

# A Performance-Based Approach to Flexible Pavement Design Integrating AASHTO 1993 Methodology with Local Calibration: A Case Study of the Gobindaganj-Hili Transport Corridor in Bangladesh\*

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## Abstract

The study utilizes localized parameters from the Roads and Highways Department (RHD) Pavement Design Guide and the empirical AASHTO 1993 methodology to explore a performance-based flexible pavement design for the Gobindaganj-Ghoraghat-Hakimpur (Hili) Road corridor in Bangladesh. By implementing actual data on axle load distributions, traffic forecasts, subgrade strength, and material properties, the study proposes a resilient, durable, and cost-effective pavement structure tailored to Bangladesh's challenging geotechnical and climatic conditions. The analysis indicates that the selected materials and thicknesses meet the required Structural Number (SN) criteria for a design life of 20 years. To enhance infrastructure sustainability, the findings stress the importance of improved drainage planning, axle load regulation, and the eventual adoption of mechanistic-empirical approaches.

## Keywords

Flexible Pavement Design, California Bearing Ratio (CBR), Equivalent Single Axle Load (ESAL), Structural Number (SN), AASHTO 1993 Methodology, Mechanistic and Empirical (M-E) Pavement Design

\*This paper employs the Gobindaganj-Hili transport corridor study in Bangladesh to propose a performance-based design for flexible pavements, utilizing the AASHTO 1993 method with local calibration.

## 1. Introduction

### 1.1. Importance of Durable Road Infrastructure in Bangladesh

Due to its strategic location in South Asia and rapidly growing economy, Bangladesh is heavily reliant on its road network to facilitate both regional trade and internal mobility. Currently, roads account for over 60% of the nation's freight and passenger traffic, making them the primary mode of transportation [1]. As Bangladesh aims to become a middle-income nation, the need for a robust and durable road infrastructure has become a national priority. This is particularly critical in rural and border regions, where poor road conditions lead to increased vehicle operating costs and logistical disruptions [2].

Pavement performance is significantly affected by increasing axle loads, seasonal flooding, frequent maintenance delays, and weak subgrades. These factors often result in premature failures such as rutting, fatigue cracking, and moisture-induced damage. Rutting, caused by repeated heavy truck loads and overloading practices, is especially common on national highways serving trade corridors [3] [4]. Fatigue cracking develops rapidly on weak subgrades and poorly drained pavements, reducing structural capacity and serviceability [5]. Similarly, prolonged monsoon exposure accelerates stripping and moisture damage, which undermines bitumen-aggregate bonding and leads to surface distress [6] [7]. Collectively, these failures shorten pavement life cycles, increase vehicle operating costs, and demand frequent rehabilitation.

Consequently, for sustainable infrastructure development, it is essential to have strong pavement systems capable of withstanding high traffic volumes and environmental stresses.

### 1.2. Justification for Flexible Pavement

Flexible pavements consist of multiple granular and bituminous layers that effectively distribute wheel loads to the underlying subgrade. This design is particularly advantageous on soft subgrades, which are common in Bangladesh's deltaic terrain, as it allows for exceptional adaptability to ground movement. Moreover, flexible pavements can be constructed more quickly, maintained or rehabilitated with greater ease, and are generally more cost-effective in terms of initial investment compared to rigid pavements [8].

Because it is essential to accommodate continuous traffic operations when constructing on soft soils with low California Bearing Ratio (CBR) values, flexible pavements are an efficient solution to this problem. It is possible to build up gradually and quickly add overlays with these pavements, which eliminates the need to tear everything down and start over. In addition, the Roads and Highways Department (RHD) [9] of Bangladesh suggests the use of flexible pavements for road segments that can carry heavy vehicle loads but do not have sufficient structural subgrade support. It is consistent with international standards such as those established by AASHTO in 1993 [10].

The performance of asphalt layers under high-temperature and heavy-load

conditions has been enhanced due to advancements in pavement materials, such as the adoption of polymer-modified bitumen, like PG64 [11]. These innovations have made flexible pavements suitable and durable for key corridors, such as the Gobindaganj-Ghoraghat-Hakimpur (Hili) Road, which connects vital border ports and logistics hubs.

Bangladesh's national road projects should use the flexible pavement system because it is the best and most long-lasting option when you look at things like environmental risks, construction logistics, soil conditions, and traffic forecasts

## 2. Literature Review

### 2.1. Pavement Design Methodologies

Pavement design is very important for making sure that road infrastructure is safe, structurally sound, and will last for a long time. Over the years, many design methods have been created around the world. One of the most well-known empirical methods is the AASHTO (1993) Guide for Design of Pavement Structures.

