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INDIANA DEPARTMENT OF TRANSPORTATION
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Implementation Study for In-Place Testing of Asphalt Treated Cold Recycled Pavements



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16. Abstract This study evaluated the feasibility of rapid in-situ strength test methods for asphalt-treated cold recycled (ATCR) pavements in Indiana, with a secondary objective of characterizing the dynamic modulus of a locally produced ATCR mixture for use as AASHTOWare Pavement ME Design inputs. The long-pin shear test (LPST) and short-pin raveling test (SPRT), developed through National Cooperative Highway Research Program (NCHRP) Project 09-62, were evaluated on a cold in-place recycling (CIR) project on SR 13 in Greenfield, Indiana. Field results for blow counts exceeded the proposed NCHRP threshold moments after compaction, with torque values approaching but not yet reaching the NCHRP criterion. Short-term monitoring during the first hours after compaction showed slight decreasing trends in both blow count and torque, the cause of which could not be confirmed with the available data. By Day 7, both threshold values were exceeded by a wide margin. Dynamic modulus testing of laboratory-compacted specimens yielded a calibrated sigmoidal master curve consistent with the NCHRP Report 863 reference range for CIR materials at intermediate temperatures. The results support the potential adoption of the LPST and SPRT as complementary indicators of curing readiness in Indiana, pending validation across additional field projects.					
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EXECUTIVE SUMMARY

Introduction

The Indiana Department of Transportation (INDOT) relies on three cold recycling techniques as part of its pavement rehabilitation framework: full-depth reclamation (FDR), cold in-place recycling (CIR), and cold central plant recycling (CCPR). These methods reuse reclaimed asphalt pavement (RAP) material at ambient temperature, using emulsified asphalt as the primary recycling agent. Because the recycling agent is applied as an emulsion rather than a heated binder, the compacted layer retains significant residual moisture immediately after construction and must undergo a curing process before developing adequate mechanical strength. INDOT currently determines readiness for traffic opening and overlay placement based on two indicators: elapsed curing time and in-situ moisture content, as specified in Sections 416 and 417 of the 2022 *INDOT Standard Specifications*. While practical to implement, these indicators are indirect proxies for mechanical strength and do not directly reflect the structural state of the recycled layer. Research has consistently shown that the relationship between moisture content and mechanical properties is material-specific and poorly correlated with in-situ strength development. Similarly, time-based criteria do not account for the significant variability in curing rate introduced by differences in ambient temperature, humidity, and mixture composition. As a result, these criteria may lead to either premature loading of inadequately cured layers or unnecessarily conservative closure periods, thereby increasing construction costs and traffic disruption.

Objectives

This study was conducted to evaluate rapid in-situ strength testing methods for asphalt-treated cold recycled (ATCR) pavements and assess their suitability for adoption by INDOT as alternatives or supplements to the current time- and moisture-based acceptance criteria. The primary focus was the evaluation of the short-pin raveling test (SPRT) and the long-pin shear test (LPST), developed through National Cooperative Highway Research Program (NCHRP) Project 09-62, on an Indiana CIR project, as well as the assessment of the consistency of the measured results with nationally proposed threshold values. A secondary objective was to characterize the dynamic modulus of an Indiana CIR mixture for use as input in AASHTOWare Pavement ME Design.

Approach

The study was organized around three main tasks. First, a comprehensive literature review was conducted to synthesize current knowledge on curing indicators, rapid in-situ test

methods, and dynamic modulus characterization of cold recycled materials. Second, SPRT and LPST fixtures were fabricated, and field testing was conducted on a CIR project on State Road (SR) 13 in Greenfield, Indiana, following the general methodology of NCHRP Project 09-62, with adaptations driven by site constraints. Finally, laboratory dynamic modulus testing was performed on CIR specimens prepared using Indiana local materials to develop a master curve and compare the results against nationally available reference values.

Key Findings

- Field testing at SR 13 demonstrated that both the LPST and SPRT produced results broadly consistent with the nationally proposed threshold values established through NCHRP Project 09-62—20 blows and 88.4 N·m (65.2 lb-ft) for the LPST; 7 blows and 27.8 N·m (20.5 lb-ft) for the SPRT. At Location 1, the LPST blow count already exceeded the threshold at Day 0, within hours of compaction, while the corresponding torque value of 85.1 N·m (62.8 lb-ft) fell only marginally below the 88.4 N·m (65.2 lb-ft) criterion. By Day 7, both threshold values were simultaneously satisfied by a wide margin, with 84 blows and 207.0 N·m (152.7 lb-ft) of torque recorded. The single SPRT measurement conducted at Day 0 satisfied both threshold criteria simultaneously, though this result was obtained within minutes of compaction completion and should be interpreted with caution. The absence of measurements between Day 0 and Day 7 prevents the determination of the exact time at which both LPST criteria were first met simultaneously, a key data gap for future monitoring programs.
- At Locations 2 and 3, LPST measurements collected over a 4-hour window on the day of compaction showed a slight decreasing trend in both blow count and torque, despite a concurrent decrease in moisture content. The observed 5 °C increase in air temperature over the monitoring period may offer a more plausible explanation, as higher temperatures are known to reduce asphalt binder stiffness and may temporarily offset early strength gains. A similar trend was reported in NCHRP Web-Only Document 376 for emulsion-based ATCR materials. The limited dataset does not allow this hypothesis to be confirmed, and further investigation is warranted.
- Dynamic modulus testing yielded a well-calibrated sigmoidal master curve for an Indiana CIR mixture, with post-curing air void contents of 14.5% and 16.1%. Comparison with the NCHRP Report 863 reference range for CIR materials showed that the Indiana mixture falls above the upper bound at low temperatures, near the upper end of the range at intermediate temperatures, and at or below the lower bound at elevated temperatures. These differences are attributed to the absence of active filler, differences in specimen preparation, and potential in-service densification of the field cores in the NCHRP 863 dataset.

Recommendations

- The LPST and SPRT show strong potential as practical tools for evaluating the readiness of CIR layers in Indiana. Both tests are portable, rapid, and operable by a single technician, making them suitable for routine construction quality assurance. INDOT is encouraged to implement these tests on future ATCR projects on a trial basis, initially as supplementary measurements alongside

existing time- and moisture-based requirements, to accumulate field experience and performance data without modifying current specifications.

- The dynamic modulus values developed in this study may be used as Level 1 inputs in AASHTOWare Pavement ME Design for Indiana CIR projects with similar material composition, offering a locally derived alternative to the NCHRP 863 catalog values.
- Additional field data are needed before Indiana-specific threshold values can be established or the national values formally adopted. Future data collection should prioritize denser monitoring during the first 3 days after compaction, testing across multiple recycling process types and seasonal conditions, and dynamic modulus characterization of field cores from additional Indiana ATCR projects.

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1. INTRODUCTION

1.1 Background

Pavement preservation and rehabilitation represent critical challenges for transportation agencies across the United States. As pavements deteriorate due to traffic loading, environmental exposure, and aging of bituminous binders, agencies must choose rehabilitation strategies that balance between structural performance, cost effectiveness, and environmental impact. In recent decades, cold recycling techniques have emerged as a compelling alternative to conventional mill-and-fill approaches, offering documented reductions in construction costs, energy consumption, raw material use, and greenhouse gas emissions (Offenbacher et al., 2021). By directly reusing reclaimed asphalt pavement (RAP) into the rehabilitated base layer at ambient temperatures, these methods reduce demand for virgin aggregates and for energy-intensive hot-mix asphalt (HMA) production, thereby providing economic, environmental, and societal benefits (Alkins et al., 2008).

The Indiana Department of Transportation (INDOT) has embraced cold recycling as part of its pavement rehabilitation framework, incorporating three distinct cold recycling processes into its standard specifications: full-depth reclamation (FDR), cold in-place recycling (CIR), and cold central plant recycling (CCPR). These processes are governed by Sections 308, 416, and 417 of the 2022 *INDOT Standard Specifications* (INDOT, 2022), respectively. Despite their growing adoption, a critical challenge common to all three methods remains unresolved: determining, in a timely and reliable manner, when a cold recycled pavement layer has developed sufficient mechanical strength to safely accommodate either construction equipment for surface paving or the return of public traffic (Diefenderfer et al., 2021).

1.2 Cold Recycling Technologies

FDR is a rehabilitation technique that involves milling and blending the full thickness of the existing asphalt pavement and a specified portion of the underlying unbound base or subbase. The resulting material is then stabilized in situ using an asphalt-based recycling agent (typically emulsified or foamed asphalt), a cementitious active filler, or a combination of both, and recompressed to form a new bound base layer (Asphalt Recycling &

Reclaiming Association [ARRA], 2015). FDR is typically employed when the existing pavement has experienced deep structural distress and requires reconstruction of the pavement foundation. Typical FDR depths range from 150 to 300 mm (6 to 12 in.), making FDR one of the most structurally transformative cold recycling techniques (Diefenderfer et al., 2021).

Cold in-place recycling (CIR) takes place also in situ but targets only the existing asphalt-bound surface and base layers, milling them to a depth generally ranging from 75 to 125 mm (3 to 6 in.) without disturbing the underlying unbound materials. The milled RAP is mixed with an asphalt-based recycling agent (either emulsified or foamed asphalt), and relaid in a single pass using a recycling train (Figure 1.1). The recycling agent content typically ranges from 2.0% to 2.5% residual asphalt by weight of dry RAP, with some agencies also incorporating active fillers such as Portland cement or lime at contents generally not exceeding 1.0% by dry weight of RAP (Bowers et al., 2020; Orosa, 2022). CIR is primarily used on intermediate-volume roadways where the pavement surface has deteriorated, but the underlying structure remains adequate.

CCPR involves the same material principles as CIR but differs in that the RAP is transported to a mixing plant, blended with the recycling agent, and then hauled back to the project site for placement (ARRA, 2015; INDOT, 2022). This off-site mixing allows for better control of mixture uniformity and quality than in-place processes and has demonstrated strong structural performance even in high-traffic applications (Diefenderfer et al., 2015; Timm et al., 2018). CCPR can be particularly advantageous on projects where centralized production is logistically feasible and where greater material consistency is required.

1.3 Curing of Emulsified Asphalt Mixtures

Unlike HMA, which develops structural capacity shortly after placement and cooling, asphalt-treated cold recycled (ATCR) mixtures are produced at ambient temperature using emulsified or foamed asphalt as the recycling agent, typically with added water to facilitate mixing and compaction. As a result, the compacted layer initially contains a significant amount of residual moisture that must dissipate before adequate mechanical properties can develop (Kim et al., 2011; Orosa et al., 2022). This process, known as curing, begins after compaction and may extend from several hours to several days,



Figure 1.1 Example of a CIR Recycling Train (Orosa, 2022).

depending on material composition and environmental conditions (Kim et al., 2011; Lee et al., 2009). Consequently, the structural performance of these pavements is closely governed by the curing process, which controls the progressive development of mechanical properties over time.

Understanding and controlling the curing process is, therefore, of critical practical importance: an ATCR layer opened to traffic prematurely may suffer permanent surface deformation under vehicle loads, while excessive waiting times increase construction delays and costs. Similarly, placing an HMA surface course over an inadequately cured recycled layer can trap residual moisture, compromising long-term bonding and pavement performance. The ability to determine, in a timely and reliable manner, when a cold recycled layer has achieved sufficient strength to safely accommodate traffic or surfacing operations is thus central to the successful implementation of these rehabilitation techniques.

1.4 Current INDOT Curing Indicators

INDOT currently relies on two primary indicators to determine when a cold recycled asphalt layer is ready for HMA surface placement or reopening to traffic: elapsed curing time and in-situ moisture content (INDOT, 2022). Specifically, ATCR pavements must cure for a minimum of 3 days and reach a moisture content below 3.0% before overlay placement is permitted. These time- and moisture-based criteria are broadly representative of industry practice across U.S. agencies, though significant variability exists among state specifications (Bowers et al., 2020), reflecting the absence of a nationally consistent, mechanistically grounded basis for these decisions.

These criteria, however, present fundamental limitations. Moisture content measures a proxy for strength rather than strength directly, and its relationship with mechanical properties is material-specific and influenced by mixture composition and environmental conditions. Curing time is equally limited, as a fixed time-based requirement cannot account for the environmental variability inherent in field construction.

