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Assessment of Subgrade Resilient Modulus for Identifying Causes of Pavement Failure: A Comparative Analysis

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Abstract

This study aims to investigate the parable causes of repetitive pavement failures of the Trimohini to Baromile road section of Rajshahi-Kushtia highway in Bangladesh. The comparison of different factors causing pavement failure between Trimohini to Baromile section and other non-repetitive failure type road (Dhaka Pabna Highway) was analyzed. Dynamic Cone Penetration (DCP) tests were carried out at six distinct locations from Trimohini to Baromile section and subgrade soil sample were collected for laboratory tests to obtain physical characteristics. The strength and physical properties at selected points of both highway sections was analyzed by examining data obtained from field tests and laboratory tests. The values of the subgrade resilient modulus of Rajshahi-Kushtia highway section were lower compared to other road sections of the Dhaka-Pabna highway. In the Trimohini-Baromile highway section, pavement failure is attributed to low subgrade resilience modulus and excessive moisture content. Conversely, the Pabna Bus Terminal-Madhupur Section maintains a higher subgrade resilience modulus, leading to a stable pavement condition. This study highlights the significance of subgrade resilience modulus and moisture content on pavement failure or stability. The findings contribute to a better understanding of subgrade behavior and can inform the design and maintenance of highway infrastructure to enhance serviceability and durability.

Keywords: Subgrade, Resilient Modulus, Dynamic Cone Penetration Test (DCPT), Pavement, Moisture Content

1. Introduction

Trimohini to Baromile part of the Rajshahi-Kushtia Highway (N704) is an important transportation route that connects the southern and northern parts of Bangladesh. This study road section has been selected based on the maintenance history of the RHD website [1] which Location Reference Points (LRP) and Chainage of this road section are LRP050a, Ch. 50+380 and LRP064a, Ch. 64+298 respectively. It is 10.260 kilometers long. This section is crucial for the flow of both passengers and cargo. But this road's pavement structure deteriorates every year, requiring constant reconstruction, rehabilitation, and repair. The RMMS [1] database of the RHD indicates that 33 contracts were executed for the maintenance of this section, funded by the Revenue budget between 2011 and 2019. Rehabilitation was the primary project that RHD worked on between 2011 and 2019. This highway segment was renovated by RHD in 2016-17, 2018-2019, 2019-2020, and 2021-2022, which is incredibly expensive for a developing nation. The construction work costs in 2016-17 were 346 million taka. By 2018-19, they had significantly dropped to 125 million taka. In 2019-2020, the costs rose to 230 million taka, and in 2021-22, they increased further to 293 million taka. The primary focus of these projects of RHD was rehabilitation, which aimed to address the persistent issues in this area. The chronology of repair was seen for a different, less-damaged section of the road, which was selected as a section of the N6.

Another road section, from Madhupur Bazar to Pabna Bus Terminal, was selected to compare failure factors using road collapse histories from the RHD official website [2]. This section is part of the Dhaka Pabna National Highway, N6. The LRP and chainage for this road section are LRP030a, 30+957 and LRP041a, 41+755, respectively. According to the RHD website, most of the maintenance work carried out by RHD was of the surfacing type [2].

