Scientific Research Publishing

Open Journal of Civil Engineering, 2026, 16(3), 427-442
https://www.scirp.org/journal/ojce
ISSN Online: 2164-3172
ISSN Print: 2164-3164

Mechanistic-Empirical Pavement Design of I-285 Interstate Highway by Multi-Scale Field and Laboratory Evaluation Techniques

Umit Seyhan[1], John Rogers[2], Vaishnavi Dabir[2*], Afshin Amini[2], Jeffery C. Sizemore[2], Stephanie M. Grahl[2]

[1]WSP USA Inc., Atlanta, GA, USA
[2]MC Squared LLC, Kennesaw, GA, USA
Email: *vdabir@mc2engineers.com

How to cite this paper: Seyhan, U., Rogers, J., Dabir, V., Amini, A., Sizemore, J.C. and Grahl, S.M. (2026) Mechanistic-Empirical Pavement Design of I-285 Interstate Highway by Multi-Scale Field and Laboratory Evaluation Techniques. *Open Journal of Civil Engineering*, **16**, 427-442.
https://doi.org/10.4236/ojce.2026.163022

Received: June 17, 2026
Accepted: July 18, 2026
Published: July 21, 2026

Abstract

The rapid deterioration of aging concrete pavements on high-volume highway systems presents a critical challenge for transportation agencies tasked with maintaining safety, mobility, and structural integrity under increasing traffic loads. Interstate 285 highway, one of the busiest freight and commuter corridors in Georgia, the USA, exemplifies the compounded pressures of advanced pavement age, insufficient historical rehabilitation, and extreme loading demands. Conventional evaluation methods, often limited to localized deflection testing or surface distress surveys, fail to capture the spatial and structural complexities required for sustainable rehabilitation design. This study introduces an integrated evaluation methodology that combines continuous deflection sensing, subsurface profiling, and mechanistic interpretation to develop a high-resolution structural performance map across a 17.4-mile corridor. A key innovation lies in the use of denoised deflection velocity signals to estimate joint load transfer efficiency at fine intervals, enabling targeted identification of deteriorated joints without disruptive testing. The analysis revealed substantial variability in pavement stiffness, concrete layer thickness, and subgrade support, with over 30 percent of joints in several segments exhibiting poor or very poor load transfer efficiency. These insights supported the development of segment-specific rehabilitation strategies optimized for structural performance, constructability, and lifecycle cost. The findings demonstrate the value of high-resolution, multi-scale evaluation for data-driven pavement renewal on heavily trafficked corridors.

Keywords

Pavement Evaluation, Mechanistic-Empirical Design, Rehabilitation Strategies

1. Introduction

I-285 is the Atlanta metropolitan region's beltway, providing critical mobility for passenger vehicles and freight carriers. With projected Annual Average Daily Traffic (AADT) exceeding 240,000 by year 2047 and truck percentages above 19%, the structural performance of I-285 is pivotal to the Georgia Department of Transportation's (GDOT) ability to maintain system reliability and safety. Since its initial construction in 1969 and subsequent widening in 1989, the corridor has experienced substantial growth in traffic, loading intensity, and pavement distress.

In response to aging Portland Cement Concrete (PCC) pavement and recurring maintenance challenges, GDOT initiated a comprehensive evaluation of the 17.4-mile section from State Route 14/Roosevelt Highway to County Road 2838/Paces Ferry Road, encompassing three major project segments identified by GDOT Project Identification Numbers (PI Nos.) 0018191, 0018192, and 0018193. The evaluation's goals were to provide an in-depth characterization of existing conditions, assess feasible rehabilitation strategies, and design solutions that optimize long-term performance, minimize user disruption, and ensure fiscal responsibility.

Despite significant advances in pavement management, many existing rehabilitation strategies lack integration of diverse testing methods that capture both surface and subsurface conditions comprehensively. This results in either over-conservative designs that waste resources or underperforming ones that fail prematurely. In high-volume corridors like I-285, with complex loading and variable subgrade conditions, a data-driven, multi-scale approach is essential to accurately capture spatial variability and inform context-sensitive rehabilitation strategies.

This paper presents a holistic framework that integrates advanced non-destructive testing of Traffic Speed Deflectometer (TSD), Ground Penetrating Radar (GPR), Falling Weight Deflectometer (FWD), along with destructive sampling (coring and laboratory testing), and mechanistic-empirical design principles. By bridging the gap between rapid network-level evaluations and detailed site-specific assessments, this study offers a scalable, risk-informed process for pavement renewal. The findings not only support GDOT's decision-making but also provide practitioners and researchers with a replicable methodology for optimizing rehabilitation on aging, high-traffic highway infrastructure.

2. Literature Review

Traditional evaluation methods often rely heavily on isolated data sources, such as localized deflection or surface distress surveys, which may overlook critical subsurface variability and performance trends. In contrast, recent literature supports a shift toward multi-scale strategies that enhance both diagnostic precision and rehabilitation outcomes [1] [2]. Advanced approaches to pavement evaluation emphasize integrating non-destructive and destructive techniques to achieve a comprehensive understanding of existing pavement conditions, particularly for high-volume highways [3] [4].

TSD has emerged as a transformative tool in pavement evaluation, enabling continuous, high-resolution assessment of pavement stiffness at normal traffic speeds [5] [6]. The TSD system uses Doppler laser sensors to measure pavement surface deflections under a moving load, allowing for rapid data collection across extensive roadway networks with minimal traffic disruption. Unlike conventional spot-testing methods, the TSD collects deflection data over long distances without lane closures, significantly reducing disruption to traffic flow. The deflection profiles generated by TSD are instrumental in identifying structurally deficient zones and differentiating between localized and systemic issues in the pavement structure.

GPR is employed to non-invasively map the internal structure of the pavement system, including layer thicknesses, moisture intrusion, and the presence of voids or delamination [3] [7]. GPR transmits electromagnetic pulses into the pavement and records the reflected signals to produce a profile of subsurface features. High-frequency radar signals penetrate the pavement layers and reflect back to a receiver, allowing for rapid data collection over extensive areas. GPR complements TSD by offering contextual subsurface data that supports interpretation of stiffness anomalies and refines design inputs.