1.5 Need for Rapid Strength Evaluation

The limitations of time- and moisture-based criteria highlight the need for field tests that directly assess the mechanical properties of the recycled layer during curing. An ideal rapid in situ test should be portable, operable by a single technician, and capable of providing results within minutes while delivering a mechanistically meaningful indication of the layer's ability to safely accommodate applied loads. The adoption of such tests would enable construction teams to make go/no-go decisions based on actual material behavior rather than elapsed time or indirect moisture measurements, thereby reducing the risk of premature loading and the economic costs associated with unnecessarily long closures.

National Cooperative Highway Research Program (NCHRP) Project 09-62 was specifically designed to address this need by developing and validating rapid in-situ test methods for ATCR pavements (Diefenderfer et al., 2021). The project produced two new test methods, the short-pin raveling test (SPRT) and the

long-pin shear test (LPST), along with threshold values for each and a guide specification integrating their use into construction quality assurance (Diefenderfer et al., 2023).

1.6 Research Objectives

This study represents a pilot effort to evaluate in-place strength test methods, particularly those developed through NCHRP 09-62, and provide guidance on their use with ATCR mixtures, specifically FDR, CIR, and CCPR, in the context of Indiana conditions and INDOT practice. The primary objective is to (i) assess the feasibility and performance of the SPRT and LPST on Indiana cold recycled pavement projects, (ii) evaluate the consistency of measured results with the national threshold values established in NCHRP 09-62, and (iii) provide preliminary guidance on the adoption of these tests by INDOT. A secondary objective is to identify and synthesize available mechanical property data for ATCR mixtures in Indiana for use as Pavement Mechanistic-Empirical (ME) Design inputs.

2. LITERATURE REVIEW

2.1 The Relevance of Curing in ATCR Mixtures

ATCR mixtures are produced by combining RAP with a bituminous recycling agent and, in some cases, an active filler such as Portland cement or hydrated lime. The RAP constituent consists of aggregate particles coated with aged asphalt binder. During the recycling process, the recycling agent supplements the aged binder, partially restores its rheological properties, and provides cohesion to the ATCR mixture. Recycling agent contents typically range from 2.0% to 2.5% residual asphalt by weight of dry RAP, while active filler contents generally do not exceed 1.0% by dry weight of RAP when used (Bowers et al., 2020; Orosa, 2022). In emulsion-based ATCR mixtures, water is present both as part of the asphalt emulsion and as additional added water to improve mixture mixing, workability, handling, and compaction. Its subsequent evaporation during curing is central to the development of mechanical properties.

The mechanical behavior of ATCR mixtures is fundamentally different from that of HMA. Immediately after compaction, ATCR layers exhibit low stiffness and limited shear resistance, as the recycling agent has not yet fully broken and the mixture retains significant residual moisture. As curing progresses, emulsion breaking, water evaporation, and (when active fillers are present) cementitious hydration reactions progressively increase the mixture's stiffness and strength (Cardone et al., 2015; Graziani et al., 2016). This evolution of mechanical properties is more pronounced during the first hours to weeks after compaction, depending on environmental conditions and mixture composition, while full curing could range from 2 to 24 months (Dave et al., 2022; Leech, 1994; Orosa, Pérez, & Pasandín, 2023), making the mechanical characterization of ATCR materials inherently time dependent.

Laboratory studies have documented substantial increases in stiffness with curing time. Kim et al. (2011) reported that both resilient modulus and indirect tensile strength of CIR mixtures

increased significantly with curing time and temperature, with most of the strength gain occurring during the first few days after compaction. Ogbo et al. (2022) confirmed that curing time is the dominant factor governing strength development, outweighing the effects of recycling agent type and content under controlled laboratory conditions. The presence of active fillers has been consistently shown to accelerate early strength gain and reduce moisture sensitivity, with Portland cement providing the most pronounced effect (Ogbo et al., 2022).

The air void content of ATCR mixtures is considerably higher than that of HMA, typically ranging from 8% to 14%, confirmed from field cores obtained from 27 CIR, CCPR, and FDR projects across the US and Canada (Schwartz et al., 2017). This is primarily attributed to the presence of water during compaction, which limits the achievable density despite the high compaction energy applied. As the water evaporates during curing, residual voids remain in the structure (Kim et al., 2011). These elevated void contents play an important role in governing both the rate of moisture evaporation during curing and the long-term mechanical performance of the layer, with higher void contents facilitating faster drying but compromising strength and durability under repeated traffic loading. This inherently time-dependent nature of ATCR mechanical behavior has severe practical implications for construction quality assurance. Determining when a recycled layer has developed sufficient strength to safely accommodate traffic or overlay placement requires reliable indicators that reflect the actual state of the material rather than elapsed time alone.

2.2 Indicators of Curing Progress in ATCR Pavements

The assessment of curing progress in ATCR pavements has traditionally relied on two indirect indicators: elapsed curing time and in-situ moisture content. These criteria are broadly

representative of industry practice across U.S. agencies, although significant variability exists in their implementation. Bowers et al. (2020) documented target moisture contents for overlay placement ranging from as low as 1.0% to as high as 3.5% across state specifications, with opening-to-traffic timelines varying from a few hours to several days. This variability reflects the absence of a nationally consistent and mechanistically grounded basis for curing decisions.

Moisture content is appealing as a curing indicator because it can be measured relatively easily in the field using a nuclear density gauge (NDG), and because residual moisture is directly linked to the curing process. As moisture evaporates, the asphalt binder consolidates and mixture strength increases. However, the relationship between moisture content and mechanical properties is not universal and is influenced by factors including the type and content of recycling agent, the presence and dosage of active filler, compaction density, and ambient temperature and humidity conditions (Ogbo et al., 2022). Critically, Mandal et al. (2023) found no meaningful correlation between NDG-measured moisture content and direct surface mechanical properties across eight field CIR projects, suggesting that nondestructive moisture measurements may not reliably represent strength development in the field. Furthermore, Dave et al. (2022) and Orosa, Pérez, & Pasandín (2023) observed that mechanical properties continued to gain beyond the point at which moisture content reached equilibrium, particularly in mixtures without active filler, reinforcing that moisture content alone is an insufficient proxy for structural readiness (Figure 2.1).

Curing time is also limited as a standalone indicator because it does not account for the environmental variability inherent to field construction. A CIR layer placed under warm, dry, summer conditions will cure substantially faster than the same material placed under cool, humid, fall conditions; however, a fixed time-based requirement treats both scenarios identically (Kim et al., 2011).

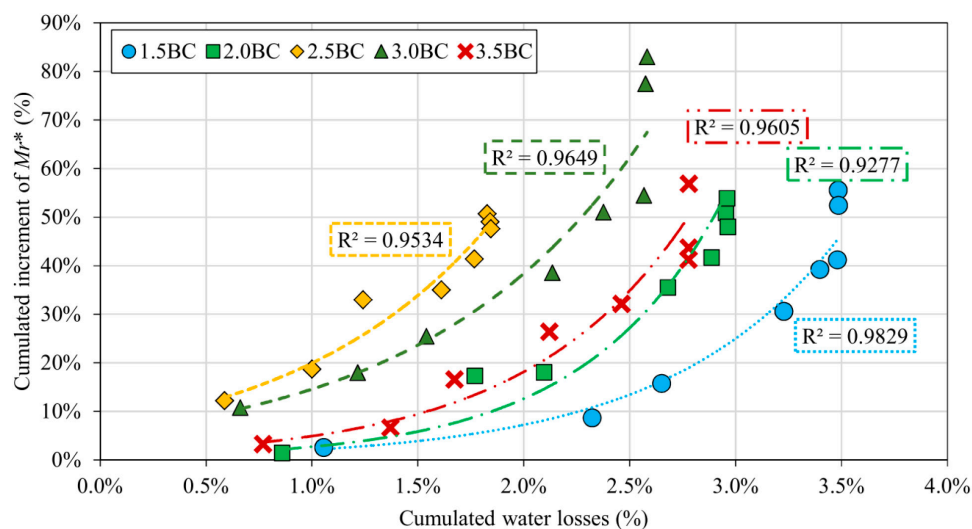


Figure 2.1 Relationship Between Cumulative Water Loss and Stiffness Gain in CIR Mixtures. The Nonlinear Response and Binder Content Dependency Suggest That Moisture Content Alone Is an Insufficient Indicator of Mechanical Readiness (Orosa, Pérez, & Pasandín, 2023).

Laboratory-based indicators, including resilient modulus, indirect tensile strength, and dynamic modulus, provide more mechanistically meaningful measures of curing progress. However, these tests require specimen preparation and controlled laboratory conditions that are incompatible with real-time construction quality assurance (Ferrotti et al., 2020). The practical consequence of these limitations is the need for rapid field tests capable of directly assessing the mechanical readiness of the recycled layer.

2.3 Rapid In-Situ Strength Tests

The limitations of time- and moisture-based curing criteria have motivated research into alternative field methods capable of directly assessing the mechanical readiness of ATCR layers. Several in-situ testing devices have been evaluated for this purpose, including the Dynamic Cone Penetrometer (DCP), the Light Weight Deflectometer (LWD), the Soil Stiffness Gauge (SSG), and, more recently, torque-based devices specifically developed for ATCR applications (Diefenderfer et al., 2020).

The DCP measures the penetration rate of a cone driven into the pavement by repeated blows from a drop hammer, providing an index of bearing capacity that can be correlated with stiffness and strength. Although the DCP has been widely used for evaluating unbound base and subgrade layers, its application to ATCR pavements is limited. Diefenderfer et al. (2020) conducted DCP testing on ATCR slabs and reported good between-specimen repeatability, with coefficients of variation below 6% at both 2 and 72 hr of curing. Quick & Guthrie (2011) monitored an emulsion-based FDR material in the field using DCP at 30 min; 2, 3, 7, and 14 days; 4 months; and 1 year after construction, demonstrating it was able to capture trends in strength development over the curing period. However, DCP testing on asphalt-bound layers can be difficult without risking damage to the instrument (Tingle & Jersey, 2007), which may similarly limit its applicability to well-cured ATCR layers.

The LWD applies a dynamic load impulse to the pavement surface and measures the resulting deflection, from which a surface modulus can be backcalculated. Although the LWD is nondestructive and relatively simple to operate, it measures the composite response of multiple pavement layers and is therefore less sensitive to the curing condition of the ATCR layer itself. In a field evaluation of six CIR projects in Minnesota, Dave et al. (2022) confirmed that the LWD was effective in tracking stiffness evolution during curing, though they noted higher measurement variability compared to other penetration-based devices evaluated concurrently. Similarly, the SSG measures the mechanical impedance of near-surface pavement layers across multiple frequencies but has shown limited sensitivity to curing-related changes in ATCR mixtures and has not been widely adopted for this application (Diefenderfer et al., 2020).

The primary distresses associated with ATCR pavements when prematurely subjected to traffic loading before adequate cohesion has developed include surface raveling and the accumulation of shear strains that lead to permanent

deformation (Wirtgen, 2012). Torque-based testing provides a more direct measure of the raveling and shear resistance of the ATCR layer and may, therefore, be more closely related to the cohesive strength developed during curing. Research conducted through the NCHRP program demonstrated that torque measurements obtained from pin-based devices embedded in the pavement surface were sensitive to curing progress and correlated well with other mechanical indicators, ultimately leading to the development of the SPRT and LPST as standardized field test methods (Diefenderfer et al., 2021, 2023).

2.4 Development of SPRT and LPST

The SPRT and LPST were developed as part of NCHRP Project 09-62, initiated in 2017 with the objectives of developing time-critical tests for CIR, FDR, and CCPR materials, as well as guide specifications for process control and product acceptance (Diefenderfer et al., 2021). The project was completed in four phases. Phase I consisted of a literature review and stakeholder survey to identify candidate test methods. Phase II included a laboratory evaluation of the candidate tests, from which the SPRT and LPST were selected for further development based on their sensitivity to curing time, recycling agent type, and active filler content, as well as their practical feasibility for field implementation (Diefenderfer et al., 2020).

Phase III involved field evaluation of both tests at multiple construction projects, together with an interlaboratory study conducted to establish preliminary threshold values. The results from Phases I through III were published in NCHRP Research Report 960 (Diefenderfer et al., 2021). A fourth phase was subsequently conducted to validate the proposed threshold values through field testing at an additional 17 recycling projects during the 2021 construction season. The results of this phase were published as NCHRP Web-Only Document 376 (Diefenderfer et al., 2023).

