics related to the six work areas to an average of about 115 attendees/participants per workshop. Over the five-year span of the cooperative agreement, CP Tech Center staff reached roughly 28,000 people via these in-person training events. A map of presentation and workshop locations is shown in Figure 2.

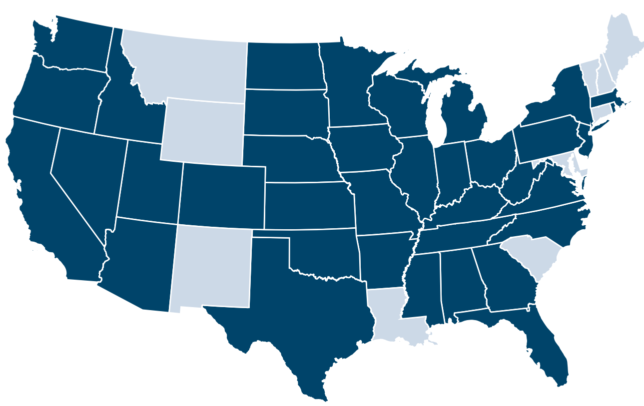


Figure 2. States where presentations and workshops were held between 2019 and 2024

A total of 40 different webinars related to cooperative agreement topics were also delivered as part of the CP Tech Center's technology transfer efforts. These webinars were held weekly during the COVID-19 shutdown and monthly after that. An average of 408 attendees participated in each webinar, for a total of over 16,000 webinar attendees. Webinar topics directly related to cooperative agreement deliverables included the following:

- Concrete Paving Field Inspection
- Concrete Quality Control and Quality Assurance
- Troubleshooting Concrete Paving Projects
- Concrete Pavement Smoothness
- Concrete Overlays (Including Section, Design, Construction, Maintenance, Repair, Fibers, Performance, Case Histories)
- Preservation of Concrete Pavement
- Pavement Resilience
- Concrete Durability and Long-Life Pavement
- Life-Cycle Cost Analysis
- Performance-Engineered Mixtures
- Concrete Pavement Design and Jointing
- Concrete Strength Estimation Using Maturity Concepts
- Alkali-Silica Reaction
- Recycled Concrete Aggregates
- Sustainability and Low-Carbon Concrete Mixtures
- Resistivity Testing
- Performance Cements
- Supplementary Cementitious Materials (Fly Ash, Slag)
- Performance Centered Concrete Construction (P3C)
- Concrete Pavement Foundations and E-Compaction Tools

Research Partners

The CP Tech Center partnered with experts in their respective fields to develop the various publications and presentations under the five-year agreement. Guides and manuals were also peer reviewed by a large pool of representatives from academia, FHWA, consultants, state agencies, contractors, trade associations, and other entities depending on the subject. The research partners were as follows:

- Advanced Concrete Pavement Consultancy
- Innis Consulting Group
- Applied Pavement Technology (APTech)
- Diversified Engineering Services
- Genex Systems
- Harrington Civil Engineering (HCE) Services
- Ingios Geotechnics
- Mark Felag LLC
- Nichols Consulting Engineers (NCE)
- Oklahoma State University
- Oregon State University
- Pavement and Materials Consultants
- Pavement Engineering and Research Consultants (PERC)
- Red Noise 6
- Snyder & Associates
- Sutter Engineering
- Square One Pavement Consulting
- The Transtec Group
- University of North Carolina at Charlotte
- University of California, Davis
- Wiss, Janney, Elstner (WJE) Associates
- Woodland Consulting

This team of experts represented a broad range of geographic areas across the United States (Figure 3).

CP Tech Center engineering staff members included Peter Taylor, PhD, PE; John Adam, PE; Gordon Smith, PE; Steve Tritsch, PE; Leif Wathne, PE; and Dan King, PhD, PE.

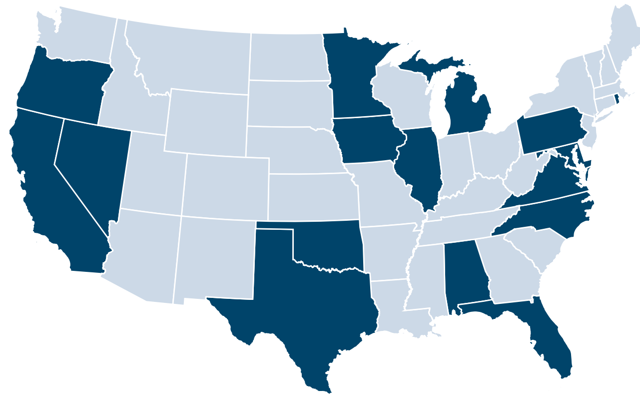


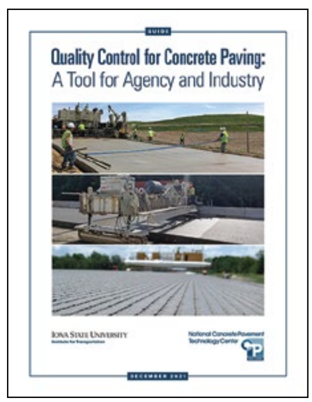
Figure 3. Research partner distribution

Deliverables

For the convenience of the reader, the array of deliverables developed under the cooperative agreement is organized into 11 topic areas. Each topic area may include several different types of deliverables.

Quality

Quality Control for Concrete Paving: A Tool for Agency and Industry (165 pages)



Quality control (QC) by contractors, concrete suppliers, and materials suppliers is an integral component of a transportation agency's quality assurance (QA) program and supports the construction of quality concrete infrastructure. *Quality Control for Concrete Paving: A Tool for Agency and Industry* is intended to serve as a tool that both contractor and agency personnel can use at the batch plant, behind the paver, and at other locations on the job. Topics include common agency QC requirements; the appropriate tools, processes, and procedures to meet these requirements; continuous improvement activities; and the benefits for contractors of good quality control, including higher efficiency and productivity, increased profit, and safer operations. This guide is the third most downloaded cooperative agreement publication from CP Tech Center's website since March 2022.

Agency Approaches to Quality Control for Concrete Paving (10 pages)


TECH BRIEF

Advancing Concrete Pavement Technology Solutions

AGENCY APPROACHES TO QUALITY CONTROL FOR CONCRETE PAVING

Summary and Disclaimers

Introduction

National Concrete Pavement Technology Center

Iowa State University

The performance-engineered mixtures (PEM) approach lets designers optimize specific concrete properties with respect to a pavement's environment, function, and design life and lets contractors and suppliers use their knowledge and new testing technologies to produce quality concrete pavements. *Agency Approaches to Quality Control for Concrete Paving* outlines the benefits an agency can obtain from contractor quality control (QC) during concrete paving projects and describes the need for enhanced contractor QC as agencies move toward PEM approaches. Typical agency approaches and requirements for QC are also presented. The document is based on *Quality Control for Concrete Paving: A Tool for Agency and Industry*.

Quality Assurance, Quality Control, and Quality Control Plans in Practice for Concrete Paving (10 pages)


TECH BRIEF

Advancing Concrete Pavement Technology Solutions

QUALITY ASSURANCE, QUALITY CONTROL, AND QUALITY CONTROL PLANS IN PRACTICE FOR CONCRETE PAVING

Summary and Disclaimers

Introduction

National Concrete Pavement Technology Center

Iowa State University

Quality control (QC) by contractors, concrete suppliers, and materials suppliers is an integral component of a transportation agency's quality assurance (QA) program and supports the construction of quality concrete infrastructure. *Quality Assurance, Quality Control, and Quality Control Plans In Practice for Concrete Paving* provides an overview of agency QA programs and their benefits, an overview of contractor QC and its benefits, and information on the use of QC plans for concrete paving projects. This document is based on *Quality Control for Concrete Paving: A Tool for Agency and Industry*.