The FWD remains a cornerstone in pavement structural evaluation due to its ability to simulate wheel loads and measure pavement deflection at discrete points [8] [9]. The FWD device applies an impulsive load to the pavement surface while an array of geophones records the resulting deflection basin, which is used to back-calculate the resilience moduli of pavement layers and subgrade. FWD data are also used to assess Load Transfer Efficiency (LTE) across joints and cracks, which is critical in rigid pavement systems. While less spatially continuous than TSD, FWD provides essential calibration data and is particularly effective in validating rehabilitation strategies. Unlike TSD, FWD requires lane closures, which cause traffic interruptions during testing.

LTE is a fundamental parameter in evaluating jointed concrete pavements, reflecting the ability of a pavement joint or crack to transfer applied wheel loads from one slab to the next. LTE is typically assessed by comparing deflections on either side of a joint under a standardized load, and values below critical thresholds indicate poor structural performance and increased risk of faulting or slab movement. The integration of LTE measurements with TSD and FWD data enables a comprehensive understanding of both the location and severity of joint-related distresses in rigid pavement systems.

Destructive sampling, including pavement coring and laboratory characterization, is essential for establishing ground truth and supplementing non-destructive findings. Core samples allow for direct observation and measurement of layer properties such as thickness, material type, and condition. Laboratory tests, such as Unconfined Compressive Strength (UCS), Dynamic Modulus (|E*|) for asphalt, Hamburg Wheel Tracking (HWT) for rutting/moisture susceptibility, and California Bearing Ratio (CBR) for subgrade soils, generate critical mechanistic parameters that feed into the design process [10] [11].

These testing methods converge under the framework of Mechanistic-Empirical Pavement Design, which combines empirical calibration with mechanistic modeling to simulate pavement response under expected traffic and environmental conditions [1] [12]. The integration of TSD, GPR, FWD, and laboratory results enables robust characterization of both structural capacity and potential failure mechanisms. This fusion of methods not only ensures more accurate and economical rehabilitation designs but also enhances long-term pavement performance by aligning interventions with actual field conditions.

Several case studies underscore the value of combining TSD, FWD, and GPR with rigorous laboratory evaluation [5] [7] [9] [13] [14]. Despite these advancements, a gap remains in translating such integrated methods into standardized practice, particularly in corridors with extreme traffic demands and complex environmental interactions [14].

Despite prior studies on combination of TSD, GPR, and FWD data, a key challenge remains in translating these multi-source diagnostics into practical rehabilitation decisions at a corridor level. Existing approaches tend to rely on either limited calibration points or qualitative assessments, which reduces their effectiveness for project-level design applications.

This study addresses that gap by applying a structured, multi-scale evaluation to one of the nation's most congested highway segments. By aligning field diagnostics with mechanistic-empirical principles and constructability considerations, the work contributes to a replicable model for pavement engineers and decision-makers seeking to enhance performance, sustainability, and cost-efficiency in roadway rehabilitation.

3. Materials and Methods

The methodological framework adopted for the pavement evaluation of the I-285 corridor represents an advanced comprehensive strategy that was designed to address the complex structural and operational challenges inherent in rehabilitating one of the nation's most heavily trafficked highway segments. The corridor, spanning approximately 17.4 miles and subdivided into three project identification numbers (PI Nos. 0018191, 0018192, and 0018193), includes both northbound and southbound directions, with lane configurations varying between four and five lanes per direction (**Table 1**).

Table 1. Specifications of the segments of the highway of interest.

Segment	ID	Length (mi)	Start mile post (MP)	End mile post	County	Directions
South	0018191	5.3	1.9	7.2	Fulton	NB/SB
Middle	0018192	4.9	7.2	12.1	Fulton	NB/SB
North	0018193	7.2	12.1	19.3	Fulton, Cobb	NB/SB

Core locations were selected to capture representative pavement conditions across the corridor observed during field survey and desktop study using google earth. A total of 21 asphalt cores were extracted from the road site and provided for the dynamic modulus test. Some of the core specimens from the site were composed of both cement concrete and asphalt concrete layers. These were separated into their respective layers. For the dynamic modulus test, 26 samples with a diameter of 38 mm and a height of 110 mm were prepared.

The foundation of the field investigation was built upon TSD testing [15], executed continuously between May 30 and June 9, 2023 (**Figure 1**). The TSD system employed Doppler laser velocimetry to measure pavement deflection velocities under normal operational speeds, allowing for full-lane coverage with minimal disruption to traffic. The TSD measurements were conducted in all lanes in both directions, capturing data along the right wheel path at an exceptionally fine resolution of 2 inches. This high-frequency data acquisition enabled the detection of localized stiffness anomalies, including transitions near transverse joints, cracks, or subgrade weaknesses. The vertical deflection velocity data obtained at

