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FHWA R&T NOW

A newsletter about research, development, and technology at the U.S. Department of Transportation's (USDOT) Federal Highway Administration (FHWA).

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Nondestructive Evaluation Laboratory

Advancing Bridge Maintenance with Multimodal NDE Data and Predictive Modeling

By Mozhgan Momtaz, NRC Postdoctoral Research Associate*, and Hoda Azari, Nondestructive Evaluation Laboratory Manager, Turner-Fairbank Highway Research Center (TFHRC), FHWA

As aging infrastructure faces increased demand and limited maintenance resources, it can lead to various challenges such as decreased performance of bridges and increased safety concerns. Many bridges across the United States have exceeded their intended design life, requiring significant upkeep and monitoring to ensure structural integrity.[1] Traditional visual inspections often fall short in assessing deterioration in a timely manner, which makes advanced methods of inspection essential for improving infrastructure management and safety.

To address these challenges, FHWA is pioneering innovative approaches using nondestructive evaluation (NDE) technologies and artificial intelligence (AI)-based predictive modeling. At TFHRC, researchers have developed a Temporal Graph Convolutional Network (TGCN) model that uses NDE data to accurately forecast bridge deck deterioration. Just as skin cancer develops beneath the surface before becoming visible, hidden damage occurs in concrete elements over time. Using deep learning, FHWA's NDE research methods predict the progression of this hidden damage, much like how medical imaging detects early-stage health issues. The accompanying figure highlights this parallel, emphasizing how advanced modeling enables proactive intervention.

This NDE research uses the Bridge Evaluation and Accelerated Structural Testing (BEAST®) facility, where bridges are subjected to traffic loads and placed in a chamber where HVAC systems control heating and cooling, inducing freeze-thaw cycles. NDE techniques like ground-penetrating radar, impact echo, electrical resistivity, ultrasonic surface waves, and half-cell potential identify issues such as delamination and corrosion and provide insights into deck condition.[2,3] The TGCN model integrates spatial and temporal data from these techniques to provide a comprehensive view of bridge deck condition. By capturing relationships between neighboring data points and tracking changes over time, TGCN helps transportation agencies predict deterioration and plan effective preservation to ensure structural integrity. The multimodal extension of the TGCN model enhances prediction accuracy by incorporating and fusing multiple NDE datasets.

The multimodal TGCN model has demonstrated superior performance over traditional methods, such as the Spatial-Temporal Autoregressive model, in reducing prediction errors across all NDE modalities. For example, the TGCN model accurately forecasts the progression of deck deterioration, which could help asset owners allocate resources effectively and extend the lifespan of infrastructure. The BEAST dataset, encompassing more than 850 days of accelerated testing, is publicly available via the InfoBridge™ platform.[3] These advancements represent a significant step toward providing predictive maintenance, reducing risks of structural failures, and optimizing repair strategies—which all impact road safety.

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Predicting Hidden Damage Progression in Concrete Over Time

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Pavement Testing Facility

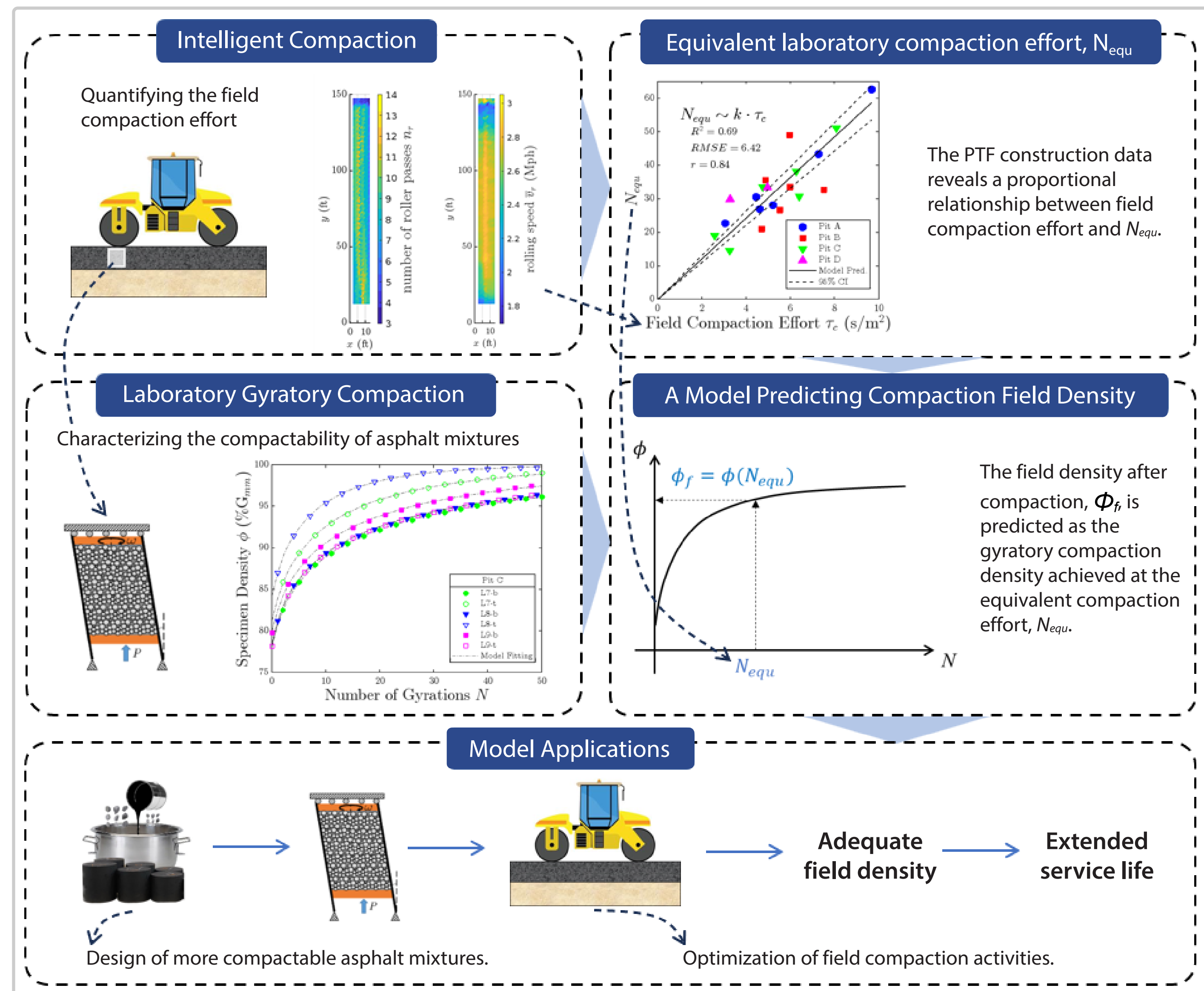
A Model for Asphalt Pavement Compaction—Bridging the Gap Between Laboratory and Field

