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Assessment of Flexible Pavement Condition Using Non-Destructive Testing Techniques for Sustainable Road Asset Management

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Abstract

Flexible pavements deteriorate over time due to increasing traffic loads, environmental variations, and material aging, making periodic condition assessment essential for effective maintenance planning. Non-destructive testing (NDT) techniques provide a reliable and economical approach for evaluating pavement structural performance without causing damage to the roadway. This study assesses the condition of flexible pavements using non-destructive testing methods to support sustainable road asset management. Selected pavement sections were evaluated through visual inspections and structural deflection measurements to determine their load-bearing capacity and overall condition. The collected data were analyzed to classify pavement performance and identify appropriate maintenance strategies based on structural requirements. The results demonstrate that NDT techniques effectively distinguish pavement sections with varying levels of deterioration and provide valuable information for maintenance prioritization. Pavements exhibiting lower deflection values were found to possess better structural integrity, while sections with higher deflection required rehabilitation interventions. The study highlights that integrating non-destructive testing with systematic pavement condition assessment enhances maintenance decision-making, optimizes resource utilization, and extends pavement service life. The findings contribute to sustainable road asset management by promoting cost-effective maintenance planning and improving the long-term performance of highway infrastructure.

Keywords

Flexible Pavement, Non-Destructive Testing, Pavement Condition Assessment, Road Asset Management, Sustainable Maintenance, Pavement Performance, Highway Engineering.

1. Introduction

Highway transportation systems are fundamental to economic development, regional connectivity, and social mobility.[1] Efficient road networks facilitate the movement of passengers and freight while supporting industrial growth and commercial activities.[2] Flexible pavements constitute the majority of road infrastructure because of their relatively lower construction costs, ease of maintenance, and adaptability to different traffic conditions. However, continuous exposure to heavy traffic loading, environmental fluctuations, moisture intrusion, and material aging gradually reduces pavement structural capacity, resulting in various forms of deterioration such as rutting, fatigue cracking, potholes, ravelling, and surface deformation.[3]

Timely identification of pavement deterioration is essential for maintaining roadway safety, ride quality, and transportation efficiency. Delayed maintenance often accelerates structural damage, leading to higher rehabilitation costs and shortened pavement service life. Consequently, highway agencies increasingly emphasize proactive pavement condition assessment as an integral component of pavement management systems. Accurate evaluation of pavement structural condition enables engineers to prioritize maintenance activities, optimize resource allocation, and improve the long-term performance of road infrastructure.[4]

Traditional pavement evaluation methods generally involve destructive testing procedures such as core extraction and trench excavation.

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Although these methods provide direct information about pavement layer properties, they interrupt traffic flow, increase operational costs, and permanently damage pavement sections. These limitations have encouraged the adoption of non-destructive testing (NDT) techniques, which evaluate pavement structural performance without affecting pavement integrity. NDT methods allow rapid data collection, minimize traffic disruption, and support continuous monitoring of pavement condition.[5]

Non-destructive testing techniques evaluate pavement strength by measuring parameters such as surface deflection, layer stiffness, and load-bearing capacity under controlled loading conditions. The obtained information helps estimate pavement structural adequacy, remaining service life, and maintenance requirements. Combined with visual condition surveys, NDT provides a comprehensive understanding of pavement performance, enabling transportation agencies to make scientifically informed maintenance decisions.

Road asset management is a systematic process that integrates engineering, economic, and environmental considerations to maximize the performance and lifespan of transportation infrastructure. Sustainable road asset management focuses on optimizing maintenance investments while minimizing environmental impacts and preserving existing pavement assets. Rather than relying solely on reactive repairs, modern asset management promotes preventive maintenance strategies supported by objective condition assessment data. Such approaches reduce lifecycle costs, improve serviceability, and contribute to sustainable infrastructure development.[6]

The present study evaluates flexible pavement condition using non-destructive testing techniques to support sustainable road asset management. The research investigates pavement structural performance through field measurements and condition assessment procedures, identifies pavement sections requiring maintenance intervention, and recommends suitable maintenance strategies. The findings provide practical guidance for transportation agencies seeking efficient methods for pavement evaluation and sustainable infrastructure management while ensuring optimum utilization of available maintenance resources.[7]

2. Literature Review

The structural condition of flexible pavements significantly influences road safety, vehicle operating costs, and maintenance expenditure. Consequently, numerous studies have investigated pavement evaluation techniques to improve maintenance planning and optimize infrastructure performance. Among these approaches, non-destructive testing (NDT) has become an essential component of pavement management because it provides reliable structural information without damaging pavement layers.