Quality Control Fundamentals and Tools for Concrete Paving (16 pages)


TECH BRIEF

Advancing Concrete Pavement Technology Solutions

QUALITY CONTROL FUNDAMENTALS AND TOOLS FOR CONCRETE PAVING

Summary and Disclaimers

Introduction

National Concrete Pavement Technology Center

Iowa State University

Quality control (QC) by contractors, concrete suppliers, and materials suppliers is an integral component of a transportation agency's quality assurance (QA) program and supports the construction of quality concrete infrastructure. *Quality Control Fundamentals and Tools for Concrete Paving* provides an overview of QC fundamentals and describes quality control tools that can be used on concrete paving projects that feature performance-engineered concrete mixtures (PEMs) or conventional concrete mixtures. This document is based on *Quality Control for Concrete Paving: A Tool for Agency and Industry*.

Quality Control for Concrete Paving with Performance-Engineered Mixtures (PEM) (12 pages)


TECH BRIEF

Advancing Concrete Pavement Technology Solutions

QUALITY CONTROL FOR CONCRETE PAVING WITH PERFORMANCE-ENGINEERED MIXTURES (PEM)

Summary and Disclaimers

Introduction

National Concrete Pavement Technology Center

Iowa State University

In recent years, some agencies have begun moving toward performance-based specifications and the use of performance-engineered mixtures (PEM). PEMs allow contractors and suppliers to use their knowledge and new testing technologies to produce quality concrete pavements with lower life-cycle costs and longer service lives. As agencies implement performance-type specification provisions, contractor quality control (QC) programs and plans will become an increasingly important component of project quality assurance (QA). *Quality Control for Concrete Paving with Performance-Engineered Mixtures (PEM)* describes QC for concrete paving projects using PEM. This document is based on *Quality Control for Concrete Paving: A Tool for Agency and Industry*.

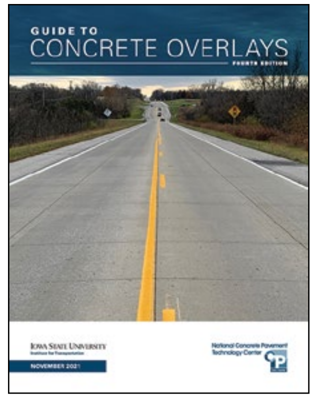
The Percent within Limits Approach for Acceptance (8 pages)

Agencies have initiated various measures to enhance confidence in their acceptance decisions, including the use of statistically based acceptance plans that consider both agency and contractor risk, are related to performance, and are readily understood and applied. The percent within limits (PWL) approach is a commonly used form of statistically based acceptance and can provide advantages to agencies and industry when implemented. *The Percent within Limits Approach for Acceptance* provides an overview of PWL acceptance approaches and provides data supporting the potential advantages of the use of PWL approaches over conventional acceptance approaches.

Concrete Overlays

Guide to Concrete Overlays (Fourth Edition) (152 pages)

The *Guide to Concrete Overlays* (Fourth Edition) presents the basic principles that a pavement engineer needs to design and construct concrete overlays on existing asphalt, composite, and concrete pavements.



The intent of this guide is to increase the technical proficiency of experienced engineers in the use of concrete overlays, provide less experienced users with the essential knowledge to address the needs of various types of concrete overlay projects, and help all users recognize the versatility of concrete overlays. The fourth edition features a revised classification scheme for the four overlay main types (Figure 4) and new or updated information on continuously reinforced concrete pavement overlays, geotextile separation layers, fiber reinforcement, concrete overlay design procedures, and lessons learned from the experiences of numerous state highway agency engineers. This guide is the second most downloaded cooperative agreement publication from the CP Tech Center's website since March 2022.

Concrete Overlays—A Proven Technology (53 pages)

The purpose of *Concrete Overlays—A Proven Technology* is to introduce concrete overlay selection, design, and construction practices to those who may not be familiar with this rehabilitation option.

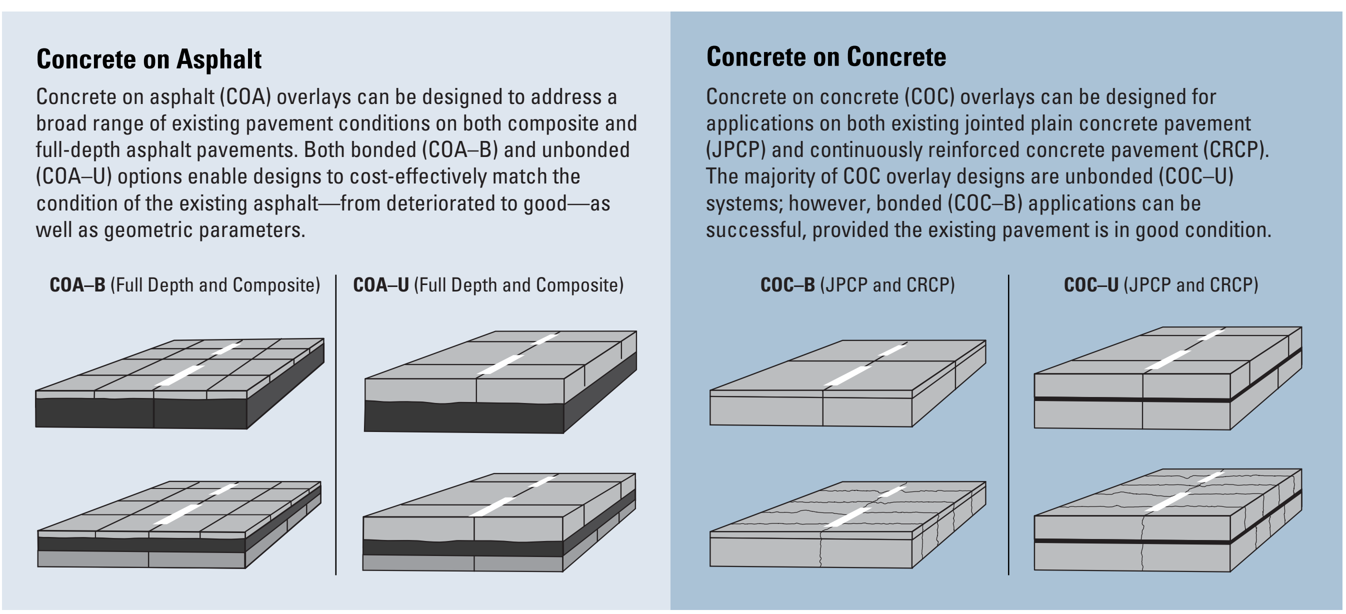


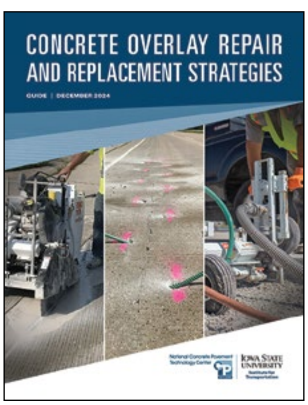
Figure 4. Revised overlay classification scheme from Guide to Concrete Overlays *(Fourth Edition)*

The material covered in the document includes a technical overview of concrete overlays, guidance on effective deployment, lessons learned from decades of projects, an annotated list of additional resources, and 11 case histories demonstrating the versatility of concrete overlays.