Road damage can result in a drop in driving speed, a reduction in load capacity, an increase in fuel consumption, and a compromise in environmental protection and traffic safety. contributing to pavement failure: unevenness index, pavement cracking, and rutting. They also highlighted the harmful effects of a clayey subgrade, which leads to surface corrugation and unevenness. Frequent pavement failures in a road section disrupt the road network in neighboring areas. Seed et al. [4] acknowledged that pavement failure can occur due to excessive plastic deformation, leading to the development of design methods to reduce this risk. The paper highlighted the resilience characteristics of clay subgrades and their role in causing failures in asphalt pavements. Islam and Gassman [5] conducted a study on identifying pavement distresses using in-situ subgrade M_R. From this study, the researcher demonstrated that in-situ stress significantly influences the calculation of subgrade M_R, and consequently, the application of MR in predicting rutting and IRI using the AASHTOWare pavement mechanistic-empirical design. They also showed that MR is essential for classifying pavement sections into Good and Fair conditions. BA [6] research to show the relation between MR and permanent deformation of the base course. The researcher found that unbound base course performance is highly dependent on resilient modulus and permanent deformation of unbound layers. Moreover, the researcher proved that the MR is a key factor in predicting pavement rehabilitation. Schmidt [7] carried out research on the effect of subgrade strength on pavement performance. The researcher demonstrated that historically, strength indices like the California Bearing Ratio (CBR) were commonly employed to assess material quality in terms of stiffness and resistance to permanent deformation. However, current trends favor direct stiffness testing using the resilient modulus (MR). Generally, strength and stiffness are strongly correlated. Shium [8] conducted a study on the effects of uncontrolled urbanization and motorization along the N704 road. The study observed that the road has a very high traffic volume, with trucks comprising 59% of the vehicles. According to the survey report, the traffic volume peaks during rush hour (5 to 6 pm), reaching approximately 1600 PCU/hr. Khatun et al. [9] carried out a study analyzing accident black spots on the N704 road section from 2017 to 2021, finding that poor road conditions are a contributing factor to accidents. In order to describe the behavior of cohesive subgrades under repeated loading, including resilient modulus and plastic deformation using the shakedown concept, Yang et al. [10] studied residual lateritic soil. The robust modulus of cohesive subgrades demonstrates a strain-hardening tendency at low stress levels, according to the experimental data. Research on Bangladesh's Sylhet-Sunamganj Road was done by Ahmed et al. [11] in order to analyze inadequate soil qualities (DCP value, CBR, PI, etc.) and unsuitable design of highway pavement current failure. Poor geotechnical qualities are a significant contributor to pavement failure, according to the study. Due to frequent road failures and ongoing construction on the Trimohini to Baromile road section, there is an unhealthy road network. This results in traffic congestion, bottlenecks, longer travel times, road accidents, higher vehicle operating costs, and overall economic loss for the country. Hasan and Sobhan [12] have conducted a study to assess the failure and maintenance of Rajshahi Metropolitan City, Rajshahi, Bangladesh. They found possible factors such as substandard bituminous mixes, poor-quality materials, heavy traffic loads, excessive rainfall, and inadequate drainage systems are attributed to pavement failures. The study also showed that pavement failure led to various problems, including traffic congestion, passenger and driver discomfort, and higher vehicle operating and maintenance costs. Hamrawy and El-Hakim [13] conducted research on the subgrade stiffness of roads in Alexandria City, Egypt. The study found that the overall rut depth of the pavement, including the rut depth in the asphalt layer, rises as subgrade stiffness decreases. Conversely, the pavement's fatigue life improves as subgrade stiffness increases. Shakhan et al. (2022) performed a study in Turkey to examine the effect of subgrade strength on flexible pavement distresses. They discovered that lowering subgrade CBR values from 50 to 5 led to an increase in both rutting depth and the extent of cracking. Jayakumar and Soon [14] conducted another study on flexible pavement failures in tropical regions, emphasizing that subgrade strength and pavement moisture content are crucial factors in pavement failures. Behiry [15] focused on the rutting and fatigue failures of flexible pavement and found that the subgrade resilient modulus and base thickness were important influencing factors. This research was conducted in Egypt. The result of this study revealed that the balance between fatigue and rutting lives is primarily governed by the base thickness and subgrade resilient modulus. the subgrade soil in the Trimohini to Baromile road section is clay, while the subgrade soil from Madhupur Bazar to Pabna Bus Terminal is silty. Venkatesh et al. [16] found that moisture affects the resilient modulus of clayey subgrade soil, leading to permanent pavement deformation. Butalia et al. [17] found that in cohesive unsaturated soils, the resilient modulus diminishes as moisture content and positive pore pressure rise. Tests on fully saturated cohesive soils revealed that their resilient modulus dropped to less than half of that observed in soil specimens tested at optimum moisture content. Rahman and Gassman [18] examined the MR of subgrade soils across various geographic regions in South Carolina. They discovered that the MR for undisturbed soil samples typically increases with higher in-situ moisture content. Ademila and Olayinka [19] investigated pavement failures in Africa. They collected eighty disturbed and forty undisturbed soil samples from various depths at twenty test pits, which included six failed sections and two stable sections. Their study concluded that the pavement failures were due to water-absorbing clayey soils, poor geotechnical properties of the soils, and inadequate drainage systems. Numerous studies have been conducted to address pavement failure by examining subgrade soil properties such as plasticity, CBR, and moisture-density. However, there is a lack of research directly linking pavement distresses to subgrade M_R. This study aims to characterize the subgrade resilient modulus responsible for repeated road failures and investigate the causes of repeated road failures on the Trimohini to Baromile section of the Rajshahi-Kushtia Highway (N704) by characterizing the subgrade resilient modulus and comparing it with other highway sections. The objectives are to characterize the subgrade MR responsible for the repeated pavement failures on the Trimohini to Baromile road section and to validate these findings by comparing the resilient modulus and failure factors of another road section, specifically from Madhupur Bazar to Pabna Bus Terminal on the Dhaka Pabna National Highway (N6). Additionally, the study seeks to identify possible causes of road failures on the Trimohini to Baromile section based on maintenance history, geotechnical properties, and traffic conditions. It also seeks to assess the impact of subgrade soil types and moisture content on the resilient modulus and pavement performance, analyze the economic implications of frequent road failures and maintenance costs for developing nations like Bangladesh, review existing literature on pavement failures related to subgrade properties, and validate findings through case studies. Finally, the study aims to propose recommendations for improving road durability and reducing maintenance costs based on the study findings.

2. Methodology

The methodology began with collecting maintenance and field data from two selected sites: Trimohini to Baromile and Madhupur Bazar to Pabna Bus Terminal Road section. The field data collection involved two tasks: conducting quality control tests (such as the Dynamic Cone Penetration -DCP Test) on subgrade soil and gathering relevant information and soil samples. From the DCP test, the in-situ CBR value for the subgrade layer was determined. Additional data such as pavement conditions, location information, and traffic data were also collected. Subgrade soil samples from both road sections were then processed to perform quality control tests on physical properties, including the Atterberg limits test, specific gravity test, Maximum Dry Density (MDD) test, and Optimum Moisture Content (OMC) test. The impact of M_R on pavement distress was assessed by comparing the test results from the two road sections.

