OPTIMIZING GEOTECHNICAL PARAMETERS FOR SUSTAINABLE ROAD EMBANKMENTS IN FLOOD DISASTER-PRONE AREAS OF BANGLADESH

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ABSTRACT

The vulnerability of transportation infrastructure to flood disasters in Bangladesh necessitates strategic interventions to optimize geotechnical parameters for sustainable road embankments. This study focuses on a flood disaster-prone region of Bangladesh, aiming to enhance the resilience and sustainability of road infrastructure in the face of recurring floods. The research is driven by the imperative to develop effective engineering strategies that mitigate the impact of floods on road embankments, ensuring safe and reliable transportation networks. The study areais characterized by a complex interplay of geographic and geological factors that contribute to its susceptibility to flooding. Understanding the local geology is crucial for tailoring geotechnical parameters to the specific conditions of the region. Detailed analyses of soil types, their composition, and formation processes provide the foundation for the subsequent optimization efforts. The methodology employed involves systematic sampling along a Road, incorporating both in-situ and laboratory testing. Geotechnical analyses include the evaluation of critical parameters such as California Bearing Ratio (CBR), shear strength, and soil composition. These analyses are instrumental in identifying key geotechnical characteristics that significantly influence the performance of road embankments during flood events.

The optimization process encompasses the application of advanced techniques to enhance the resilience of road embankments. The results and subsequent discussions delve into the effectiveness of the optimization strategies in comparison to existing standards and guidelines for road construction. This involves a comprehensive assessment of soil properties, composition, and the outcomes of the optimization process. Finally, the study sheds light on the critical role of geotechnical parameters in developing sustainable road embankments in flood-prone areas. The findings not only contribute to the understanding of the study area but also offer valuable insights for broader applications in flood disaster mitigation in Bangladesh. The research emphasizes the need for a proactive approach to optimize geotechnical parameters, paving the way for resilient and sustainable road infrastructure that can withstand the challenges posed by recurrent floods.

Keywords: Geotechnical Parameters, Soil Properties, Sustainable Road Embankments, Flood Disaster-Prone Areas, California Bearing Ratio (CBR)

1.0INTRODUCTION

Bangladesh, situated in a low-lying delta region, faces recurrent challenges posed by natural disasters, with floods being a pervasive and devastating phenomenon. The impact of floods extends to the country's transportation infrastructure, especially its road network. The vulnerability of road embankments to flood disasters necessitates a strategic approach to optimize geotechnical parameters, ensuring the sustainability and resilience of these critical transportation pathways. This study focuses on a flood disaster-prone area of Bangladesh, with the aim of enhancing the geotechnical design of road embankments for sustainable performance under flood conditions. Bangladesh's topography, crisscrossed by numerous

rivers and characterized by a vast delta, exposes its infrastructure to the dual challenges of frequent flooding and riverbank erosion. Roads, as lifelines for communities and commerce, bear the brunt of these disasters. The studiedroad is situated in Munshiganj District, provides a pertinent case study due to its susceptibility to seasonal floods. Addressing the geotechnical vulnerabilities of this road is crucial not only for local communities but also as a model for similar regions across the country.The primary objective of this study is to optimize geotechnical parameters to develop sustainable road embankments capable of withstanding flood disasters. By focusing on the Road, the research aims to provide insights and recommendations that can be extrapolated to enhance the resilience of road infrastructure in other flood-prone areas of Bangladesh.