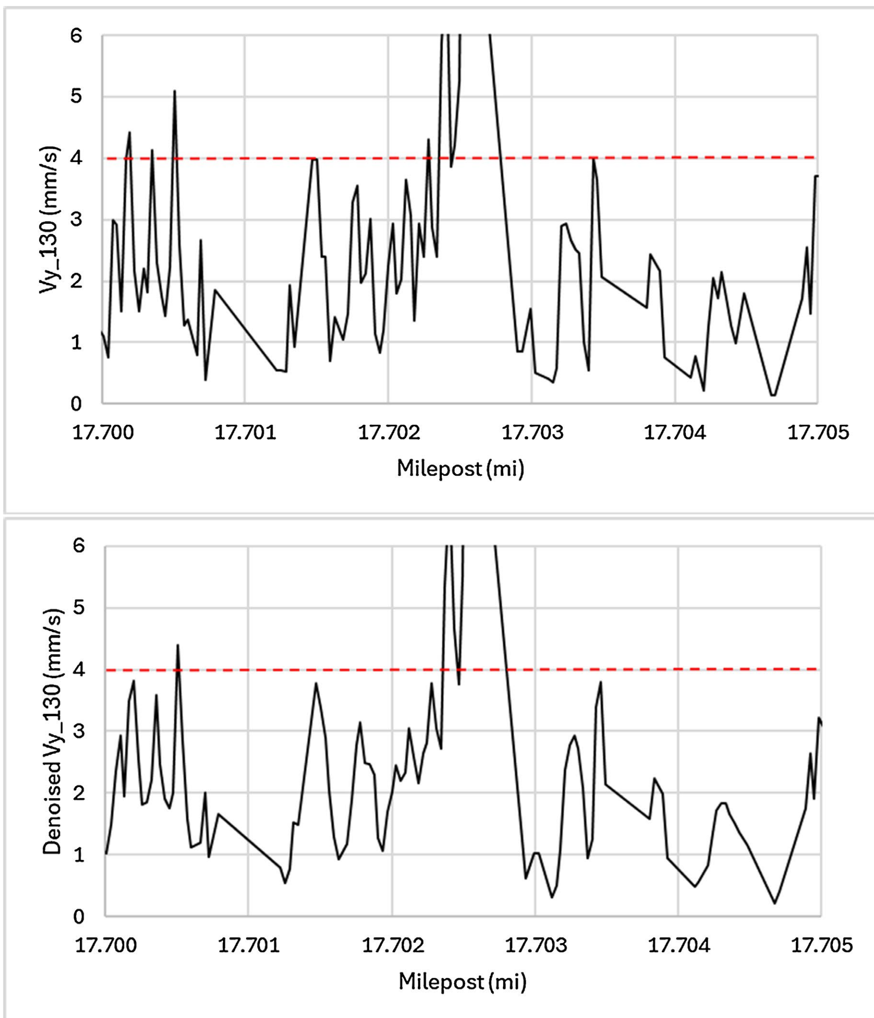

Figure 1. Example of denoising process showing TSD raw data (Left) and denoised data (Right) on NB lane 4.

each measurement point were subsequently integrated numerically to derive deflection slopes, which serve as proxies for dynamic pavement stiffness. In recognition of the challenges posed by jointed concrete systems, the raw TSD data were processed to identify and mitigate measurement inconsistencies, such as missing or non-monotonic deflection values. Approximately 137.5 lane-miles of TSD data were ultimately processed and analyzed, yielding stiffness and velocity metrics at 0.01-mile intervals suitable for design-level interpretation.

Simultaneous to TSD acquisition, the evaluation employed a Kontur Modal DX-2125 3D GPR system [16], which collected subsurface imaging data across 25 transversely distributed channels, each spaced at three-inch intervals across the width of the vehicle. The system was configured to scan at a resolution of 2.8 inches longitudinally, allowing for high-fidelity delineation of pavement layer boundaries, including asphalt overlays, PCC slabs, and underlying base layers. Data processing was conducted using Examiner software for frequency-to-time domain transformation and WinDecar tools for layer interface tracking (**Figure 2**). The analysis emphasized the GPR channel aligned with the TSD load path to ensure exact spatial correspondence. Concrete thickness values were computed as rolling averages over 25-foot windows at each TSD test location and synchronized using GPS coordinates. This approach ensured that the structural geometry inferred from GPR data was accurately merged with the deflection-based mechanical response recorded by the TSD, thereby enabling a co-registered structural performance map of the entire corridor.

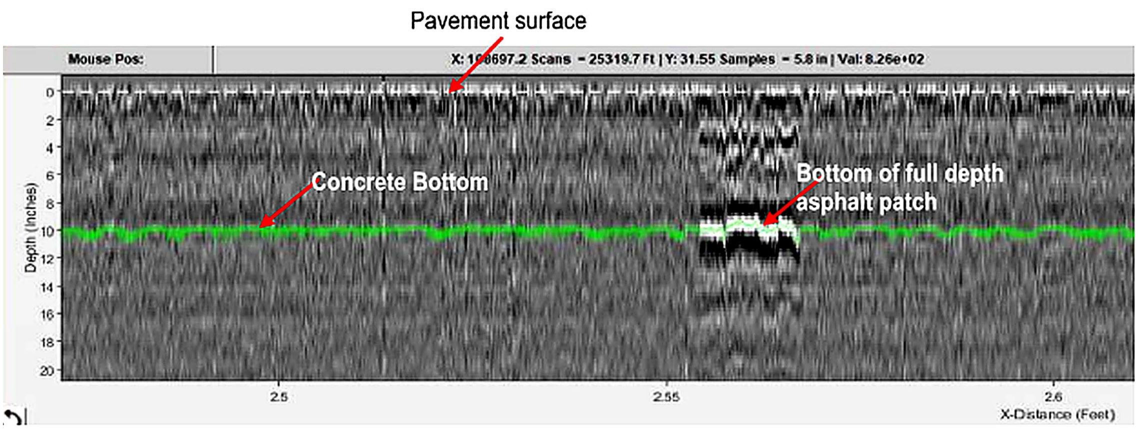

Figure 2. Sample of tracked GPR data from NB near SR-14.

To validate and calibrate the non-destructive testing results, selective destructive sampling was carried out in the form of pavement coring across general-purpose lanes and ramps (**Figure 3**). Extracted specimens underwent laboratory testing to determine UCS of concrete and subgrade, dynamic modulus of asphalt materials (|E*|), and HWT performance to assess rutting and moisture susceptibility [10] [17]. Subgrade characterization further included CBR (**Table 2**), Atterberg limits, and Proctor compaction tests. These measurements furnished mechanistic inputs necessary for the subsequent design phase and served to confirm interpretations derived