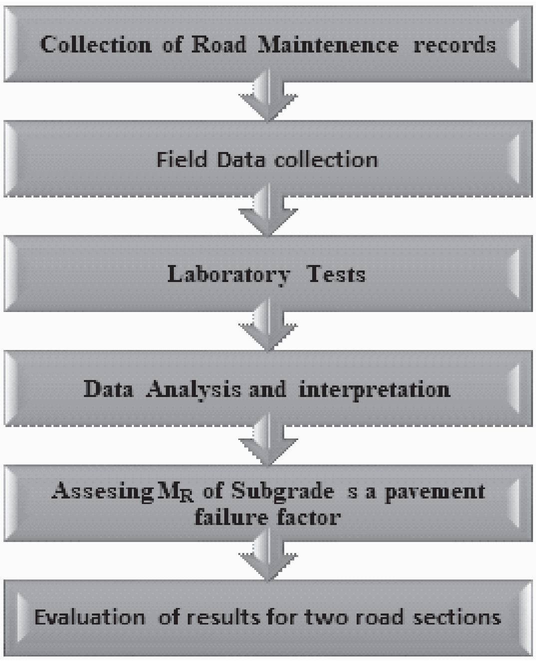

Figure 1. Flow Chart of the Methodology

3. Data Collection

The Kushtia-Ishwardi road section resembles a dirt road in a remote area. However, this road serves as the sole communication link between the southern and northern regions of the country. The following describes how pavement failure data was collected.

3.1. Road Maintenance Records

Pavement failures occur frequently along the Trimohini to Baromile section, whereas maintenance needs are significantly lower on the Pabna Bus Terminal to Madhupur road in comparison. Data from the Roads and Highways Department's (RHD) were gathered to assess maintenance severity across these two road sections.

i. Madhupur to Pabna Bus Terminal Road section (N6):
The Road Maintenance Card for the Pabna Bus Terminal to Madhupur road section (N6) was sourced from the Roads and Highways Department's Road Maintenance Management System (RMMS) database. Between 2007 and 2019, the data indicates a single rehabilitation project, conducted on June 17, 2012. Other entries primarily document pavement-related activities during this period.

ii. Trimohini to Baromile road section (N704)
The Trimohini to Baromile segment, which connects Bangladesh's southern and northern regions, is the subject of this study since it is essential for the movement of people and products. The Rajshahi-Kushtia Highway's Trimohini to Baromile segment (N704) is 10.260 km long. Its corresponding Location Reference Point (LRP) is between LRP050a (Chainage 50+038) and LRP064a (Chainage 64+298). The data below is taken from the RHD website's RMSS database.

3.2. Pavement Condition Data

i. Trimohini-Baromile road section
The pavement conditions varied across different sections. At Talbaria-Kadamtola, the surface lacked visible bituminous topping and showed depressions resembling wavy patterns under loaded vehicles. Ranakharia (Shown in Figure 2) exhibited severely poor conditions with no bituminous layer, exposing the base coarse and demonstrating inadequate drainage. Baromile-Chandgram section and Bahalbaria Bazar showed excessive surface rutting (Figures 3 and 4)

Figure 2. Pavement Condition at Ranakharia Mosque (23°57'47.1"N 89°04'11.2"E)

Figure 3. Rutting with high depth at Baromile (24°00'17 .3"N 89°00'57.4"E)

Figure 4. Rutting at Bahalbaria Bazar section (23°58'06.4"N 89°02'03.1"E)

ii. Pabna Bus Terminal-Madhupur Road section (N6)

The pavement surface on Dhaka-Pabna Highway showed good condition with no visible signs of pavement failure. Overall, the pavement section provided good serviceability and a comfortable riding quality due to its smooth surface which is shown in Figures 5, 6, 7 and 8 below.

Figure 5. DCP location at Rajapur-PUST road section (24°00'49.1"N 89°16'38.3"E)

Figure 6. DCP location at Jalalpur in front of Ratnodweep resort (24°01'14.6"N 89°17'26.9"E)

Figure 7. DCP location at Dhopaghata Uttorpara road section (24°01'47.9"N 89°19'10.7"E)

Figure 8. DCP Location of Madhupur Dokkhinpara road section (24°02'12.5"N 89°21'08.3"E)

3.3. Pavement Composition

During pavement condition surveying, the pavement composition data (Figure 9) of different locations of Trimohini to Baromile road section were collected as shown in Table 1.

Figure 9. The Pavement composition is measured

Table 1. Pavement layer composition of Trimohini to Baromile road section

Sl No	Location	Thiknes (mm)			Pavement Condition
		Sub-base Course	Base Course	Surface Coarse	
1	Talbaria Kadamtola (23°57'32.6"N 89°04'15.5"E)	300	275	None	Under Construction
2	Ranakharia Mosque (23°57'47.1"N 89°04'11.2"E)	400	300	None	Pavement Failure
3	Ranakharia Graveyard (23°57'51.1"N 89°03'52.1"E)	400	300	25	Pavement Depressed
4	Bahalbaria Bazar Bazar (23°58'06.4"N 89°02'03.1"E)	350	300	75	Extreme Rutting
5	Khadimpur- Athmile Bazar (23°58'23.6"N 89°01'41.5"E)	230	300	80	Pavement got Partially Deppressed
6	Baromile Chadgram (24°00'17.3"N 89°00'57.4"E)	320	300	80	Rutting

Table 2. Pavement layer composition of Madhupur to Pabna Bus Terminal Road section.

Sl No	Location	Thiknes (mm)			Pavement Condition
		Sub-base Course	Base Course	Surface Coarse	
1	Rajapur-PUST (24°00'49.1"N 89°16'38.3"E)	370	300	80	Good
2	Jalalpur-Ratnodweep resort (24°01'14.6"N 89°17'26.9"E)	300	290	80	Good
3	Dhopaghata Uttorpara (24°01'47.9"N 89°19'10.7"E)	330	300	70	Good
4	Madhupur Dokkhinpara (24°02'12.5"N 89°21'08.3"E)	290	300	70	Good

The pavement layer composition was also identified for the other comparatively better road section (Madhupur to Pabna Bus Terminal) in Table 2. From Tables 1 and 2, it was observed that the pavement composition of the road section is almost the same.