Both tests use the same base fixture, consisting of a steel plate driven into the recycled layer using the upper assembly of a DCP. After installation, a torque wrench is used to apply rotational force to the embedded fixture, and the maximum torque value is recorded. The two tests differ primarily in pin geometry. The LPST uses five long pins approximately 85 mm (3 in.) in length, designed to evaluate the shear resistance through the full depth of the recycled layer. In contrast, the SPRT uses one long center pin and four short outer pins approximately 19 mm (0.75 in.) in length, intended to evaluate the raveling resistance of the near-surface material (Diefenderfer et al., 2021).

For each test, two parameters are recorded: the number of blows required to drive the fixture to the level of the base plate and the maximum torque value. Both threshold criteria must be satisfied simultaneously for the layer to be considered ready for traffic opening or overlay placement. The blow count parameter primarily reflects the resistance of the material to fixture penetration, while the torque measurement reflects the shear or raveling resistance mobilized during rotation of the embedded fixture. The use of both parameters simultaneously was

intended to provide a more comprehensive assessment of early mechanical readiness than either parameter alone (Diefenderfer et al., 2021).

The recommended testing protocol consists of three replicate measurements per test block, with a minimum center-to-center spacing of 300 mm (12 in.) between measurement points. The test block is typically located near the center of the recycled lane, away from wheel paths and adjacent to a nuclear density gauge measurement location (Diefenderfer et al., 2023). Revisions to the fixture geometry and data collection procedures were introduced between Phases III and IV based on field experience, including modifications to pin dimensions and standardization of the blow count metric. Specifically, two blow count definitions were initially differentiated for the SPRT: N1, defined as the number of blows required to drive the fixture to the tip of the shorter outer pins, and N2, defined as the number of blows required to drive the fixture until the base plate becomes flush with the pavement surface. The latter was ultimately adopted as the recommended metric in place of the earlier N1 definition (Diefenderfer et al., 2023).

2.5 Threshold Values Proposed in Previous Research

The threshold values for the SPRT and LPST were established using a statistical approach based on the lower tail of the field dataset distribution. For each test metric, the threshold value was calculated as the mean minus 1.645 times the pooled standard deviation, where 1.645 corresponds to the z-statistic associated with a 5% left-tail probability. This approach was intended to classify approximately 95% of field observations as acceptable (Diefenderfer et al., 2021). The methodology is conceptually similar to the percent-within-limits approach commonly used in statistical quality assurance programs for pavement materials.

It should be noted that the proposed threshold values were not directly calibrated against long-term pavement performance or mechanistic failure criteria, but rather derived statistically from field measurements collected during active construction projects. Consequently, the thresholds should be interpreted as empirically derived field acceptance benchmarks rather than direct mechanistic indicators of failure or long-term performance.

For both the SPRT and LPST, the blow count and torque criteria must be satisfied simultaneously for the recycled layer to be considered acceptable. Satisfying only one of the two criteria is insufficient.

Threshold values were initially proposed at the conclusion of Phase III based on data collected from 13 field projects. Phase IV testing was subsequently conducted at an additional 17 projects to verify and refine these values. A Student's t-test comparison between the Phase III and Phase IV datasets indicated that the difference in means was statistically significant only for the SPRT blow count metric, with an approximate difference of 1.4 blows. However, the research team concluded that this difference was not practically significant because of the integer nature of the measurement and because it remained within the established test precision (Diefenderfer et al., 2023). Consequently,

the Phase III and Phase IV datasets were combined into a single dataset representing 30 field projects to establish the final recommended threshold values.

The final threshold values recommended from the combined dataset are 7 blows and 27.8 N·m (20.5 lb-ft) of torque for the SPRT, and 20 blows and 88.4 N·m (65.2 lb-ft) of torque for the LPST (Diefenderfer et al., 2023). These values are intended to be applicable to CIR, CCPR, and FDR materials stabilized with either emulsified or foamed asphalt, with or without active filler contents up to 1.5% by weight. The proposed approach therefore recommends a single set of threshold values independent of recycling process type or stabilizing agent.

The analysis of covariance (ANCOVA) conducted during Phase IV identified active filler presence and moisture content as statistically significant variables for all four test metrics. Recycling process type was statistically significant for three of the four metrics, while pavement temperature and recycling agent type were significant for two metrics. In contrast, curing time was statistically significant for only one metric. Although pavement temperature and curing time are known to influence ATCR curing behavior, the Phase IV ANCOVA identified active filler presence and moisture content as the variables most consistently associated with variability in the SPRT and LPST measurements (Diefenderfer et al., 2023).

2.6 Pavement ME Design Inputs for ATCR Materials

The incorporation of ATCR materials into mechanistic-empirical pavement design frameworks has historically been limited by the lack of material-specific design inputs. AASHTOWare Pavement ME Design requires layer-specific mechanical properties, most notably the dynamic modulus $|E^*|$, to characterize the viscoelastic behavior of bound pavement layers. Prior to the NCHRP Research Report 863 from Schwartz et al. (2017), no standardized catalog of $|E^*|$ values existed specifically for CIR, CCPR, or FDR materials. As a result, practitioners were often forced to assume HMA-derived properties or rely on unbound granular layer models, neither of which adequately represents the behavior of ATCR layers (Schwartz et al., 2017).

Schwartz et al. (2017) addressed this gap by characterizing the dynamic modulus and repeated-load permanent deformation behavior of cold-recycled materials obtained from 27 field projects across the US and Canada. The study included CIR, CCPR, and FDR materials stabilized with both emulsified and foamed asphalt, with and without active filler. Based on these results, the study developed a catalog of representative $|E^*|$ values at standard AASHTO testing temperatures and loading frequencies for use as Level 3 inputs in Pavement ME Design, that is, default values representative of a material class when project-specific laboratory characterization is unavailable.

The study found that CIR, CCPR, and FDR materials stabilized with emulsified or foamed asphalt without active filler exhibited similar ranges of dynamic modulus, generally lower than HMA but substantially higher than unbound granular

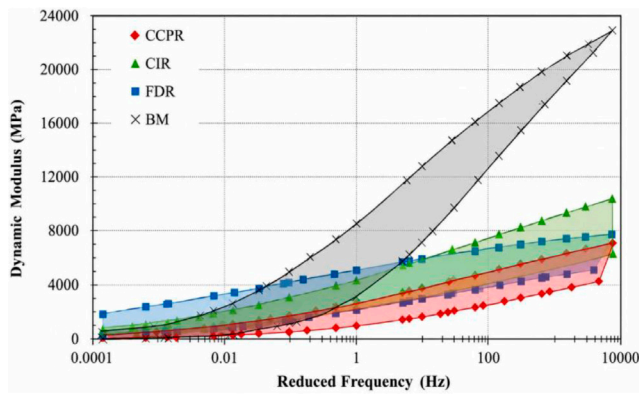


Figure 2.2 Dynamic Modulus Master Curve Envelopes for FDR, CIR, and CCPR, and Asphalt Base Mixtures (Schwartz et al., 2017).

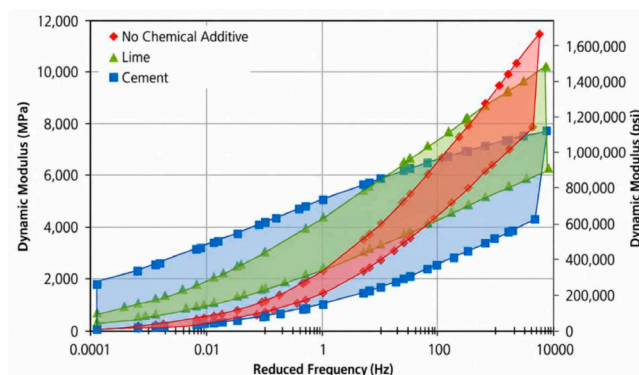


Figure 2.3 Dynamic Modulus Master Curve Envelopes for ATCR Mixtures With No Chemical Additive, With Lime, and With Cement (Schwartz et al., 2017).

materials (Figure 2.2). The incorporation of active filler, particularly Portland cement, significantly increased $|E^*|$ values and reduced temperature sensitivity (Figure 2.3).

Subsequent studies have further characterized the viscoelastic behavior of cold-recycled materials. Kim et al. (2009, 2012) demonstrated that dynamic modulus is sensitive to RAP source, recycling agent type, and residual binder stiffness for both foamed and emulsified asphalt CIR mixtures. Del-Valle-Corte et al. (2025) characterized the viscoelastic behavior of cold-mix asphalt (CMA) mixtures with and without fly ash using the 2S2P1D rheological model, generating master curves that provide a useful basis for comparison with CIR mixtures stabilized with emulsified asphalt. Notably, CMA mixtures without active filler exhibited dynamic modulus values at intermediate temperatures broadly comparable to those reported by Schwartz et al. (2017) for CIR with emulsified asphalt, reflecting the similar binding mechanisms of both material types.

Despite these advances, regionally calibrated $|E^*|$ values for ATCR materials under specific state conditions, including Indiana, remain limited. The use of nationally derived Level 3 inputs from NCHRP Research Report 863 provides a reasonable

starting point for pavement design in Indiana; however, the applicability of these values to local materials, climate conditions, and construction practices has not yet been fully validated.

2.7 Summary of Literature Review

The body of literature reviewed in this chapter establishes the following key findings relevant to the present study:

- ATCR mixtures gain mechanical strength through a time-dependent curing process governed primarily by moisture evaporation, emulsion breaking, and, when active filler is present, cementitious hydration. The evolution of mechanical properties is most pronounced during the first hours to weeks after compaction, while full curing can take from 2 to 24 months. Current agency acceptance criteria based on elapsed time and moisture content thresholds, while practical, do not directly reflect the mechanical state of the recycled layer and have been shown to be poorly correlated with in-situ strength development.
- Among the in-situ testing methods evaluated for ATCR applications, torque-based tests acting directly on the recycled layer have demonstrated superior sensitivity to curing progress compared to surface-based stiffness devices such as the LWD and SSG, which measure the composite response of multiple pavement layers. The SPRT and LPST, developed through NCHRP Project 09-62, represent the most advanced and best-validated tools currently available for this purpose, with threshold values established from a dataset of 30 field projects across three recycling processes, two recycling agents, and multiple active filler combinations.
- For pavement design purposes, NCHRP Research Report 863 provides the most comprehensive catalog of dynamic modulus values for ATCR materials available to date, but regionally specific data, particularly for Indiana materials and construction conditions, remain limited. Addressing this gap through laboratory and field characterization of Indiana-specific ATCR mixtures is a key objective of the present study.

3. RESEARCH METHODOLOGY

3.1 Overview of Research Approach

The research conducted under SPR-4822 was organized around sequential tasks. The study began with a comprehensive literature review to identify current and emerging in-situ test methods for evaluating the strength of ATCR materials, with particular focus on the work conducted under NCHRP Project 09-62 (Diefenderfer et al., 2021, 2023). Building on those findings, the research team proceeded with the identification of cold recycling projects in Indiana, targeting pavement rehabilitation projects involving CIR, CCPR, and FDR. Site visits to active ATCR construction projects were then planned to conduct in-situ strength tests at multiple intervals following material compaction, with the field-collected data intended to support the development and verification of test threshold values under Indiana conditions. Finally, laboratory dynamic modulus testing was performed on a CIR mixture prepared with Indiana materials to develop a master curve and establish preliminary Pavement ME Design inputs for Indiana CIR projects. As discussed in Section 3.4, the execution of this plan was shaped by the limited availability of qualifying ATCR projects during the study period.

3.2 Selection of In-Situ Test Methods

Based on the literature review, the SPRT and LPST were selected for implementation in this study. These two tests were developed specifically for evaluating the time-critical properties of ATR layers and have been validated across multiple states and recycling processes (Diefenderfer et al., 2021, 2023). Their selection was based on four key considerations:

- They directly measure the mechanical properties most relevant to time-critical construction decisions: raveling resistance for traffic opening (SPRT) and shear resistance for surface layer placement (LPST).
- They are rapid, portable, and can be performed without specialized laboratory equipment.
- Proposed American Association of State Highway and Transportation Officials (AASHTO) standard test methods have been developed for both tests (Appendices C and D of NCHRP Research Report 960), providing a well-defined procedural framework that this study could directly adopt.
- Phase IV validation work demonstrated that SPRT and LPST results reflect the variations in density, moisture content, and temperature already embedded in the recommended threshold values, eliminating the need for supplementary proxy measurements to make opening decisions (Diefenderfer et al., 2023).