Concrete Overlays: The Value Proposition (18 pages)

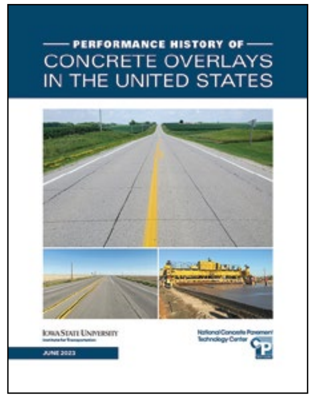
While concrete overlays have proven to be very successful and cost-effective for many state and local agencies over decades of service, agencies with limited experience with the technology would also benefit from including concrete overlays in their approach to strategic pavement preservation and rehabilitation. <u>*Concrete Overlays: The Value Proposition*</u> provides an overview of the value proposition offered by concrete overlays, including the technology's excellent performance history and low lifetime costs, and offers advice for agencies seeking to introduce concrete overlays into their "mix of fixes."

Concrete Overlay Repair and Replacement Strategies (54 pages)



<u>*Concrete Overlay Repair and Replacement Strategies*</u> presents a comprehensive set of preservation and repair solutions tailored to concrete overlay distresses and discusses end-of-life strategies that will enable agencies to preserve their investment for the longest possible time. Comprehensive details are provided on pressure relief cuts, full-depth and partial-depth repairs, dowel bar retrofits, cross-stitching, diamond grinding, overlay replacement, partial and full inlays, and reconstruction. The guide is intended for engineers, contractors, and others interested in concrete overlay solutions.

Performance History of Concrete Overlays in the United States (31 pages)



The historical performance of concrete overlays as an economical, long-lasting solution for extending pavement life can make them an attractive option for addressing a variety of pavement preservation and rehabilitation scenarios. <u>*Performance History of Concrete Overlays in the United States*</u> summarizes performance information for 17 concrete overlay projects from across the United States to demonstrate the versatility of concrete overlays as an asset management solution on a wide array of existing pavement types and roadway classifications. It concludes with a short list of additional resources.

Concrete Overlay One-Page Summaries (TOPS)

A series of six one-page summaries illustrating examples of concrete overlay solutions was developed to support the FHWA Every Day Counts (EDC) effort on Targeted Overlay Pavement Solutions (TOPS). These summaries are published on FHWA's website at <u>https://www.fhwa.dot.gov/innovation/everydaycounts/edc_6/docs/tops_concrete_overlays.pdf</u>.

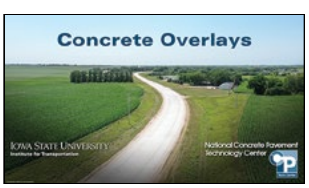
Case Studies Developed for Targeted Overlay Pavement Solutions (TOPS)

Eleven two-page case studies developed under the Targeted Overlay Pavement Solutions (TOPS) program and published by FHWA between 2022 and 2024 summarize the design, construction, and performance of a variety of concrete overlay projects. The overlay types documented in the case studies include unbonded concrete on asphalt, unbonded concrete on composite, unbonded concrete on concrete, bonded concrete on asphalt, bonded concrete on composite, and bonded concrete on concrete overlays.

- Colorado SH-13: Concrete on Asphalt–Bonded
- Missouri Route D: Concrete on Concrete–Unbonded
- Alabama I-59: Concrete on Concrete–Unbonded
- Worth County, Iowa, Highway 105: Concrete on Asphalt–Unbonded
- Richland County, Illinois, Highway 9: Concrete on Asphalt–Unbonded
- Delaware I-495: Concrete on Concrete–Unbonded
- Arkansas I-40: Continuously Reinforced Concrete (CRC) on Concrete–Unbonded
- Florida US 92: Precast Concrete on Concrete–Unbonded
- Virginia US 58: Concrete on Continuously Reinforced Concrete (CRC)–Bonded and Unbonded
- Oregon I-5: Concrete on Asphalt–Unbonded (Continuously Reinforced Concrete Overlay)
- Kansas I-70: Concrete on Asphalt–Bonded

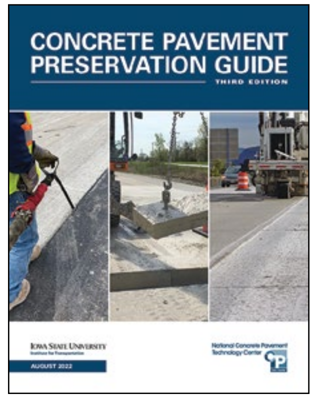
Video

Concrete Overlays



Preservation

Concrete Pavement Preservation Guide (Third Edition) (276 pages)



The *Concrete Pavement Preservation Guide* (Third Edition) provides guidance and information on the selection, design, and construction of cost-effective concrete pavement preservation treatments. Its overall aim is to assist highway agencies in effectively managing their concrete pavement networks through the application of timely and effective preservation treatments. The preservation approach typically uses low-cost, minimally invasive techniques to improve the overall condition of the pavement. This guide is the most downloaded cooperative agreement publication from the CP Tech Center's website since March 2022.

Extensive workshop materials to accompany this guide were also developed. These materials include the following 12 sessions:

1. Introduction
2. Pavement Preservation Concepts
3. Concrete Pavement Evaluation
4. Slab Stabilization and Slab Jacking
5. Partial-Depth Repairs
6. Full-Depth Repairs
7. Retrofitted Edge Drains
8. Dowel Bar Retrofit, Cross Stitching, and Slot Stitching
9. Diamond Grinding and Grooving
10. Joint Resealing and Crack Sealing
11. Concrete Overlays
12. Treatment Strategy Selection

Performance-Engineered Mixtures

PEM Model Specification Language

AASHTO's *Standard Practice for Quality Assurance of Concrete* provides the minimum requirements to establish and maintain a quality assurance (QA) plan for the control, verification, and acceptance of concrete. It contains requirements for quality control (QC) administered by the contractor and for acceptance and independent assurance (IA) administered by the agency. The standard practice also provides the framework for a QC plan that establishes minimum requirements and activities for a contractor's QC system related to concrete production and placement. These requirements include the inspections and tests necessary to substantiate material and mixture conformance to relevant specifications.

Using Performance-Engineered Concrete Mixture (PEM) Concepts to Design Low-Impact Concrete Transportation Infrastructure (13 pages)

Many opportunities exist in the construction, maintenance, and operation of transportation infrastructure to move toward agencies' goals for responsible and efficient use of material, environmental, and financial resources. Progress toward these goals can be achieved through performance-based approaches to concrete mixture specifications and acceptance included in the performance-engineered concrete mixtures (PEM) initiative. *Using Performance-Engineered Concrete Mixture (PEM) Concepts to Design Low-Impact Concrete Transportation Infrastructure* provides information to support the specification and acceptance of long-life, low-impact concrete pavement systems through PEM approaches. Resources and tools to support agencies, contractors, suppliers, and other stakeholders in using PEM are also introduced and described.

Updates to AASHTO R 101, Standard Practice for Developing Performance Engineered Concrete Pavement Mixtures

AASHTO R 101 was updated using input received from a stakeholder feedback meeting held in McLean, Virginia, in July 2024. Updates proposed during the meeting were balloted and adopted as part of the standard in fall 2024.