The AASHTO (1993) Guide [10], which was based on the AASHO Road Test, is still a widely used empirical method around the world. To guess how well a pavement will work, we use Equivalent Single Axle Loads (ESALs), subgrade properties, and environmental variables. Using the Structural Number (SN) concept [8] [10], it figures out the needed pavement layer thickness based on the properties of the material and the expected traffic over a certain analysis period. Some important design factors are

- Reliability Level ( $R$ ) and Standard Normal Deviate ( $Z_R$ )
- Standard Deviation ( $S_o$ )
- Serviceability Index Loss ( $\Delta PSI$ )
- Resilient Modulus ( $M_R$ )
- Drainage Coefficient ( $m_i$ )
- Layer Coefficients ( $a_i$ )

Particularly in nations where the initial road test conditions closely resemble local traffic and soil characteristics, the AASHTO method is a preferred standard worldwide due to its adaptability in incorporating both empirical data and localized adjustments [8].

Nowadays, there are more advanced modeling tools available through mechanistic-empirical (M-E) techniques [12]-[14]. However, the AASHTO 1993 Guide is still often used when testing options are limited.

### 2.2. Maintaining the Integrity of the Specifications

The Roads and Highways Department (RHD) published the Pavement Design Guide in 2005, which outlines the procedures for pavement design and construction in Bangladesh. This guide builds upon the AASHTO standards and considers local conditions, such as low CBR (California Bearing Ratio) soils, a monsoonal climate, high groundwater levels, and the capabilities of local construction practices.

The AASHTO method for predicting cumulative traffic loading over the pavement's design life, using Equivalent Single Axle Loads (ESAL), remains a component of the RHD guideline. To address the practical limitations of the local context, certain aspects of the design process are streamlined. For instance:

- In floodplains of Bangladesh, where the natural subgrade exhibits a CBR of less than 5%, the guidelines recommend the incorporation of an Improved Subgrade (ISG) layer.
- For locally used materials such as natural sand and brick aggregate, the guidelines adapt layer coefficients and resilient modulus values accordingly.
- The guideline places significant emphasis on stage construction, allowing for gradual improvements as traffic volume increases.
- Generalized coefficients simplify drainage design in Bangladesh's humid, flood-prone climate, where pavements are often saturated for long periods.

The RHD guidelines specify Vehicle Equivalent Factors (VEF) that are tailored to the traffic composition in Bangladesh, which features a high proportion of overloaded trucks and buses. These guidelines recommend the use of improved subgrades, locally calibrated VEFs that account for overloading practices, stage construction, and modified layer coefficients for regional materials [4].

### **2.3. Integrated Design Approach**

The AASHTO equations for structural number (SN) and the Roads and Highways Department (RHD) values for California Bearing Ratio (CBR), Vehicle Equivalent Factors (VEF), and drainage coefficients are utilized in highway projects throughout Bangladesh. This is particularly true for projects funded by development partners, such as the Asian Development Bank (ADB), which adopt a hybrid approach [5] [9].

To design pavement structures that are technically sound, economically viable, and resilient to the challenging traffic and environmental conditions in Bangladesh, a blended approach is employed. This approach ensures both technical accuracy and local relevance.

## **3. Methodology**

The Roads and Highways Department (RHD) Pavement Design Guide [9] indicates that this study employs an empirical approach to flexible pavement design by integrating locally adapted parameters with the AASHTO 1993 methodology. The methodology consists of two main components: 1) collecting and analyzing design input data and 2) applying the AASHTO pavement design equation using actual data.

### **3.1. Data Collection and Input Parameters**

To gather the necessary input data, a thorough review of the Pavement Design Report was conducted. This review included examining axle load distributions, subgrade strength parameters, material properties, drainage conditions, traffic

forecasts, and serviceability indices [4]. Below is a summary of the data sources and assumptions:

### 1) Traffic Data and ESAL Calculations

- Traffic count surveys, along with forecasts from the Traffic Demand Forecast Report, provided data on traffic volume and classification.
- The following Vehicle Equivalent Factors (VEF) were obtained from the RHD Pavement Design Guide (RHD, 2005) [9]:
  - Heavy Truck: 4.80
  - Medium Truck: 4.62
  - Small Truck and Large Bus: 1.00
  - Minibus: 0.50
- Although the RHD 2005 VEF values are used in the design for consistency with national standards, it should be noted that the actual degree of overloading on Bangladeshi highways likely exceeds these calibration factors. This underscores the importance of strict axle load enforcement, as discussed further in Section 5.3-3.
- For a 20-year design life, cumulative equivalent single axle load (ESAL) values were calculated. According to the Pavement Design Report [15], Section 1 of the project reported an ESAL of 35.05 million for a 10-year period and 81.34 million for a 20-year period.