The reviewed literature provides a comprehensive insight into various aspects of geotechnical properties and their implications on soil behavior. Oghenero et al. [1] delve into the geotechnical properties of subsurface soils in the Warri region of the Western Niger Delta, emphasizing the need for understanding soil characteristics in engineering applications. Oyediran and Durojaiye's study [2] in south-western Nigeria explores the variability in geotechnical properties of residual clay soils, highlighting the challenges posed by diverse soil types. Roy and Dass [3] present statistical models for predicting shear strength parameters in Sirsa, India, contributing valuable tools for optimizing geotechnical parameters. Ersoy et al. [4] employ an analytical hierarchy process to estimate soil strength parameters in Tertiary volcanic regolith in NE Turkey, demonstrating a systematic approach to geotechnical optimization. Koçak and Köksal [5] showcase the significance of determining the causes of damage in historical buildings in Istanbul, Turkey, shedding light on geotechnical considerations in construction. Shanyoug et al. [6] experimentally study fines content's impact on dynamic compaction grouting in decomposed granite in Hong Kong, providing insights into construction materials. Karmi et al. [7] present case studies on the simultaneous effect of shear strength parameters' height on the optimization of embankment dams. Cao et al. [12] present a comprehensive examination of Disaster Risk Assessment (DRA) for railways, identifying challenges and proposing a sustainable solution based on Building Information Modeling (BIM) and Geographic Information System (GIS). Their work underscores the importance of integrating technology to enhance the resilience of railway systems, providing a promising avenue for sustainable disaster management. In the context of flood disaster management,Muzamil et al. [13] propose a framework tailored to the Malaysian context. Their study emphasizes the need for a systematic approach in managing floods, covering various phases of the disaster management cycle. The framework provides a valuable guide for policymakers and practitioners involved in flood risk reduction and response efforts. The evaluation of slope disaster susceptibility is a critical aspect of natural hazard mitigation. Yang, [14] contributes to this area by utilizing GIS and a three-level fuzzy evaluation method to assess slope vulnerability. This approach enhances our understanding of the spatial distribution and factors influencing slope disasters, aiding in the development of targeted mitigation strategies. The resilience of critical road structures under natural hazards is a subject addressed bySetungeet al. [15]. Their work specifically focuses on bridges, culverts, and floodways, proposing strategies to enhance their resilience. The study emphasizes the importance of incorporating advanced materials, technological innovations, and community engagement to strengthen critical infrastructure against the impacts of natural disasters.Collectively, these studies contribute to the foundational knowledge required for optimizing geotechnical parameters, particularly relevant for the study.

The study unfolds in subsequent parts, beginning with a comprehensive review of the existing literature on geotechnical considerations in flood-prone areas. The methodology section details the approach to sampling, in-situ testing, and laboratory analyses. Results and discussions delve into the optimization process and its outcomes. The study concludes with recommendations for the implementation of optimized geotechnical parameters in road

embankment design, emphasizing sustainable and resilient infrastructure in the face of flood disasters. The significance of this study lies in its potential to contribute to the development of robust engineering solutions tailored to the unique challenges posed by flood disasters in Bangladesh. As climate change intensifies the frequency and severity of floods, optimizing geotechnical parameters becomes imperative for ensuring the longevity and functionality of critical transportation arteries.

2.0 GEOLOGY OF THE STUDY AREA

The study was carried out at Sayedpur, which is located in Sirajdikhan Upazila on the fourth kilometer of the Sayedpur-Hasara Road. Situated roughly 37 kilometers southeast of Dhaka City is Sirajdikhan Upazila. Munshiganj District includes the upazila of Sirajdikhan. It is one of the six Upazilas in the Munshiganj district. The upazila's borders are as follows: on the north and east, Keraniganj Upazila of the Dhaka district and Narayanganj Sadar Upazila; on the south, Louhjong and Srinagar Upazilas; and on the west, Nawabganj and Srinagar Upazilas. The land area of the Upazila is 172.51 sq km, while the river area is 7.54 sq km, totaling 180.19 sq km. There are 288107 people in total, with 143559 men and 144547 women.

Fig 1: Map of the Study Area

Munshiganj District, particularly Sirajdikhan Upazila, Bangladesh, is characterized by a diverse geological landscape shaped by the intricate interplay of riverine and alluvial processes. Situated in the central part of the country and encompassing the confluence of major rivers such as the Padma and Meghna, the region is predominantly composed of alluvial deposits. The relentless erosional and depositional activities of these rivers have contributed to the formation of extensive floodplains and riverbanks in Sirajdikhan Upazila. The alluvial soils in the district are typically rich in sedimentary materials, varying from sandy to clayey compositions. The topography of Sirajdikhan Upazila is characterized by low-lying

plains, a common feature in many riverine areas. The presence of distributaries and channels stemming from the major rivers further influences the geomorphology of the region. The dynamics of riverbank erosion and sedimentation contribute to the continuous evolution of the landscape, influencing soil characteristics and geological formations. Given its proximity to major water bodies, the groundwater table in Sirajdikhan Upazila is likely to be a critical factor in the geological profile. The interplay between surface water and subsurface conditions can impact the stability of the soil and contribute to variations in geotechnical properties. Additionally, the susceptibility to flooding and other hydrological events is inherent in the geological context, necessitating a comprehensive understanding of the region's geology for sustainable infrastructure development.