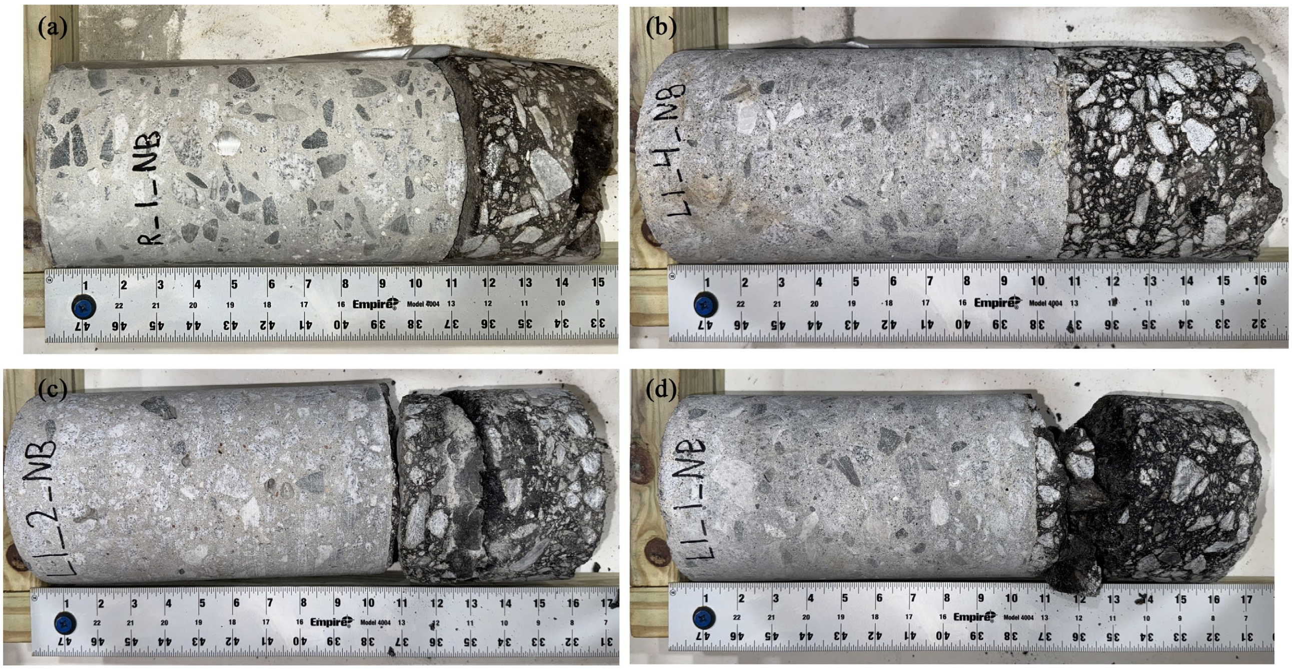

Figure 3. Sample pavement core photographs (a) R-1-NB (b) L1-4-NB (c) L1-1-NB (d) L1-2-NB.

Table 2. Thickness and mechanical properties of representative samples taken from the pavement.

Sample ID	PCC (in)	AC (in)	Base (in)	Subgrade CBR (%)	UCS (psi)
L1-1-NB	10.50	5.25	18	—	6036
L1-5-NB	10.25	5.25	11	—	5403
L2-4-SB	9.50	—	12	—	4841
L2-5-NB	10.25	—	18	—	5881
L3-1-NB	10.25	—	16	—	4799
L3-3-SB	11.00	—	16	—	7252
L3-5-SB	9.25	—	16	—	5622
L4-1-SB	10.25	—	18	—	7454
L4-3-NB	10.00	—	17	—	6345
L4-5-NB	9.75	—	16	—	5941
OS-1-SB	6.50	—	17	—	7448
OS-4-SB	6.50	—	18	—	7130
R-3-NB	10.50	—	16	—	4664
R-5-NB-A	10.50	—	16	—	8173
IS-2-NB	—	8.25	9	34	—
OS-6-NB	6.25	—	16	4	—
OS-9-NB	6.75	—	20	11	—
IS-4-SB	—	8.00	12	5	—

from remote sensing technologies. Notably, the extracted asphalt specimens were particularly critical for evaluating moisture sensitivity and permanent deformation resistance, thus influencing overlay design thickness and material selection.

To supplement the TSD-derived assessment of structural performance and validate load transfer across concrete joints, FWD testing [18] was performed in May 2024 at three representative segments of the corridor. FWD loading was conducted in northbound lanes 1 and 4 (L1 NB, L4 NB), and southbound lane 2 (L2 SB), with deflection basins collected for each test point to facilitate back-calculation of elastic resilient moduli and computation of joint LTE. It must be noted that TSD data was collected during the daytime and FWD data was collected during the nighttime because of the need for lane closure. Differences in temperature of the concrete panels impacts load transfer at the joints regardless of the device used to assess LTE. No explicit temperature correction was applied in reconciling the two datasets. As a result, temperature-related variability in slab behavior may contribute to increased scatter in the LTE calibration.

In addition to standard core sampling and mechanical characterization, the laboratory testing program incorporated HWT tests to evaluate the rutting resistance and moisture susceptibility of asphaltic concrete (AC) sampled along the inside shoulders of the corridor. Specimens were prepared from extracted AC cores in accordance with AASHTO T 324, with each sample subjected to repeated wheel loading in a temperature-controlled water bath. The rut depth was continuously monitored, and the progression of deformation was recorded until the samples reached a predetermined failure criterion or a maximum number of wheel passes. This approach enabled the direct quantification of rutting potential and provided an empirical basis for assessing moisture-induced damage under simulated field conditions. The resulting data served as a critical input for validating overlay material selection and optimizing rehabilitation strategies for long-term pavement performance.

The final methodological phase entailed the application of Mechanistic-Empirical Pavement Design Guide (MEPDG) procedures in accordance with GDOT basic guidelines. The rich dataset assembled from TSD, GPR, FWD, and laboratory testing allowed for the development of segment-specific mechanistic input parameters, including layer elastic moduli, joint efficiency, and subgrade support conditions. These parameters informed rehabilitation strategy simulations, which considered various combinations of overlay, full-depth patching, and full-depth reconstruction. Design alternatives were evaluated not only for structural adequacy and lifecycle performance but also for constructability constraints such as vertical clearance at bridge underpasses, phased construction sequencing, and user delay impacts. By ensuring methodological rigor and technical depth, this approach provided a robust foundation for data-driven decision-making and rehabilitation optimization.