### 2) Subgrade and Soil Data

- According to RHD specifications, a 250 mm Improved Subgrade (ISG) layer with a California Bearing Ratio (CBR) of at least 8% is necessary due to the project's location on soft soil, which has a CBR of less than 2%.
- AASHTO's empirical relationship [10] was utilized to determine the resilient modulus ( $M_R$ ) of the improved subgrade:

$$M_R = 1500 \times \text{CBR} = 1500 \times 8 = 12000 \text{ psi}$$

### 3) Design Parameters

- Design period of 20 years with phased construction, including an overlay after 10 years.
- The reliability level ( $R$ ) is 90%, showing a  $Z_R$  value of  $-1.282$ .
- Standard deviation ( $S_o$ ) = 0.45
- Loss of the Serviceability Index ( $\Delta\text{PSI}$ ):

$$\Delta\text{PSI} = P_o - P_t = 4.2 - 2.0 = 2.2$$

- The regions are susceptible to monsoons; therefore, a drainage coefficient of 1.0 is recommended under optimal drainage conditions (greater than 25% moisture exposure).

### 4) Layer Coefficients and Thickness

In accordance with AASHTO guidelines and RHD specifications:

- Wearing Course (Dense Bituminous Surfacing PG64):  $a_1 = 0.42$ .
- Aggregate Base Type I (CBR > 80):  $a_2 = 0.13$ ,  $M_R = 28,500$  psi.
- Aggregate Base Type II (CBR > 50):  $a_2 = 0.12$ ,  $M_R = 24,500$  psi.
- Granular Sub-base (CBR > 25):  $a_3 = 0.10$ ,  $M_R = 20,000$  psi.

### 3.2. Application of the AASHTO Design Equation

Structural Number (SN) is determined using the AASHTO 1993 equation, which is:

$$\log_{10} W_{18} = Z_R \times S_o + 9.36 \times \log_{10} (SN + 1) - 0.20 + \frac{\log_{10} \frac{\Delta PSI}{4.2 - 1.5}}{0.40 + \frac{1094}{(SN + 1)^{5.19}}} + 2.32 \times \log_{10} M_R - 8.07 \quad (1)$$

where:

- $W_{18}$ : Total 18-kip ESALs (81.34 million in Section 1).
- $Z_R$ : Reliability level standard normal deviation =  $-1.282$
- $S_o$ : Combined standard error of traffic prediction and performance prediction =  $0.45$ .
- $M_R$ : Subgrade's resilient modulus =  $12,000$  psi
- $\Delta PSI$ : Change in serviceability =  $2.2$
- SN: Structural Number (to be calculated)

#### 1) Structural Number Determination

The required structural numbers were determined based on the ESAL values and design inputs, as outlined in the Pavement Design Report.

- On Improved Subgrade ( $SN_3$ ):  $4.730$
- On Subbase ( $SN'_2$ ):  $4.007$
- On Base ( $SN'_1$ ):  $3.556$

#### 2) Design Thickness Calculation

Each pavement layer's thickness was determined based on drainage values and layer coefficients.

$$SN = a_1 \cdot D_1 + a_2 \cdot D_2 \cdot m_2 + a_3 \cdot D_3 \cdot m_3 \quad (2)$$

Example (Section 1):