The SPRT measures the raveling resistance of the recycled layer, quantified by the number of blows required to drive the fixture into the pavement and the peak torque observed during rotation. It is intended to indicate when the material can withstand trafficking without surface deterioration. The LPST, on the other hand, measures the shear resistance of the layer at greater depth, using the same metrics (number of blows and peak torque), and is intended to indicate when the layer can support the loading from paving equipment for surface layer placement. Both tests are applicable to ATR layers with a minimum thickness of 76 mm (3 in.; Diefenderfer et al., 2021).

3.3 Test Equipment and Procedures

3.3.1 Test Fixture Fabrication

The SPRT and LPST fixtures used in this study were custom fabricated by a commercial machine shop in Lafayette, Indiana, based on the proposed AASHTO standard specifications

included in Appendices C and D of NCHRP Research Report 960 (Diefenderfer et al., 2021). Both fixtures share a common base assembly consisting of a 127-mm (5.0-in.) diameter circular flange base plate, an 82.55-mm (3.25-in.) circular bottom plate, and a 25.4-mm (1.00-in.) diameter upper center shaft with a hexagonal milled end for torque wrench attachment. All components were machined from case-hardened AISI-8620 alloy steel, in accordance with the material specifications of the proposed standard methods.

The key distinction between the two fixtures lies in the pin configuration. On the one hand, the LPST fixture is equipped with five long pins, each 12.7 mm (0.50 in.) in diameter and 85.7 mm (3.375 in.) in length, which penetrate the full depth of the recycled layer to mobilize shear resistance. The SPRT fixture uses four short outer pins with 12.7 mm (0.50 in.) in diameter and 28.6 mm (1.125 in.) in length, along with a single long center pin, designed to evaluate the near-surface zone's resistance to raveling. Components common to both the LPST and SPRT are a 127mm (5.0-in.) diameter circular flange base plate, an 82.55-mm (3.25-in.) circular bottom plate, and a 25.4-mm (1.00-in.) diameter upper center shaft with a hexagonal milled end. A counterweight of 9.07 kg (20 lb) is placed over the upper shaft after driving to prevent fixture uplift during torque application. Figure 3.1 shows a rendering representation of the assembled LPST fixture, detailed drawings of all fixture components are shown in Figure 3.2, and the fabricated LPST and SPRT fixtures used in this study are shown in Figure 3.3.

The DCP upper assembly used to drive the fixtures consists of an 8.0-kg (17.6-lb) sliding hammer with a standard drop height of 575 mm (22.6 in), conforming to the requirements of ASTM D6951 (ASTM International [ASTM], 2023). The torque wrench employed (Figure 3.4) had a measurement range of 15 to 300 lb-ft (20.3 to 406.7 N·m), with an accuracy of $\pm 2\%$, and was compatible with the 21mm (0.8125in) socket required for the fixture shaft.

3.3.2 Long-Pin Shear Test Procedure

The LPST follows the proposed AASHTO Standard Method of Test for Evaluating Shear Resistance of Asphalt-Treated Recycled Pavement Applications Using a Long-Pin Fixture (Appendix C of NCHRP Research Report 960). For this test,

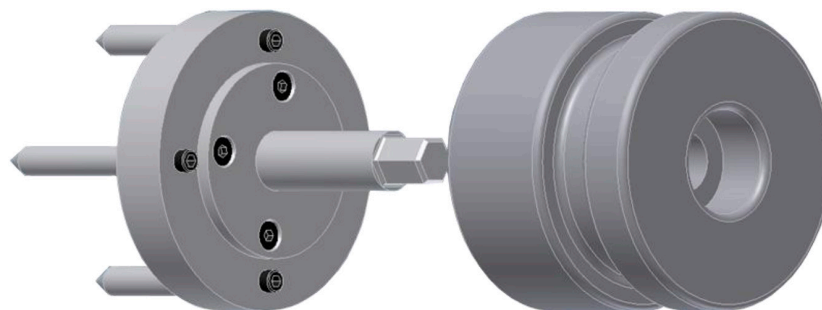


Figure 3.1 Three-Dimensional Rendering of the LPST Fixture Components (Diefenderfer et al., 2021).

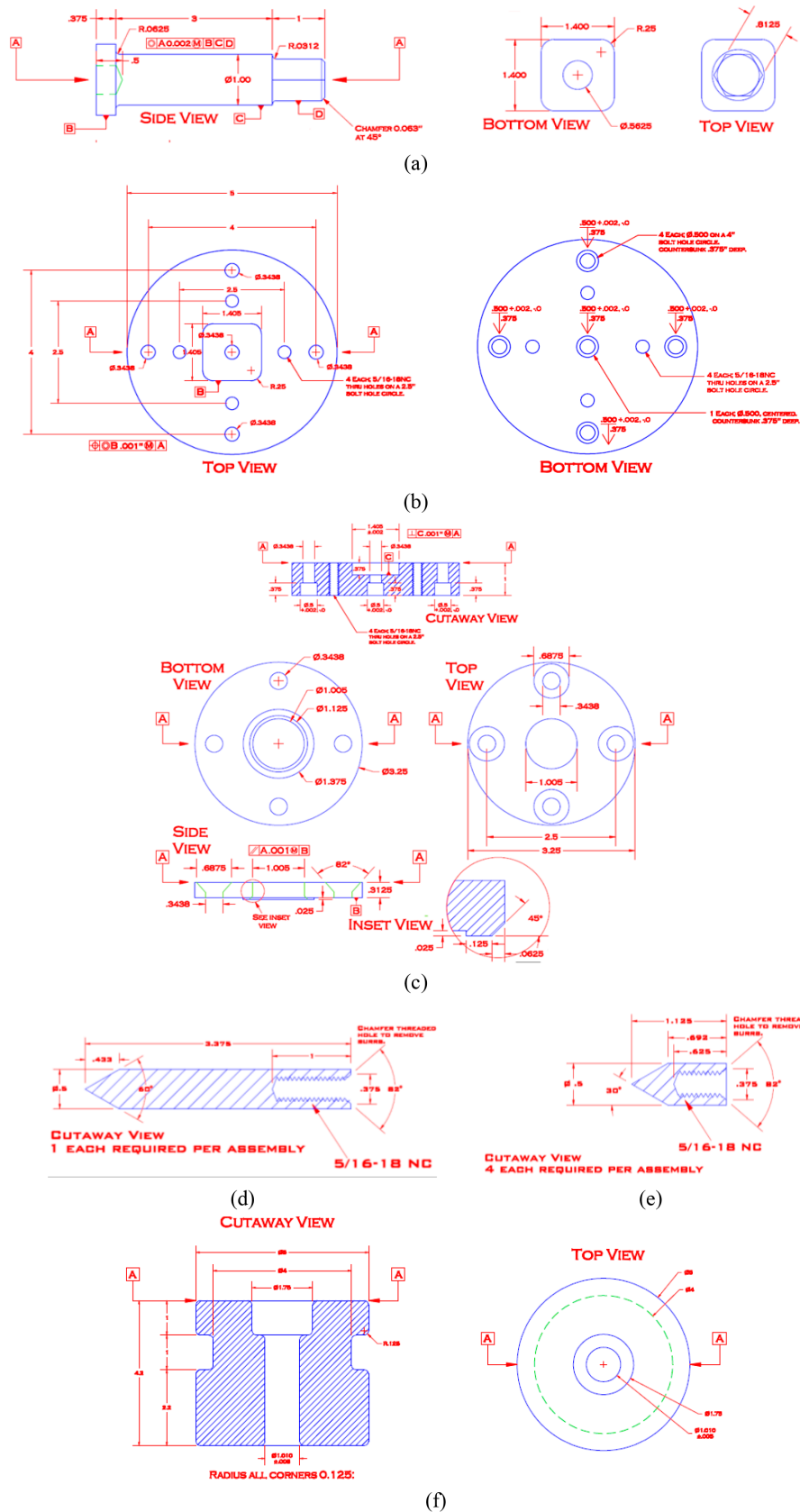


Figure 3.2 Engineering Drawings of the SPRT and LPST Components, With Dimensions in Inches: (a) Shank, (b) Flange, (c) Bottom Plate, (d) Long Pin, (e) Short Pin, and (f) Counterweight (Diefenderfer et al., 2021).

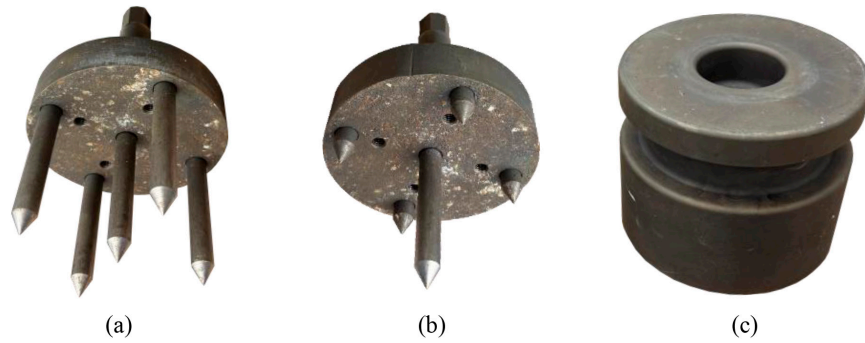


Figure 3.3 Photographs of the (a) Assembled Long-Pin Fixture, (b) Assembled Short-Pin Fixture, and (c) Counterweight.



Figure 3.4 Digital Torque Wrench Used During LPST and SPRT.

the long-pin fixture configuration is used (Figure 3.3a), in which all five pins are long—85.7 mm (3.375 in.)—and penetrate the recycled layer to greater depth, mobilizing the material's bulk shear resistance. The test is performed as follows:

The test surface is prepared by lightly brushing away loose particles at the selected location, which should be located in approximately the center of the lane and away from the wheel paths. The LPST fixture is connected to the DCP upper assembly while lying on its side, and the combined unit is lifted to a vertical position. A bubble level is used to confirm that the base plate is parallel to the pavement surface before driving begins.

The DCP hammer is lifted to the standard drop height and released repeatedly, driving the fixture into the recycled layer (Figure 3.5). The handle is kept plumb throughout the operation, without applying downward pressure. Driving continues until the base plate rests uniformly flush with the pavement surface, at which point the number of blows is recorded. A practical indicator of full seating is a noticeable change in the sound produced by the hammer impact: the impact takes on a duller, deeper tone once the base plate makes full contact with the pavement surface, compared to the sharper sound heard while the pins are still penetrating the material. If the base plate cannot be seated uniformly, the fixture is extracted, and the test is repeated at a new location.

The DCP upper assembly is then removed, and the 9.07-kg (20-lb) counterweight is placed over the upper shaft to prevent uplift. A 21-mm (0.8125-in.) socket is used to attach the digital torque wrench to the upper shaft. Using a template or chalk lines drawn on the pavement surface—a 305-mm (12-in.) line from the center of the base plate, followed by a 102-mm (4-in.) perpendicular line at the far end—the torque wrench is rotated clockwise through the 102-mm (4-in.) arc at a constant rate over approximately 4 s (Figure 3.6). The peak torque is normally recorded in lb-ft.

The proposed AASHTO standard recommends conducting three replicate tests at each test block, with a minimum center-to-center spacing of approximately 305 mm (12 in.) between locations (Figure 3.7). The average of the three

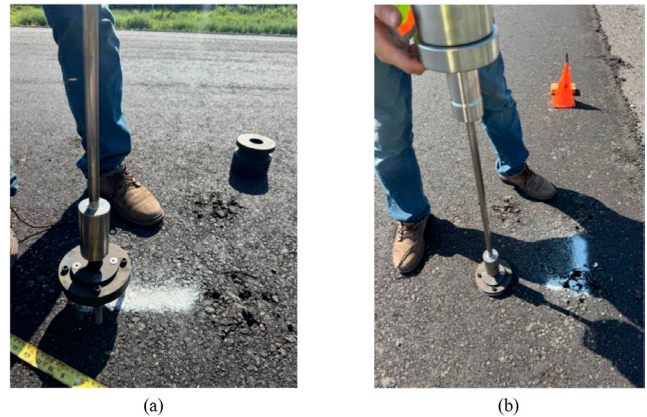


Figure 3.5 Researcher Driving LPST Fixture Using a DCP Hammer.