4. Results and Data Analysis

The integration and interpretation of the multi-source data collected along the I-

285 corridor revealed a complex, yet coherent, narrative of pavement performance degradation and structural inefficiency. Analysis began with the processing of the TSD vertical velocity signals, specifically those measured by sensors Vy_130 and Vy_215, which are located near and equidistant from the applied load path. Given the high sensitivity of these signals to minor structural variations, raw data were subjected to a Bayesian wavelet-based denoising algorithm as described by Katicha *et al.* (2013), a technique particularly suited for mitigating high-frequency noise while preserving discontinuities indicative of physical distress, such as joint movement or material interface debonding [15]. Post-denoising velocity profiles revealed consistent patterns of stiffness drops in transition zones and allowed for the precise identification of defective joints and slabs (**Figure 4**).

The GPR data, synchronized with the TSD profiles, confirmed structural uniformity in PCC thickness, which was generally maintained between 9.5 and 10.5

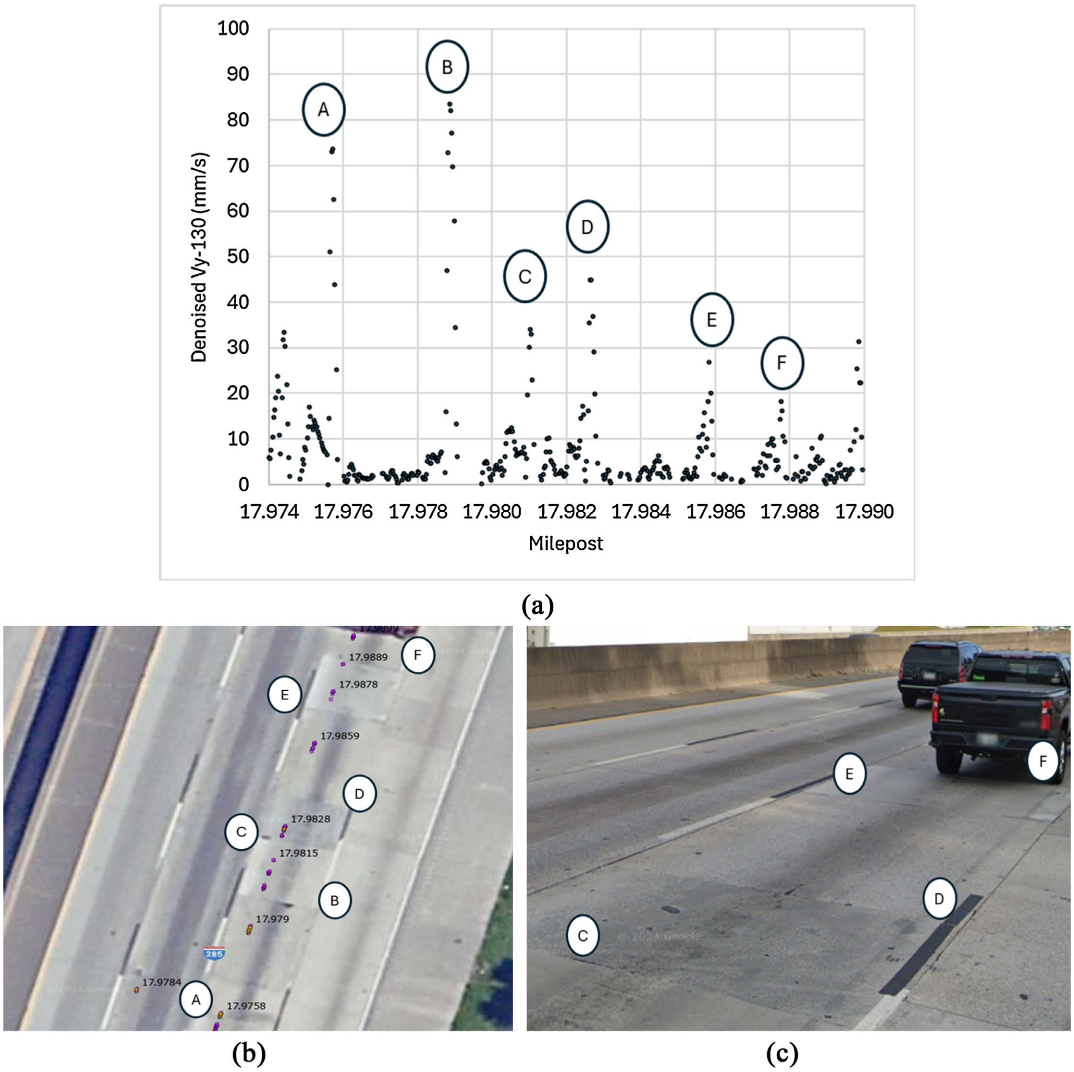

Figure 4. Example of TSD Vertical Velocity Values (a) Possible joint identification based on denoised signal (b) Aerial view of I-285 NB (MP 17.97 - 17.99) (c) Street view of I-285 NB (MP 17.97 - 17.99) at Locations of Transverse Joints/Cracks.

inches throughout the corridor. Variability in asphalt thickness for the inside shoulders ranged from approximately 6.25 to 8.5 inches and was closely correlated with prior construction history and surface distress manifestations. Joint locations identified in denoised TSD data aligned well with GPR-based layer discontinuities and were verified using high-resolution satellite and street-view imagery. Notably, the combined interpretation of TSD and GPR allowed for triangulation of pavement anomalies, such as voids, delamination, and base layer erosion, which often escape detection in single-method evaluations.

