DETERIORATION PATTERNS AND MAINTENANCE PRIORITIES OF PAVEMENTS IN NORTHERN BANGLADESH: A PCI-BASED ANALYSIS

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ABSTRACT

Pavement management is a crucial approach for achieving and extending the full life span of a roadway infrastructure. Timely maintenance and rehabilitation with appropriate technique can save a significant budget for expensive repair and reconstruction. For a developing country like Bangladesh, proper identification and selection of road maintenance strategies are of utmost importance to minimize maintenance costs. This study aims to investigate the existing condition of the Saidpur-Parbatipur Road (Z-5011) by utilizing the Pavement Condition Index (PCI) approach as described in ASTM D 6433-07. The primary objective was to measure the type, severity, and extent of pavement distress of the road in order to identify maintenance and rehabilitation strategies. The investigation involved a field examination of a 12-kilometer segment, assessing 146 sample units. Field measurements were conducted to collect distress data along with historical photographs from street view images, which were used to compare the periodic changes in pavement surface quality. The survey documented several distresses, such as alligator (fatigue) cracking, stripping of binder, large potholes, and channelized rutting, which were evaluated and categorized according to their extent and severity levels. The PCI ratings for the sampled regions ranged from 8 (Failed) to 65 (Fair), with a weighted average PCI score of 37.25, indicating a pavement quality category of "Very Poor." This classification indicates an urgent necessity for suitable repair and restoration techniques in specific sections that demand prompt action. The analysis identified various reasons that contribute to the deterioration of the pavement, such as poor drainage provision, improper camber and longitudinal slope, inadequate shoulder or lateral confinement, heavily loaded trucks, frequent speed breakers, and poor maintenance. Based on these findings, certain maintenance strategies were suggested to extend the lifespan of the roads and minimize expenditures over the long run. The findings provide empirical insights for road maintenance authorities such as the Roads and Highways Department, emphasizing the need for pavement evaluations and the use of standardized procedures such as PCI to ensure effective roadway infrastructure maintenance.

Keywords: *Pavement Condition Index; Pavement management; Road maintenance; Pavement Rehabilitation; Pavement distress*

1. INTRODUCTION

The Pavement Condition Index (PCI) is a standardized and widely adopted measure for evaluating and maintaining roadway infrastructure performance. Developed originally by the U.S. Army Corps of Engineers and later standardized under ASTM D6433-20, PCI provides a numerical representation (0–100) of pavement health based on observed surface distresses such as cracks, potholes, rutting, and depressions, allowing for quantitative condition assessment and systematic maintenance planning (Shahin, 2005; ASTM, 2020). Its principal objective is to assess the structural integrity and functional efficiency of pavement systems, thereby supporting timely rehabilitation and life-cycle management of road networks. The significance of PCI lies in its integration within pavement management systems (PMS) as a decision-support tool for civil engineers and transportation agencies (Roads and Highways Department, 2005). By enabling objective condition evaluation, PCI helps prioritize maintenance interventions and optimize limited budgets, which is especially relevant in developing regions facing increased vehicular loads and fiscal constraints (Ahmed et al., 2017). Figure 1 presents a schematic of the pavement condition life cycle, emphasizing how early interventions guided by PCI-based monitoring can substantially reduce long-term rehabilitation costs and extend pavement service life (ASTM, 2020). This research applies the PCI framework to the Saidpur–Parbatipur Corridor, an important regional transportation link in Bangladesh. The corridor faces challenges due to high traffic volumes, fluctuating climatic conditions, limited maintenance resources, and other factors that accelerate pavement deterioration. Although several international studies have proposed enhanced PCI-based models incorporating image processing and machine learning (Sarfaraz et al., 2017; El Hakea & Fakhr, 2023). Few analyses have contextualized these frameworks under local environmental and traffic conditions in South Asian Road networks. Thus, this study bridges this research gap by combining field survey data with PCI evaluations to generate a nuanced understanding of regional pavement performance.