Shahin (2019) emphasized that pavement condition assessment is fundamental to modern pavement management systems. The author reported that periodic structural evaluation enables highway agencies to detect deterioration at an early stage, thereby reducing rehabilitation costs and extending pavement service life through timely maintenance interventions.

Huang (2020) discussed the application of non-destructive testing methods for evaluating pavement structural capacity. The study highlighted that deflection measurements provide direct information regarding pavement stiffness and load-bearing characteristics. The author concluded that NDT techniques improve maintenance planning by accurately identifying structurally deficient pavement sections.

According to *IRC:81 (2022)*, pavement deflection remains one of the most reliable indicators of structural condition. The guidelines recommend

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the use of deflection-based evaluation techniques for strengthening design, pavement rehabilitation, and maintenance prioritization. The standardized testing procedures ensure consistency in pavement condition assessment across different roadway networks.

Elseifi et al. (2022) investigated the integration of structural evaluation with pavement management systems and reported that combining field measurements with engineering analysis significantly improves rehabilitation decision-making. Their research demonstrated that objective structural data support cost-effective allocation of maintenance resources while minimizing unnecessary repairs.

Rahman and Karim (2021) examined the influence of environmental factors on pavement performance. They observed that pavement temperature, moisture content, and seasonal variations significantly affect structural response and should be considered during pavement condition assessment. Appropriate environmental corrections improve the reliability of structural evaluation.

Recent studies have also focused on sustainable road asset management. *Zhang et al. (2023)* reported that digital pavement databases combined with non-destructive testing enhance maintenance prioritization and support long-term infrastructure planning. Their findings indicated that predictive maintenance based on pavement condition data reduces lifecycle costs while improving network performance.

Similarly, *Kumar and Rastogi (2021)* emphasized that integrating structural evaluation with pavement condition indices enables transportation agencies to develop scientifically based maintenance strategies. Their study concluded that preventive maintenance guided by objective pavement assessment substantially improves pavement durability and serviceability.

Although considerable progress has been achieved in pavement condition assessment, many previous studies have concentrated on individual evaluation techniques rather than integrating structural assessment with sustainable road asset management principles. Limited research has comprehensively examined how non-destructive testing can support maintenance prioritization, lifecycle optimization, and sustainable infrastructure planning. Therefore, the present study addresses this research gap by evaluating flexible pavement condition through non-destructive testing techniques and demonstrating their contribution to effective road asset management.

3. Materials and Methodology

The study was undertaken to evaluate the structural condition of flexible pavements using non-destructive testing techniques and to develop maintenance recommendations that support sustainable road asset management. A systematic methodology was adopted to ensure reliable pavement condition assessment and accurate interpretation of structural performance.[8]

Initially, representative flexible pavement sections were selected based on traffic volume, pavement age, surface condition, and accessibility. The selected road sections represented different levels of structural deterioration to enable comprehensive comparison of pavement performance. Before conducting structural testing, a detailed visual condition survey was carried out to identify common pavement distresses including longitudinal and transverse cracking, rutting, potholes, ravelling, edge failures, and localized settlements. The severity and extent of these defects were documented for each pavement section.[9]

Following the visual inspection, non-destructive testing was performed to evaluate pavement structural capacity. Deflection measurements were collected using standardized testing equipment under controlled loading conditions.

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Multiple observations were recorded at each test location to improve measurement reliability and minimize random errors. Environmental conditions such as pavement surface temperature and weather were monitored during testing because these factors influence pavement response. Necessary corrections were applied to standardize the measured values.

The collected structural data were organized and processed using spreadsheet software for detailed analysis. Descriptive statistical techniques including mean deflection, standard deviation, and coefficient of variation were calculated to evaluate pavement performance.[10] The measured deflection values were subsequently compared with established evaluation criteria to classify pavement sections into different condition categories such as excellent, good, fair, poor, and very poor.[11]

Based on the structural assessment results, appropriate maintenance strategies were recommended for each pavement section. Pavements exhibiting low deflection and satisfactory structural capacity were assigned routine maintenance, whereas moderately deteriorated sections were recommended for preventive maintenance or rehabilitation. Pavements showing excessive deflection and inadequate structural performance were identified for major rehabilitation or reconstruction.[12]

The final stage of the methodology involved integrating pavement condition assessment with sustainable road asset management principles. Maintenance priorities were established considering structural condition, expected pavement performance, lifecycle cost implications, and efficient utilization of available maintenance resources. This integrated approach supports evidence-based decision-making while promoting long-term pavement sustainability.[13]

4. Results and Discussion

The structural condition of the selected flexible pavement sections was evaluated using non-destructive testing (NDT) techniques to determine their load-bearing capacity and overall pavement performance.[14] The assessment integrated field observations, pavement deflection measurements, and condition rating to identify appropriate maintenance strategies for sustainable road asset management. The results demonstrated noticeable variations in structural condition among the investigated pavement sections, reflecting differences in traffic loading, pavement age, and environmental exposure.[15]