One-Page Summaries of PEM Test Methods

The Performance Engineered Mixtures (PEM) program sought to bring the latest developments in concrete testing technologies to state agencies and to help those agencies adopt new test methods. As part of its approach, the PEM program outlined critical concrete mixture properties for concrete durability and recommended test methods to assess each of these properties. Four one-page summaries were developed that detail key test methods recommended under this program:

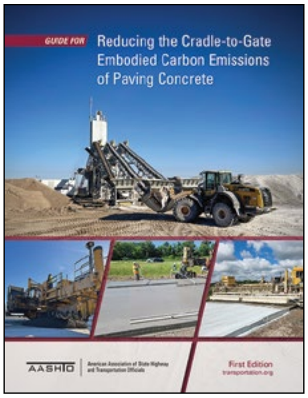
- PEM Test for Workability: The VKelly Test
- PEM Test for Workability: The Box Test
- PEM Test for Cold Weather: Super Air Meter
- PEM Test for Transport: Resistivity

Website

A dashboard illustrating states' adoption of performance-engineered mixtures recommendations was developed and posted on the CP Tech Center's Performance-Engineered Mixtures (PEM) website.

Reduced-Impact Concrete Pavement Mixtures

AASHTO Guide for Reducing the Cradle-to-Gate Embodied Carbon Emissions of Paving Concrete (58 pages)



Transportation agencies across the nation are striving to quantify and reduce the cradle-to-gate embodied carbon emissions of their pavement materials—the embodied carbon emissions incurred during the production of paving concrete before it leaves the concrete plant. Developed by the CP Tech Center under the FHWA cooperative agreement and published by AASHTO, *Guide for Reducing the Cradle-to-Gate Embodied Carbon Emissions of Paving Concrete, First Edition* offers several practical and implementation-ready strategies for material selection and proportioning that transportation agencies, contractors, and concrete suppliers can use to reduce the cradle-to-gate embodied carbon emissions of paving concrete in readily quantifiable ways.

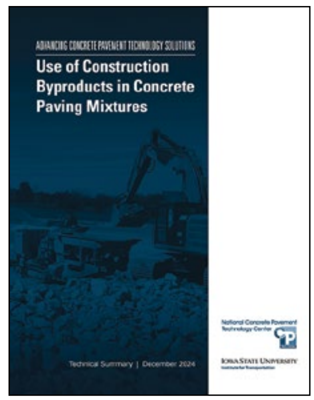
A one-page overview of information in the guide and a video explaining the guide's concepts were also produced.

Use of Industrial Byproducts in Concrete Paving Applications (28 pages)

Use of Industrial Byproducts in Concrete Paving Applications presents some industrial wastes (often called industrial byproducts, waste products, or waste materials) that can be beneficially used as replacements for virgin aggregates or pozzolans.

These industrial wastes include fly ash from coal combustion that does not meet typical specifications or agency requirements, bottom ash, municipal solid waste incinerator ash, ground glass, foundry sand, recycled concrete aggregate, and other materials. The document discusses the use of industrial waste in several bound and unbound applications in concrete paving projects.

Use of Construction Byproducts in Concrete Paving Mixtures (31 pages)



Construction byproducts—including recycled asphalt pavement, recycled concrete aggregate (RCA), slurries, and RCA fines—are produced during concrete pavement construction and rehabilitation or during aggregate production. Although many construction byproducts are disposed of in landfills, research has shown that they can be beneficially reused in several bound and unbound applications, sometimes on the same project from which they are produced. *Use of Construction Byproducts in Concrete Paving Mixtures* presents an overview of the production and beneficial reuse of construction byproducts in concrete paving projects. Topics include, among others, the potential impacts of byproduct reuse, handling and processing considerations, and a suggested protocol for characterizing and assessing byproducts.

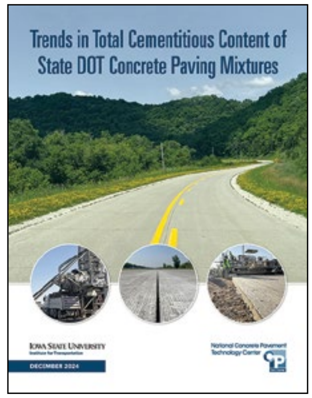
Use of Recycled Concrete Aggregate in Concrete Paving Mixtures (15 pages)

As virgin aggregate sources and landfill space become limited, the use of recycled concrete aggregate (RCA) is, for both environmental and economic reasons, becoming increasingly attractive as a full or partial replacement for coarse and/or fine aggregate in concrete paving mixtures. _Use of Recycled Concrete Aggregate In Concrete Paving Mixtures_ provides information about the effective use of RCA in new concrete mixtures and presents example projects that illustrate the successful use of RCA in new concrete pavements.

Use of Harvested Fly Ash in Highway Infrastructure (11 pages)

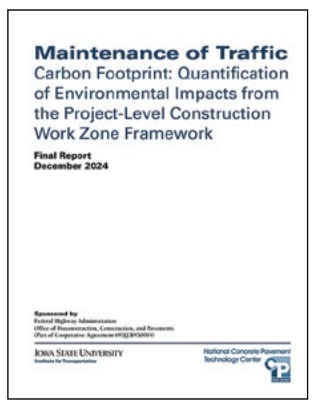
Coal fly ash is an integral part of durable concrete for use in highway infrastructure. Historically, fly ash has been obtained directly from coal-fired power plants as it is being produced. Recent changes in fly ash production and availability, however, have resulted in challenges regarding both the supply and quality of fly ash in some markets, which in turn has caused providers to turn to a new source for the material, harvested fly ash. _Use of Harvested Fly Ash in Highway Infrastructure_ describes the characteristics of harvested coal fly ash and identifies considerations for its use in highway infrastructure. A video addressing this topic and a presentation on Trends in Fly Ash Use and Supply were also produced.

Trends in Total Cementitious Content of State DOT Concrete Paving Mixtures (14 pages)



It has been asserted that the concrete paving industry has reduced the greenhouse gas (GHG) emissions associated with paving concrete over the past few decades by reducing the amount of portland cement in the cementitious binder and reducing the total cementitious content in paving concrete. _Trends in Total Cementitious Content of State DOT Concrete Paving Mixtures_ presents an investigation of this assertion through an examination of available data from several sources. Data to support the assertion are limited and, at times, conflicting. The available data suggest that total cementitious content has remained about the same or possibly increased slightly since the late 1990s.

Maintenance of Traffic – Carbon Footprint: Quantification of Environmental Impacts from the Project-Level Construction Work Zone Framework (43 pages)



Maintenance of Traffic – Carbon Footprint: Quantification of Environmental Impacts from the Project-Level Construction Work Zone Framework demonstrates the use of a life-cycle assessment (LCA) framework for quantifying the fuel use and environmental impacts of vehicles traveling in construction work zones (CWZ) under different traffic closure conditions for highway maintenance and rehabilitation projects. Based on the results, a decision-support framework was developed that can help users identify which closure type in a CWZ scenario for a particular region is most beneficial in terms of lower global warming impact.

Draft Model Special Provision for Concrete Quality Control (QC), Concrete Mixture, Construction Performance, and Construction Practices and Monitoring for Low-Carbon Transportation Materials

Four items designed to meet the requirements of FHWA's Low-Carbon Transportation Materials program were drafted. These items require the contractor to (1) develop and follow an agency-approved quality control (QC) plan for the project, (2) develop concrete mixtures with reduced global warming potential (GWP) to meet program requirements, (3) develop a plan to monitor concrete properties related to long-term performance, and (4) document the use of new technologies or test methods that may contribute to longer-lasting pavements or structures.