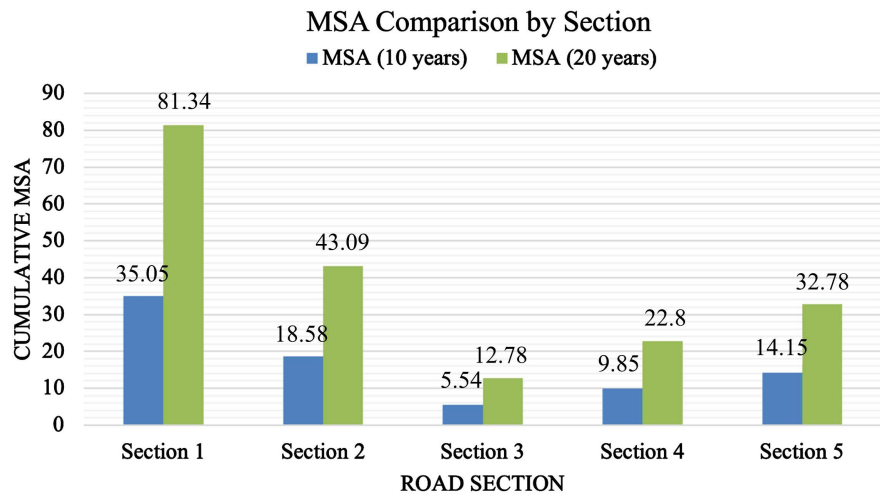
- Wearing Course:  $50$  mm ( $1.97''$ ),  $a_1 = 0.42$
- Binder Course:  $90$  mm ( $3.54''$ ),  $a_1 = 0.42$
- Base Layers (I + II):  $(150 + 200) = 350$  mm
- Subbase:  $200$  mm

## 4. Results

### 4.1. Equivalent Single Axle Load (ESAL) and Million Standard Axle (MSA) Computation

The cumulative Equivalent Single Axle Loads (ESALs) for a 20-year analysis period were determined using axle load distributions and traffic forecasts. To facilitate interpretation, the design ESALs were converted into Million Standard Axles (MSA). The calculations follow the AASHTO methodology and are based on Vehicle Equivalent Factors (VEF) and Annual Average Daily Traffic (AADT).

The increase in MSA over the 20-year design period is illustrated in **Figure 1** for each section:



**Figure 1.** Cumulative MSA by road section for 10 and 20 years.

## 4.2. Structural Number (SN) Calculation

The AASHTO 1993 formula was used to calculate the necessary Structural Number (SN):

$$SN = a_1 \cdot D_1 + a_2 \cdot D_2 \cdot m_2 + a_3 \cdot D_3 \cdot m_3$$

where:

- $a_1, a_2, a_3$ : Layer coefficients.
- $D_1, D_2, D_3$ : Base, subbase, and asphalt layer thicknesses (in inches)
- $m_2, m_3$ : Drainage coefficients (assumed as 1.0 for good drainage conditions)

The following SN values were calculated for Section 1, which had the highest 20-year MSA = 81.34

- Required SN on Improved Subgrade ( $SN'_3$ ): 4.730
- Required SN on Subbase ( $SN'_2$ ): 4.007
- Required SN on Base ( $SN'_1$ ): 3.556

### Step 1 – Asphalt thickness for $SN'_1$

If the entire  $SN'_1$  is provided by asphalt alone:

Asphalt Concrete Layer thickness ( $D_1$ ):

$$D_1 = \frac{SN_1}{a_1} = \frac{3.556}{0.42} = 8.47 \text{ in} \approx 215 \text{ mm}$$

This is a theoretical reference value only. In practice, the structural number is shared by asphalt and granular layers.

### Step 2 – Adopt practical asphalt lifts

Select a conventional dense bituminous surfacing (DBS, PG 64) lift to balance rutting resistance, fatigue performance, and constructability:

- Wearing course: 50 mm (1.97 in)
- Binder course: 90 mm (3.54 in)
- Total asphalt: 140 mm (5.51 in)

Asphalt contribution to SN:

$$\text{Therefore, } SN_1 = a_1 \times D_1 = 0.42 \times 5.51 = 2.315$$

The adjustment reflects standard practice: the initial 215 mm result was theoretical, and the adopted 140 mm is supplemented by base and subbase layers to meet the required SN values.

### Step 3 – Add base layers to satisfy $SN'_2$ (on subbase)

For base layer thickness,

$$D_2 = \frac{SN'_2 - SN_1}{a_2 m_2} = \frac{4.007 - 2.315}{0.12 \times 1.0} = 14.10 \text{ in} \approx 358 \text{ mm}$$

Take 350 mm, comprising Aggregate Base I at 150 mm ( $a_2 = 0.13$ ) and Aggregate Base I at 200 mm ( $a_2 = 0.12$ ) that are standard in local specifications:

- Base I (CBR  $\geq 80$ ): 150 mm (5.91 in),  $a_2 = 0.13$
- Base II (CBR  $\geq 50$ ): 200 mm (7.87 in),  $a_2 = 0.12$

Cumulative SN up to top of subbase:

$$SN_2 = (0.13 \times 5.91) + (0.12 \times 7.87) + 2.315 = 4.028 > SN'_2 = 4.007 \text{ (Required)}$$

### Step 4 – Add subbase to satisfy $SN'_3$ on Improved Subgrade (ISG)

For subbase layer thickness,

$$D_3 = \frac{SN'_3 - SN_2}{a_3 m_3} = \frac{4.730 - 4.028}{0.10 \times 1.0} = 7.02 \text{ in} = 178 \text{ mm}$$

Adopted 200 mm for subbase.