By Tianhao Yan, NRC Postdoctoral Research Associate*, and
Maryam S. Sakhaeifar, Asphalt Materials Research Engineer, TFHRC

Compaction (i.e., the process of densifying pavement) is a critical construction step for installing asphalt pavements, directly influencing the load-bearing capacity and durability of pavements. However, inadequate compaction still exists in current practice, leading to premature distresses, such as accelerated aging, water damage, cracking, and raveling, all of which shorten the pavement's service life and increase the maintenance cost.[1–3] To improve compaction quality, a more indepth understanding of asphalt mixture compaction is needed, especially regarding the connection between laboratory and field compaction.

During the construction of the recently renovated FHWA Pavement Testing Facility (PTF) at TFHRC, researchers gathered data, including intelligent compaction measurements (including the sensor data of accelerometers, infrared thermometer, and Global Positioning System), field core density, and laboratory gyratory compaction, that provided a unique set of resources for asphalt pavement compaction.[4] Using these data, the team developed and validated a theoretical model for determining the optimal level of asphalt pavement compaction.

The proposed asphalt pavement compaction model predicts the as-constructed field density of asphalt pavements based on the material's compactability (i.e., the ease with which pavement materials can be compacted to achieve the desired density and strength) and the field compaction effort. This model uses gyratory compaction, a laboratory compaction test, to evaluate the compactability of mixtures. The field compaction effort is quantified by the intelligent compaction measurements and is converted into an equivalent laboratory compaction effort, termed N_{equ}, bridging the gap between laboratory and field compaction. Analysis of the PTF construction data revealed a proportional relationship between the field compaction effort and N_{equ}. The field density is then predicted as the gyratory compaction density achieved at N_{equ} gyrations.



Source: FHWA.
A theoretical model for asphalt pavement compaction and its potential applications.
This theoretical model for asphalt pavement construction is divided into five parts. 1) Intelligence compaction involves quantifying the field compact effort. 2) Equivalent laboratory compaction effort, N_{equ}, involves determining an equivalent compaction effort to that performed in the field characterized by the intelligent compaction data. The PTF construction data reveals a proportional relationship between field compaction effort and N_{equ}. 3) Laboratory gyratory compaction involves characterizing the compactability of the asphalt mixtures used in the field. 4) A model predicting compaction field density Φ_f uses the gyratory compaction curve and N_{equ}, which is calculated based on its relationship with the field compaction effort. Field density Φ_f after compaction is predicted as the gyratory compaction density achieved at N_{equ}. 5) Potential applications of this model include the design of more compactable asphalt mixtures and the optimization of field compaction activities leading to adequate field density and extended service life.

The proposed model establishes the connection between laboratory and field compaction, enabling more informed material design and field compaction planning to improve asphalt pavement compaction quality, resulting in significant potential for enhancing pavement performance and extending its service life.