Videos

- *Reclaimed Fly Ash in Highway Infrastructure*
- *Strategies for Reducing the Cradle-to-Gate Embodied Carbon Emissions of Paving Concrete*

Reduced Clinker Factor Mixtures

Blended Cements for Next Generation Paving (17 pages)


TECH BRIEF

BLENDED CEMENTS FOR NEXT GENERATION PAVING

Blended cements—where portland cement is the major ingredient and materials such as limestone, slag cement, and pozzolans are included at the point of cement production—are becoming increasingly common for a number of reasons. It is anticipated that the use of these cements will continue to increase significantly in the immediate future, and a return to the use of straight portland cement will, for all practical purposes, not be realistic. *Blended Cements for Next Generation Paving* introduces the blended cement concept and discusses the types of blends that can be anticipated as the industry moves forward.

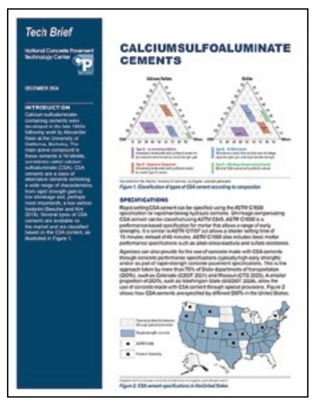
Integrating Alternative Supplementary Cementitious Materials into Next Generation Paving (16 pages)


TECH BRIEF

INTEGRATING ALTERNATIVE SUPPLEMENTARY CEMENTITIOUS MATERIALS INTO NEXT GENERATION PAVING

Alternative supplementary cementitious materials (ASCMs) are entering the concrete industry, and over time these materials will provide specifiers options to address reductions in coal fly ash supplies and limited quantities of other supplementary cementitious materials (SCMs). The purpose of *Integrating Alternative Supplementary Cementitious Materials into Next Generation Paving* is to provide background information on ASCMs but to do so by placing them in the context of current SCMs and SCM specifications; in this regard, it is important to view ASCMs as a continuation of SCM use rather than as a new direction, as the term "alternative" might suggest.

Calcium Sulfoaluminate Cements (3 pages)


Tech Brief

CALCIUM SULFOALUMINATE CEMENTS

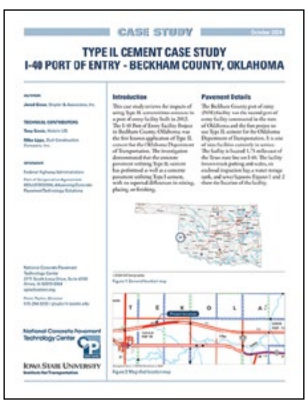
Calcium sulfoaluminate (CSA) cements are a class of alternative cements exhibiting a wide range of characteristics, from rapid strength gain to low shrinkage and a low carbon footprint. CSA cement is a useful material for low-carbon, rapid rehabilitation of concrete pavements and concrete structures that meets or exceeds most performance specifications for these applications. It has been implemented successfully in cases involving accelerated opening and high-restraint environments and in patching applications. *Calcium Sulfoaluminate Cements* summarizes the properties, applications, and benefits of CSA cements; the specifications governing their use; and their availability on the market.

Type IL Cement Case Study; I-40/I-77 Interchange Project - Statesville, North Carolina (22 pages)


CASE STUDY
TYPE IL CEMENT CASE STUDY
I-40 / I-77 INTERCHANGE PROJECT
STATESVILLE, NORTH CAROLINA

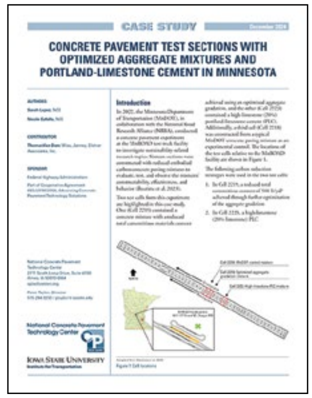
Like many agencies and industry partners, the North Carolina Department of Transportation (NCDOT) knew that most producers supplying cement to the southeast region would be transitioning their production from Type I or II cements to Type IL cement between 2021 and 2023. The plant supplying cement to the I-40/I-77 interchange project in Statesville, North Carolina, switched from producing Type I cement to Type IL cement in early 2022. *Type IL Cement Case Study; I-40/I-77 Interchange Project - Statesville, North Carolina* provides information regarding the impact of this change on the project, the first NCDOT project that used Type IL cement.

Type IL Cement Case Study; I-40 Port of Entry - Beckham County, Oklahoma (5 pages)


CASE STUDY
TYPE IL CEMENT CASE STUDY
I-40 PORT OF ENTRY - BECKHAM COUNTY, OKLAHOMA

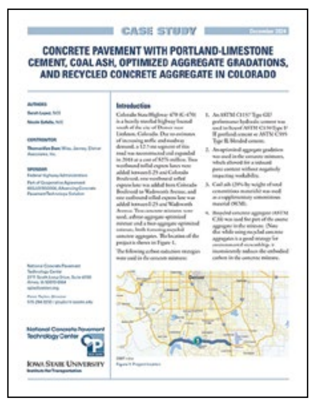
Type IL Cement Case Study; I-40 Port of Entry - Beckham County, Oklahoma describes the impacts of using Type IL cementitious concrete on the I-40 Port of Entry Facility Project in Beckham County, Oklahoma, in 2012. This was the first known application of Type IL cement for the Oklahoma Department of Transportation. The investigation demonstrated that the concrete pavement utilizing Type IL cement has performed as well as a concrete pavement utilizing Type I cement, with no reported differences in mixing, placing, or finishing.

Concrete Pavement Test Sections with Optimized Aggregate Mixtures and Portland-Limestone Cement in Minnesota (7 pages)


CASE STUDY
CONCRETE PAVEMENT TEST SECTIONS WITH OPTIMIZED AGGREGATE MIXTURES AND PORTLAND-LIMESTONE CEMENT IN MINNESOTA

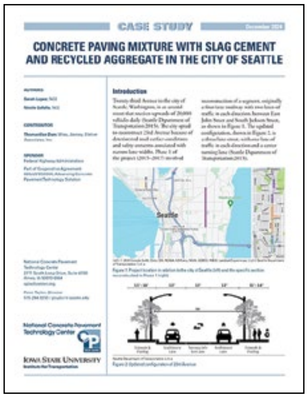
Concrete Pavement Test Sections with Optimized Aggregate Mixtures and Portland-Limestone Cement in Minnesota documents the constructability, effectiveness, and behavior of two mixtures with reduced embodied carbon content at the MnROAD test track facility. One mixture featured an optimized aggregate gradation, and the other featured a high-limestone (20%) portland-limestone cement (PLC). Both mixtures achieved adequate fresh and hardened concrete properties, though the PLC mixture resulted in higher estimated carbon emissions relative to conventional cement.