Cumulative SN on ISG

$$SN_3 = (0.10 \times 7.87) + 4.028 = 4.815 > SN'_3 = 4.730 \text{ (Required)}$$

### Step 5 – Confirm stage construction overlay

In line with the stage construction strategy, a 50 mm overlay is planned after 10 years. This is not counted towards the initial SN calculations, but the choice of a 50 mm wearing course facilitates later overlay integration.

Thus, the adopted design thicknesses (50 mm wearing + 90 mm binder + 150 mm Base I + 200 mm Base II + 200 mm subbase, over a 250 mm improved subgrade) meet the required SN values while remaining constructible and consistent with specifications. The calculated SN values for asphalt, base, and subbase layers are summarized in **Table 1**, which presents the properties of each layer according to AASHTO and RHD specifications.

**Table 1.** The properties of each layer based on AASHTO and RHD specifications.

Layer	CBR (%)	Thickness (mm)	Thickness (in)	$a_i$	$m_i$	SN Cont.	SN Cum.	Specification
AC Wearing (DBS, PG64)		50	1.97	0.42		0.827	0.827	AASHTO M 320/M 323
AC Binder (DBS, PG64)		90	3.54	0.42		1.488	2.315	AASHTO M 320/M 323
Base I (Aggregate Base I)	80	150	5.91	0.13	1	0.768	3.083	RHD Specification

Continued

<b>Base II (Aggregate Base II)</b>	50	200	7.87	0.12	1	0.945	4.028	RHD Specification
<b>Subbase (Granular Subbase)</b>	25	200	7.87	0.1	1	0.787	4.815	RHD Specification

\***Table 1** presents the attributes for each layer according to AASHTO and RHD standards.

### 4.3. Layer Thickness Design

The final adopted layer thicknesses for each section are presented in **Table 2**. These thicknesses align with the calculated Structural Number (SN) values and ensure constructability under local standards. The design incorporated the following components:

**Table 2.** Pavement structural analysis of different layers.

Section	Wearing	Binder	Base I	Base II	Subbase	Total Thickness
1	50	90	150	200	200	690
2	50	70	150	200	200	670
3	50	50	150	150	200	600
4	50	70	150	150	200	620
5	59	80	150	150	200	630

\*A 250 mm layer of ISG is present in every section to support the pavement.

Over a 20-year period, traffic projections estimate ESAL values reaching as high as 81.34 million. The Structural Number (SN) values for the subgrade, subbase, and base are 4.73, 4.01, and 3.56, respectively. The designed thicknesses met or exceeded these specifications, with Section 1 having a thickness of 690 mm as an example.

## 5. Discussion

### 5.1. Suitability of Selected Materials and Layer Thicknesses

The project's pavement structure was designed based on geotechnical studies, regional climate conditions, and projected cumulative traffic loading over a 20-year period. The recommended materials—Dense Bituminous Surfacing (PG 64), Aggregate Base (Types I & Type II), Granular Subbase, and Improved Subgrade (ISG)—are locally suitable and economically viable. Additionally, these materials are technically sound and readily accessible in Bangladesh.

- At 63.2°C at 20 mm depth, pavement surface temperatures require increased rutting resistance, which supports the use of PG 64 asphalt as a binder and wearing course [11]. This critical temperature value was calculated using the SHRP (Strategic Highway Research Program) climatic model, which estimates

pavement temperatures at a 20 mm depth based on 7-day average maximum air temperatures and site latitude [16]. PG 64 bitumen can withstand harsh summer conditions and frequent loading from large commercial vehicles.

- Aggregate Base Types I and II have 80% and 50% CBR values, respectively, and provide structural support. These materials maintain layer flexibility and enable staged load distribution, which is crucial for soft subgrades.
- The 200 mm granular subbase has a CBR of 25%, which effectively stops fines from moving up and provides a strong drainage layer to support the base.
- Add a 250 mm ISG layer to weak natural soils (CBR value less than 2%) to strengthen the structure and prevent it from falling apart [5].