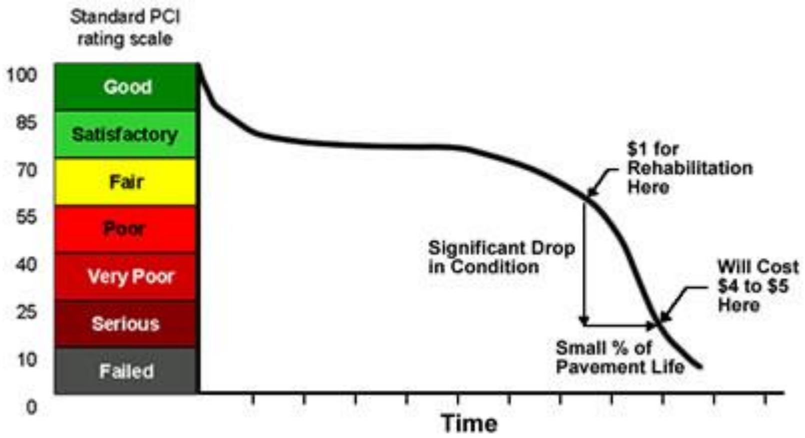

Figure 1: Illustration of a pavement condition life cycle (ASTM, 2020)

The scope of this study encompasses visual inspection and PCI-based evaluation across a 12 km segment of the Saidpur–Parbatipur corridor. The approach provides insight into surface distress typology, severity, and distribution. However, limitations exist in data collection where the data depends on visual observation and may introduce subjectivity and surveyor bias. Additionally, the study does not capture all potential factors affecting pavement deterioration (e.g., subgrade variations or extreme climatic events). The suggested maintenance strategies developed from the collected dataset are therefore bounded by data availability and methodological assumptions. Nevertheless, the findings aim to inform evidence-based maintenance planning, improve infrastructure resilience, and contribute to sustainable pavement management policy at the regional level.

1.1 Pavement Management

Infrastructure management requires careful assessment and maintenance of pavement conditions, with the Pavement Condition Index (PCI) serving as a key evaluation tool. The ASTM D6433-07 standard outlines procedures for conducting PCI surveys, including guidelines for identifying and classifying distress types essential for accurate PCI values (ASTM, 2020). By distinguishing between load-related and climate-related distresses, this standard enhances diagnostic precision. Shahin (2005) introduced the PCI as a numerical rating from 0 to 100 to evaluate pavement condition based on visual inspection. The PCI has gained widespread adoption, notably in the AASHTO Pavement Management Guide, which consolidates complex data into actionable formats for policy development (AASHTO, 2012). The Federal Highway Administration (FHWA, 2009) also emphasizes PCI in its Pavement Distress Identification Manual. These documents underscore PCI's role in maintaining performance and safety. Recent studies have examined factors affecting PCI. For example, Abo-Hashema and Sharaf (2009) identified challenges posed by heterogeneous traffic and overloaded vehicles, which accelerate pavement deterioration and complicate distress identification. Additional contributors include poor drainage, flawed geometric design, and reduced effective road width. Another study conducted at Dhaka found the riding quality was related to edge cracking, block cracking, drainage inadequacy, and Annual Average Daily Traffic (AADT) in a correlation test of the connected variables (Hasan et al., 2025). Inclusion of both severity and extent ratings of distresses is expected to provide a strong basis for eventual maintenance cost computations (Bandara & Gunaratne, 2001). Research also explores maintenance strategies such as overlaying, patching, and seal coating to enhance PCI scores (Hajj et al., 2011). Hasan et al. (2025) demonstrated that timely, cost-effective interventions based on PCI ratings can be successfully implemented. Another growing area involves advanced technologies like machine learning and image processing for automated distress detection, which promise greater efficiency and accuracy in PCI assessments (Nguyen et al., 2023). Overall, PCI remains a valuable tool for evaluating road safety and guiding pavement maintenance decisions. This paper aims to apply the PCI model to a highway in Saidpur, Bangladesh, identifying key distresses and proposing suitable rehabilitation strategies.