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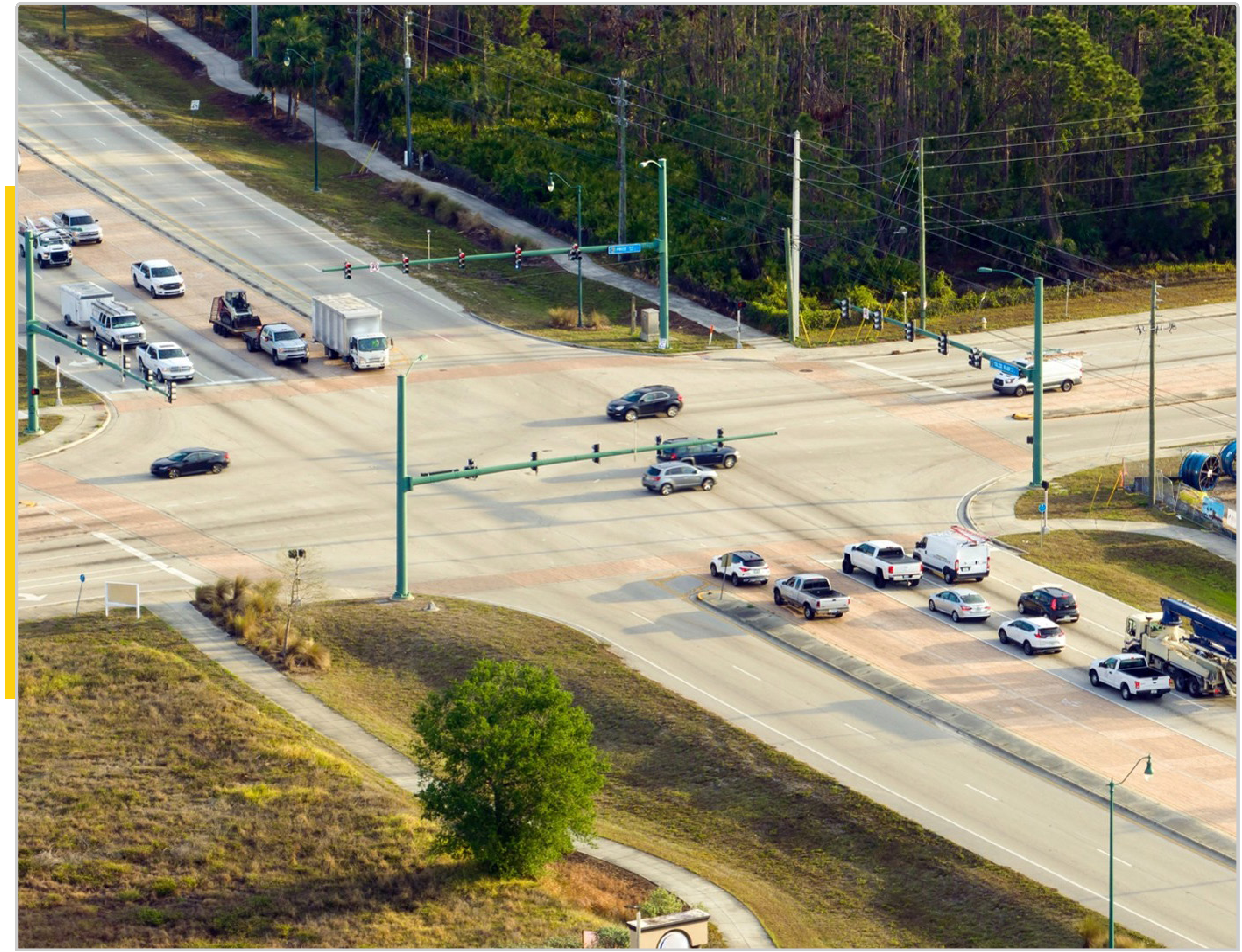
Saxton Transportation Operations Laboratory

Smart Signals, Smarter Streets: How Cooperative Driving Automation Is Optimizing Traffic Flow

By Pavle Bujanović, Highway Research Engineer, Office of Safety and Operations Research and Development



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Vehicles entering and exiting a signalized intersection.

The National Highway Traffic Safety Administration estimated that 39,345 people were killed in motor vehicle crashes in the United States in 2024.[1] According to FHWA's Office of Safety, "Each year roughly one-quarter of traffic fatalities and about one-half of all traffic injuries in the United States are attributed to intersections."[2] To eliminate such deaths on the Nation's roads while enhancing the movement of people and goods, State and local transportation agencies, metropolitan planning organizations, and private sector stakeholders continually seek innovative solutions to increase mobility, safety, and efficiency. One emerging technology that holds significant promise is cooperative driving automation (CDA), which enables vehicles to communicate with infrastructure to optimize traffic flow, reduce congestion, and improve overall efficiency.

FHWA's Saxton Transportation Operations Laboratory is leading research efforts in this space, recently publishing findings on how automated vehicles can interact with fixed-time traffic signals to optimize vehicle trajectories. These insights could inform future infrastructure investments, operational strategies, and policy decisions, shaping the next generation of intelligent transportation systems.

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Advancing Traffic Signal Efficiency Through Vehicle–Infrastructure Communication

Fixed-time traffic signals operate on predetermined schedules, often leading to inefficiencies when traffic volumes fluctuate. CDA introduces real-time communication between vehicles and traffic signals, creating new opportunities to enhance intersection efficiency.

Here's how the technology works: As an automated vehicle approaches an intersection, it transmits real-time operational data—such as speed, location, and intended trajectory—to a roadside unit.(3) The roadside unit, connected to the traffic signal controller, provides signal phase and timing messages back to the vehicle.(3,4) This communication enables automated vehicles to adjust their approach speed, either passing through the intersection smoothly or decelerating in advance, minimizing abrupt stops and delays.(5)

Benefits for Transportation

Integrating CDA with fixed-time signals presents numerous advantages, including the following:

- **Optimized traffic management:** Real-time vehicle–infrastructure coordination reduces stop-and-go traffic, improving intersection throughput.(6)
- **Improved operational performance:** Smoother acceleration and deceleration patterns can optimize vehicle efficiency by up to 30 percent, contributing to cost savings in vehicle operation.(6)
- **Enhanced safety:** Predictable and coordinated vehicle movements decrease the likelihood of sudden stops and collisions.(6)
- **Reduced travel delays:** Research indicates that CDA could cut stop times by as much as 50 percent, improving network reliability.(6)

Implementation Considerations

As transportation agencies evaluate the potential of CDA, key considerations include the following:

- **Infrastructure readiness:** Deployment requires investment in connected signal controllers, roadside communication units, and data management systems.
- **Policy and regulatory frameworks:** CDA aligns with existing transportation policies and future regulatory needs.
- **Public–private partnerships:** Collaboration with industry stakeholders can facilitate technology deployment and innovation.
- **Scalability and interoperability:** Adaptable solutions established across different jurisdictions and signal control systems will be critical for widespread adoption.

The Road Ahead

FHWA's research underscores the transformative potential of CDA in modernizing traffic signal operations. As State and local agencies plan for the future, integrating this technology into transportation networks could substantially benefit mobility, safety, and efficiency.(6)

By continuing to invest in research, pilot programs, and infrastructure modernization, transportation agencies and industry partners can help accelerate the transition toward a more connected and efficient roadway system. The next step is turning these insights into actionable strategies that enhance roadway operations and advance national transportation goals.