3.4. Traffic Volume Data

Table 3 and Table 4 describes the composition of traffic from the Trimohini to Baromile road section and Madhupur to Pabna Bus Terminal. Tables 3 and 4 can be compared to see how similar the traffic compositions on both road sections are.

Table 3: Motorized Traffic (Commercial) Data of Madhupur-Pabna Bus Terminal Road sections

Survey Year : 2019			Motorised									
			Truck			Bus						
Link No	Count Station Name	Location	Heavy	Medium	Small	Large	Medium	Micro	Utility	Car	Auto-Rickshaw	Motor Cycle
N6-5	TS-N6-5	LRP031+ 1,040m ~ 32.000Km	75	561	626	473	69	235	66	151	3573	978
N704-7	TS-N704-7	LRP055+ 252m ~ 55.000Km	124	660	584	244	251	165	12	151	3633	2644

Source: RHD Divisional offices of Pabna and Kustia.

Table 4. Motorized Traffic (Commercial) Data of Madhupur-Pabna Bus Terminal Road sections

Source: RHD Divisional offices of Pabna and Kustia.

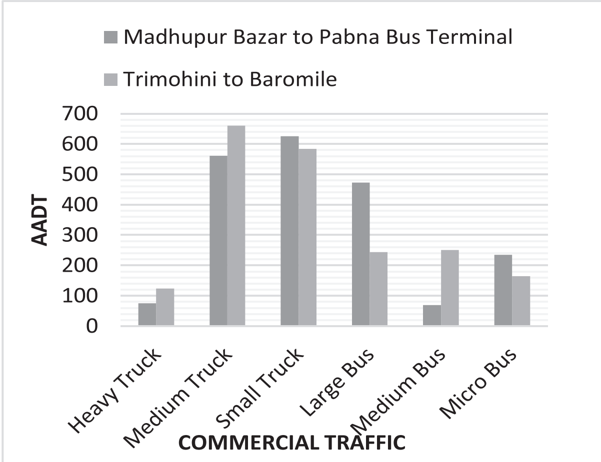

Figure 10. Commercial traffic volume of two sections.

The traffic volumes especially commercial vehicles of the two road sections are quite similar, as shown in Figure 10.

3.5. M_R Calculation Using DCP-CBR Value

The resilient modulus is an essential parameter for assessing subgrade stiffness. It can be determined directly through a cyclic triaxial test or estimated using correlations based on DCP and CBR values. In the field, a DCP test was performed to measure the cumulative penetration per number of blows and calculated the penetration for each blow, known as the DCP index or penetration ratio. After the DCP tests were completed, the DPI (DCP Penetration Index) was correlated with the CBR value using an empirical formula (Webster, 1994).

$$CBR = \frac{292}{DPI^{1.12}}. \quad \ldots\ldots \quad (1)$$

Here, DCPI is expressed in millimetres per blow, while CBR is expressed as a percentage.

The resilient modulus (M_R) is a vital metric for assessing a material's elastic response under load, which is critical for pavement design. It can be estimated from theCBR using the formula provided by the Transport & Road Research Laboratory (TRRL):

$$M_R = 2555\times(CBR)^{0.64} \quad \ldots\ldots \quad (2)$$

In this formula, 2555 is a scaling constant, and 0.64 is an exponent that reflects the non-linear relationship between CBR and M_R, allowing for a straightforward conversion of CBR values into the resilient modulus for practical engineering applications. The M_R was expressed in psi, which was then converted to MPa.

This research is intended to determine the role of the subgrade resilient modulus by conducting DCP tests according to the ASTM-D6951 code on two different highway sections, comparing their strength and physical properties to identify potential causes of pavement failure. DCP tests were performed (Figured 13) at six different locations along the Trimohini to Baromile road section at approximately 2.5 km intervals (Figure 11). Additionally, DCP tests were conducted on the Dhaka-Pabna highway (Pabna Bus Terminal, LRP041a to Madhupur Dokkhinpara, LRP030a) at four different locations (Figure 12).