The measured pavement deflection values indicated that sections with lower deflection exhibited better structural stability and higher stiffness, whereas sections with higher deflection reflected weakened pavement layers requiring maintenance intervention. The overall trend confirmed that pavement deflection increased with the degree of structural deterioration, making deflection measurements an effective indicator of pavement health. Visual inspections also supported the structural findings, as pavement sections with higher deflection generally exhibited more severe surface distresses such as rutting, cracking, and localized settlements.[16]

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Table 1. Pavement Condition Rating and Recommended Maintenance Strategy

Pavement Section	Average Deflection (mm)	Pavement Condition	Structural Rating	Recommended Maintenance
Section A	0.62	Excellent	Strong	Routine Maintenance
Section B	0.81	Good	Stable	Preventive Maintenance
Section C	1.05	Fair	Moderate	Minor Rehabilitation
Section D	1.28	Poor	Weak	Major Rehabilitation
Section E	1.48	Very Poor	Critical	Reconstruction

The data presented in Table 1 illustrate a gradual decline in pavement condition as deflection values increased. Section A exhibited the lowest average deflection of **0.62 mm**, indicating excellent structural performance and sufficient load-bearing capacity. This pavement section required only routine maintenance activities such as crack sealing, surface cleaning, and drainage maintenance to preserve its condition.[17]

Section B recorded an average deflection of **0.81 mm** and was classified as being in good structural condition. Preventive maintenance measures, including localized patch repairs and surface treatment, were considered adequate to prevent further deterioration and extend pavement service life.[18]

Section C exhibited a moderate structural condition with an average deflection of **1.05 mm**. The pavement showed early signs of structural weakening accompanied by minor surface deterioration. Consequently, minor rehabilitation measures such as thin asphalt overlays and localized strengthening were recommended to restore pavement performance before extensive damage developed.[19]

Sections D and E exhibited the highest deflection values of **1.28 mm** and **1.48 mm**, respectively, indicating poor structural integrity. These pavement sections displayed extensive cracking, rutting, and permanent deformation, suggesting that the existing pavement layers had lost significant load-carrying capacity. Major rehabilitation or complete reconstruction was therefore recommended to restore satisfactory structural performance and ensure long-term serviceability.[20]

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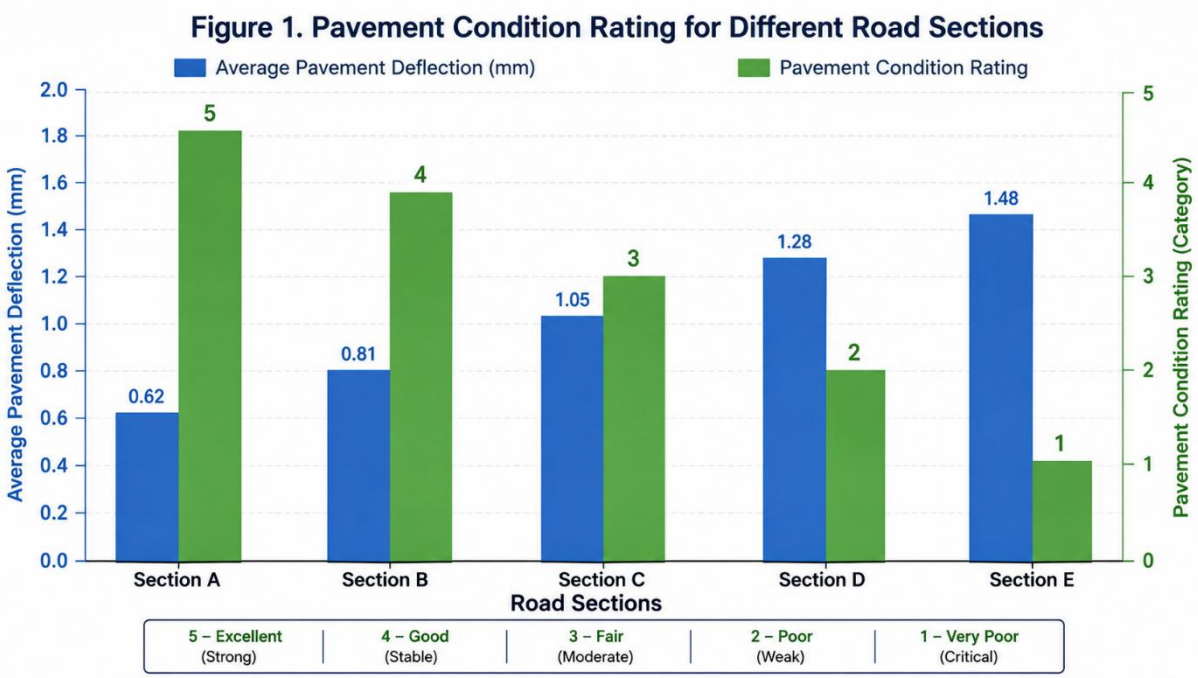