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R&T Evaluation Program

R&T Evaluations Fine-Tune and Provide More Program Focus, Efficiency, and Safety

By Mary Huie, Innovation Management/Technology Transfer Program Manager, Office of Research, Development, and Technology

FHWA established the Research and Technology (R&T) Evaluation Program in 2014 in response to the Transportation Research Board's R&T Coordinating Committee recommendation that it build into its research and development (R&D) program a category of research project funding for evaluating specific research, development, and technology initiatives and portfolios—both to determine the anticipated benefits and longer term impact of the research project. Also, per 23 U.S. Code 503, the objective of the R&D program is to identify research topics; coordinate R&D activities; carry out research, testing, and evaluation activities; provide technology transfer and technical assistance; engage with public and private entities to spur advancement of emerging, transformative innovations through accelerated market readiness; and consult frequently with public and private entities on new transportation technologies.[1] To date, 20 evaluations have been completed and published via the R&T Evaluation Program; this article summarizes the latest three.

Evaluation of the Exploratory Advanced Research (EAR) Program[2]

FHWA's EAR Program addresses the need for longer term and higher risk breakthrough research. An evaluation examined 86 EAR-funded projects between 2007 and 2019, assessing their results, processes, and effectiveness in driving advancements.

The evaluation's findings indicate that the program has generated valuable research tools (e.g., new software and datasets); catalyzed investments; strengthened collaboration between FHWA, academia, industry, and Government stakeholders; and contributed to transportation and emerging technologies.

Based on the evaluation's findings, the EAR Program has improved the documentation and communication of program processes to better work with program stakeholders within FHWA. The program also increased the documentation and publication of research results to increase awareness of and value from program investments among external partners in State departments of transportation (DOTs), academic institutions, and industry. "The independent evaluation was critical for reinforcing where program efforts paid off and where there was a benefit to increasing effort, particularly around documentation and communication of results," said David Kuehn, EAR program manager, Research Innovation Management Team.

Evaluation of the Asphalt Binder Quality Tester (ABQT)[3]

Methods for testing the quality of asphalt binder used in road construction can be time-consuming and labor intensive. FHWA funded ABQT development to provide a rapid, cost-effective method to verify binder quality before a binder is used on a roadway and to increase the pavement's longevity and reduce costs in the long run.

An evaluation (including interviews with subject matter experts (SMEs) and a probabilistic model to estimate cost savings from ABQT adoption) found that using ABQT as a screening tool could yield substantial financial benefits regarding road maintenance and replacement costs, with potential savings of more than $300 million across all 50 State DOTs over 15 years. During ABQT's development, FHWA loaned devices to State DOTs for testing and gathering feedback. The evaluation suggests additional outreach opportunities, including completion of the American Association of State Highway and Transportation Officials (AASHTO) certification process to increase the device's visibility and credibility.

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During testing, ABQT used an artificial neural network to estimate a binder's performance grade. Since the evaluation, AI models have been upgraded with the additional capability of predicting multiple stress creep recovery (AASHTO M 332).[4] To date, seven State agencies have successfully evaluated ABQT and AI prediction models, and the Oklahoma DOT is conducting an ongoing implementation study.

Evaluation of Ultra-High Performance Concrete Connections (UHPC-C)[5]

Connecting prefabricated bridge components in the field has traditionally been done using materials and systems that suffered from exposure to the passage of traffic and the weather (such as corrosion on metals or cracks on bridge decks), leading to costly repairs and disruptions. UHPC-C can help enhance the durability and lifespan of the Nation's transportation infrastructure.

The evaluation (reviewing publicly available bridge data and conducting interviews with SMEs) assessed the benefits of UHPC-C compared to traditional connections. Findings indicate that using UHPC-C in accelerated bridge construction projects could yield long-term cost savings for initial construction and additional future annual savings due to reduced rehabilitation needs.

However, barriers to adopting UHPC-C remain, including initial high material costs and a lack of contractor familiarity with the required construction methods. According to the evaluation, addressing these barriers could further enhance the adoption of UHPC-C.

Therefore, based on the evaluation's findings, as the uses for UHPC-class materials in infrastructure construction continue to expand—including using UHPC overlays to armor bridge decks and UHPC girders to extend bridge spans—the owner and contractor communities are expected to become more comfortable engaging with this innovative and robust solution, leading to significant improvements in bridge infrastructure resilience and cost-effectiveness across the Nation.

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Source: FHWA.

UHPC strengthens bridges on roadways ranging from county routes to interstate highways.