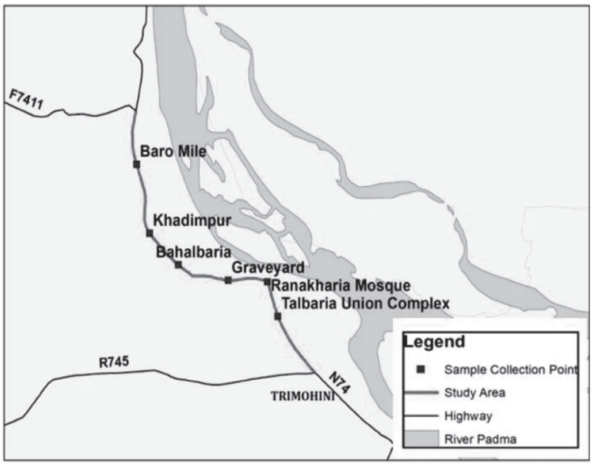

Figure 11. DCP Test and Sample Collection Spots of Trimohini to Baromile Highway

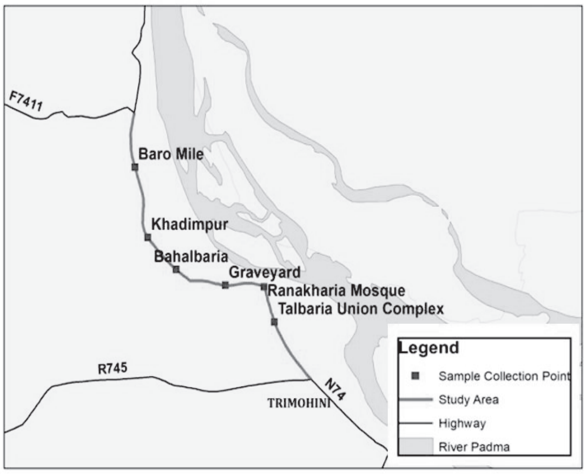

Figure 12. DCP Test and Sample Collection Spots of Madhupur to Pabna Bus Terminal Highway

Figure 13. Subgrade layer saturated by water at Ranakharia Mosque

Using the DCP test results, we prepared a resilient modulus vs. subgrade depth graph for the two different highway sections, with the comparison shown in Figures 14 and 15. As illustrated in Figure 14, in the Trimohini to Baromile Chadgram section of the Rajshahi-Kushtia highway, the subgrade soil in Talbaria Kadamtola and Bahalbaria Bazar exhibited significantly reduced resilience. In these locations, the resilient modulus slightly increased with subgrade depth, reaching a maximum value between 600mm and 800mm. In the subsoil of Ranakharia mosque and Ranakharia graveyard, the resilient modulus displayed a similar pattern: it initially increased, then suddenly dropped, before increasing to a maximum value at greater depths. Conversely, in the Madhupur to Pabna terminal section (Figure 15), the resilient modulus increased rapidly before 100mm depth, reached its maximum value, and then gradually decreased with depth.

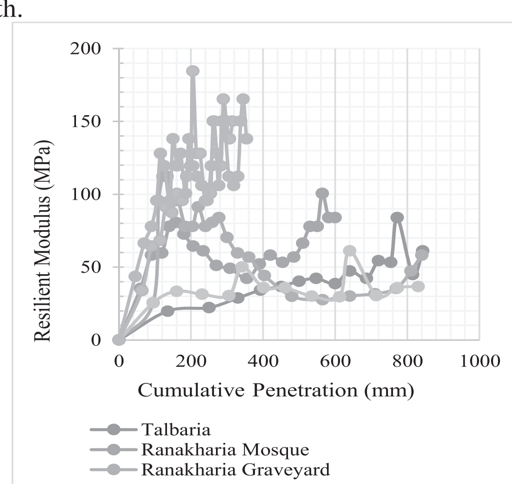

Figure 14. Resilient Modulus at Trimohoni-Baromile road section

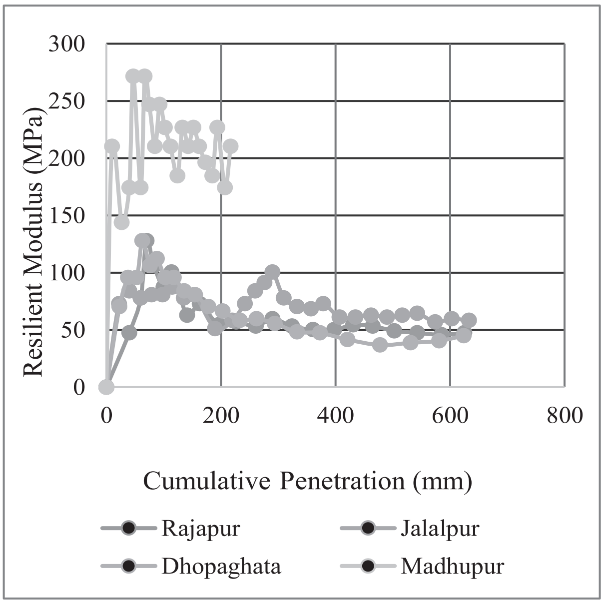

Figure 15. Resilient Modulus Data of Madhupur to Pabna Bus Terminal Road section.

The primary difference between the two highway sections was that in the Trimohini to Baromile section, the resilient modulus increased with greater depth of penetration, whereas in the Pabna bus terminal to Madhupur section, it decreased with depth. It was concluded that the Trimohini to Baromile highway section exhibited poor resistance to dynamic vehicular loads, leading to regular depressions and damage to the pavements. However, there was an exception in the Khadimpur-Athmile Bazar and Baromile regions, which showed superior resilient modulus values due to their deviation from cohesive behavior and lower moisture content. Figure 15 shows significant M_R variation within the same highway section. Some areas had higher M_R values, while others were significantly lower. Pavement performance was influenced by the weakest subgrade sections, leading to localized failures even if the road's overall condition appears good. In the Trimohini to Baromile Chadgram section, locations like Talbaria Kadamtola and Bahalbaria Bazar exhibited reduced resilience, causing regular depressions and damage. These failures can cause overall pavement deterioration over time. It is to be agreed that drawing a direct correlation between subgrade strength and failure intensity at different points is crucial. The observations indicated that weaker subgrade areas are more susceptible to dynamic vehicular loads, contributing to localized failures. While Khadimpur-Athmile Bazar and Baromile regions showed superior resilient modulus values, the presence of random failure patterns suggests that other factors, such as traffic load variations, construction quality, drainage conditions, and environmental factors, may also significantly influence pavement performance. However, this recognizes the need for a more detailed correlation analysis, which we will include.