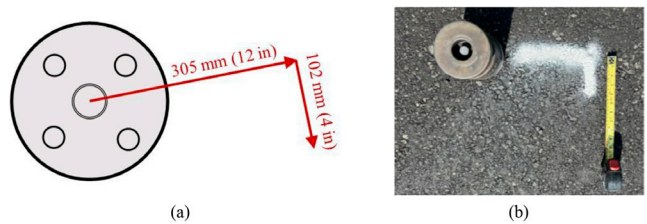


Figure 3.6 (a) Template of the Rotation Required for Torque Measurements and (b) Detail During Field Data Collection.

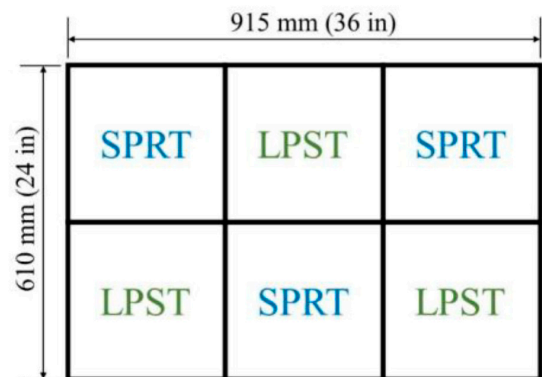


Figure 3.7 Recommended Testing Layout Per Testing Block.

measurements for the number of blows and torque is then compared to the threshold values. Based on the revised threshold values established in NCHRP Web-Only Document 376 (Diefenderfer et al., 2023), the recommended LPST threshold values are 20 blows and 88.4 N·m (65.2 lb-ft) of torque. Both criteria must be satisfied for the layer to be considered ready for surface placement.

3.3.3 Short-Pin Raveling Test Procedure

The SPRT procedure follows the proposed AASHTO Standard Method of Test for Evaluating Raveling Resistance of Asphalt-Treated Recycled Pavement Applications Using a Short-Pin Fixture (Appendix D of NCHRP Research Report 960). The general procedure is identical to the LPST, with the key difference that the short-pin fixture configuration is used (Figure 3.3b), in which only the central pin is long—85.7 mm (3.375 in.)—and the four pins in the perimeter are short—25.4 mm (1.0 in.)—mobilizing the material's near-surface raveling resistance.

The same test block layout is used for both tests (Figure 3.7). After completing one full set of LPST and SPRT replicates at a test block, the fixture is carefully extracted by twisting it slightly clockwise and counterclockwise to unseat it, then removing it vertically. To complete the process properly, any loosened material is tamped back with the counterweight or by foot to restore the layer surface.

The revised SPRT threshold values are 7 blows and 27.8 N·m (20.5 lb-ft) of torque. As with the LPST, both criteria must be met for the layer to be considered ready for opening to traffic.

3.4 Field Testing Plan and Practical Constraints

The original field-testing plan called for site visits to multiple Indiana ATCR pavement projects throughout the 2024 and 2025 construction seasons, covering a variety of recycling processes (CIR, CCPR, and FDR) and recycling agents. It was anticipated that multiple test sessions per project (conducted at progressive intervals following compaction) would enable characterization of strength gain with curing time and comparison with the NCHRP-recommended threshold values.

In practice, the availability of qualifying ATCR projects proved to be a significant constraint. No ATCR projects were identified during the 2024 construction season. In 2025, one project was identified and successfully visited for data collection. The project consisted of a CIR section on SR 13 in Greenfield, Indiana, with field testing beginning in August 2025.

Traffic control limitations at the site further restricted the duration and frequency of visits, making it infeasible to conduct the originally planned dense monitoring during the critical early curing period immediately following compaction and during the first days. Additionally, due to time constraints at the site, SPRT was only conducted once on this project.

Despite these constraints, the SR 13 dataset provides a first, informative benchmark for evaluating the LPST and SPRT under Indiana field conditions and assessing the consistency of local results with the nationally proposed threshold values.

The development of Indiana-specific thresholds will require a substantially expanded field database, encompassing multiple recycling processes, recycling agents, and seasonal conditions, and remains a priority for future construction seasons.

4. FIELD DATA COLLECTION

4.1 Site Description

Field data collection was carried out on a CIR project located on SR 13 in Greenfield, Indiana. Recycling operations were performed using a Wirtgen WR 250i reclaimer with 2.0% asphalt emulsion as the recycling agent and 0.5% cement as the active filler, producing an ATCR layer approximately 102 mm (4 in.) thick. Testing began on the morning of August 8, 2025. Following compaction operations, test locations were selected, and the first measurements were obtained within minutes of the compaction train passing. Additional site visits for data collection were conducted during the following days. Figure 4.1 shows the reclaimer equipment used during recycling operations at the project site.

4.2 Test Equipment

The primary test equipment used in this study consisted of the custom-fabricated LPST and SPRT fixtures described in Section 3.3, along with a DCP upper assembly and a digital torque wrench. As shown in Figure 3.5, the fixtures were first driven into the pavement, and the corresponding blow count was



Figure 4.1 CIR Recycling Operations at SR 13 Project Site.

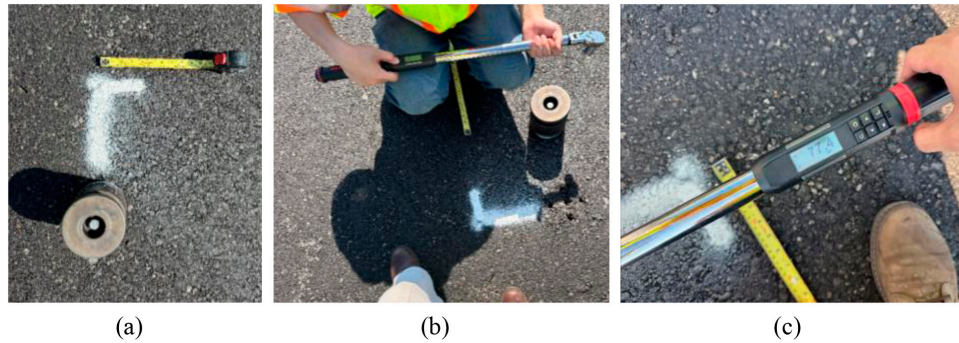


Figure 4.2 Field Testing Activities at SR 13: (a) White Spray Marking and LPST Fixture Before Torque Application, (b) Torque Wrench Positioning Using the Chalk-Line Template, and (c) Digital Torque Wrench Display Showing Peak Torque Reading.

recorded. Figure 4.2 illustrates the white spray marking used to identify the test location and the required rotation angle, the application of the torque wrench, and the corresponding peak torque reading.

4.3 Testing Locations and Data Collection Plan

Three testing locations were established within the SR 13 studied section. Testing conducted at Location 1 captured the evolution of blow count and shear resistance using the LPST over an extended curing period, up to 19 days after compaction, while testing at Locations 2 and 3 assessed short-term variability over a 4-hr window on the day of compaction. The scope of both locations was shaped in part by the traffic control and scheduling constraints described in Section 3.4, which limited the number of test locations, repetitions, and frequency of measurements that could be performed.

LPST and SPRT were conducted at Location 1, with LPST conducted at three different times: Day 0 (August 8, 2025, at 10:00 a.m.), Day 7 (August 15, 2025, at 10:20 a.m.), and Day 19 (August 27, 2025, at 9:30 a.m.); while SPRT was conducted only at Day 0. LPST was conducted at approximately the same time of day across visits, minimizing the influence of diurnal temperature variation on the results. At each visit, the LPST recorded both the number of blows and the peak torque. Testing at Location 1 allowed documenting the strength gain of the CIR layer as curing progressed and comparing the results against the proposed LPST and SPRT threshold values (Diefenderfer et al., 2023).

A second segment of SR 13 included two additional test locations, Locations 2 and 3, where LPST was conducted at five consecutive time points on Day 0 (August 22), from 10:00 a.m. to 2:00 p.m. at 1-hr intervals. Both locations were within the same general test section, separated by a distance sufficient to ensure independent measurements. For each LPST test, the number of blows was recorded five times. Torque readings were collected only at the start (10:00 a.m.) and end (2:00 p.m.) of the observation period due to technical malfunctions with the torque wrench.

In parallel with LPST testing, ATCR material samples were collected from the recycled layer surface at both locations at

each interval. Sealed samples were brought to the laboratory for oven-drying to determine moisture content. This supplementary data was collected to explore potential relationships between surface moisture and LPST results during the early curing period.

5. FIELD TESTING RESULTS AND DISCUSSION

Figure 5.1 presents the LPST results obtained at Location 1 over the 19-day monitoring period following compaction. The triangular blue markers indicate the blow count, while the green circular markers denote torque. Additionally, the blue and green dashed lines represent the proposed NCHRP thresholds previously described.

Both the number of blows and the torque increased substantially with curing time. At Day 0, the Location 1 exhibited an average of 23 blows and 85.1 N·m (62.8 lb-ft) of torque, already exceeding the NCHRP blow count threshold of 20 blows while remaining slightly below the torque threshold of 88.4 N·m (65.2 lb-ft). By Day 7, both parameters had increased markedly to 84 blows and 207.0 N·m (152.7 lb-ft), respectively. They continued to rise through Day 19, reaching 168 blows and a torque exceeding the instrument capacity, > 406.7 N·m (> 300 lb-ft).

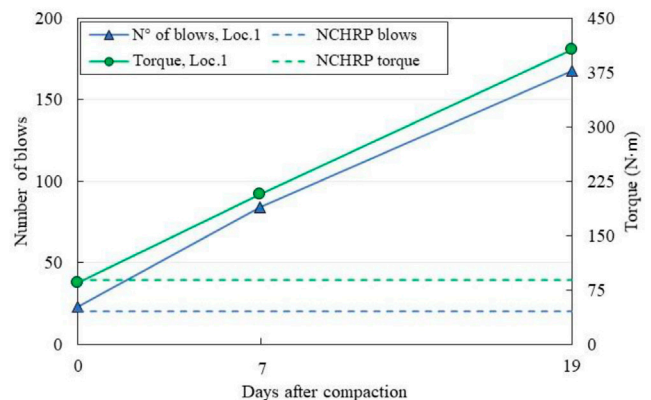


Figure 5.1 LPST Blow Count and Torque Results at Location 1 as Function of Curing Days—SR 13 (Greenfield, IN, 2025).

The results indicate a rapid gain in structural integrity during the first curing days, consistent with emulsion breaking and progressive mixture stiffening over time. From Day 0 to Day 7, the blow count increased by 61 blows (8.7 blows/day), and from Day 7 to Day 19, by an additional 84 blows (7.0 blows/day). A more linear trend was observed for the torque results, with increases of 17.35 N·m/day (12.8 lb-ft/day) from Day 0 to Day 7 and 16.68 N·m (12.3 lb-ft/day) from Day 7 to Day 19. These trends are consistent with the literature on ATCR materials, which generally reports that strength gains are more pronounced during the initial curing stages. Nevertheless, the values measured after 7 days were substantially above the proposed thresholds, suggesting that the material could adequately allow traffic opening or overlay placement, in accordance with the NCHRP study recommendations. These findings further indicate that evaluation at shorter curing intervals may be necessary to better validate the proposed thresholds.

Figure 5.2 presents the LPST blow count results recorded at Locations 2 and 3 during the first four hours following compaction on August 22, 2025, along with the corresponding air temperature measurements. Triangular and square blue markers indicate the number of blows at Locations 2 and 3, respectively, while circular and diamond green markers represent the torque values at Locations 2 and 3, respectively. Blue and green dashed lines indicate the proposed NCHRP thresholds. Additionally, orange cross markers denote the air temperature recorded at each testing interval.

At both locations, blow counts ranged from 17 to 22 throughout the monitoring period, with Location 2 recording 18 to 21 blows and Location 3 recording 17 to 22 blows. Torque was measured only at 0 and 4 hr after compaction, yielding values of 82.6 and 73.4 N·m (60.9 and 54.1 lb-ft) at Location 2, and 76.4 and 67.7 N·m (56.4 and 49.9 lb-ft) at Location 3. All torque values remained below the NCHRP threshold of 88.4 N·m (65.2 lb-ft). Air temperature increased from 20.0 °C to 25.0 °C over the same period.