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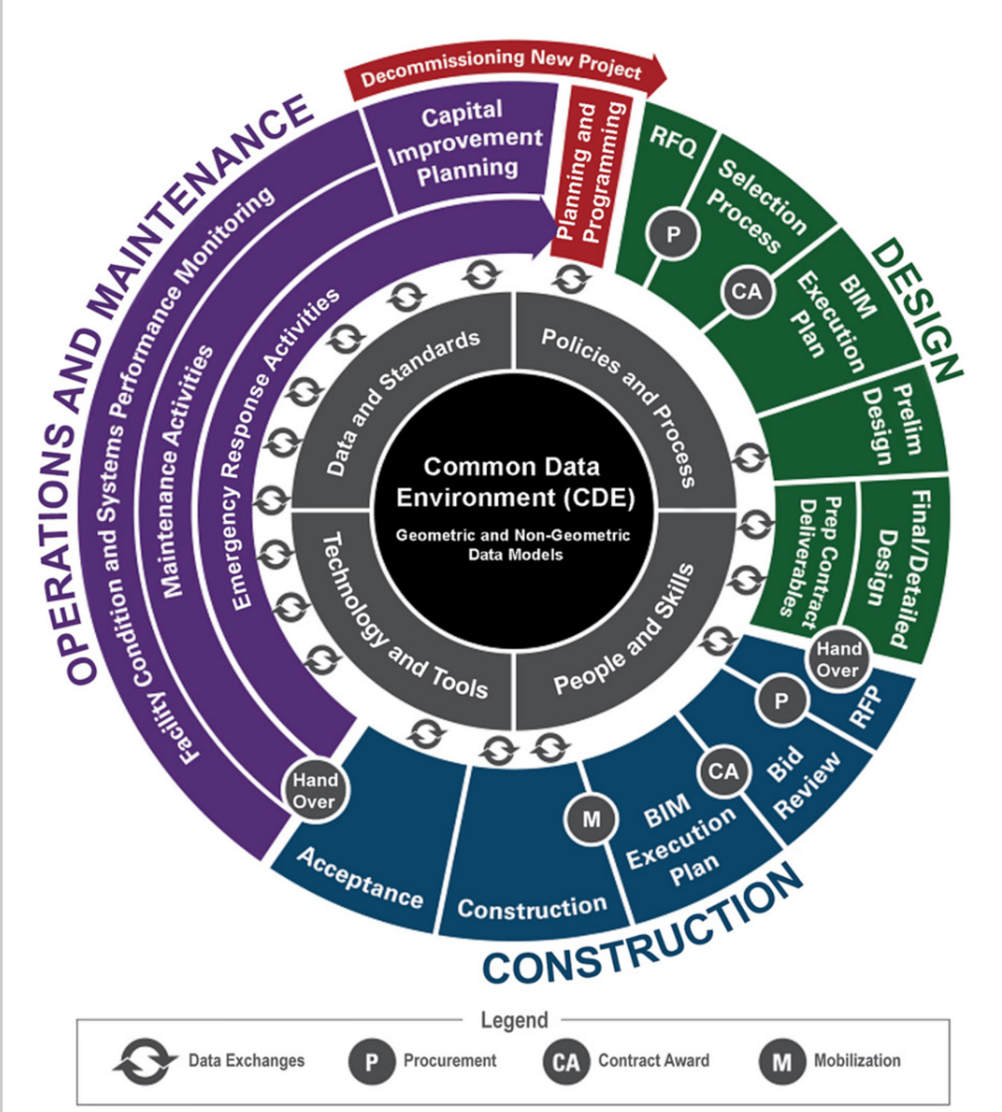
State Planning and Research and Pooled Fund Program

Driving National Standards and Adoption of Data Management Across Asset Lifecycle

By Khyle Clute, State Planning and Research and Pooled Fund Programs Manager, Iowa DOT

Addressing Data Silos with BIM in the Transportation Infrastructure Sector

Transportation agencies generate significant data throughout road and bridge asset lifecycles. However, much of the data remains in disconnected systems, hindering collaboration and timely decisionmaking either during project delivery or during the maintenance, operation, or management of these assets. Building Information Modeling (BIM) addresses these challenges by providing a collaborative, structured approach to managing project and asset data across the lifecycle activities of infrastructure. This structured approach aligns with FHWA's Advancing BIM for Infrastructure National Strategic Roadmap, improving efficiency, enhancing project delivery, and enabling data-driven decisions.(1)



© 2016 Federal Ministry of Transport and Digital Infrastructure. Modified by FHWA to include U.S. practices and lifecycle phases, specific report recommendations, writing style conventions, and Section 508 color contrast requirements.(2)

The three-phase project cycle that surrounds the Common Data Environment—from design to construction to operations and maintenance—highlights the different components of the cycle, including policies and processes, people and skills, technology and tools, and data and standards.

Pooled Fund Collaboration and Key Successes

A significant step in the adoption of open BIM was taken in 2019 when AASHTO recommended the adoption of the Industry Foundation Classes (IFC) schema (international standard ISO 16739-1) for digital data exchange across all disciplines for AASHTO States.(3) Building on this pivotal adoption, more than 30 State DOTs and FHWA have initiated several pooled fund efforts to adopt national open data and process standards for highway and bridge construction.(4) The standards and their pilot deployments are expected to provide the foundation for a consistent, vendor-neutral, BIM-enabled, data-centric approach for lifecycle delivery and management of transportation assets.