Regions like Khadimpur-Athmile Bazar and Baromile, with higher M_R values, performed better due to lower moisture content and non-cohesive behavior. However, these exceptions do not negate the overall trend. Despite the road's relatively good condition in some areas, a comprehensive assessment of all subgrade points is crucial. Weak subgrade points contribute to localized pavement failures, leading to more extensive damage over time.

We recommend long-term monitoring and additional testing to correlate M_R values with actual pavement performance over time. Addressing these points provides a nuanced understanding of the relationship between subgrade quality and pavement performance, supporting our claim that poor subgrade conditions contribute to pavement failures despite the road's overall good condition.

3.6. Geotechnical Properties of Subgrade Soil

Soil samples were obtained from the subgrade to undergo various laboratory tests such as moisture content, plasticity index (PI), and specific gravity assessments to determine soil characteristics. The samples were manually extracted from a depth of 101.6 mm and preserved in airtight containers for subsequent laboratory analysis. The moisture content was evaluated using the oven-dry method, and the PI was determined using the Casagrande method.

i. Analysis of Moisture Content

Figures 16 and 17 illustrate a comparison of the moisture content between the Trimohini to Baromile highway section and the Pabna Bus Terminal to Madhupur highway section. As shown in Figure 16, the moisture content in the Trimohini to Baromile section was significantly higher than in the Pabna Bus Terminal to Madhupur section. Particularly, the subgrade soil in Talbaria Kadamtola, Ranakhria Mosque, and Ranakhria Graveyard contained excessive moisture, leading to a soft subgrade. Consequently, these locations exhibited lower resilient modulus values (Figure 14) and deteriorated surface conditions (Figures 2, 3, and 4). These three locations are situated near the Padma River (Table 5), contributing to the saturated subgrade conditions. In contrast, the moisture content in the Pabna Bus Terminal to Madhupur section was normal, as shown in Figure 17, with no nearby rivers or water sources affecting the subgrade.

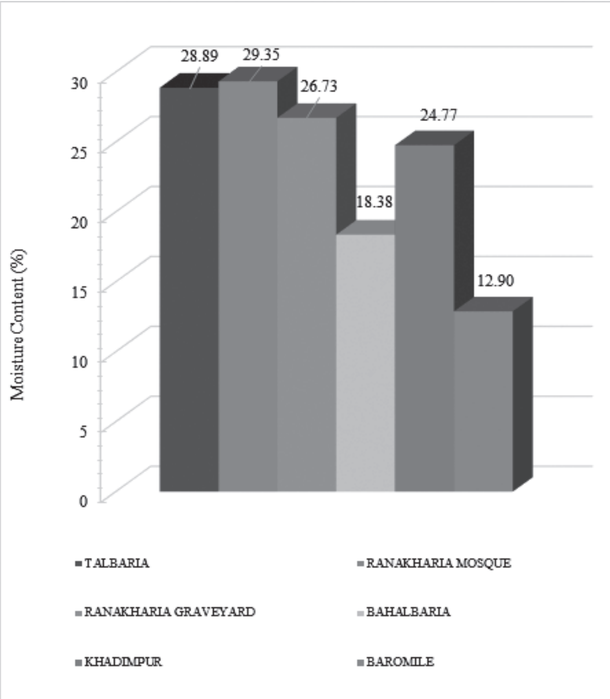

Figure 16. Moisture content chart at Trimohini-Baromile Section.

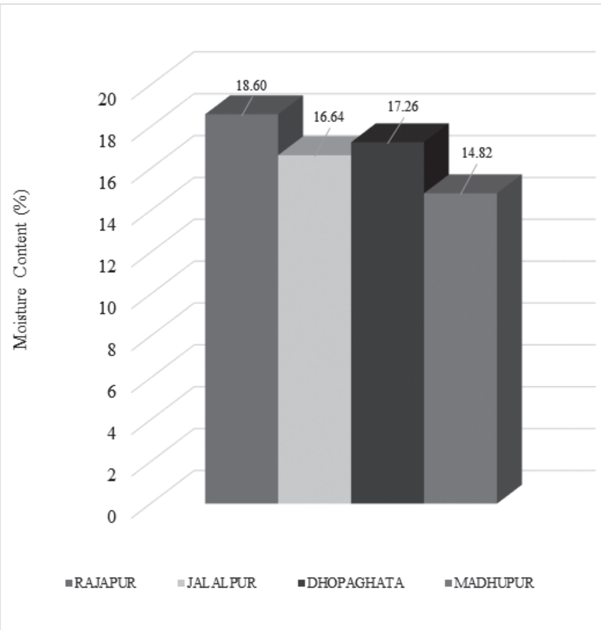

Figure 17. Moisture Content chart at Pabna bus terminal-Madhupur section.

Table 5. Distance of Padma River from the test location

Test Location	Distance from Padma River (m)
Talbaria Kadamtola	480
Ranakharia Mosque	160
Ranakharia graveyard	270
Bahalbaria Bazar	1400
Khadimpur- aathmile Bazar	1500
Baromile Chadgram	1500

ii. Analysis of Plasticity Index

The PI of the subgrade soil from the Trimohini to Baromile section was determined using the Casagrande Plasticity chart, as depicted in Figures 18. These charts classified the soil based on the Unified Soil Classification System (USCS). As illustrated in Figure 18, the Plasticity chart for the Trimohini to Baromile section showed that soil from Bahalbaria Bazar, Ranakhria Mosque, and Ranakhria Graveyard was located in the CL region, indicating it was lean clay or inorganic clay with medium plasticity according to the USCS. Such clay is unsuitable for highway subgrade, particularly in areas with excessive moisture. The subgrade soil from Talbaria Kadamtola was positioned along a line that slightly entered the ML region, suggesting clayey silt or silty clay.