While strength development would typically be expected during curing, the results obtained during the evaluated 4-hr window showed a slight decreasing trend at both locations.

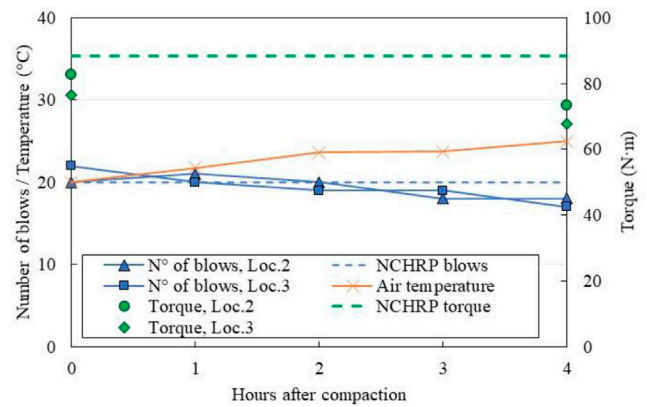


Figure 5.2 LPST Blow Count, Torque, and Air Temperature Measurements at Locations 2 and 3 as a Function of Time After Compaction—SR 13 CIR (Greenfield, IN, 2025).

Blow counts decreased from 20 to 18 blows at Location 2 and from 22 to 17 blows at Location 3. Similarly, torque values decreased 9.2 N·m (6.8 lb-ft) at Location 2 and 8.7 N·m (6.4 lb-ft) at Location 3. A similar decreasing trend during the first hours after compaction was also reported in NCHRP Web-Only Document 376 for emulsion ATCR materials, though no definitive explanation was provided. In the present study, the concurrent 5 °C rise in air temperature over the 4-hr monitoring window suggests a potential influence of thermal conditions on early LPST results; however, the limited dataset and the absence of a controlled temperature variable prevent this hypothesis from being confirmed.

Table 5.1 summarizes all LPST and SPRT field measurements collected at the three test locations on SR 13. The table includes the test location, testing date, curing time (expressed in days or hours, depending on the monitoring period), test type, blow count, torque reading, moisture content, and air temperature at the time of testing. Moisture content measurements

TABLE 5.1
Summary of LPST and SPRT Field Test Results—SR 13 CIR (Greenfield, IN, 2025).

Loc.	Date	Curing Days	Curing Hours	Test	Blow Count	Torque (N·m)	Moisture Content (%)	Air Temperature (°C)
1	8/8/2025	0	0	SPRT	7	36.1	-	26.50
1	8/8/2025	0	0	LPST	23	85.1	-	26.50
1	15/8/2025	7	n/a	LPST	84	207.0	-	27.11
1	27/8/2025	19	n/a	LPST	168	> 406.7	-	17.11
2	22/8/2025	0	0	LPST	20	82.6	4.0	20.00
2	22/8/2025	0	1	LPST	21	-	3.7	21.78
2	22/8/2025	0	2	LPST	20	-	-	23.61
2	22/8/2025	0	3	LPST	18	-	3.4	23.72
2	22/8/2025	0	4	LPST	18	73.3	3.2	25.00
3	22/8/2025	0	0	LPST	22	76.5	4.0	20.00
3	22/8/2025	0	1	LPST	20	-	3.8	21.78
3	22/8/2025	0	2	LPST	19	-	3.4	23.61
3	22/8/2025	0	3	LPST	19	-	3.3	23.72
3	22/8/2025	0	4	LPST	17	67.7	3.3	25.00

†NCHRP 09-62 min. thresholds (Diefenderfer et al., 2023): LPST—20 blows, 88.4 N·m (65.2 lb-ft); and SPRT—7 blows, 27.8 N·m (20.5 lb-ft). Both criteria must be met simultaneously.

were only available for selected LPST measurements conducted during the short-term monitoring period (Locations 2 and 3).

According to INDOT Specifications Sections 416 and 417 (INDOT, 2022), ATCR pavements must cure for a minimum of 3 days and reach a moisture content below 3.0% before overlay placement is permitted. The moisture content measured at Locations 2 and 3 dropped from 4.0% to 3.3%–3.2% during the first four hours after compaction, indicating that the 3.0% moisture threshold had not yet been reached. However, the LPST blow count result at Location 1 on Day 0 (23 blows) already exceeded the NCHRP threshold of 20 blows, while the corresponding torque measurement of 85.1 N·m (62.8 lb-ft) remained slightly below the 88.4 N·m (65.2 lb-ft) threshold. Notably, the SPRT results at Day 0 satisfied both threshold criteria simultaneously—7 blows and 36.1 N·m (26.6 lb-ft), compared with thresholds of 7 blows and 27.8 N·m (20.5 lb-ft)—suggesting that the mixture had already developed sufficient early strength to allow traffic opening shortly after compaction. Similarly, the LPST blow count results measured at Locations 2 and 3 during the first hours after compaction also satisfied the proposed threshold criteria. Nevertheless, these measurements showed a slight downward trend over time, which warrants further investigation to better understand the underlying mechanisms.

These findings suggest that strength-based criteria, such as the LPST or SPRT, may be able to identify overlay placement readiness earlier than the current time- and moisture-based criteria prescribed by INDOT. Nevertheless, further research is needed to validate this hypothesis and establish reliable implementation criteria.

6. ASSESSMENT OF STRENGTH-BASED ACCEPTANCE CRITERIA

The field results obtained at SR 13 provided a limited but informative snapshot of the early mechanical behavior of a CIR layer stabilized with 2.0% asphalt emulsion and 0.5% cement. While the dataset is insufficient for formal statistical validation of the NCHRP threshold values, the observed trends are broadly consistent with the mechanistic understanding of curing in ATCR materials and with findings from previous NCHRP research (Diefenderfer et al., 2021, 2023).

The progressive strength gain observed at Location 1 between Day 0 and Day 19 reflects the sequential nature of the curing process described in the literature: emulsion breaking in the hours immediately following compaction, followed by gradual water evaporation and consolidation of the asphalt binder film around aggregate particles. The fact that both LPST blow count and torque approached or exceeded the proposed NCHRP thresholds on Day 0, within minutes of compaction completion, suggests that emulsion breaking occurred rapidly under the warm and dry conditions present during construction. This observation is consistent with the known sensitivity of emulsion breaking rate to ambient temperature and mixture composition.

The slight decreasing trend in both blow count and torque observed at Locations 2 and 3 during the first four hours after compaction is less straightforward to interpret mechanistically. One plausible explanation is that thermal softening of the freshly

placed mixture, as air temperatures increased, temporarily reduced its resistance to pin penetration and rotation, partially offsetting any early strength gains associated with emulsion breaking. This hypothesis is consistent with the known temperature sensitivity of weakly bound ATCR granular materials (Orosa, Pérez, Pasandín, & Haddock, 2023) and with similar observations reported in the referenced NCHRP 09-62 study (Diefenderfer et al., 2023). Nevertheless, a definitive mechanistic explanation remains uncertain. Controlled laboratory testing under varying temperature and moisture conditions would be required to isolate and quantify these competing effects.

Taken together, the SR 13 results suggest that the NCHRP threshold values for the LPST and SPRT are practically attainable within the first day after construction for CIR mixtures stabilized with asphalt emulsion under favorable climatic conditions, and that the current INDOT 3-day curing requirement may be conservative in such cases. If confirmed through broader field validation, this finding would support earlier overlay placement and traffic opening decisions, with direct benefits for construction scheduling and lane closure durations. However, given the limited scope of the field dataset, this interpretation should be considered a preliminary hypothesis rather than a definitive conclusion.

From a practical standpoint, the consistency between the SR 13 results and the NCHRP threshold values raises the question of whether Indiana-specific thresholds must be developed independently or whether the nationally proposed values could be adopted directly by INDOT. Based on the available evidence, direct adoption appears plausible for CIR mixtures stabilized with asphalt emulsion and cement under summer conditions similar to those evaluated in this study. However, a single field project conducted under favorable climatic conditions is insufficient to generalize this conclusion across the full range of mixture types, recycling agents, active filler contents, and seasonal conditions encountered in Indiana practice. In particular, the behavior of ATCR layers placed under cooler or wetter conditions, where emulsion breaking and moisture evaporation are substantially slower, remains uncharacterized in the Indiana context.

Nonetheless, the results of this study demonstrate that the LPST and SPRT are feasible and informative tools for evaluating early strength development in CIR pavements under Indiana field conditions, and that the NCHRP threshold values provide a meaningful and practically relevant benchmark for interpreting their results. Expanding the field dataset to encompass a broader range of projects, seasons, and mixture types remains the critical next step toward establishing a reliable, regionally grounded framework for strength-based acceptance of ATCR pavements in Indiana.

7. LOCAL PAVEMENT ME DESIGN INPUTS FOR CIR MIXTURES

The mechanistic-empirical pavement design framework implemented in AASHTOWare Pavement ME Design requires layer-specific dynamic modulus ($|E^*|$) values to characterize the viscoelastic behavior of bound pavement layers. As discussed in Chapter 2, the absence of regionally calibrated $|E^*|$ data for ATCR materials in Indiana has led practitioners

to rely on nationally derived default values or approximations based on other materials' mechanical properties. To address this gap, a laboratory CIR mixture was prepared using RAP and an emulsion produced in Indiana, and tested for dynamic modulus following the AASHTO T 378-22, Standard Method of Test for Determining the Dynamic Modulus and Flow Number for Asphalt Mixtures Using the Asphalt Mixture Performance Tester (AMPT; AASHTO, 2022). This mixture, referred to as the Indiana CIR mixture, differs from the SR 13 field mixture evaluated in Chapters 4 through 6, which included 0.5% Portland cement as active filler; the Indiana CIR mixture contains no active filler, providing a baseline characterization for emulsion-only CIR applications. This chapter presents the material characterization, specimen preparation, and dynamic modulus results, and compares the findings with the Level 3 input ranges proposed in NCHRP Research Report 863 (Schwartz et al., 2017), providing a baseline for establishing Indiana-specific Pavement ME Design inputs for ATCR mixtures.

7.1 Materials, Specimen Preparation, and Curing

The RAP used in this study was sourced from a local quarry in Lafayette and characterized prior to mixture preparation. Gradation analysis was performed on five randomly selected RAP samples to assess material consistency. The average gradation curve and maximum density line are presented in Figure 7.1, indicating a gradation representative of commonly reported CIR RAP sources, characterized by a relatively coarse aggregate distribution and a deficiency of fines. The standard deviation of percent passing was below 1.6% across all sieve sizes, confirming a highly uniform RAP source. The recycling agent used was a cationic asphalt emulsion with a residual asphalt content of 64.7%. The mixture was proportioned with an emulsion content of 4.0% and an added water content of 2.5% by dry weight of RAP, based on a previous mixture design, resulting in a residual binder content of approximately 2.6% by dry weight of RAP.

Cylindrical specimens were prepared at room temperature using a Superpave Gyratory Compactor (SGC) at 100 gyrations.

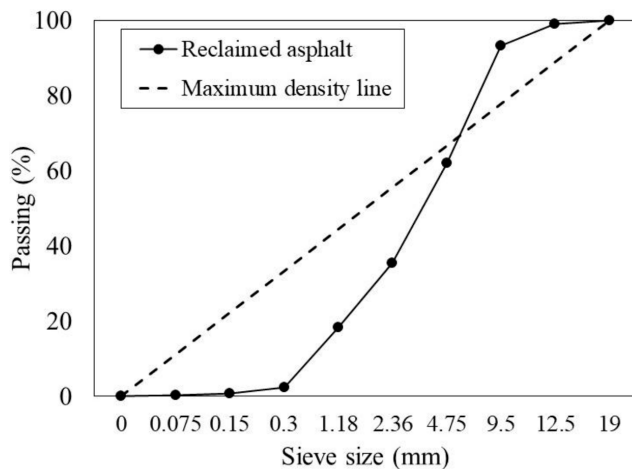


Figure 7.1 Gradation of RAP Sourced From Lafayette, IN.