The estimated Structural Number (SN) for each section demonstrates that the layer thicknesses either fully comply with or slightly deviate from the requirements, ensuring long-term serviceability and providing an additional safety margin.

## 5.2. Comparison with RHD Pavement Design Standards

The design closely follows the RHD Pavement Design Guide (2005) [9] and aligns with its guidelines regarding:

- Minimum CBR for each pavement layer.
- Using VEF values for different vehicles (4.80 for heavy trucks).
- Improvements to road subgrade on poor soils.
- For well-drained materials, use drainage coefficients ( $m_i = 1.0$ ).
- Stage construction or overlay after 10 years is common in RHD standards.

The AASHTO (1993) method, which has been improved with RHD design values, is the best way to bring international best practices to a local level. The design has a 90% reliability level, which gives you a better guarantee of performance. This is especially important for the trade corridor across borders, though the RHD usually suggests lower levels of reliability for collectors in rural areas.

## 5.3. Risk Analysis: Climate, Flooding, Soil, and Traffic Loading

### 1) Climate and Flooding

The monsoon, which brings heavy rainfall from May to September, has a significant impact on Bangladesh's climate. Waterlogging and flooding are common occurrences on roads, which hasten the formation of potholes, aggregate loss, and pavement stripping [6]. The design tackles climate resilience in this context by:

- $m_i = 1.0$  indicates a good base and subbase drainage system.
- PG 64 performance-graded bitumen resists softening in extreme temperatures.
- Thicker base and subbase layers reduce moisture exposure.

However, without the installation of adequate subsurface drainage systems during construction, there remains a risk of early pavement distress in areas susceptible to flooding or lacking proper drainage. To address these concerns, it is essential to reevaluate these risks through hydrological studies during the detailed design and construction phases.

## 2) Soil Conditions

The alignment goes through low-lying land with soft alluvial soils that aren't forceful and can be easily compressed. To lower these risks, a 250-mm-thick layer of improved subgrade is put on top of the natural soil:

- Increase the load-bearing capacity.
- Refraining from excessive deformation.
- Wheel load distribution over large areas.

The phenomenon of differential settlement can lead to challenges, especially in areas undergoing widening or embankment work. Continuous geotechnical monitoring is essential during construction to adjust the subgrade treatment as needed. This monitoring is crucial for effectively addressing these issues.

## 3) Heavy Traffic Loads

The road is expected to handle a substantial volume of overloaded trucks, as it serves as a crucial trade route to Hili Land Port, especially during peak periods for industrial and agricultural transportation. This has been considered in the design with:

- A high Vehicle Equivalent Factor (VEF) application as 4.80 for heavy trucks.
- The busiest section has 81.34 MSA.
- Flexible pavement is better for stage-by-stage rehabilitation and repeated dynamic loading.

Following the allowed axle load limits is essential to keep the pavement from wearing out too quickly. If these limits are not followed, the pavement may fail before it should, even if the design is sound. This is because axle loads that are much higher than what was planned could cause the pavement to fail prematurely [3] [4]. Moreover, while the RHD 2005 VEFs provide a calibrated basis for design, actual truck overloading in Bangladesh likely exceeds these values, further reinforcing the urgency of enforcement [5].

In addition, the pavement design incorporates resilience measures that mitigate some of the risks of overloading. The adoption of a 90% reliability factor ensures a conservative margin of safety, providing greater assurance that the pavement will perform under uncertain and variable traffic conditions. Similarly, the use of conservative material properties, such as high-quality aggregate bases (CCBR 50 - 80) and polymer-modified PG 64 asphalt, adds durability and resistance to rutting and fatigue. Together, these choices strengthen the pavement structure's ability to withstand higher than expected loading, even if a strict environment is not always achieved.

## 6. Conclusions

The Gobindaganj-Ghoraghat-Hakimpur (Hili) Road was the focus of this study, which utilized the AASHTO 1993 methodology along with local parameters from the RHD Pavement Design Guide [9] [10] to identify the optimal design for a flexible pavement. The analysis concentrated on several key areas: selecting appropriate material properties, assessing the strength of the subgrade, estimating

axle load distributions, and predicting traffic flow patterns.