Figure 2: Illustration of a distressed pavement in front of the BAUST Campus

1.2 Problem Statement

The Saidpur-Parbatipur Road is a twelve-kilometer highway connecting the towns of Saidpur and Parbatipur. Despite being constructed just a few years ago, the road has experienced significant damage in various sections. Such premature deterioration raises questions over structural integrity and long-term sustainability. Reduced width of the road, heterogeneous traffic with heavily loaded trucks contribute to fast wear and tear on the surface. Furthermore, a lack of drainage structures leads to the formation of ponds on which its condition deteriorates further. Besides, poor slope design along with wrong camber and gradient also accounts for some other reasons why it cannot be without distress. These factors result in lower effective roadway widths, making it unsafe to drive as well as costly to maintain. Figure 2 shows one such distressed pavement section in front of Bangladesh Army University of Science & Technology (BAUST), Saidpur, showcasing how critical this scenario has become. This study evaluates the present status of a certain segment of this highway based on ASTM D 6433-07 standards while proposing rehabilitative measures. The aim is to identify the necessary steps the road agency should take to minimize maintenance costs and enhance the road's longevity.

1.3 Objectives

1. To evaluate the current condition of the Saidpur-Parbatipur Road through the use of Pavement Condition Index (PCI) methodology as outlined in ASTM D 6433-07, with a prime focus on identifying the types, severity, and extent of distress.
2. To analyze the underlying causes of pavement deterioration, such as structural, traffic, drainage, and maintenance issues.
3. To provide insights for maintenance and rehabilitation strategies based on calculated PCI ratings and observed types of distress for pavements that will increase their lifespan while minimizing life cycle costs.
4. To provide data-driven recommendations for the local road agency to aid in decision-making through evidence-based information on future maintenance schedules.

2. METHODOLOGY

In this research pavement section for Saidpur- Parbatipur Zilla Highway (Z-5011) has been defined and condition survey has been conducted on it. In this study, the visual survey method was employed to assess the condition of the pavement along the 12 km highway block from Parbatipur mor to BAUST Campus. This method involved a systematic visual manual inspection of the pavement surface, conducted by a team of trained surveyors. The team documented visible surface distresses, including cracks, potholes, ruts, and other forms of deterioration. Each distress type was recorded with specific attention to its extent, severity, and location. Distressed areas were physically measured using measuring tapes and rulers, while the lengths and widths of the affected sections were noted for precise quantification. The severity levels of the distress were categorized as low, medium, or high, based on predefined criteria aligned with the ASTM D 6433-07 standard. Photographic evidence was also collected to complement the written records, providing a visual reference for the observed conditions. This comprehensive visual survey approach enabled a thorough assessment of the pavement's current state, facilitating an accurate calculation of the Pavement Condition Index. During the visual survey, various types of pavement distresses were observed and documented. These included longitudinal and transverse cracking, alligator cracking, potholes, raveling, rutting, and edge cracking. Each distress was characterized based on its visual appearance and measured for extent and severity. Potholes, which pose significant safety risks, were identified and measured for their size and depth similar to Figure 3 and Figure 6. Longitudinal and transverse cracking was noted along the pavement lanes, indicating potential issues with pavement structure and environmental factors. Alligator cracking, indicative of structural failure, was observed in several locations as shown in Figure 4. Raveling, characterized by the loss of surface material, and rutting, indicative of deformation under traffic loads, were also documented like Figure 8. Edge cracking similar to Figure

5 occurred likely due to inadequate support at the pavement edges, was recorded along the roadway's periphery. Longitudinal cracks of low severity were also observed as shown in Figure 7. These distresses were classified and analyzed according to the ASTM D 6433-07 standard to assess their impact on the overall pavement condition. The research involved several steps to systematically assess and quantify the pavement's condition, which are detailed below.

Figure 3: Pothole in the vicinity of a speed breaker

Figure 4: Medium severity alligator cracking

Figure 5: High severity edge failure

Figure 6: High severity pothole

Figure 7: Low severity longitudinal crack

Figure 8: Medium severity rutting

2.1 Pavement Network Definition

The network under study includes the N-5 (Dhaka-Rangpur-Saidpur-Banglabandha National Highway), N-518 (Dhaka-Rangpur-Saidpur National Highway), and Z-5011 (Saidpur-Parbatipur Zilla Highway). These highways form critical links between major cities such as Saidpur, Parbatipur, and Rangpur, as well as connecting several towns and villages in the surrounding area. The N-5 Highway, in particular, serves as a bypass from Saidpur Terminal, extending northward to Banglabandha land port, approximately 140 kilometers from Saidpur.