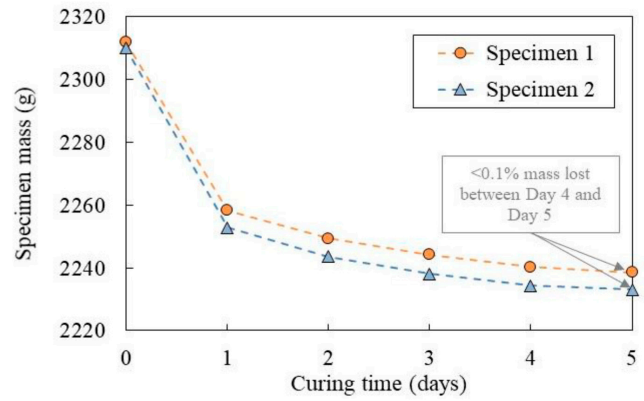


Figure 7.2 Mass Loss During Oven Curing at 40 °C.

Two replicate specimens were fabricated, each with a diameter of 100 mm and heights of 137.0 and 139.4 mm, respectively. The theoretical maximum specific gravity (G_{mm}) of the mixture was 2.432, while the bulk specific gravity (G_{mb}) values measured after compaction were 2.148 and 2.110, corresponding to air void contents of 11.69% and 13.24%, respectively. Following material curing, the evaporation of residual moisture increased the air void content to 14.50% and 16.14%. This behavior is consistent with that expected for emulsified CIR mixtures, in which voids initially occupied by water become part of the air void structure after moisture loss.

The curing protocol consisted of placing the specimens in a forced-draft oven at 40 °C to simulate accelerated curing. Specimen mass was recorded daily to monitor moisture loss. As shown in Figure 7.2, mass loss was most pronounced during the first 24 hr, after which the rate decreased substantially. Curing was considered complete when the daily mass loss fell below 0.1% of the total specimen mass, a criterion met after 5 days of oven curing.

7.2 Dynamic Modulus Testing

Dynamic modulus testing was performed on both specimens after curing was complete using an AMPT in accordance with AASHTO T 378 (Figure 7.3; AASHTO, 2022). Testing was conducted at three temperatures (5, 25, and 35 °C) and three loading frequencies (10, 1, and 0.1 Hz), yielding a total of nine test conditions per specimen. The average measured $|E^*|$ values are summarized in Table 7.1.

As observed in Table 7.1, the between-specimen COV ranged from 2.4% to 14.9%, with higher variability observed at elevated temperatures and low frequencies, consistent with findings reported in the literature for cold-recycled mixtures.

The measured $|E^*|$ values were used to calibrate an AASHTO sigmoidal master curve at a reference temperature of 21.1 °C, following the model in Equation 7.1:

$$\log(E^*) = \delta + \frac{\alpha}{1 + e^{\beta + \gamma \cdot \log(f_r)}} \quad \text{Equation 7.1}$$

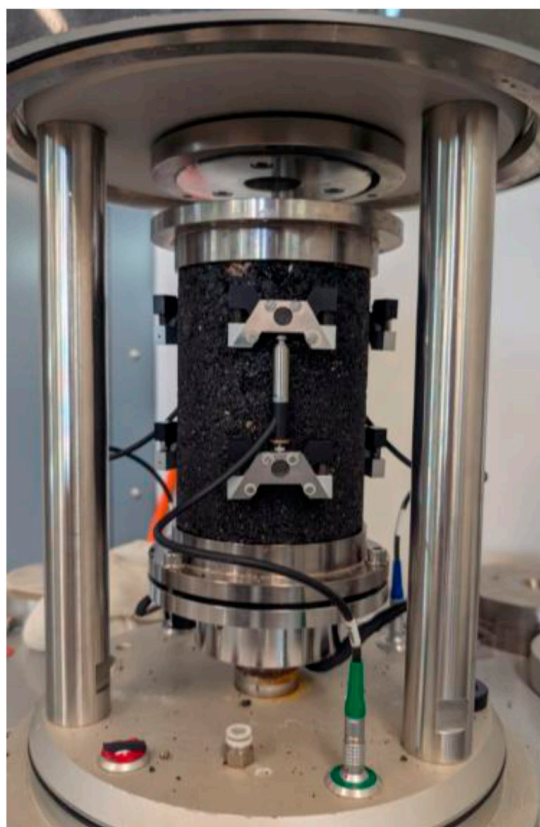


Figure 7.3 Indiana CIR Specimen Mounted in the AMPT Before Dynamic Modulus Testing.

TABLE 7.2
Sigmoidal Model Parameters.

Parameter	Symbol	Value
Lower asymptote	δ	1.096
Range	α	3.193
Shape parameter	β	-0.937
Shape parameter	γ	-0.39
Quadratic shift factor	c_1	0
Linear shift factor	c_2	-0.125
Constant shift factor	c_3	2.651
Reference temperature	$T_{ref} (^{\circ}C)$	21.1
Sum of squared errors	SSE	0.0018

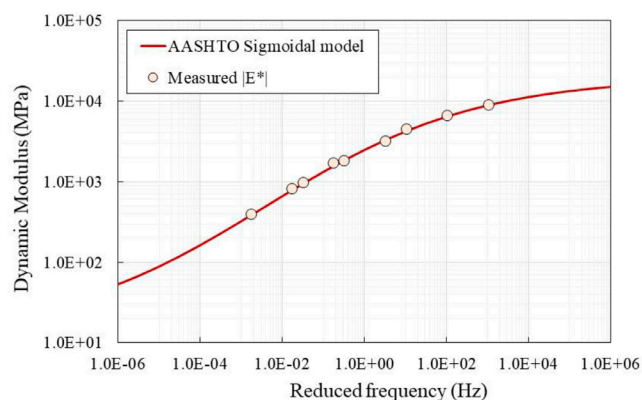


Figure 7.4 Dynamic Modulus Master Curve for Lab-Prepared Indiana CIR Mixture at a Reference Temperature of 21.1 °C.

TABLE 7.1
Measured $|E^*|$ Values by Temperature and Frequency—Individual Specimens, Average, and Coefficient of Variation (COV).

Temperature ($^{\circ}C$)	Frequency (Hz)	Specimen 1 (MPa)	Specimen 2 (MPa)	Average (MPa)	COV (%)
5	10	8691	8991	8841	2.4
5	1	6249	6667	6458	4.6
5	0.1	4217	4641	4429	6.8
25	10	3067	3199	3133	3
25	1	1716	1836	1776	4.8
25	0.1	891	996	943	7.9
35	10	1577	1745	1661	7.1
35	1	732	859	796	11.3
35	0.1	344	425	385	14.9

Where $\log(f_r)$ is the logarithm of the reduced frequency at the reference temperature, defined as:

$$\log(f_r) = \log(f) + \log(a_T) \quad \text{Equation 7.2}$$

The logarithm of the shift factor, $\log(a_T)$, was expressed as a linear function of temperature (Equation 7.3), with the quadratic term equal to zero ($c_1 = 0$) given the limited number of tests:

$$\log(a_T) = c_2 \cdot T + c_3 \quad \text{Equation 7.3}$$

The calibrated model parameters are summarized in Table 7.2, and the resulting master curve is shown in Figure 7.4, along with the measured average data points. The low sum of squared errors (SSE = 0.0018) indicates excellent agreement between the measured and predicted values.

7.3 Comparison With National Reference Input Values

Table 7.3 presents the suggested Level 3 $|E^*|$ input ranges for CIR projects reported in NCHRP Research Report 863 (Schwartz et al., 2017), and Table 7.4 presents the corresponding values

TABLE 7.3
NCHRP 863 Suggested $|E^*|$ Value Ranges for CIR Projects.

Temp. (°C)	Dynamic Modulus (MPa)					
	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz
-10	5598–9929	5196–8788	4889–7937	4174–6055	3869–5305	3184–3752
4.4	6294–11493	5907–10354	5608–9488	4899–7511	4590–6695	3879–4940
21.1	3758–5040	3367–4146	3079–3533	2338–2450	1923–2199	1174–1673
37.8	1631–1917	1404–1632	1126–1434	652–1038	509–894	280–618
54.4	587–809	456–587	104–385	148–251	84–192	52–104

TABLE 7.4
Predicted $|E^*|$ Values for Indiana CIR Mixture.

Temp. (°C)	Dynamic Modulus (MPa)					
	25 Hz	10 Hz	5 Hz	1 Hz	0.5 Hz	0.1 Hz
-10	13777	13038	12438	10924	10228	8547
4.4	9990	9035	8301	6607	5901	4378
21.1	5031	4202	3626	2481	2075	1329
37.8	1628	1253	1021	624	503	306
54.4	384	290	235	148	122	81

predicted by the calibrated Indiana CIR master curve at the standard Pavement ME Design temperature-frequency combinations.

To allow simpler comparison, Figure 7.5 presents a graphical representation of the Indiana CIR mixture $|E^*|$ values against the NCHRP Report 863 range across the five standard test temperatures and at the different frequencies.

At low temperatures (–10 °C and 4.4 °C), the Indiana CIR mixture exhibits $|E^*|$ values above or near the upper bound of the NCHRP 863 reference range. At intermediate temperature (21.1 °C), the Indiana CIR mixture falls near the upper end of the reference range. At elevated temperatures (37.8 °C and 54.4 °C), the Indiana CIR mixture $|E^*|$ approaches or falls below the lower bound of the NCHRP range, particularly at higher loading frequencies, indicating greater susceptibility to temperature softening than the broader CIR dataset reported in NCHRP 863. This behavior may partially reflect differences in mixture composition, as the national dataset included not only emulsified CIR mixtures without active filler, but also mixtures containing active fillers such as Portland cement, which are known to exhibit higher stiffness at elevated temperatures. Additionally, differences in specimen air-void content and potential in-service densification of the field cores included in the NCHRP 863 dataset may collectively contribute to the observed differences.

Overall, the Indiana CIR dynamic modulus is broadly consistent with the NCHRP 863 reference values, confirming that the master curve developed in this study is representative of the CIR material behavior documented in the literature. The resulting $|E^*|$ values may be used as Level 1 inputs in Pavement ME Design for Indiana CIR projects with similar material composition, offering a locally derived alternative to the NCHRP 863 catalog values; however, given that the characterization was performed

on a single RAP source using laboratory-compacted specimens, validation through dynamic modulus testing of field cores from multiple Indiana projects is recommended before adopting these values for routine design practice.

8. RECOMMENDATIONS FOR INDOT

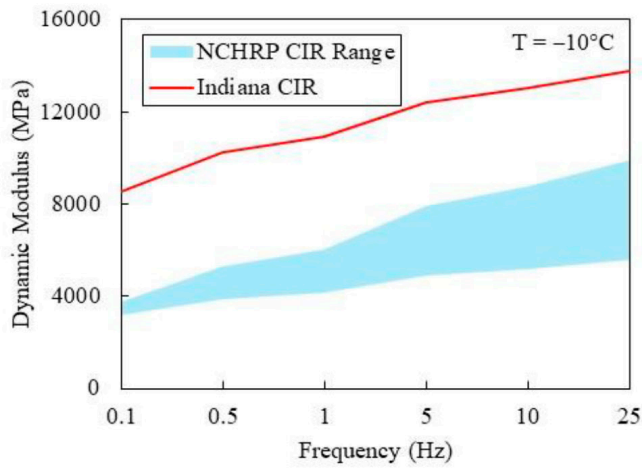
8.1 Potential Implementation of Rapid Strength Tests

The results of this study indicate that the LPST and SPRT have potential as practical tools for evaluating the readiness of CIR layers for traffic opening and overlay placement in Indiana. Both tests are portable, rapid, and can be performed by a single technician, making them suitable for typical construction site conditions. The NCHRP threshold values—20 blows and 88.4 N·m (65.2 lb-ft) torque for the LPST, and 7 blows and 27.8 N·m (20.5 lb-ft) torque for the SPRT—provided a meaningful basis for interpreting the SR 13 field results and may serve as interim benchmark values pending additional regional validation.