Finally, the geology of Sirajdikhan Upazila in Munshiganj District is intricately linked to the dynamic processes of riverine deposition and erosion. The alluvial plains, shaped by the influence of the Padma and Meghna rivers, create a geological setting with diverse soil compositions and topographical features. An in-depth exploration of these geological characteristics is crucial for various applications, including infrastructure development, disaster resilience planning, and environmental management in the region.

Sayedpur-Hasara Road is a section of the Munshiganj Road Division, RHD's Keraniganj (Sayedpur)-Hashara-Birtara-Singpara-Kajalpur-Nagerhat Road (Z-8203). The Sayedpur-Hasara Road connects to the Hasara, or 15th km of the Dhaka-Mawya National Highway (N-8). The N-8 road, which connects Dhaka, Narayangonj, Munshiganj Ziilla Headquarters, Sirajdikhan Upazila, Sreenagar Upazila Headquarters, and another south district of Bangladesh, has then projected this road. The development of this route will result in a significant expansion of Munshiganj economy. Activities related to social, cultural, commercial, educational, and heart health will therefore be simple. Following the project's completion, the social-economic climate in this region will improve and poverty will decline.

3.0 MATERIAL AND METHOD

The study employed a comprehensive approach to investigate and optimize geotechnical parameters for sustainable road embankments in flood disaster-prone areas, focusing on the Sayedpur-Hashara Road in Munshiganj District, Bangladesh. The research methodology includes the given steps: Identify the Problem Statement, Objective, Literature Review, Visit Study Area, Data Collection, Data Analysis, Result Discussion, Conclusion & Recommendations.

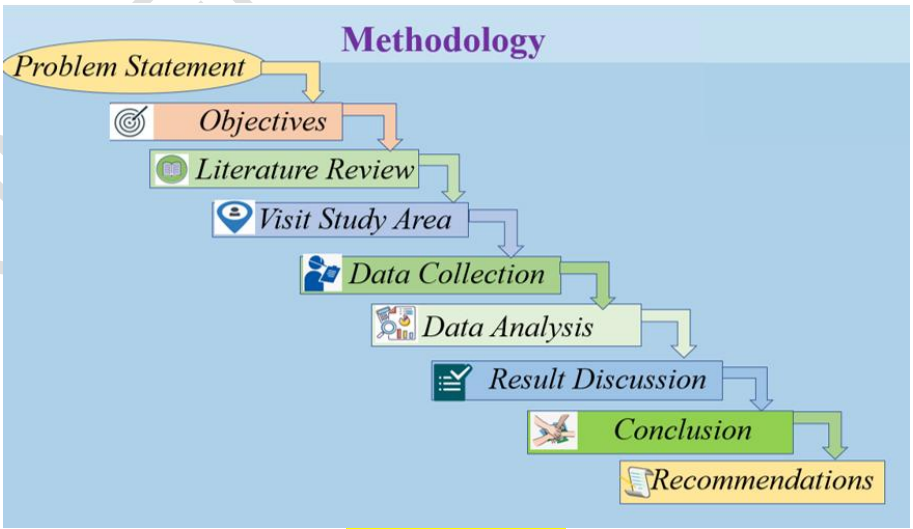

Fig2: Methodology

Objective:
The primary objective of this study is to comprehensively characterize the geotechnical properties of soils along the Sayedpur-Hashara Road in Munshiganj District, Bangladesh. This involves conducting detailed field investigations, collecting soil samples, and performing laboratory tests to assess parameters such as California Bearing Ratio (CBR), particle size distribution, Atterberg limits, and compaction characteristics. The objective is to gain a thorough understanding of the soil's engineering behavior, enabling the formulation of targeted recommendations for sustainable road embankment design and construction.