The highways comprising this network are:

- N-5 (Dhaka-Rangpur-Banglabandha National Highway)
- N-518 (Dhaka-Rangpur-Saidpur National Highway)
- Z-5011 (Saidpur-Parbatipur Zilla Highway)

2.1.1 Branch & Section:

The pavement network for this study comprises the Z-5011 (Saidpur-Parbatipur Zilla Highway) section shown in Figure 9, specifically the 12 km stretch from Parbatipur mor, Saidpur to BAUST Campus. This section was chosen due to its critical regional connectivity, extensive use by the local citizens and observed pavement distresses.

The selected road section (Z-5011) was divided into smaller manageable units called "sections" and further into "sample units" for detailed analysis. The total road surface area was calculated, and based on the standard area for an asphalt road sample unit, the section was divided into smaller sample units.

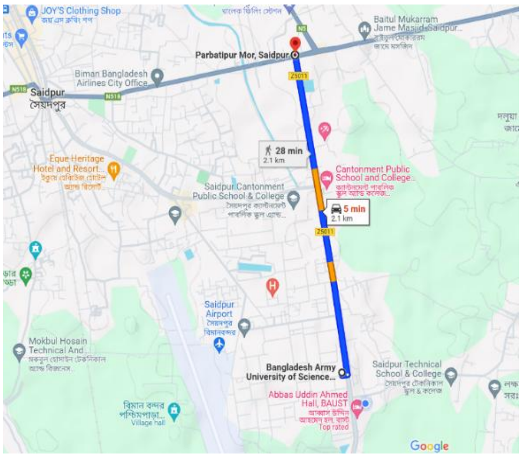

Figure 9: Study Area Selection

2.1.2 Sample Units in the Z 5011 Section:

Before conducting the physical condition survey of the Z-5011 road section, the area was divided into 146 sample units to facilitate a systematic analysis. The road, spanning 40,000 feet (12.1 km) with a total surface area of 720,000 square feet, was segmented based on a target sample unit area of approximately 2,500 square feet. Each final sample unit measured 150 feet in length and 18 feet in width, ensuring that the survey provided comprehensive and representative data for the Pavement Condition Index (PCI) analysis.

2.1.3 Sample Units to be Inspected:

Inspecting each sample unit in a large pavement section was a very resource intensive endeavor. Therefore, a sampling plan was created to achieve the PCI assessment of large pavement section in an accurate manner while minimizing the required resources. The number of sample units to be inspected was based on the road's usage and whether the survey was conducted at a network or project level. A project-level inspection is being used here. Out of the 146 total sample units along the 40,000 feet road section, 12 were chosen randomly for inspection. Such quantity was obtained from the survey manual graph as explained in ASTM D6433-07 which has a standard deviation (PCI) of 10, range of 25 (PCI) and an allowable error of plus/minus 5, thus ensuring that an appropriate sample size was selected to have a reliable estimate of the overall condition of pavement

2.1.4 Sampling Interval:

To implement a systematic approach within the random sampling process, a sampling interval was established, resulting in a method known as systematic random sampling. The sampling interval, calculated as the total number of sample units divided by the number of units to be surveyed (146/12), yielded an interval of approximately 3.83, which was rounded to 4. A random starting point was then selected, set arbitrarily at 2. This systematic method ensured that 12 sample units were evenly and objectively chosen for the condition survey, facilitating a thorough and unbiased assessment of the pavement section.

2.2 Calculation of Pavement Condition Index

2.2.1 Sample Unit PCI Calculation:

Once the condition survey is completed for each sample unit, the results are used to estimate the PCI. The PCI calculation is based on deduct values, which are weighing factors from 0 to 100 that indicate the impact of each distress on pavement condition. During the pavement condition survey of Saidpur-Parbatipur Highway (Z-5011), the quantity and intensity of each distress type were measured according to the definitions and procedures for asphalt roads. The calculation steps for asphalt pavements are summarized in Table 1, with an explanation of each step provided below.