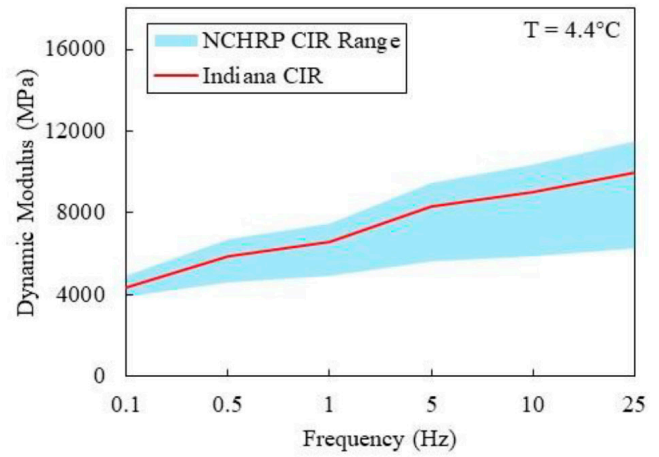
INDOT is encouraged to implement the LPST and SPRT on future ATCR construction projects on a trial basis, initially as supplementary measurements used alongside the current time- and moisture-based requirements. This approach would allow the agency to become familiar with the testing procedures and to accumulate additional field performance data without modifying existing specification requirements. Preliminary field observations from SR 13 suggest that the proposed LPST and SPRT threshold values may be met earlier than INDOT's current requirements of a minimum 3-day curing period and moisture content below 3.0%. If confirmed through additional field validation, the use of strength-based acceptance criteria could provide significant opportunities to accelerate construction schedules, reduce lane closure durations, and minimize traffic disruption while maintaining adequate early structural stability of the recycled layer. Once a broader field database has been established, a formal evaluation should be conducted to determine whether the NCHRP threshold values are directly applicable to Indiana conditions or require regional calibration.

8.2 Recommended Future Data Collection Strategy

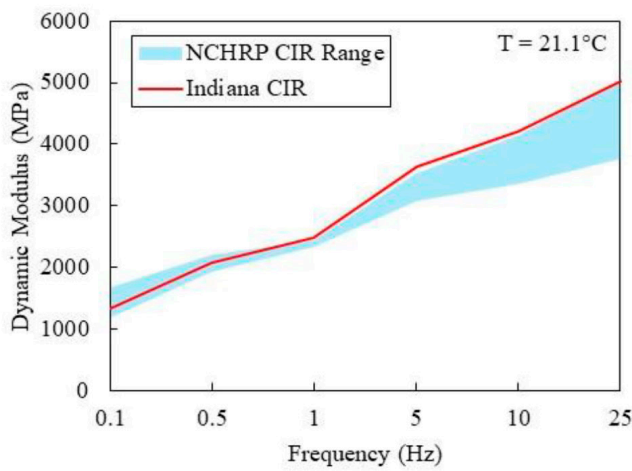
To establish a robust basis for strength-based acceptance of ATCR pavements in Indiana, future data collection efforts should address the limitations identified in this study. The following priorities are recommended:



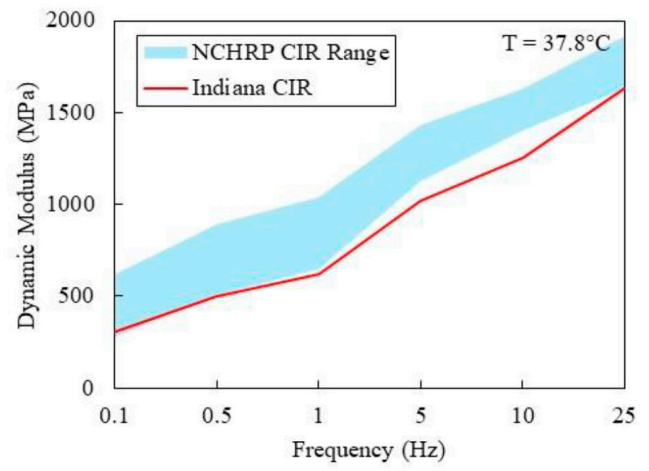
(a)



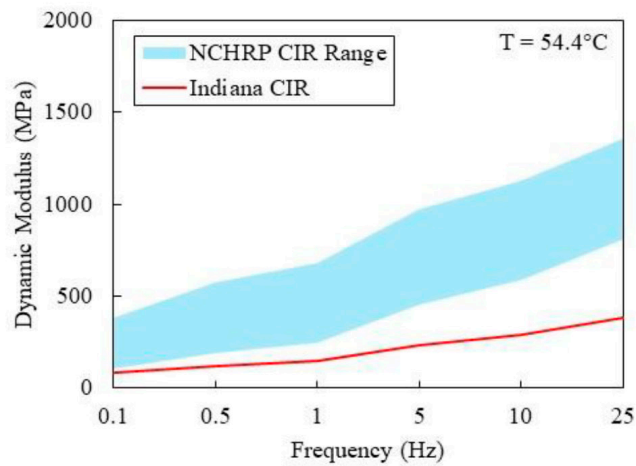
(b)



(c)



(d)



(e)

Figure 7.5 Dynamic Modulus of the Indiana CIR Mixture Compared to the Range Reported for CIR Mixtures in NCHRP Report 863 at Five Test Temperatures: (a) -10°C , (b) 4.4°C , (c) 21.1°C , (d) 37.8°C , and (e) 54.4°C .

- Evaluation of multiple recycling process types, including CIR, CCPR, and FDR, incorporating different recycling agents and active filler contents to assess the applicability of the NCHRP threshold values to Indiana conditions and determine whether regional calibration or adjustment is required across the range of practices used in the state.
- Testing under different seasonal conditions, with particular emphasis on spring- and fall-construction projects, where lower temperatures and higher moisture levels may significantly slow curing and affect LPST and SPRT results.
- Denser monitoring during the first three days after compaction, including measurements at Days 1, 2, and 3, which were not captured in this study due to traffic control and construction schedule constraints. This period is especially critical for evaluating whether the proposed NCHRP thresholds are met before the current INDOT minimum curing period of three days and before achieving the specified moisture threshold.
- Implementation of LPST and SPRT measurements following the complete test block layout recommended in the NCHRP study (Figure 3.7), including a minimum of three replicate measurements per block with a center-to-center spacing of 305 mm (12 in.). This approach would provide statistically representative results and enable meaningful comparisons between the two test methods at each monitoring interval.

8.3 Steps Needed to Develop Indiana-Specific Thresholds

Expanding the Indiana field database is a prerequisite for determining whether the NCHRP 09-62 threshold values can be directly adopted or whether regional calibration is required. The following sequential steps are recommended to support this determination:

- Expand the Indiana field database through evaluation of at least five to ten additional ATCR projects representing the range of materials, recycling processes, and seasonal conditions described in Section 8.2.
- Conduct a statistical comparison between the Indiana field results and the NCHRP Phase III and Phase IV datasets used to establish the existing threshold values, to determine whether the Indiana measurements fall within the same statistical distribution.
- Based on this analysis, determine whether the NCHRP threshold values can be directly adopted for Indiana conditions or whether regional calibration is required. If calibration is deemed necessary, develop Indiana-specific threshold values using the expanded dataset following the methodology established in NCHRP Project 09-62.
- Incorporate the validated threshold values into INDOT Specifications Sections 416 and 417 as either an alternative or supplementary acceptance criterion to the current time- and moisture-based requirements.

8.4 Dynamic Modulus Data for AASHTOWare Pavement ME Design

The dynamic modulus master curve developed in this study for the Indiana CIR mixture represents a first step toward establishing locally derived Level 1 inputs for Pavement ME Design. INDOT is encouraged to incorporate dynamic modulus characterization into future CIR research projects, with the following recommendations:

- Expand dynamic modulus testing to additional Indiana CIR projects with varying RAP sources, recycling agents, and active filler contents to develop a statewide database of material properties.
- Prioritize testing of field cores from in-service CIR layers to validate the laboratory-derived master curve and assess the influence of field compaction conditions and long-term curing on stiffness.
- Consider adopting the Indiana-specific $|E^*|$ values presented in Table 7.4 as interim Level 1 inputs for emulsion-only CIR mixtures with a similar mixture design, pending broader regional validation.

9. SUMMARY OF FINDINGS AND FUTURE WORK

9.1 Findings

This study evaluated the feasibility of rapid in-situ strength testing methods for asphalt-treated cold recycled pavements under Indiana conditions and within the context of INDOT practice, with a secondary objective of characterizing the dynamic modulus of a locally produced CIR mixture for use as input in AASHTOWare Pavement ME Design. The following key findings are reported.

9.1.1 Field Evaluation of LPST and SPRT

Field testing was conducted on a CIR project on SR 13 in Greenfield, Indiana, using asphalt emulsion as the recycling agent and cement as active filler. At Location 1, LPST results showed a rapid and consistent increase in structural integrity with curing time, with blow counts increasing from 23 at Day 0 to 168 at Day 19 and torque values rising from 85.1 N·m (62.8 lb-ft) to beyond the instrument's capacity of 406.7 N·m (300 lb-ft). The LPST blow count threshold (20 blows) was already exceeded at Day 0, with the torque value of 85.1 N·m (62.8 lb-ft) falling only marginally below the 88.4 N·m (65.2 lb-ft) criterion. By Day 7, both threshold values were simultaneously satisfied by a wide margin—84 blows and 207.0 N·m (152.7 lb-ft). However, the absence of measurements between Day 0 and Day 7 prevents the determination of the exact time at which both criteria were simultaneously met, a key gap for future field monitoring programs. The single SPRT measurement conducted at Day 0 at Location 1 satisfied both threshold criteria simultaneously—7 blows and 36.1 N·m (26.6 lb-ft). Yet, this result was obtained within minutes of compaction completion, before significant curing had occurred, and should therefore be interpreted with caution. Additional early-age SPRT measurements from multiple projects would be needed to better understand this test's behavior at very early curing stages.

9.1.2 Short-Term Variability

LPST measurements collected at Locations 2 and 3 during the first four hours after compaction showed blow counts ranging from 17 to 22 blows and torque values ranging from 82.6 to 67.7 N·m (60.9 to 49.9 lb-ft), with a slight decreasing trend observed throughout the monitoring period. This trend is counterintuitive, as the concurrent reduction in moisture content would generally be expected to contribute to progressive

strength gain rather than strength loss. Yet, the approximately 5 °C increase in air temperature occurred during the same period may provide a more plausible explanation, as elevated temperatures are known to reduce asphalt binder stiffness and may temporarily offset early curing-related strength gains in emulsion-based mixtures. A similar decreasing trend during the first hours after compaction was reported in NCHRP Web-Only Document 376 for emulsion-based ATCR materials, although no definitive explanation has yet been provided.

The limited dataset collected in this study does not allow this hypothesis to be confirmed, and further investigation is warranted. Blow count thresholds were satisfied during the initial measurements at Locations 2 and 3; however, values decreased throughout the 4-hr monitoring period, falling below the 20-blow criterion by the end of the monitoring window, and torque values remained below the 88.4 N·m (65.2 lb-ft) threshold throughout the monitoring period.

9.1.3 Dynamic Modulus Characterization

A dynamic modulus master curve was developed for an Indiana CIR mixture using the sigmoidal model, calibrated from laboratory measurements at 5, 25, and 35 °C and six loading frequencies. Post-curing air void contents of 14.5% and 16.1% were recorded. The Indiana mixture exhibited dynamic modulus values above or near the upper bound of the NCHRP 863 reference range at low temperatures (−10 °C and 4.4 °C), near the upper end of the range at intermediate temperatures (21.1 °C), and at or below the lower bound at elevated temperatures (37.8 °C and 54.4 °C). These differences are attributed to a combination of factors, including the absence of active filler, differences in specimen air void content, and potential in-service densification of the field cores in the NCHRP 863 dataset. The resulting $|E^*|$ values may be used as Level 1 inputs in AASHTOWare Pavement ME Design for emulsion-only Indiana CIR projects.

9.2 Future Work

The following areas are identified as priorities for future research to build upon the findings of this study:

- Dynamic modulus characterization of field cores: Validation of the laboratory-derived master curve through testing of field cores from Indiana ATCR projects is needed to assess the influence of field compaction conditions and long-term in-situ curing on stiffness properties, and to establish regionally calibrated Pavement ME Design inputs for routine use.
- Correlation between mechanical properties and LPST/SPRT results: Establishing relationships between LPST and SPRT measurements and laboratory-measured mechanical properties, such as dynamic modulus and resilient modulus, would strengthen the mechanistic foundation of the threshold values and support the future development of Indiana-specific calibration.
- Development of Indiana-specific threshold values: Once a sufficient field database has been accumulated following the strategy outlined in Chapter 8, a statistical comparison with the NCHRP 09-62 Phase III and Phase IV datasets should be conducted to determine whether the proposed national threshold values are directly applicable to Indiana conditions or whether regional calibration is required.

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About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1 — evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,600 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at docs.lib.purdue.edu/jtrp/.

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