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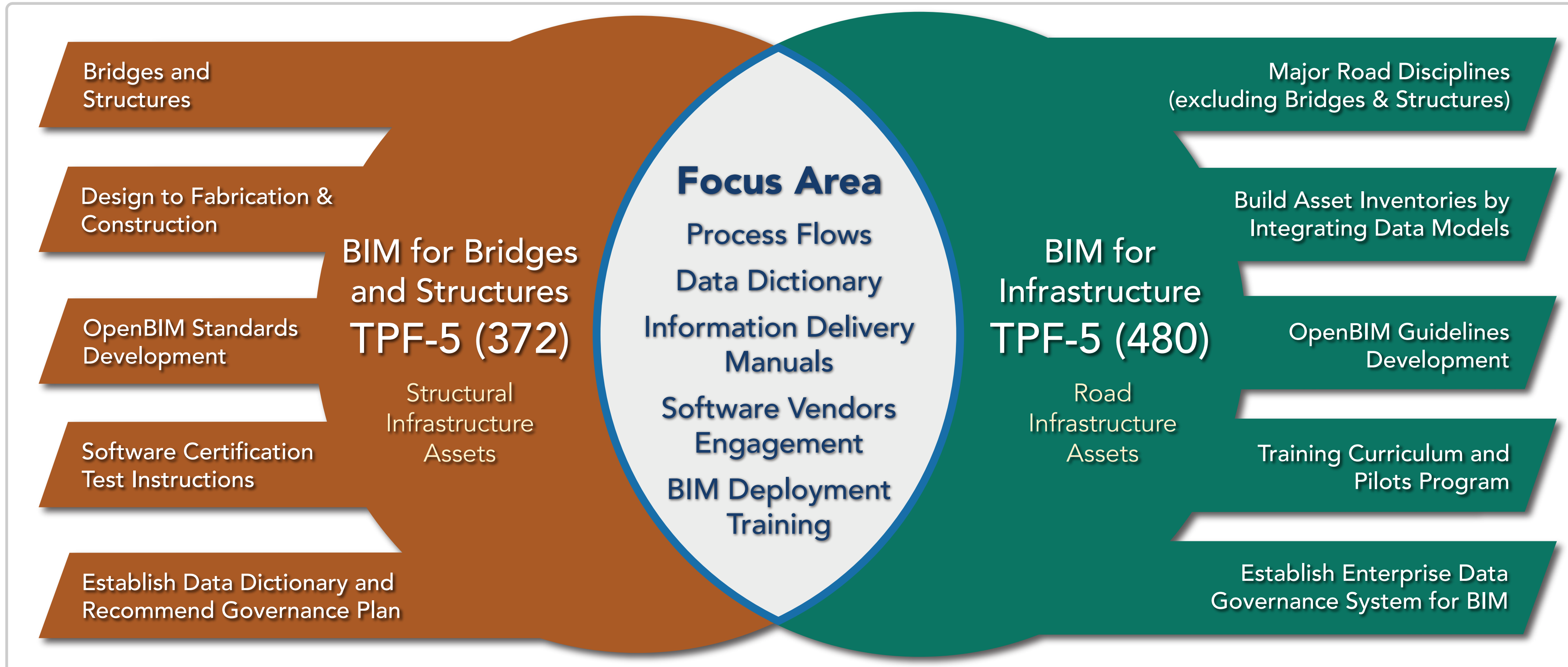

Source: FHWA.
A Venn diagram shows the overlapping focus areas between the studies: BIM for Bridges and Structures Transportation Pooled Fund (TPF)-5 (372) (Structural Infrastructure Assets) and BIM for Infrastructure TPF-5 (480) (Road Infrastructure Assets).

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TPF-5(372)/TPF-5(523) BIM for Bridges and Structures Pooled Fund Efforts[5]

The BIM for Bridges and Structures pooled fund effort, managed by the Iowa DOT since Phase I in 2018, involves 23 State DOTs and FHWA. The project has made significant progress in standardizing BIM practices across the bridge lifecycle.[6,7] Major accomplishments include the following:

- Developing the AASHTO *Information Delivery Manual (IDM) for Design to Construction Data Exchange for Highway Bridges* (2023).[8]
- A complementary Information Delivery Specifications (IDS) and bSI Data Dictionary (bsDD).
- Establishment of a common digital framework for sharing construction models.
- Supporting Advanced Digital Construction Management System pilot projects using IFC 4.3 for bridges.[3]

Building on this success, Phase II (initiated in 2024) is actively collaborating with software vendors, industry groups, and piloting practical BIM implementations, further expanding IDM, IDS, bsDD, and their testing.[9]

TPF-5(480) BIM for Infrastructure Pooled Fund Effort[5]

In parallel initiation in 2023, the BIM for Infrastructure pooled fund effort, also managed by Iowa DOT, with participation from 24 State DOTs and FHWA, is advancing open standards and digital workflows for roadway infrastructure assets.[10] Key achievements include the following:

- Establishing a common framework for standardizing BIM practices to unify and guide the multidisciplinary roadway industry toward seamless collaboration.
- Launching an AI-driven BIM Clearinghouse, providing streamlined access to essential resources, best practices, and implementation guidance.[11]
- Prioritizing the Design-to-Construction and Digital As-Built data exchanges as foundational to industry-wide digital transformation.

Work is ongoing to produce an IDM and IDS to standardize and streamline the information content and delivery for the Design-to-Construction information exchange responding to the needs of the State DOTs for roadway infrastructure.

Vision for the Future

In the future, the BIM pooled fund studies will look to translate the national BIM standards into practical workflows, creating a robust foundation for data interoperability across structural and roadway assets. These collaborative efforts are developing open data standards, training materials, and implementation guidance to support deployment over the next several years. Leveraging ongoing activities, these initiatives prioritize engagement with software vendors, targeted workforce training, and close collaboration with industry partners.[12] By aligning vendor engagement, industry outreach, and workforce training, these programs ensure the transition to digital delivery and open BIM standards becomes a practical reality—driving efficiency, interoperability, and digital transformation in transportation.

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Concrete Laboratory

New Generation of Concrete Incorporates Calcined Clay

By Timothy J. Barrett, Office of Research and Development, TFHRC

It is no secret that a high-quality binder is the glue that can help improve the durability and integrity of concrete infrastructure. Following the recent industry-led introduction of portland limestone cement (or Type IL cement as defined in standards AASHTO M 240M/M 240 and ASTM C 595/C595M), substantial innovation in the market has led to the further introduction of numerous new cements and alternative supplementary cementitious materials (ASCMs).[1, 2] These novel binder systems may bring various improvements to the concrete industry, including improved performance, reduced costs, increased material availability, and lower material variability. Cements and ASCMs face many common barriers to entry in practice, with a key question being whether they may be used without modification to provisions within the AASHTO *LRFD* [Load and Resistance Factor Design] *Bridge Design Specifications* (BDS).[3]

One such material gaining popularity is calcined clay, which has an abundant raw material supply in the United States and is considered a Class N pozzolan (a naturally occurring, raw or calcined material that reacts with lime and water to form cementitious compounds) under standards AASHTO M295 and ASTM C618.[4, 5] The material has historically been sold in a highly refined and highly reactive form, making it most suitable for specialized applications and being typically used in relatively low volumes with limited commercial use in concrete. More recently, a less reactive version of calcined clay was proposed as more advantageous, particularly when used in a higher quantity and with higher amounts of ground limestone.[6] The initial conception of this material was branded limestone calcined clay cement (LC3), which is made by intergrinding limestone and calcined clay with cement clinker at the mill. Alternatively, the calcined clay may be independently manufactured and sold as ASCM for use with a Type IL cement to form an ASTM C595 Type IT blended cement, sometimes called "LC2."[2]

Source: FHWA.
The industrial ready-mixed concrete truck charged with the first batch of LC2 concrete.