Concrete Pavement with Portland Limestone Cement, Coal Ash, Optimized Aggregate Gradations, and Recycled Concrete Aggregate in Colorado (5 pages)


CASE STUDY
CONCRETE PAVEMENT WITH PORTLAND-LIMESTONE CEMENT, COAL ASH, OPTIMIZED AGGREGATE GRADATIONS, AND RECYCLED CONCRETE AGGREGATE IN COLORADO

Concrete Pavement with Portland Limestone Cement, Coal Ash, Optimized Aggregate Gradations, and Recycled Concrete Aggregate in Colorado documents the constructability, effectiveness, and behavior of a three-aggregate optimized mixture and a four-aggregate optimized mixture, both featuring recycled concrete aggregates, on Colorado State Highway 470 (C-470). Both mixtures achieved sufficient workability and finishing, effectively reduced the estimated carbon emissions, met the required performance targets, and are performing well.

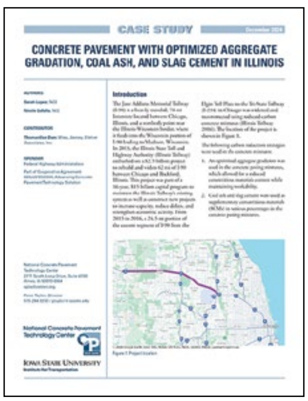
Concrete Paving Mixture with Slag Cement and Recycled Aggregate in the City of Seattle (4 pages)


CASE STUDY

CONCRETE PAVING MIXTURE WITH SLAG CEMENT AND RECYCLED AGGREGATE IN THE CITY OF SEATTLE

Concrete Paving Mixture with Slag Cement and Recycled Aggregate in the City of Seattle documents the constructability, effectiveness, and behavior of a mixture featuring 25% slag cement by weight of total cementitious materials and recycled concrete aggregate on 23rd Avenue in Seattle, Washington. The mixture exceeded the required strength, exhibited good performance, and reduced the estimated carbon emissions, with room for additional carbon reductions through aggregate optimization.

Concrete Pavement with Optimized Aggregate Gradation, Coal Ash, and Slag Cement in Illinois (6 pages)

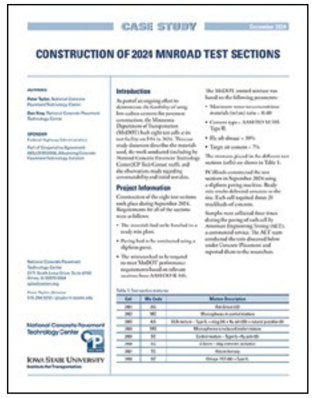

CASE STUDY

CONCRETE PAVEMENT WITH OPTIMIZED AGGREGATE GRADATION, COAL ASH, AND SLAG CEMENT IN ILLINOIS

Concrete Pavement with Optimized Aggregate Gradation, Coal Ash, and Slag Cement in Illinois documents the constructability, effectiveness, and behavior of three mixtures featuring an optimized aggregate gradation and varying percentages of coal ash and slag cement on the Jane Addams Memorial Tollway (I-90) west of Chicago, Illinois. The carbon reduction strategies effectively reduced the estimated carbon emissions of the mixtures, and all three mixtures met the required performance targets and performed well.

Construction of 2024 MnROAD Test Sections (4 pages)

As part of an ongoing effort to demonstrate the feasibility of using low-carbon cements for pavement construction, the Minnesota Department of Transportation (MnDOT) built eight test cells at its test facility on I-94 in 2024.


CASE STUDY

CONSTRUCTION OF 2024 MNROAD TEST SECTIONS

Construction of 2024 MnROAD Test Sections describes the materials used, the work conducted, and the observations made regarding constructability and initial test data.

Website

The CP Tech Center created a Reduced-Clinker Concrete website to compile several resources on the topic.

Foundations

Engineered Pavement Foundations and Field Verification of Design Inputs (18 pages)


TECH BRIEF

ENGINEERED PAVEMENT FOUNDATIONS AND FIELD VERIFICATION OF DESIGN INPUTS

Engineered Pavement Foundations and Field Verification of Design Inputs explores the critical relationship between pavement foundation quality and long-life pavements, emphasizing the implications for design, construction quality verification, and overall pavement performance. A roadmap is provided for departments of transportation (DOTs) interested in implementing engineered pavement foundation designs and engineering verification of the as-constructed properties of the foundation layers. Examples of the pilot projects and field demonstrations conducted under Advancing Concrete Pavement Technology Solutions are included, along with a recommended five-step implementation process.

Demonstration Projects

In collaboration with FHWA, the CP Tech Center initiated six field demonstration projects in the 2023 and 2024 construction seasons to disseminate advanced technology for on-site verification of foundation layer design assumptions. Project sites were as follows:

- I-494 Eastbound: Bloomington, Minnesota
- US 20: Elkhart County, Indiana
- I-465/I-69: Indianapolis, Indiana
- I-70 Eastbound: Westmoreland County, Pennsylvania
- I-94: MnROAD, Albertville, Minnesota
- I-70 Eastbound: Indianapolis, Indiana

Advancing Concrete Pavement Technology Solutions: Modulus Verification Using Roller Mapping (26 pages)


ADVANCING CONCRETE PAVEMENT TECHNOLOGY SOLUTIONS: MODULUS VERIFICATION USING ROLLER MAPPING

Final Report March 2024

Advancing Concrete Pavement Technology Solutions: Modulus Verification Using Roller Mapping describes a project that demonstrated to departments of transportation how the stiffness values achieved by various pavement foundation materials can be directly measured in the field during construction and how these values compare to design assumptions. The demonstrations presented in the report show how soil compaction equipment can be instrumented with technology that enables direct measurement of the modulus of subgrade reaction (k-value) and resilient modulus (Mr-value) and that generates real-time e-Compaction reports for use by field personnel in assessing compliance with specification requirements.

Engineering the Pavement Foundation Layers Workshop

The Engineering the Pavement Foundation Layers Workshop, held on August 27, 2024, at the 13th International Conference on Concrete Pavements (Figure 5), discussed how to engineer and field-control the construction of pavement foundations using currently available advanced technologies in order to meet design requirements reliably.

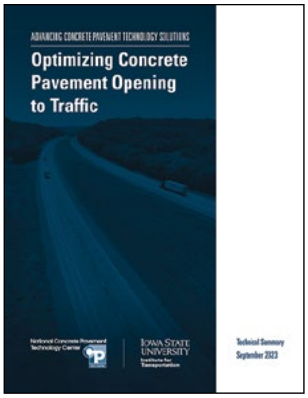
Figure 5. Engineering the Pavement Foundation Layers Workshop

Accelerated Construction

Accelerating the Delivery of Concrete Paving Projects (49 pages)

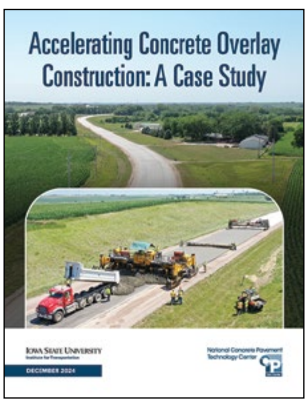
The demands placed on state highway agencies (SHA) for cost-effective and timely project delivery are exacerbated by the deteriorating condition of the national highway network, increased traffic levels, a diminishing pool of technical staff, and expectations from the public to minimize disruption. *Accelerating the Delivery of Concrete Paving Projects* explores the benefits, development, and implementation of accelerated delivery. Case studies illustrating the successful application of several of these strategies demonstrate the value of accelerated project delivery in various situations.