**Key findings include:**

- Over the course of 20 years, the design concept for high-traffic areas can support cumulative ESAL values that reach 81.34 million. Standard parameters are utilized to ascertain the Structural Numbers (SN). These parameters consist of a reliability factor ( $R$ ) of 90%, a moisture ratio ( $M_R$ ) of 12,000 psi, and a variation in pavement serviceability index ( $\Delta$ PSI) of 2.2.
- In situations where there is soft soil and a significant amount of truck traffic, the optimal pavement structure is a solution that is both technically robust and climate adaptive. These components are included in the composition: a PG 64 dense bituminous surfacing, aggregate base layers, granular subbase, and an enhanced subgrade measuring 250 millimeters.
- The design adheres to AASHTO and RHD standards, with all layer thicknesses exceeding the minimum structural requirements, thereby ensuring performance reliability.
- While the project's soil, climate, and construction limitations justify the use of the flexible pavement method, challenges such as flooding, subgrade settlement, and overloading continue to be prevalent [17].

## 7. Recommendations

### 7.1. Implementation and Monitoring

- To ensure the validity of the assumed design parameters and to make necessary adjustments to layer thicknesses, material testing and field validation, including CBR and  $M_R$  values, should be conducted during the construction phase.
- Following construction, it is imperative to implement a monitoring program that assesses pavement performance under actual loading and environmental conditions. This information is essential for scheduling forthcoming maintenance and enhancements.

### 7.2. Improvement in Drainage Design

- Though the design assumes “adequate” drainage ( $m_i = 1.0$ ), the actual field conditions during the monsoon season may vary quite a bit. To effectively resolve this issue, it is necessary to conduct comprehensive hydrological and hydraulic analyses during the detailed design phase. These analyses should be performed to integrate subsurface drainage systems and raise embankments in areas that are prone to flooding.

### 7.3. Overloading Enforcement

- It is advisable to implement suitable axle load restrictions via weighing stations and legislative actions [4]. Overloaded trucks present a considerable threat to the pavement, which cannot be entirely alleviated through design alone. Consequently, the risk cannot be entirely eradicated.

#### 7.4. Future Research Directions

- Future research should focus on exploring mechanistic-empirical (M-E) design methodologies, which could significantly enhance the simulation of pavement responses to diverse traffic loads and environmental conditions. By integrating these advanced methodologies, researchers can develop more accurate models that represent real-world conditions, leading to improved pavement durability and performance. This approach may enhance design practices and maintenance strategies, thereby alleviating the detrimental impacts of overloaded vehicles and environmental stressors on pavement infrastructure [12]-[14].
- A life-cycle cost analysis must be performed to evaluate flexible and rigid pavement alternatives under diverse regional conditions [11]. This comparison seeks to guide and facilitate future investment decisions.
- The utilization of recycled materials, including fly ash, geosynthetics, and reclaimed asphalt pavement, offers a substantial opportunity to decrease construction expenses while concurrently mitigating environmental issues. The incorporation of these materials can promote more sustainable practices in pavement construction, aligning with the objective of improving pavement durability and performance under diverse conditions. Future research in this domain may concentrate on optimizing the types and proportions of recycled materials employed, alongside evaluating their long-term effects on pavement life cycle and environmental sustainability [18]. By emphasizing the utilization of recycled materials, the construction sector can enhance environmentally sustainable infrastructure development while simultaneously promoting economic efficiency.
- Future research should focus on integrating climate-resilient materials and adaptive paving technologies into national design guidelines as a proactive approach to combat climate change impacts on infrastructure. One example of a climate-resilient material is polymer-modified asphalt, which enhances flexibility and durability against extreme temperatures and moisture variations. Such studies could explore innovative materials like this that withstand extreme weather conditions, thereby extending the lifespan of pavements and reducing maintenance costs. Additionally, adaptive technologies could enhance the performance of pavements in variable climates, promoting sustainability in construction practices. As highlighted by Hossain *et al.* (2020) [19], incorporating advanced materials and designs can significantly improve durability and environmental performance, ultimately contributing to more resilient infrastructure.