Step 1: Deduct Value Determination

First, the quantity of each distress type is measured and recorded in a tabular form like Table 1. This quantity is then converted to a percentage density by dividing by the total area of the sample unit. Deduct values are obtained from the distress deducts value curve provided in the ASTM D6433-07 Distress Manual. Figure 10 gives an example of obtaining deduct value when the observed distress is alligator cracking.

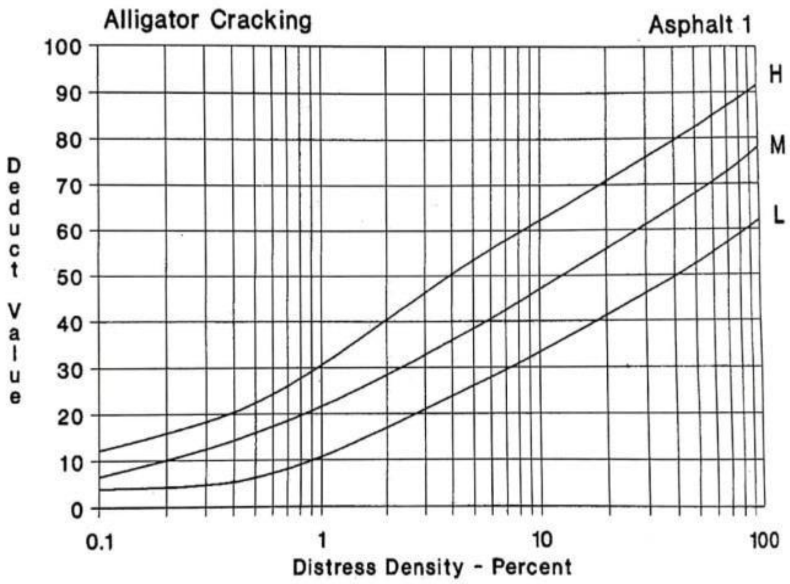

Figure 10: Deduct Value Curves for Asphalt Road (Alligator Cracking) (ASTM, 2020)

Table 1: Asphalt Surfaced Pavement sample unit condition survey sheet

Conditional Survey Data Sheet for Sample Unit of Saidpur-Parbatipur Highway (Z 5011)

Branch: Z 5011	Section: 001	Sample Unit: 1
Surveyed By: AHH	Date: 26 Jan 25	Sample Area: 5000 Sft.

1. Alligator Cracking(ft^2)	6 Depressions(ft^2)	11 Patching & Util. Cut(ft^2)	16 Shoving(ft^2)
2. Bleeding(ft^2)	7 Edge Cracking(ft)	12 Polished Aggregate(ft^2)	17 Slippage Cracking(ft^2)
3 Block Cracking(ft^2)	8 Joint Reflection Cracking (ft)	13 Potholes (count)	18 Swell (ft^2)
4 Bump and Sags(ft)	9 Lane & Shoulder Drop Off (ft)	14 Railroad Crossing(ft^2)	19 Weathering/Ravelling(ft^2)
5 Corrugations (ft^2)	10 Long. & Trans. Cracking (ft)	15 Rutting(ft^2)	

Distress Severity	Quantity		Total	Density %	Deduct Value
1 M	56	88	144	2.88	52
1 H	156		156	3.12	67
3 H	94		94	1.88	37
7 H	14	28	42	0.84	18
13 H	6		6	0.12	8
15 M	66		66	1.32	24

L = Low M = Medium H = High

Step 2: Maximum Allowable Number of Deducts (m)

If the highest individual deduct value exceeds 2, the allowable number of deducts is determined using a formula specific to asphalt roads. This step ensures that the correct number of distresses is considered in the PCI calculation.

The allowable number of deducts, m (Figure 11), was determined using the formula for AC roads:

$$m_i = 1 + (9/98)\,(100 - HDV_i) \tag{1}$$

Where; m_i = allowable number of deducts, including fractions, for sample unit *i;* HDV*i* = highest individual deduct value for sample unit *i*.