Optimizing Concrete Pavement Opening to Traffic (38 pages)



Optimizing Concrete Pavement Opening to Traffic reviews the science and strategy behind current practices related to the decision to open new pavement surfaces to traffic and how opening to traffic can be accelerated when necessary. The topics covered include planning and contracting considerations, pavement strength development, traffic loading, pavement stresses, early-age concrete pavement fatigue damage, nondestructive testing applications, and materials and construction considerations for early opening of concrete pavements. Case studies from Iowa, Georgia, Ohio, California, Virginia, and Indiana are also presented.

Accelerating Concrete Overlay Construction: A Case Study (21 pages)



While agencies across the United States have demonstrated interest in adopting or expanding their use of concrete overlays, perceived challenges include complex project staging requirements and the potential for lengthy and disruptive roadway closures. Accelerating Concrete Overlay Construction: A Case Study highlights an innovative project undertaken in the summer of 2022 to demonstrate ways to accelerate concrete overlay construction while minimizing impacts to local traffic and ensuring a safe environment for both construction crews and the traveling public. The project team paved 8.6 mi of a 6 in. thick, 36 ft wide concrete overlay and fully re-opened the roadway to traffic just 25 calendar days after the first closure.

Precast Concrete Pavement Peer Exchange

A peer exchange program on precast concrete pavements was scheduled for the summer/fall of 2020 but was ultimately cancelled due to COVID-19 restrictions. A list of hosting and attending agencies was compiled in August 2020, and slides were prepared for a presentation to be delivered at the exchanges, Precast Concrete Pavement: State of the Technology.

Truck Corridors

Autonomous Truck Corridors: Concept and Implementation Plan (22 pages)

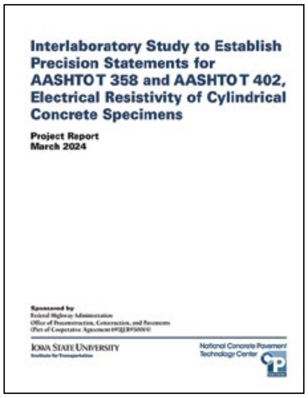
While freight trucks are central to the design and operation of the US National Highway System (NHS), the trucking industry faces significant challenges: fuel is costly and emits greenhouse gases, there is a 30% shortage of qualified truck drivers, and traffic delays lead to an estimated loss of $63 billion per year. Autonomous and electric trucks are being developed to address these challenges, but their limited haul distances have not allowed them to enter the market. Autonomous Truck Corridors: Concept and Implementation Plan describes the vision for an autonomous truck corridor (ATC), a long-life corridor for autonomous, powered, heavy freight trucks that have both electric and diesel engines.

Environmental and Economic Cost Evaluation of Autonomous Truck Corridors: Case Study: I-35 (Oklahoma City–Dallas) (12 pages)

Environmental and Economic Cost Evaluation of Autonomous Truck Corridors: Case Study: I-35 (Oklahoma City–Dallas) compares different trucking scenarios featuring both human drivers and autonomous vehicles using conventional engines, overhead cable lines (OCL), and batteries on a 200 mi segment of I-35. One scenario, an autonomous truck corridor (ATC), involves a dedicated lane and specialized infrastructure to power trucks using electricity supplied by overhead feedlines running along the road. The findings suggest that by using autonomous trucks with internal batteries and a 50 mi long overhead cable for battery charging, this system can result in potential cost savings of over 50% and a carbon footprint reduction of over 40% relative to conventional trucks.

Test Methods

Interlaboratory Study to Establish Precision Statements for AASHTO T 358 and AASHTO T 402, Electrical Resistivity of Cylindrical Concrete Specimens (21 pages)


Interlaboratory Study to Establish Precision Statements for AASHTO T 358 and AASHTO T 402, Electrical Resistivity of Cylindrical Concrete Specimens

Project Report
March 2024

Iowa State University
National Concrete Pavement Technology Center

Interlaboratory Study to Establish Precision Statements for AASHTO T 358 and AASHTO T 402, Electrical Resistivity of Cylindrical Concrete Specimens documents an interlaboratory study (ILS) that was conducted to establish single-operator and multi-laboratory precision and bias statements for AASHTO T 358-22, Surface Resistivity Indication of Concrete's Ability to Resist Chloride Ion Penetration, and AASHTO T 402-23, Electrical Resistivity of a Concrete Cylinder Tested in a Uniaxial Resistance Test.

Interlaboratory Study to Establish a Multi-Laboratory Precision Statement for AASHTO T 395-22, Characterization of the Air-Void System of Freshly Mixed Concrete by the Sequential Pressure Method (29 pages)

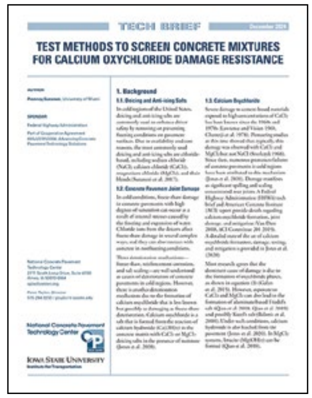

Interlaboratory Study to Establish a Multi-Laboratory Precision Statement for AASHTO T 395-22, Characterization of the Air-Void System of Freshly Mixed Concrete by the Sequential Pressure Method

Project Report
September 2023

Iowa State University
National Concrete Pavement Technology Center

Interlaboratory Study to Establish a Multi-Laboratory Precision Statement for AASHTO T 395-22, Characterization of the Air-Void System of Freshly Mixed Concrete by the Sequential Pressure Method details an interlaboratory study (ILS) that was conducted to establish a multi-laboratory precision statement for AASHTO T 395-22, Characterization of the Air-Void System of Freshly Mixed Concrete by the Sequential Pressure Method. The ILS was performed in one location over two days by 14 different operators using different equipment conforming to that described in AASHTO T 395-22. The precision statement was determined through statistical examination of 106 air content test results and 93 Super Air Meter (SAM) results obtained by 14 operators on 8 samples. ASTM E691 was followed for the design and analysis of the data.

Test Methods to Screen Concrete Mixtures for Calcium Oxychloride Damage Resistance (10 pages)


TECH BRIEF

TEST METHODS TO SCREEN CONCRETE MIXTURES FOR CALCIUM OXYCHLORIDE DAMAGE RESISTANCE

Three deterioration mechanisms—freeze-thaw, reinforcement corrosion, and salt scaling—are well understood as causes of concrete pavement deterioration in cold regions. However, a less well known deterioration mechanism that is possibly as damaging as freeze-thaw deterioration is the formation of calcium oxychloride, a salt that forms from the reaction of calcium hydroxide ($Ca(OH)_2$) in the concrete matrix with $CaCl_2$ or $MgCl_2$ deicing salts in the presence of moisture. *Test Methods to Screen Concrete Mixtures for Calcium Oxychloride Damage Resistance* provides information on calcium oxychloride formation, the damage that can result, and test methods and prevention strategies.

Using Embedded Sensors to Measure Concrete Formation Factor (2 pages)


TECH BRIEF

USING EMBEDDED SENSORS TO MEASURE CONCRETE FORMATION FACTOR

To better predict the long-term durability of concrete materials, reliable testing methods such as surface resistivity and bulk resistivity are utilized. While concrete resistivity tests are easy to conduct, it has traditionally been difficult to measure pore solution resistivity (PSR), which is necessary for normalizing the resistivity measurements. *Using Embedded Sensors to Measure Concrete Formation Factor* details a new embedded sensor system that enables easier measurement of PSR and overcomes current limitations of resistivity testing.