Researchers at TFHRC have successfully scaled up a new industrial source of calcined clay to make an LC2 concrete (Type IT(L7)(P30)) using locally available raw materials and conventional admixtures. TFHRC's first large-scale production of the material shows promise for technology transfer to practice to improve the integrity and durability of concrete. Industrial-scale production was achieved by manual batching, which used super sack bags for dry materials and water metered from a tote on a scale to charge a conventional ready-mixed concrete truck. Researchers produced the concrete according to methods of AASHTO M157 and ASTM C94/C94M,[7, 8] with target slumps and entrained air contents achieved in line with laboratory trial batch results. Potential opportunities for further research include a study to evaluate whether the new material used in reinforced concrete applications conforms to the existing codified expressions within the AASHTO LRFD BDS or whether any updates are recommended.

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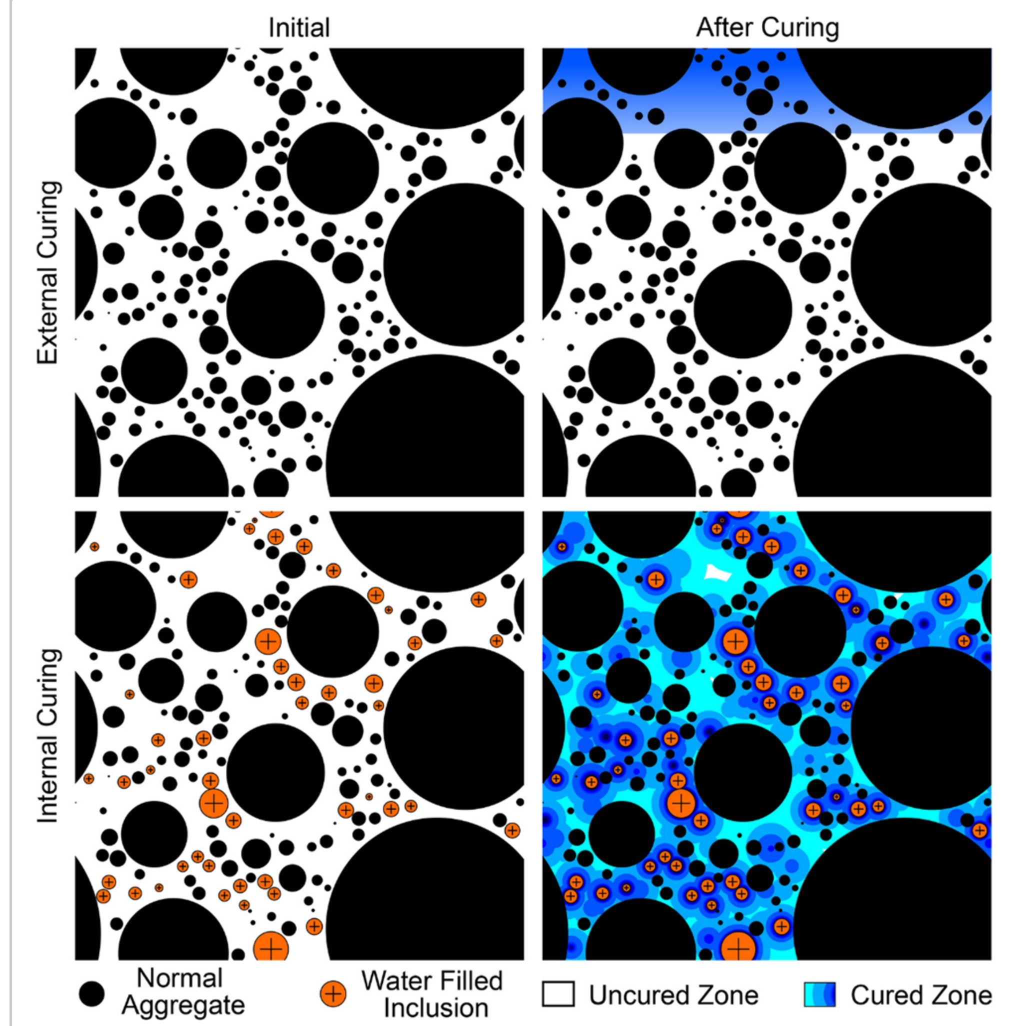
Federal Lands Highway Program

Internally Cured Concrete Extends the Service Life of the Nation's Bridges

By Megan Chatfield, Construction Operations Engineer, Western Federal Lands Highway Division

Cracking can substantially reduce the service life of concrete bridge decks. Cracking provides water and chloride ions a free path to penetrate the concrete bridge deck to reach the embedded reinforcing steel. This process accelerates corrosion and results in increased maintenance, repair, and rehabilitation needs, frequently leading to the need for deck replacement. Finding ways to mitigate this cracking results in fewer unplanned bridge deck stewardship expenditures by bridge owners.[(1)]

Shrinkage is one cause of early-age cracking in concrete bridge decks. Shrinkage happens when water is lost from concrete pores during the concrete curing process. Shrinkage is also more prominent in concretes designed to achieve high durability, such as the types of concrete often used in bridge decks.[(1)] FHWA's Enhancing Performance with Internally Cured Concrete (EPIC²) initiative promotes using internally cured concrete (ICC) to overcome the challenge of shrinkage and early-age cracking. ICC uses an internal reservoir of water for curing purposes to prevent shrinkage.[(2,3)] The internal reservoir is commonly formed by replacing some of the normal fine aggregates in the concrete mixture with highly absorptive lightweight fine aggregate. This highly absorptive fine aggregate retains water and later automatically releases it, mitigating the drying of the concrete pores that can cause shrinkage and early-age cracking.[(1)] ICC increases the service life of bridge decks, making some last up to an estimated 75 years or more.[(4)]



Source: FHWA.[(5)]
Water hydrates the interior of internally cured concrete.