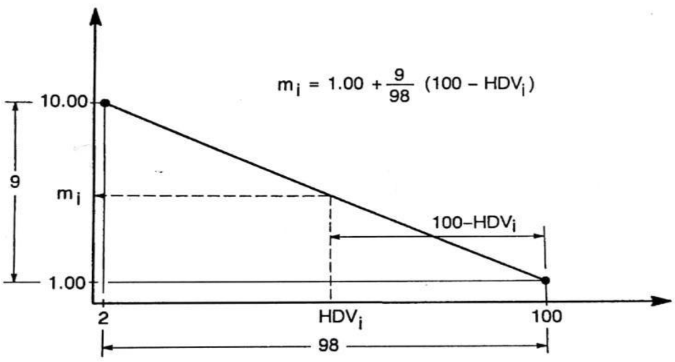

Figure 11: Max Allowable Number of Deducts (m) (ASTM, 2020)

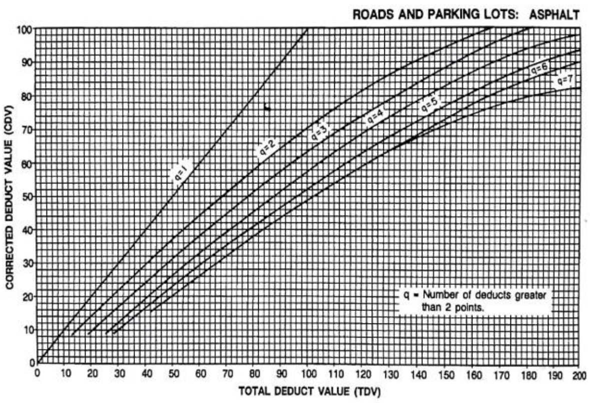

Figure 12. Corrected Deduct Value (CDV) graph for AC roads and Parking Lots (ASTM, 2020)

Step 3: Maximum Corrected Deduct Value (CDV) Determination

The CDV is calculated by summing individual deduct values and applying a correction factor according to Figure 12. This process is repeated iteratively, reducing the smallest deduct value greater than 2 until only one deduct remains. Table 2 shows a summary of PCI calculation for a random sample unit.

Table 2: CDV sheet for calculation of PCI

CDV (Corrected Deduct Values) Sheet									
Branch: Z-5011	Section: Parbatipur Mor to BAUST								Sample Unit #: 1
S/No	Deduct Values						Total	q	CDV
1	67	52	37	24	18	8		6	
2	67	52	37	24	18	2		5	
3	67	52	37	24	2	2	180	4	92
4	67	52	37	2	2	2	156	3	88
5	67	52	2	2	2	2	119	2	80
6	67	2	2	2	2	2	67	1	65
m = 4.03	Discard q=5,6 value								Max. CDV = 92
PCI = 100 – CDV = 100 – 92 = 08									

Step 4: Calculation of PCI

Finally, the PCI is calculated by subtracting the maximum CDV from 100. This value represents the condition of the pavement section. For instance, a PCI value of 08 indicates the sample unit of the pavement section condition to be categorized as failed. When multiple sample units are evaluated, a weighted average is used to determine the overall PCI for the entire section.

2.3 Calculation of the PCI for entire Section Z-5011

The individual PCIs of all the twelve random sample units are summarized in Table 3. The total and average have also been calculated. The PCI for Saidpur-Parbatipur Road (Z-5011) section is the average PCI for 12 sample units calculated by this procedure and comes out to be 37.68. And two additional sample units are also inspected hence a weighted average must be used. The weighted average is calculated by using the equation as below:

$$PCI_S = ((N - A)\ PCI_r + A\ PCI_a)/N \tag{2}$$

Where; PCI_S = PCI of pavement section, PCI_r= avg PCI of random (or representative) samples, PCI_a= avg PCI of additional samples, N= total no. of samples in the section, A= no. of additional samples surveyed.