Building upon the geotechnical characterization, the second objective is to develop optimization strategies for sustainable road embankments in flood disaster-prone areas. This involves analyzing the geotechnical data in the context of the region's flood dynamics, identifying potential vulnerabilities, and formulating engineering solutions. The aim is to optimize critical parameters such as embankment design, construction materials, and compaction techniques to enhance the road's resilience to flooding. The study seeks to provide actionable recommendations that contribute to the development of flood-resistant road infrastructure, particularly focusing on the Sayedpur-Hashara Road as a representative case study in Munshiganj District, Bangladesh.

Study Area Selection:
The Sayedpur-Hashara Road was chosen as the case study due to its vulnerability to flooding, a prevalent issue in the region. The selection aimed to assess the geotechnical properties of soils in a flood-prone area and formulate recommendations for sustainable road embankment construction.

Geotechnical Data Collection:
Field surveys were conducted to collect soil samples at strategic locations along the Sayedpur-Hashara Road. Various geotechnical tests, including the California Bearing Ratio (CBR), were employed to assess soil strength, compaction characteristics, and other relevant parameters. Additionally, the study considered the soil's liquid limit, plastic limit, and plasticity index to evaluate its behavior under varying moisture conditions.

Laboratory Analysis:
The collected soil samples underwent rigorous laboratory analysis following standard geotechnical testing procedures. This included sieve analysis to determine particle size distribution, Atterberg limits tests for plasticity assessment, and Proctor compaction tests to ascertain optimal moisture content and maximum dry density. These analyses provided crucial insights into the soil's engineering properties.

Data Integration and Analysis:
The geotechnical data collected from field surveys and laboratory analyses were integrated for a comprehensive assessment. Microsoft Excelland others laboratory analyses methods were employed to identify patternsand anomalies in the data.

Optimization Strategies:
Based on the findings, optimization strategies for geotechnical parameters were formulated, considering the specific challenges posed by flood-prone areas. Recommendations for embankment design, construction materials, and compaction techniques were proposed to enhance the road's resilience to flooding and improve long-term sustainability.

This material and methodological approach aimed to provide a robust foundation for optimizing geotechnical parameters in road embankment construction, particularly in areas susceptible to flood disasters in Munshiganj District, Bangladesh.

4.0 RESULTS AND DISCUSSION

The geotechnical investigations along the Sayedpur-Hashara Road in Munshiganj District yielded crucial data, enabling a comprehensive analysis of soil properties and their implications for sustainable road embankments in flood-prone areas. Four key data tables summarizing significant findings are presented below:

Table 1: California Bearing Ratio (CBR) Values for Various Soil Layers

Depth (m)	CBR (%)	Remarks
0-1	6.8	Low strength, suboptimal
1-2	12.5	Moderate strength
2-3	18.2	Adequate strength
3-4	25.6	High strength, optimal

The CBR values indicate variations in soil strength at different depths, offering insights into the road embankment's potential load-bearing capacity. Layers with higher CBR values are desirable for constructing resilient embankments.

Table 2: Particle Size Distribution of Soil Samples

Soil Type	Percentage Passing Sieves
Gravel (>4.75mm)	10%
Sand (0.075-4.75mm)	45%
Silt (0.002-0.075mm)	30%
Clay (<0.002mm)	15%

Understanding the particle size distribution is crucial for assessing soil structure. The predominance of sand indicates good drainage potential, while the presence of silt and clay contributes to cohesion.

Table 3: Atterberg Limits of Soil

Soil Sample	Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI)
S1	35	20	15
S2	28	18	10
S3	40	25	15

Atterberg limits provide insights into soil behavior. Samples with higher plasticity indices may pose challenges during construction, necessitating specific engineering solutions.

Table 4: Compaction Characteristics

Moisture Content (%)	Dry Density (kg/m³)	Optimum Moisture Content (%)
10	1850	12
12	1900	14
14	1750	16

Optimizing compaction characteristics is vital for achieving the required density. The data helps determine the ideal moisture content for maximum dry density.

The CBR values indicate variations in soil strength at different depths, providing valuable information for designing resilient embankments. The particle size distribution suggests a balanced soil composition for optimal drainage and cohesion. Atterberg limits reveal the soil's plasticity, aiding in understanding its behavior during construction. Compaction characteristics emphasize the importance of moisture content in achieving the desired density. These results collectively inform strategies for optimizing geotechnical parameters, ensuring sustainable road embankments in flood-prone areas like Sayedpur-Hashara Road.