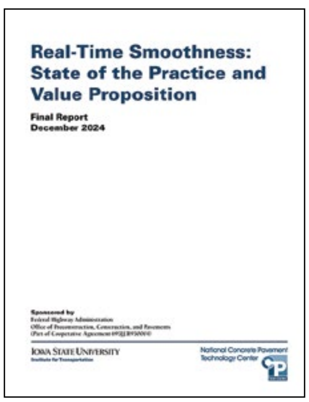
Concrete Resistivity: Interim Observations Due to Potential Aggregate Impacts (30 pages)


Concrete Resistivity: Interim Observations Due to Potential Aggregate Impacts

White Paper
December 2024

The electrical properties of concrete have long been used as a surrogate to assess fluid transport properties. However, some state highway agencies have reported that, all else being equal, the use of certain aggregates tends to reduce the resistivity values of the concrete. *Concrete Resistivity: Interim Observations Due to Potential Aggregate Impacts*, examines a fundamental assumption of resistivity testing in concrete, i.e., that the aggregate is resistive or nonconductive. The document explores the implications of conductive aggregate for resistivity results using both an analytical and finite element approach and discusses a procedure to account for aggregate resistivity.

Real-Time Smoothness: State of the Practice and Value Proposition (32 pages)


Real-Time Smoothness: State of the Practice and Value Proposition

Final Report
December 2024

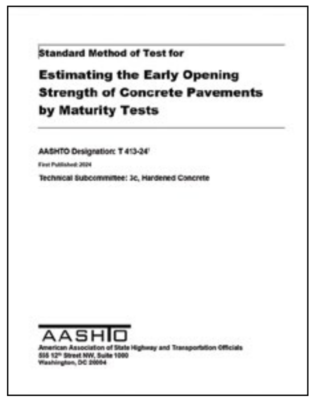
Real-time smoothness (RTS) is a valuable quality control tool for improving the as-constructed smoothness of concrete pavements. To facilitate the implementation of RTS measuring technologies, FHWA and later the CP Tech Center administered an equipment loan program that allowed owner-agencies and contractors the opportunity to evaluate RTS technology on active concrete paving projects using FHWA-owned RTS systems. *Real-Time Smoothness: State of the Practice and Value Proposition* summarizes key findings from these implementation efforts through documentation of the current state of the practice and an explanation of the value proposition of RTS technology.

Real-Time Smoothness Field Reports

Five field reports were published detailing state agencies' experiences with real-time smoothness (RTS) technologies under an equipment loan program administered by FHWA and the CP Tech Center.

- Field Report: Caltrans I-5 Equipment Loan
- Field Report: Colorado I-25 Equipment Loan
- Field Report: Louisiana US 90 (New Iberia) Equipment Loan
- Field Report: Louisiana US 90 Equipment Loan
- Field Report: Missouri DOT I-270 Equipment Loan

AASHTO Test Method for Early Opening Strength Using Maturity


Standard Method of Test for

Estimating the Early Opening Strength of Concrete Pavements by Maturity Tests

AASHTO Designation: T 413-24

Technical Subcommittee: 3c, Hardened Concrete

AASHTO

A new maturity test method focused specifically on early opening strength prediction was drafted for AASHTO. AASHTO T 413, Estimating the Early Opening Strength of Concrete Pavements by Maturity Tests, was approved and adopted by AASHTO in 2024.

Software

- A spreadsheet companion to AASHTO T 413, Estimating the Early Opening Strength of Concrete Pavements by Maturity Tests, was created as part of the development of that standard.

Stakeholder Feedback Meetings

Concrete Pavement & Materials Stakeholder Feedback Meetings

Concrete Pavement & Materials Stakeholder Feedback meetings were held periodically to discuss program-level challenges and opportunities concerning the performance and sustainability of concrete pavements and provide technical information to FHWA. Participants included representatives from owner agencies (including state departments of transportation and local agencies), industry, and academia. Six meetings were held between 2022 and 2024 (Figure 6):

- Advancing Sustainable Solutions for Cement and Concrete Materials, May 2022, Chicago, IL
- Advancing Sustainable Solutions – Workshop #2, November 2022, Austin, TX
- Advancing Sustainable Solutions – Workshop #3, June 2023, Minneapolis, MN
- AASHTO R 101 Feedback Group, July 2024, McLean, VA
- Shrinkage Summit, August 2023, McLean, VA
- Stakeholder Feedback on Concrete Pavement Resources, October 2024, St. Charles, MO

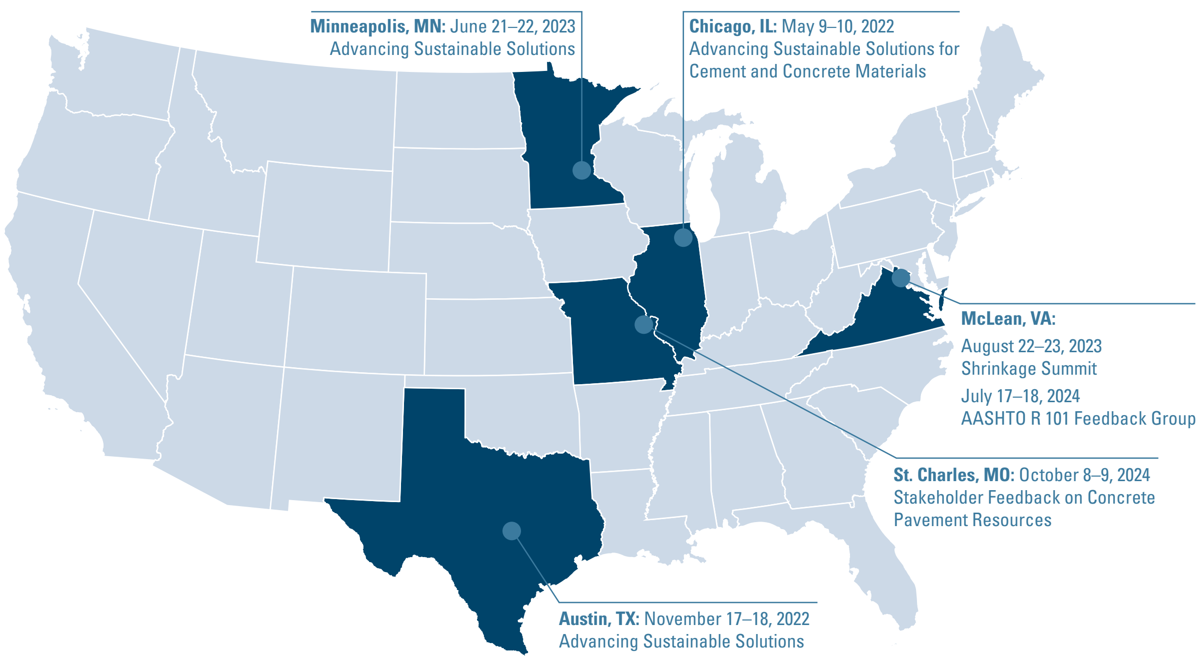


Figure 6. Stakeholder feedback meetings between 2022 and 2024

ABOUT THE CP TECH CENTER

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 advancing concrete pavement technology through research, technology transfer, and technology implementation.

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National Concrete Pavement Technology Center

CP Tech Center

2711 South Loop Drive, Suite 4700 | Ames, IA 50010-8664 | Phone: 515-294-5798 | cptechcenter.org