LTE analysis emerged as a cornerstone of the data interpretation process. Using empirically established threshold values of ±0.39 in/sec for Vy_130 and ±0.63 in/sec for Vy_215, denoised TSD profiles were systematically scanned to identify joints exhibiting differential vertical displacement indicative of poor LTE. These joints were then binned into LTE categories using regression models derived from FWD comparisons. Although FWD tests are inherently discrete and localized, they remain indispensable for calibrating the continuous data provided by the TSD. LTE values obtained from FWD were used as ground truth for validating TSD-based velocity thresholds used to infer joint degradation. All collected data streams were harmonized within a geospatial platform using differential GPS, enabling both chainage-based and spatial visualizations. Histograms of predicted LTE revealed a concerning trend: in numerous segments, particularly in the northbound direction, more than 30% of joints were classified within the "poor" (25% - 49%) or "very poor" (<25%) LTE ranges. For example, in PI No. 0018192, average LTE across NB lanes ranged between 42.8% and 64.1%, while in PI No. 0018193, LTE values fell below 60% in several lanes, underscoring a systemic need for structural intervention (Figure 5).

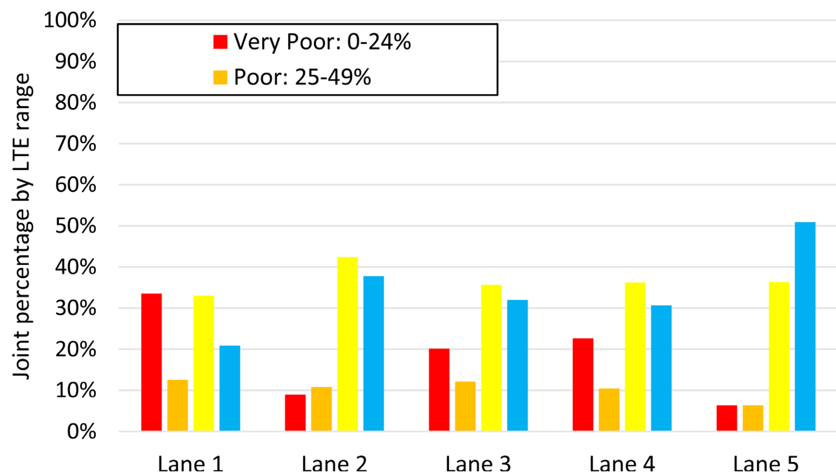

Figure 5. LTE Distribution for the joint percentage of northbound lanes Based on the Vy_130 regression model.

The FWD tests performed in May 2024 provided the empirical foundation for predictive models. Correlation analysis between TSD-derived vertical velocity metrics and FWD-measured LTE demonstrated inverse relationships between these parameters. Additionally, a strong correlation was observed between the two TSD-derived velocity parameters (Vy_130 and Vy_215), with $R^2 = 0.8878$, demonstrating internal consistency of the TSD measurements and reliability of the denoised velocity indicators.

The regression models yielded moderate coefficients of determination of $R^2 = 0.4228$ for Vy_130 and $R^2 = 0.4045$ for Vy_215, where joints with lower LTE tend to exhibit higher vertical velocities, while joints with good LTE (80% and above) typically show much lower vertical velocities. These levels of correlation are consistent with expected variability between continuous TSD measurements and discrete FWD testing conducted under different loading and environmental conditions. The regression relationship was statistically significant ($p < 0.05$). Additionally, spatial variability in LTE was quantified through lane- and segment-level analysis, where average LTE values ranged from approximately 42.8% to 76.8% across the corridor. Several lanes consistently exhibited lower LTE values, indicating that poorer load transfer conditions are concentrated within specific lanes and segments rather than uniformly distributed.

These results confirmed that elevated vertical velocities are reliable indicators of diminished joint integrity and support the continued use of TSD as a scalable LTE estimation tool. Furthermore, back-calculated elastic moduli from FWD testing corroborated TSD estimates, with PCC elastic modulus values ranging from approximately 2.1 to 2.9 million psi and modulus of subgrade reaction values spanning 445 to 563 pci, depending on the location and direction of traffic.

Advanced statistical modeling extended the analysis to explore the interdependencies among multiple variables, including stiffness indices, layer thicknesses, joint efficiency, and subgrade quality. Regression analysis and spatial clustering techniques revealed that areas with low LTE were strongly associated with thinner PCC layers, lower subgrade support (as measured by CBR), and higher asphalt rutting susceptibility. These findings validate the hypothesis that structural degradation is not uniform but highly dependent on localized conditions such as traffic loading, material variability, and construction practices. By integrating these correlations into the mechanistic-empirical design framework, the analysis yielded actionable insights, allowing GDOT to target its interventions not merely based on surface-level distress but rooted in a comprehensive understanding of subsurface performance and joint behavior.

The HWT test results indicated a generally satisfactory rutting resistance for the majority of AC samples extracted from the I-285 inside shoulders (**Table 3**). Measured rut depths were consistently low, with representative samples with a rut depth of only 0.25 in after completion of the test protocol, corresponding to a low susceptibility to moisture damage. These outcomes confirm the effectiveness of current AC mixtures in withstanding both rutting and moisture-related distresses under accelerated loading and environmental conditions.

This analytical strategy culminated in a high-resolution performance map of I-285 that allowed for both strategic planning and tactical design implementation.

The ability to cross-validate findings from multiple sources of TSD, GPR, FWD, and laboratory testing such as modulus of subgrade reaction (M_r) ensured a high level of diagnostic reliability (**Table 4**). More importantly, it demonstrated that a multi-scale evaluation protocol, when executed with scientific rigor and analytical precision, can yield a holistic understanding of pavement systems far superior to what any single test method can provide. The correlations derived through this study form the basis for robust, context-sensitive rehabilitation strategies and serve as a replicable model for future assessments of high-volume, high-risk highway infrastructure.

Table 3. HWT results for asphalt concrete samples extracted from I-285 inside shoulders.

Sample ID	Max rut depth (Left) (in)	Max rut depth (Right) (in)	Moisture damage assessment
IS-1-SB/IS-2-NB	0.30	0.40	Low
IS-3-NB/IS-3-SB	0.20	0.22	Low
IS-4-SB/IS-8-NB	0.27	0.13	Low
IS-10-NB/IS-11-SB	0.15	0.16	Low

Table 4. Determined FWD LTE and Mr Values.