Table 3: Calculated PCI of each Sample unit

Summary of PCI of Random Sample Units			
Sr. No	Sample Unit PCI	Sr. No	Sample Unit PCI
1	8	7	34
2	41	8	56
3	65	9	44
4	58	10	21
5	43	11	38
6	32	12	11
Subtotal	247	Subtotal	204
Total = 451			
Average (PCI) = 37.58			

A weighted average was calculated that included both the primary and additional sample units. The average PCI of the 12 random sample units was 37.58, while the average PCI for the two additional units was 35.27. Using these values, the weighted average PCI for the entire section was calculated as 37.25. This result categorizes the pavement condition as "Very Poor," indicating significant distress and a need for substantial maintenance or rehabilitation efforts.

3. RESULTS AND DISCUSSIONS

Pavement Condition Index (PCI) was recorded against twelve random sample units on the Saidpur-Parbatipur Highway (Z-5011). The PCI values ranged from 8 to 65, indicating different degrees of pavement distress along the section. Table 4 below summarizes the results of PCI evaluation.

The analysis shows that the condition of the pavement varies significantly, with the majority of the section falling under Poor to Very Poor categories. In particular, three sample units were classified as Failed or Serious (sample units - 1, 10 and 12), which need immediate reconstruction.

Table 4: Summary of sample unit PCI and corresponding measures

Serial No.	Sample Unit PCI	Standard PCI Rating	*Decision*
1	8	Failed	*Reconstruction*
2	41	Poor	
3	65	Fair	*Major Rehabilitation*
4	58	Fair	
5	43	Poor	*Reconstruction*
6	32	Very Poor	
7	34	Very Poor	
8	56	Fair	*Major Rehabilitation*
9	44	Poor	*Reconstruction*
10	21	Serious	
11	38	Very Poor	
12	11	Serious	

Four sample units (6, 7, 9 and 11) were classified as Poor or Very Poor indicating that they had severe distress which necessitates the need for major structural rehabilitation or overlay on them. The other remaining units had PCI values between 56 to 65 which implied Fair category thus showed that those sections had to undergo minor restoration works for them to return to their original state of perfection.

The overall Pavement Condition Index (PCI) for the entire stretch was calculated to be 37.25, categorizing this portion as Very Poor. This indicates the necessity for an extensive rehabilitation program to address the gradual deterioration of pavements, with special emphasis for a prompt repair of sections where the damage is very severe. The results aligned with the findings of the visual distress survey, providing more evidence of the importance of early maintenance and rehabilitation.

4. CONCLUSION

The pavement condition of the road being surveyed was found to be ranging from 8 (indicating failed state) to 65 (fair condition). Consequently, it was observed that the PCI of this stretch of road was approximately 37.25, thereby categorizing it as “very poor.” This shows that a significant portion of this road requires repair and rehabilitation at the same time. The study sought to find out the main reasons for pavement deterioration. The reasons include improper transverse and longitudinal slope, overloaded trucks carrying materials, poor drainage design, and lack of proper maintenance among others. All these findings point out to an urgent need for specialized maintenance strategies aimed at addressing these problems with an intention of expanding the life span of pavements. The study also proposed specific rehabilitation measures based on PCI scores along with types and severities of observed distresses. Results provide important insights driven by site-specific data, which help road maintenance authorities make prompt action and decisions. It is possible to keep desired service levels on highways while minimizing total expenses incurred by pavements during their entire lifetime by applying proposed maintenance practices. The necessity for periodic assessment of pavement conditions and use of standard methodologies like PCI to inform and optimize maintenance and rehabilitation efforts was a key focus of this study.

5. DECLARATION OF USE OF AI

The authors declare that AI tools were used in a limited and supportive capacity during the preparation of this manuscript. Specifically, Grammarly**,** ChatGPT (OpenAI, 2026 version)**,** and SciSpace Research Assistant were utilized to check grammar, improve sentence structure and clarity, and assist with citation formatting in accordance with the ICCESD 2026 submission guidelines. No AI tools were employed for research design, data generation, analysis, or interpretation of results. All scientific concepts, findings, and conclusions presented in this paper were entirely developed and verified by the authors, who take full responsibility for the accuracy and integrity of the work.

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