Figure 1. Pavement Condition Rating for Different Road Sections

The comparative analysis confirmed that pavement condition assessment using non-destructive testing provides an efficient basis for maintenance prioritization. Pavement sections requiring immediate intervention were clearly distinguished from those needing only routine maintenance, enabling transportation agencies to allocate maintenance resources more effectively. Such prioritization minimizes unnecessary rehabilitation expenditures while maximizing pavement service life.[21]

The findings further demonstrate the significance of integrating structural evaluation with sustainable road asset management. Rather than adopting reactive maintenance practices after severe pavement failure, periodic non-destructive testing enables highway authorities to implement preventive maintenance strategies based on objective structural data. This proactive approach significantly reduces lifecycle costs, minimizes traffic disruptions, and improves overall pavement performance.[22]

Furthermore, the use of non-destructive testing contributes to environmental sustainability by reducing unnecessary reconstruction activities and promoting efficient utilization of construction materials. Timely maintenance based on pavement condition assessment decreases material consumption, energy requirements, and greenhouse gas emissions associated with large-scale rehabilitation projects. Consequently, sustainable maintenance planning not only improves economic efficiency but also supports environmentally responsible infrastructure management.[23]

Overall, the study demonstrates that non-destructive testing techniques provide reliable information regarding pavement structural condition and maintenance requirements. The classification of pavement sections according to measured deflection values enables highway engineers to prioritize maintenance activities objectively while supporting evidence-based decision-making. The integration of pavement condition assessment with sustainable road asset management offers a practical framework for

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extending pavement service life, optimizing maintenance budgets, and enhancing the long-term performance of transportation infrastructure. These findings highlight the importance of routine structural monitoring as a key element of modern pavement management systems.[24]

5. Conclusion

The present study assessed the structural condition of flexible pavements using non-destructive testing (NDT) techniques to support sustainable road asset management. The investigation demonstrated that systematic pavement condition assessment provides reliable information for evaluating structural performance, identifying deterioration, and selecting appropriate maintenance strategies. The adoption of NDT methods enables highway agencies to evaluate pavement integrity without causing damage to the existing roadway, making these techniques highly suitable for routine monitoring and long-term infrastructure management.

The results indicated that pavement sections with lower deflection values possessed greater structural strength and load-bearing capacity, whereas sections exhibiting higher deflection values reflected progressive deterioration and reduced structural stability. The condition classification developed in this study effectively differentiated pavement sections into excellent, good, fair, poor, and very poor categories, providing a practical basis for maintenance prioritization. Pavements in satisfactory condition required only routine or preventive maintenance, while severely deteriorated sections demanded rehabilitation or complete reconstruction to restore structural performance.

An important outcome of the study is the demonstration that non-destructive testing significantly improves maintenance decision-making by providing objective engineering data rather than relying solely on visual inspection. Integrating structural assessment with pavement condition surveys enables engineers to identify hidden structural deficiencies before they become visible on the pavement surface. This proactive approach minimizes unexpected pavement failures, reduces maintenance expenditure, and enhances roadway safety.

The study further emphasizes the importance of sustainable road asset management in optimizing maintenance investments and extending pavement service life. By accurately identifying maintenance priorities, highway agencies can allocate financial and technical resources more efficiently while minimizing unnecessary rehabilitation activities. Preventive maintenance based on structural evaluation not only improves pavement durability but also reduces environmental impacts associated with excessive material consumption, construction activities, and traffic disruptions. Consequently, sustainable pavement management contributes to both economic efficiency and environmental conservation.

Another significant finding is that the integration of non-destructive testing with modern pavement management systems supports data-driven infrastructure planning. Continuous monitoring of pavement condition allows transportation agencies to establish maintenance schedules based on actual structural performance rather than predetermined time intervals. Such an approach enhances network reliability, improves service quality, and maximizes the return on public infrastructure investment.

Overall, the study confirms that non-destructive testing techniques are effective tools for evaluating flexible pavement condition and supporting sustainable road asset management. Their application facilitates accurate structural assessment, evidence-based maintenance planning, and efficient utilization of available resources. Future research should focus on integrating advanced sensing technologies,

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Geographic Information Systems (GIS), artificial intelligence, machine learning, and digital pavement management platforms to further improve pavement performance prediction, maintenance optimization, and long-term infrastructure sustainability.

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