Test point	LTE (%)	M_r (ksi)	Description
MP 3.22	82	4500	Good condition
MP 5.06	68	3100	Cracking, weak base
MP 9.56	85	4750	Acceptable
MP 11.84	73	3850	Joint deterioration

5. Discussion

The pavement design evaluation for the I-285 corridor was grounded in a mechanistic-empirical approach that combined plan-specific traffic projections, material characterization, and in-situ structural assessment. The design process began with a thorough analysis of existing pavement conditions, leveraging the latest field investigations and laboratory test data. Historical performance, distresses, and prior rehabilitation records were systematically reviewed to identify critical segments requiring intervention.

Central to the design procedure was the use of the AASHTO Pavement ME Design software, which facilitated the simulation of future pavement performance under site-specific loading and environmental conditions. The design inputs included calibrated traffic forecasts, accounting for projected increases in heavy vehicle volumes, and climate data specific to the Atlanta region. Material properties for new construction and rehabilitation alternatives were defined based on laboratory-tested values for modulus of subgrade reaction, strength, and durability. For rigid sections, parameters for jointed plain concrete pavement (JPCP), dowel bars, and underlying support layers were included.

The outcomes of the design simulations indicated that, for most segments, the existing pavement structure was insufficient to carry future traffic loads without a significant increase in maintenance requirements. Before and after existing bridges where grade could not be raised, full-depth reconstruction with flexible pavement was recommended. The proposed pavement structure included 16 inches of asphalt concrete over 16 inches of graded aggregate base, supported by subgrade improvements where CBR values were marginal. In segments where the existing JPCP was structurally sound, the design favored asphalt overlay of 6 inches to extend service life and delay reflective cracking, as verified by predicted performance metrics within Pavement ME software v2.3.

Performance predictions highlighted fatigue cracking and rutting as the most likely failure mechanisms in flexible pavement sections in inside shoulders, and faulting or loss of LTE in JPCP segments. The chosen design alternatives for each corridor segment were thus guided by the balance between construction feasibility, lifecycle cost, and risk of early distress. The application of Superpave mixtures with enhanced rutting resistance and high-performance base courses was critical in mitigating the effects of heavy axle loads and minimizing rut depth accumulation. Where subgrade conditions were poor, slabs were replaced to ensure long-term reliability. As a result of continuous high-resolution data collection, the design team was able to develop a plan that identified all existing slabs for this project. Each slab was labeled with the appropriate required action, such as repair or complete replacement, prior to the asphalt overlay. This enabled contractors to plan ahead, optimize construction sequences, and select equipment best suited for the project.

A key discussion point arising from the analysis is the importance of integrating multi-source data, traffic, materials, and performance modeling, to inform both immediate rehabilitation and future preservation strategies. The use of mechanistic-empirical design methods provided a quantitative foundation for optimizing pavement thickness and material selection, reducing the potential for overdesign while safeguarding against premature failures. Furthermore, the iterative feedback between field observations and modeling outputs underscored the need for ongoing monitoring and calibration of design inputs, especially as traffic patterns evolve and climate variability becomes more pronounced.

The findings of this study underscore the transformative value of a truly integrated, multi-scale evaluation framework for corridor-scale pavement design. By blending continuous, non-destructive measurements with targeted destructive sampling and advanced mechanistic modeling, the approach enables a level of diagnostic clarity that far surpasses traditional methodologies.

For the I-285 corridor, the use of denoised deflection velocities and high-resolution subsurface mapping revealed spatial patterns of stiffness loss and load transfer inefficiency that would not have been detected by conventional spot testing or surface visual surveys alone. Importantly, this allowed for the targeted identification of critical segments, such as areas approaching bridges or with historic subgrade variability, where the risk of rapid performance decline is greatest.

These insights directly informed the segmentation of overlay thicknesses, base and subgrade treatments, and the rational placement of full-depth repairs, resulting in a design that is not only structurally sound but also highly optimized for lifecycle cost and constructability. The methodology demonstrates that comprehensive risk assessment, based on high-fidelity data, is essential to avoiding both over-design and under-design in heavily trafficked urban highways.

A key contribution of this study to the broader pavement engineering field is the demonstration of how integrated diagnostic methods can serve as a decision-support platform for both design and asset management. The incorporation of mechanistic-empirical principles, combined with segment-specific material and traffic projections, enables engineers to develop context-sensitive, performance-driven rehabilitation strategies that are resilient to future uncertainty. This approach is especially salient for corridors like I-285, where phased construction, bridge constraints, and intense truck loading all interact to shape the risk envelope. By embedding constructability considerations and quality assurance at each stage, from initial evaluation through design package development, the case study sets a benchmark for how transportation agencies can align technical rigor with programmatic realities. In essence, this study advances the state of practice by illustrating that data-rich, scientifically grounded evaluation is not just a technical exercise but a foundational strategy for sustainable infrastructure renewal on the nation's most critical highway systems.

6. Conclusions

This study implemented an integrated, mechanistic-empirical approach to evaluate and design pavement rehabilitation strategies for the Interstate 285 corridor, one of Georgia's highest-demand highway segments. By employing continuous, high-resolution deflection measurements, subsurface profiling, and laboratory characterization, the methodology enabled a comprehensive structural assessment that transcended the limitations of conventional spot-testing.

Major findings revealed pronounced variability in pavement stiffness, layer thickness, and subgrade quality, with more than 30 percent of joints in critical segments exhibiting poor to very poor LTE. The application of advanced data processing, such as denoising deflection velocities, allowed for the detection of hidden structural deficiencies and guided the segmentation of slab replacements and base treatments to areas of greatest need. This targeted strategy optimized both the structural and economic aspects of the rehabilitation plan.

Critically, the study demonstrated that multi-scale, data-rich evaluation frameworks can substantially enhance the reliability of rehabilitation design in complex urban highway environments, reducing the risk of premature failure while avoiding unnecessary overdesign. However, the project also exposed gaps in current practice, such as the need for real-time, network-level monitoring to capture dynamic changes in traffic patterns and climate impacts.