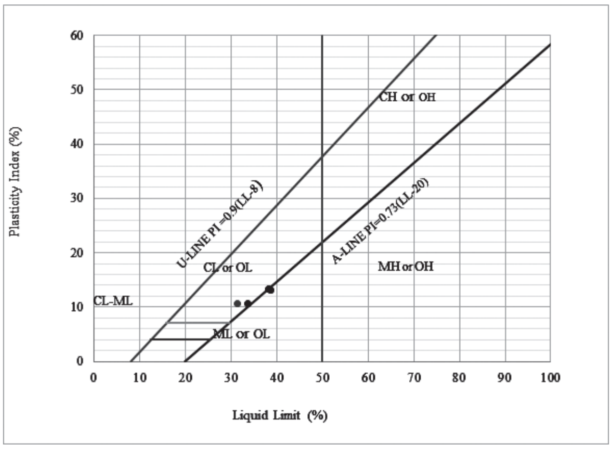

Figure 18. Plasticity Chart for Trimohini-Baromile Section

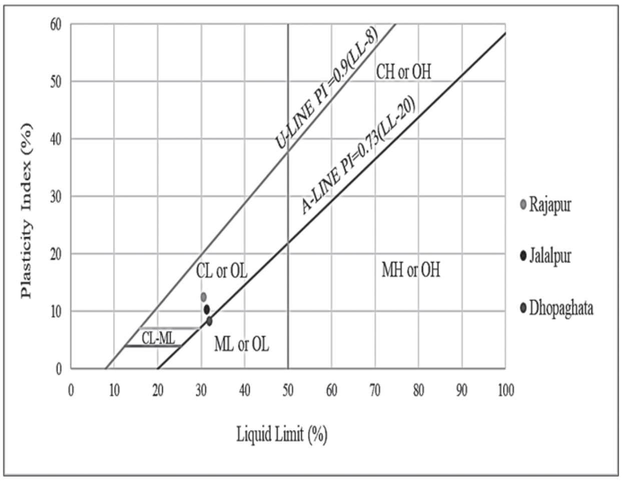

Figure 19. Plasticity Chart for Pabna Bus Terminal-Madhupur Section.

The PI properties of the subgrade soil from the Pabna Bus Terminal to the Madhupur highway section are illustrated in Figure 19. The subgrade soil from Rajapur-PUST and Jalalpur-Ratnodweep Resort is classified in the CL region, while the soil from Dhopaghata Uttorpara falls in the ML region. This classification indicates that the subsoil at Rajapur-PUST and Jalalpur-Ratnodweep Resort is clayey, whereas the soil at Dhopaghata Uttorpara is silty clay. In both highway sections, the subgrade soils are primarily clay or silty clay, but their resilient modulus differs due to the moisture content. The Trimohini-Baromile highway section has a higher moisture content, leading to a soft subgrade and resulting in pavement deterioration. In contrast, the same type of soil in the Pabna Bus Terminal to Madhupur section demonstrates good resilience due to lower moisture levels.

iii. Analysis of specific gravity data

The specific gravity of the subgrade soil from two highway sections was discussed using bar charts shown in Figures 20 and 21. According to Figure 20, the specific gravity of the subgrade soil from Bahalbaria Bazar and Ranakhria Mosque indicates a clayey type of soil, while the subsoil from Talbaria Kadamtola and Ranakhria Graveyard is identified as silt or silty clay. These four locations, part of the Rajshahi-Kushtia highway section, are significantly affected because this type of soil has low dynamic resistance to moisture. In contrast, the specific gravity values for Baromile and Khadimpur-Aathmile Bazar indicate silty or clayey sand, which exhibit a higher degree of dynamic resistance.

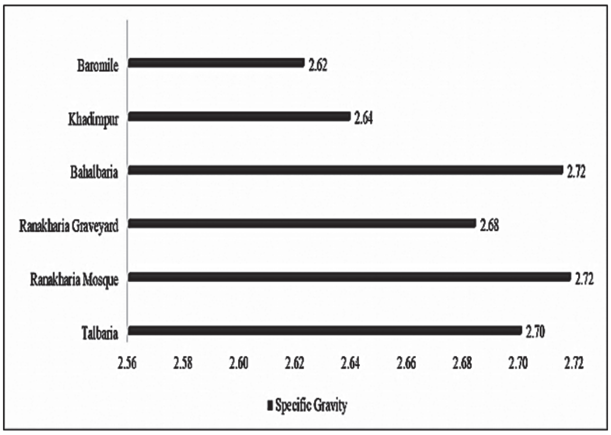

Figure 20. Specific Gravity bar chart at Trimohini-Baromile Road Section.