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## Conflicts of Interest

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

## References

- [1] Asian Development Bank (ADB) (2020) Bangladesh Transport Sector Assessment, Strategy, and Road Map. ADB. <https://www.adb.org/documents/philippines-transport-sector-assessment-strategy-and-road-map>
- [2] World Bank (2021) Seamless Transport Connectivity Can Create Significant Economic Gains for Bangladesh and India. World Bank. <https://www.worldbank.org/en/news/press-release/2021/03/09/seamless-transport-connectivity-can-create-major-economic-gains-for-bangladesh-and-india>
- [3] Alam, J.B. and Sultana, R. (2017) Performance of flexible pavements under overloaded traffic in Bangladesh. *Journal of Transportation Engineering, Part B: Pavements*, **143**, Article ID: 04017002.
- [4] Hoque, M.S. and Mahmud, K. (2009) Overloading on Highways: A Serious Threat to Infrastructure Sustainability in Bangladesh. *Journal of Bangladesh Institute of Planners*, **2**, 57-64.
- [5] Rahman, M.A. and Haque, M.M. (2012) Calibration of AASHTO Pavement Design Guide for Bangladeshi conditions. *Journal of Civil Engineering (IEB)*, **40**, 121-132.
- [6] Rahman, M.M., Gassman, S.L. and Islam, K.M. (2023) Effect of Moisture Content on Subgrade Soils Resilient Modulus for Predicting Pavement Rutting. *Geosciences*, **13**, Article 103. <https://doi.org/10.3390/geosciences13040103>
- [7] Wijaya, I.P.K., Joshi, A., Alam, M.N., Jayasinghe, S. and Laila, N. (2022) Climate Change Induced Landslide Susceptibility Assessment—For Aiding Climate Resilient Planning for Road Infrastructure: A Case Study in Rangamati District, Chittagong Hill Tracts, Bangladesh. *IOP Conference Series: Earth and Environmental Science*, **1091**, Article ID: 012010. <https://doi.org/10.1088/1755-1315/1091/1/012010>
- [8] Huang, Y.H. (2004) Pavement Analysis and Design. 2nd Edition, Pearson Prentice Hall.
- [9] Roads and Highways Department (RHD) (2005) Pavement Design Guide. Government of the People's Republic of Bangladesh, Ministry of Road Transport and Bridges. <https://rhd.gov.bd/Documents/RoadDesignAndSafety/PavementDesignGuideforRHD/Index.pdf>
- [10] American Association of State Highway and Transportation Officials (AASHTO) (1993) Guide for Design of Pavement Structures. AASHTO. <https://habib00ugm.wordpress.com/wp-content/uploads/2010/05/aashto1993.pdf>
- [11] Mallick, R.B. and El-Korchi, T. (2008) Pavement Engineering: Principles and Practice. CRC Press. <https://doi.org/10.1201/9781420060317>
- [12] Von Quintus, H.L. and Moulthrop, J.S. (2007) Mechanistic-Empirical Pavement Design Guide Flexible Pavement Performance Prediction Models: Volume II Reference Manual (No. FHWA/MT-07-008/8158-2). Montana. Department of Transportation. Research Programs. <https://rosap.ntl.bts.gov/view/dot/24869>

- 
- [13] Olidis, C. and Hein, D. (2004) Guide for Mechanistic Empirical Design of New and Rehabilitated Pavement Structures. NCHRP Rep. 1-37A.  
<http://conf.tac-atc.ca/english/resourcecentre/readingroom/conference/conf2004/docs/s13/olidis.pdf>
- [14] Li, R. and Luo, R. (2019) Evaluation of Mechanistic-Empirical Pavement Design for Flexible Pavements. *International Journal of Pavement Engineering*, **20**, 959-967.
- [15] SMEC-OCG-DOHWA-SYSTRAL-ACE-DDC JV (2025) Draft Preliminary Design Report for Gobindaganj-Ghoraghat-Hakimpur (Hili) Road (Sub-Project 08), Volume 2 of 4: Pavement Design Report (Document No. 5060145-N1EXP-HGY-RPT-0006). Roads and Highways Department, Ministry of Road Transport and Bridges, Government of the People's Republic of Bangladesh.  
<https://rhd.portal.gov.bd/>
- [16] Kennedy, T.W., Huber, G.A., Harrigan, E.T., Cominsky, R.J., Hughes, C.S., Von Quintus, H. and Moulthrop, J.S. (1994) Superior Performing Asphalt Pavements (Superpave): The Product of the SHRP Asphalt Research Program.  
<https://onlinepubs.trb.org/onlinepubs/shrp/SHRP-A-410.pdf>
- [17] Paterson, W.D. (1987) Road Deterioration and Maintenance Effects: Models for Planning and Management. World Bank.
- [18] Dar, A.R. and Singh, S. (2020) Use of Recycled Materials in Pavement Construction. *International Journal of Scientific Development and Research*, **5**, 295-304.  
<https://ijsdr.org/papers/IJSDR2008038.pdf>
- [19] Hossain, M., *et al.* (2020) Performance of Polymer-Modified Asphalt: An Overview. *Journal of Construction and Building Materials*, **234**, Article ID: 117358.