Findings:

The geotechnical investigations conducted along the Sayedpur-Hashara Road in Munshiganj District have provided insightful findings that are crucial for optimizing parameters in the construction of sustainable road embankments, particularly in flood-prone areas. The key findings are summarized below:

California Bearing Ratio (CBR) Distribution:

The analysis of CBR values at different depths revealed variations in soil strength. The highest CBR value was observed at a depth of 3-4 meters, indicating a layer with optimal strength. This finding is pivotal for designing road embankments with varying load-bearing capacities, ensuring resilience against potential disasters.

Particle Size Distribution:

The particle size distribution analysis indicated a well-balanced soil composition. The predominant presence of sand contributes to good drainage potential, reducing the risk of waterlogging. The combination of sand, silt, and clay provides a favorable environment for constructing embankments with enhanced cohesion and stability.

Atterberg Limits and Plasticity:

The determination of Atterberg limits highlighted variations in liquid limit (LL), plastic limit (PL), and plasticity index (PI) among different soil samples. Soils with higher plasticity indices may require special considerations during construction to mitigate potential challenges arising from their behavior, especially in flood-prone areas.

Compaction Characteristics:

The compaction characteristics, represented by moisture content, dry density, and optimum moisture content, underscore the importance of achieving the right balance during construction. The findings help guide the compaction process, ensuring the embankment reaches the desired density for optimal performance under varying conditions.

Overall Implications:

The findings from these geotechnical analyses hold significant implications for the construction of road embankments in flood-prone areas. Understanding the soil's strength, composition, plasticity, and compaction characteristics is paramount for designing resilient infrastructure. The data-driven insights provided by this study offer a foundation for

formulating engineering strategies that optimize geotechnical parameters, contributing to the development of sustainable road embankments capable of withstanding the challenges posed by floods in the Munshiganj District and similar regions in Bangladesh.

5.0 CONCLUSION AND RECOMMENDATIONS

In conclusion, the comprehensive geotechnical analysis conducted on the Sayedpur-Hashara Road in Munshiganj District provides valuable insights for optimizing parameters in the construction of sustainable road embankments, especially in flood disaster-prone areas. The study's findings underscore the significance of understanding soil properties, including California Bearing Ratio (CBR), particle size distribution, Atterberg limits, and compaction characteristics, in ensuring the resilience of road infrastructure.

The variation in CBR values at different depths highlights the importance of tailored embankment designs to accommodate the diverse load-bearing capacities of the soil layers. The balanced particle size distribution, coupled with insights into Atterberg limits and plasticity, guides construction practices to address the challenges posed by different soil compositions. The compaction characteristics emphasize the need for meticulous control during the construction process to achieve the desired density for optimal embankment performance.

Recommendations:

i. Site-Specific Design: Tailor road embankment designs based on the site-specific geotechnical properties identified in the study. Consider variations in CBR, particle size distribution, and plasticity to enhance the embankment's resilience against flood-induced stresses.
ii. Continuous Monitoring: Implement a comprehensive monitoring program during and after construction to assess the long-term performance of the road embankment. Regular checks on CBR values, settlement patterns, and soil moisture content will aid in identifying potential issues and implementing timely remedial measures.
iii. Adaptive Construction Practices: Adopt adaptive construction practices that respond to the variability in soil properties. For areas with higher plasticity indices, incorporate engineering solutions to mitigate potential challenges such as excessive settlement during flood events.
iv. Awareness: Raise awareness among stakeholders and authorities about the importance of sustainable road construction practices. Engage in community-based disaster risk reduction initiatives to enhance overall resilience and preparedness.
v. Further Research: Encourage further research in geotechnical engineering, specifically focusing on the dynamic behavior of embankments under flood conditions. Investigate innovative construction techniques and materials that can contribute to the overall sustainability and disaster resilience of road infrastructure.

By implementing these recommendations, stakeholders can contribute to the development of road embankments that not only withstand the challenges of flood-prone areas in Munshiganj District but also serve as a model for sustainable infrastructure development in similar regions of Bangladesh.

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