For future research, it is recommended to investigate the integration of sensor-based long-term pavement monitoring with predictive analytics, and to explore adaptive design strategies that can be dynamically updated as new field data becomes available. Such advancements would further align design practices with the evolving demands on aging highway infrastructure, supporting more resilient, sustainable, and cost-effective transportation networks.

Acknowledgements

The authors gratefully acknowledge the financial support provided by GDOT for this research. We extend our sincere appreciation to GDOT's Office of Program Delivery for their guidance and collaboration, particularly Albert V. Shelby, III, Kimberly Wells Nesbitt, Gretel Sims, and Nebyou E. Negash, P.E., C.B.I., P.M.P. We also thank Ian Douglas Rish, P.E., of GDOT's Office of Materials and Testing (OMAT) for his valuable input and support. Additionally, we are grateful to the State Construction Office, including John D. Hancock, P.E., and Jeremiah Daniel, P.E., for their contributions and insights throughout the course of this work.

We would also like to acknowledge Nick Weitzel, P.E., at Nichols Consulting Engineers, CHTD, and Ken Maser, Ph.D., P.E., at Infrasense, Inc., for their technical support, which was instrumental to the success of this study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] American Association of State Highway and Transportation Officials (2020) Mechanistic-Empirical Pavement Design Guide: A Manual of Practice. Interim Edition, AASHTO.

[2] Timm, D.H., Priest, A.L. and Brown, R.L. (2004) NCHRP Report 573: Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structures. Transportation Research Board.

[3] Elseicy, A., Alonso-Díaz, A., Solla, M., Rasol, M. and Santos-Assunçao, S. (2022) Combined Use of GPR and Other NDTs for Road Pavement Assessment: An Overview. *Remote Sensing*, **14**, Article 4336. https://doi.org/10.3390/rs14174336

[4] Domitrović, J. and Rukavina, T. (2013) Application of GPR and FWD in Assessing Pavement Bearing Capacity. *Romanian Journal of Transport Infrastructure*, **2**, 11-21. https://doi.org/10.1515/rjti-2015-0015

[5] Jiang, D., Wang, D., Pei, Z., Sun, Z. and Yi, J. (2025) A Comprehensive Survey of the New Generation Pavement Structural Condition Assessment in Pavement Management System: Traffic Speed Deflection Device. *IEEE Transactions on Intelligent Transportation Systems*, **26**, 11206-11226. https://doi.org/10.1109/tits.2025.3560418

[6] Muller, W.B. (2015) A Comparison of TSD, FWD and GPR Field Measurements. *Proceedings of the Internation Symposium Non-Destructive Testing in Civil Engineering*, Berlin, 15-17 September 2015, 713-722.

[7] Plati, C., Loizos, A. and Gkyrtis, K. (2020) Integration of Non-Destructive Testing

Methods to Assess Asphalt Pavement Thickness. *NDT & E International*, **115**, Article 102292. https://doi.org/10.1016/j.ndteint.2020.102292

[8] Smith, K.D., Bruinsma, J.E., Wade, M.J., Chatti, K., Vandenbossche, J. and Yu, H.T. (2017) Using Falling Weight Deflectometer Data with Mechanistic-Empirical Design and Analysis, Volume I. United States Federal Highway Administration.

[9] Pandya, H.I., Ali, A.A. and Mehta, Y.A. (2024) Enhancing Falling Weight Deflectometer (FWD) Testing: Comprehensive Review and Development of Robust Procedure in the United States. *Journal of Testing and Evaluation*, **52**, 2039-2054. https://doi.org/10.1520/jte20230389

[10] Yildirim, Y., Jayawickrama, P.W., Hossain, M.S., Alhabshi, A., Yildirim, C., Smit, A.D. and Little, D. (2007) Hamburg Wheel-Tracking Database Analysis. Texas Department of Transportation and Federal Highway Administration.

[11] Schram, S., Williams, R.C. and Buss, A. (2014) Reporting Results from the Hamburg Wheel Tracking Device. *Transportation Research Record*: *Journal of the Transportation Research Board*, **2446**, 89-98.

[12] Li, J., Pierce, L.M. and Uhlmeyer, J. (2009) Calibration of Flexible Pavement in Mechanistic-Empirical Pavement Design Guide for Washington State. *Transportation Research Record*: *Journal of the Transportation Research Board*, **2095**, 73-83.

[13] Smith, K., Ram, P., Peshkin, D. and Signore, J. (2024) Practices for Maintaining and Resurfacing Existing Composite Pavements. U.S. Department of Transportation, Federal Highway Administration.

[14] Wang, Z., Zhou, H., Mandapaka, V. and Nguyen, L. (2021) Pavement Maintenance and Rehabilitation Practices in California: A Study of 35-Year As-Built Data in PaveM. *International Journal of Transportation Science and Technology*, **10**, 380-392. https://doi.org/10.1016/j.ijtst.2021.04.005

[15] Katicha, S., Flintsch, G. and Diefenderfer, B. (2022) Ten Years of Traffic Speed Deflectometer Research in the United States: A Review. *Transportation Research Record*: *Journal of the Transportation Research Board*, **2676**, 152-165. https://doi.org/10.1177/03611981221094579

[16] Loizos, A. and Plati, C. (2007) Accuracy of Pavement Thicknesses Estimation Using Different Ground Penetrating Radar Analysis Approaches. *NDT & E International*, **40**, 147-157. https://doi.org/10.1016/j.ndteint.2006.09.001

[17] Lu, Q. and Harvey, J.T. (2006) Evaluation of Hamburg Wheel-Tracking Device Test with Laboratory and Field Performance Data. *Transportation Research Record*: *Journal of the Transportation Research Board*, **1970**, 25-44. https://doi.org/10.1177/0361198106197000103

[18] Nega, A., Nikraz, H. and Al-Qadi, I.L. (2016) Dynamic Analysis of Falling Weight Deflectometer. *Journal of Traffic and Transportation Engineering* (*English Edition*), **3**, 427-437. https://doi.org/10.1016/j.jtte.2016.09.010