From 2016 to 2018, the Federal Lands Highway (FLH) Program first used ICC to construct three bridge decks. Two of the three bridges, the Manning Crevice and Shoup Bridges, are in Idaho. The third bridge, the Fort Pulaski Bridge, is outside Savannah, GA. Each bridge's span length ranges from 220 ft to 1,285 ft. The Fort Pulaski Bridge presented several challenges due to the hot climate and the bridge's proximity to seawater. This bridge was initially designed for a 75-year lifecycle, emphasizing increased need for enhanced durability. During maintenance, ICC was used for the bridge deck placement. Years after work ended, comprehensive testing indicated that ICC significantly improved the service life of the bridge deck with minimal deck cracking. The Manning Crevice and Shoup Bridges have seen similar performance improvements.[(1)]

Based on the success of these ICC projects, FLH has incorporated the use of ICC into the *Standard Specifications for Construction of Roads and Bridges on Federal Highway Projects (FP-24)*.[(5)] It is part of Section 552—Structural Concrete, recommending use of ICC on bridge decks and other structural elements to minimize early-age cracking and maximize the structure's service life.[(1,6)]

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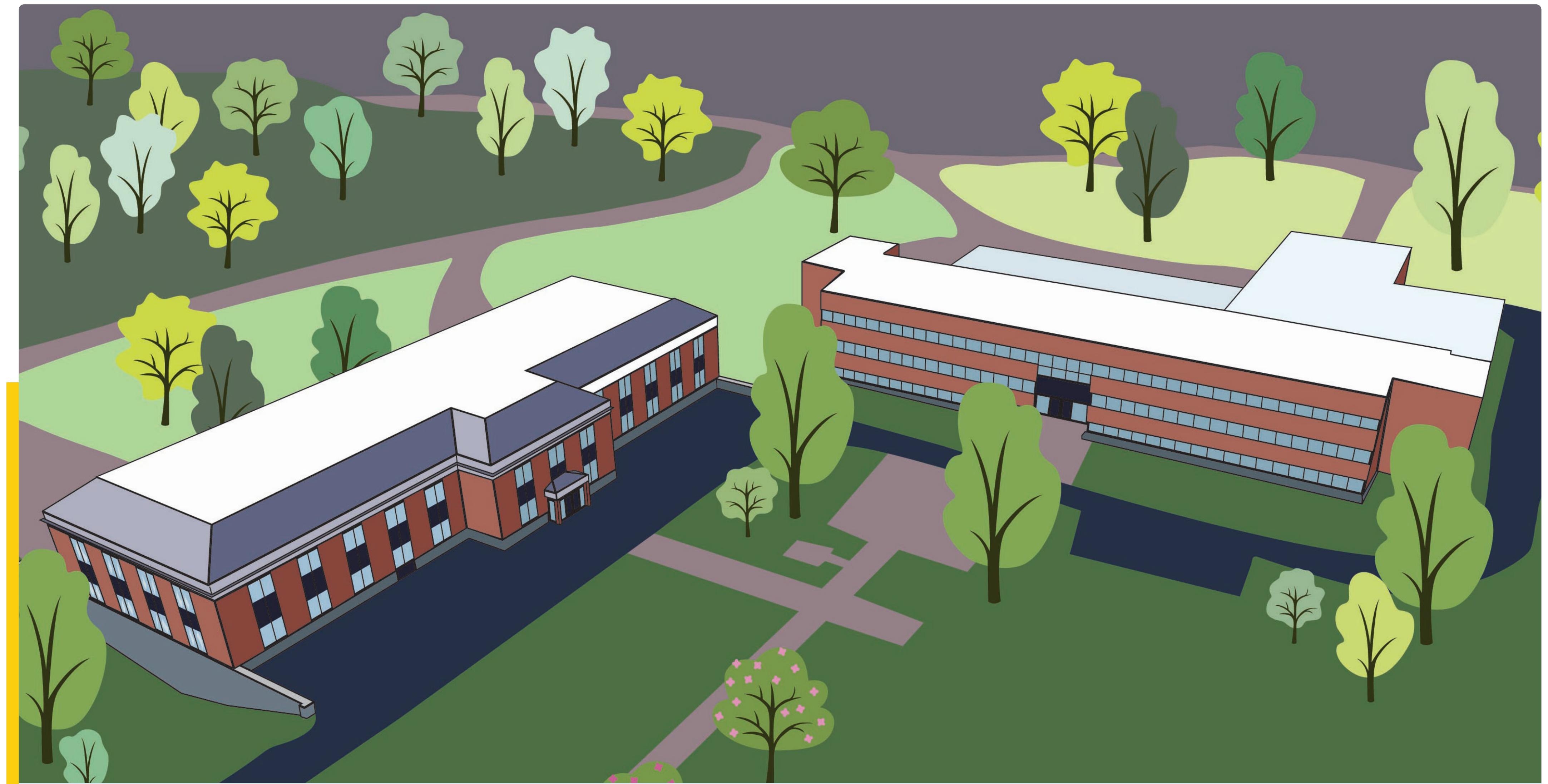

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