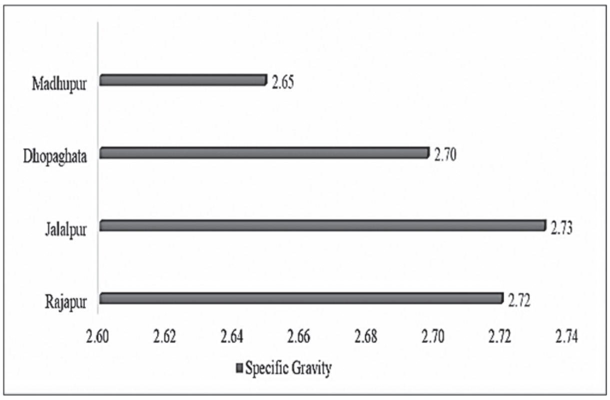

Figure 21. Specific Gravity bar chart at Pabna Bus Terminal-Madhupur Road Section

In the Pabna Bus Terminal to Madhupur highway section, a similar pattern is observed: the soil at Rajapur-PUST, Jalalpur-Ratnodweep Resort, and Dhopaghata Uttorpara is clayey. However, these locations exhibit satisfactory dynamic resistance due to lower moisture content.

4. Results and Discussion

The Trimohini to Baromile section of the Rajshahi-Kushtia Highway (N704) is a vital transportation route connecting southern and northern Bangladesh. This study focuses on understanding the frequent pavement failures in this section and compares them with the more stable conditions found in the Madhupur Bazar to Pabna Bus Terminal section of the Dhaka Pabna National Highway (N6).

4.1. Road Maintenance History:

The Trimohini to Baromile section has undergone extensive rehabilitation efforts over the years, reflecting its critical maintenance needs. From 2011 to 2022, multiple projects were executed by the RHD, totaling significant costs due to the road's susceptibility to frequent pavement failures. In contrast, the Madhupur to Pabna section shows relatively fewer maintenance interventions, indicating better pavement durability.

4.2. Pavement Condition and Composition:

Pavement conditions along the Trimohini to Baromile section varied significantly. Locations like Talbaria-Kadamtola, Ranakharia, Baromile-Chandgram, and Bahalbaria Bazar exhibited severe issues such as rutting and surfacing deficiencies, which contribute to reduced road serviceability and increased maintenance costs. In comparison, the Madhupur to Pabna section displayed good pavement conditions with no visible distress signs, ensuring smoother travel and lower operational costs.

4.3. Traffic and Load Factors:

Both sections experience high traffic volumes, predominantly consisting of commercial vehicles, which exert substantial loads on the pavements. The traffic data underscores the critical role of subgrade strength in supporting these heavy loads without pavement distress.

4.4. Resilient Modulus Analysis:

The resilient modulus of the subgrade soil, a key indicator of its stiffness and load-bearing capacity, was analyzed using DCP tests and correlated with CBR values. In the Trimohini to Baromile section, the M_R varied significantly across different locations, influenced by factors like moisture content and subgrade depth. Locations such as Talbaria-Kadamtola and Bahalbaria Bazar showed lower M_R values, indicating poorer subgrade conditions prone to pavement failures. In contrast, the Madhupur to Pabna section exhibited higher and more consistent M_R values, reflecting superior subgrade performance.

4.5. Geotechnical Properties:

Laboratory tests on subgrade soil samples revealed higher moisture content and PI in the Trimohini to Baromile section compared to the Madhupur to Pabna section. These properties contribute to reduced subgrade strength and increased susceptibility to deformation under traffic loads.

4.6. Economic Implications:

Frequent pavement failures along the Trimohini to Baromile section result in substantial economic losses due to increased maintenance and repair costs, traffic delays, and vehicle operating expenses. Improving subgrade resilience through targeted interventions could potentially mitigate these costs and enhance overall road performance. The study focuses narrowly on specific road sections, relies on potentially inconsistent data from RHD databases, lacks comprehensive environmental impact assessment, briefly considers traffic patterns, covers a limited timeframe (2011-2022), may not generalize to all Bangladeshi roads, and suggests areas for further research in road infrastructure studies in Bangladesh.

4.7. Recommendations

Based on the findings, recommendations include:

- Implementing enhanced subgrade stabilization techniques in vulnerable sections.
- Improving drainage systems to manage moisture levels and reduce subgrade saturation.
- Conducting regular monitoring and maintenance to identify early signs of pavement distress.

5. Conclusion

The study comparing the Trimohini to Baromile section of the Rajshahi-Kushtia Highway (N704) and the Madhupur Bazar to Pabna Bus Terminal section of the Dhaka Pabna National Highway (N6) provides critical insights into pavement performance and subgrade resilience. The extensive and costly rehabilitation efforts on the Trimohini to Baromile section highlight its susceptibility to frequent failures, in contrast to the fewer interventions and better durability seen in the Madhupur to Pabna section. Severe issues such as rutting and surface deficiencies in the Trimohini to Baromile section reduce serviceability and increase costs, while the Madhupur to Pabna section maintains good pavement conditions.

Both sections experience high traffic volumes, underscoring the importance of subgrade strength in supporting heavy loads to prevent pavement distress. The Trimohini to Baromile section exhibited variable and lower M_R values, indicating weaker subgrade conditions compared to the more consistent and higher M_R values in the Madhupur to Pabna section. Additionally, higher moisture content and PI in the Trimohini to Baromile section contribute to its reduced subgrade strength and increased deformation susceptibility. https://doi.org/10.3390/geotechnics3020021

Frequent failures in the Trimohini to Baromile section led to significant economic losses due to maintenance, repairs, traffic delays, and increased vehicle operating costs. To address these issues, the study recommends enhanced subgrade stabilization, improved drainage systems, and regular monitoring and maintenance. Implementing these measures can potentially mitigate frequent pavement failures and improve the overall resilience and economic efficiency of the road infrastructure.

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