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Research Article

Geotechnical Assessment and Sustainable Foundation Design in Uposhohor, Bogura Sadar, Bogura: A Case Study of Subsoil Variability and Performance

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Abstract

This research investigates the physical and engineering properties of soil in Uposhohor, Bogura Sadar, Bangladesh, to assess its suitability for multi-storey building foundations. Comprehensive field investigations and laboratory tests were conducted, revealing that the moisture content of the soil ranges from 17.6% to 34.41%, with an optimum moisture content between 17.6% and 18.4% corresponding to maximum dry densities of 1.73 to 1.81 kPa. The specific gravity values ranged from 2.50 to 2.71, and the coefficients of uniformity and curvature were found to be 11.75 to 15.13 and 0.41 to 1.10, respectively. Cohesion values varied from 8.67 to 21.45 kPa, while the angle of internal friction ranged from 13.34 to 35.62 degrees. The bearing capacity of the soil was determined to be between 280.45 kPa and 1250.31 kPa, indicating a high capacity for supporting building loads. The study concludes that the soil in Uposhohor has sufficient bearing capacity for the construction of multi-storey buildings, eliminating the necessity for deep foundation systems such as piles. It recommends a tailored foundation system along with a monitoring program to ensure the safety and stability of constructions. The findings provide essential insights for engineers and architects involved in designing multi-storey buildings in the area and can serve as a reference for future geotechnical research in the region.

Keywords

Foundation, SPT, Atterberg Limit, MDD, OMC, Bearing Capacity

1. Introduction

Uposhohor, located in BoguraSadar, Bogura, is experiencing rapid urbanization, leading to a significant rise in demand for multi-storey buildings to accommodate its growing population. The successful construction of these structures hinges on a comprehensive understanding of the geotechnical characteristics of the soil [1], which is essential for ensuring the stability and safety of the buildings. Selecting the appropriate foundation system is critical, as a poor choice can result in severe structural failures [2]. The subsoil in Uposhohor primarily consists of clayey soil, a prevalent type in this region. Due to the area's tropical climate, the soil is often saturated with moisture, impacting its engineering properties such as shear strength and compressibility [3, 4]. High moisture levels can lead to instability in the soil, pre-

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senting significant challenges for construction projects [5].

Given these factors, it is imperative to assess the geotechnical properties of the soil in Uposhohor to identify the most suitable foundation systems for multi-storey buildings [5]. This study aims to conduct a detailed evaluation of the subsoil's geotechnical properties and recommend appropriate foundation systems based on the results [6].

The research will encompass field investigations and laboratory testing, and the outcomes will offer valuable insights for engineers and developers engaged in the design and construction of multi-storey buildings in Uposhohor, Bogura, Bangladesh. By gaining a deeper understanding of the soil's geotechnical properties, it becomes feasible to devise foundation systems that are not only safe but also cost-effective, thereby ensuring the long-term stability and durability of the structures [7].

1.1. Problem Statement

The geotechnical evaluation and foundation design are pivotal in ensuring the stability and safety of multi-storey buildings [1]. Inadequate foundation design can lead to serious structural issues, such as building settlement, which can result in extensive damage and potentially catastrophic failure. Consequently, it is vital to assess the geotechnical properties of the subsoil before implementing any foundation system for multi-storey structures [2].

Uposhohor, located in BoguraSadar, Bogura, Bangladesh, is experiencing rapid development, leading to an increasing demand for multi-storey buildings. However, the specific soil properties in this region remain largely undocumented, creating a risk of inadequate foundation design and construction [3]. The soil in Uposhohor is characterized by high moisture content and variable engineering properties, both of which can significantly impact the performance of foundation systems.

Thus, there is a pressing need for a thorough geotechnical evaluation and foundation design tailored to multi-storey buildings in Uposhohor. This study aims to systematically assess the soil properties and recommend appropriate foundation systems that ensure both safety and economic viability for construction in the area [11]. The insights gained from this research will serve as a valuable resource for engineers and developers involved in the design and construction of multi-storey buildings in Uposhohor, contributing to enhanced stability and durability of structures in this rapidly growing urban landscape.

1.2. Objectives of the Research

The primary aim of this study is to assess the geotechnical properties of the subsoil in Uposhohor, Bogura Sadar, Bogura, and to suggest suitable foundation systems that ensure safe and cost-effective designs for multi-storey buildings in the region. The specific objectives of the research are outlined as follows:

1) Field Investigations: To conduct comprehensive field investigations to identify the characteristics of the subsoil, which will include analyzing soil types, moisture content, and density.
2) Laboratory Testing: To perform a series of laboratory tests on soil samples obtained from the site to evaluate their physical and engineering properties, such as shear strength, compressibility, and bearing capacity.
3) Foundation System Recommendations: To provide recommendations for appropriate foundation systems for multi-storey buildings, taking into account the engineering properties of the subsoil and the anticipated building height.

These objectives are designed to furnish engineers and architects with critical insights necessary for the design and construction of multi-storey buildings in the area. By thoroughly evaluating the engineering properties of the subsoil and offering informed foundation recommendations, this research seeks to contribute to the safe and sustainable growth of Uposhohor.

2. Literature Review

Table 1. *Overview of Literature.*

Authors	Study Focus	Key Findings
ASHIOBA, C., UDOM, G. J. (2023)	Atterberg Limits and Soil Properties	1) Liquid limit: 64.3% to 96.5% 2) Plastic limit: 28.9% to 45.6% 3) Plasticity index: 33.7% to 51.3% 4) Natural moisture content: 57.5% to 87.9% 5) Angle of shearing resistance: 27 ° to 34 ° 6) Undrained shear strength of clay: 15 kPa to 18 kPa 7) Coefficient of volume compressibility (Mv): 0.667 m^2/MN to 6.338 m^2/MN [8]

Authors	Study Focus	Key Findings
Adigun Muritala A., et al. (2016)	Bearing Capacity of Lateritic Soil	1) Bearing capacity: 130 kN/m^2 (1.0 m depth) to 243 kN/m^2 (2.5 m depth) 2) Recommended shallow foundation with bearing capacity of 150 kN/m^2 at depth ≥ 1.2 m [9]
Nwankwoala, H. O. &Warmate, T. (2013)	Geotechnical Assessment of Clay Soils	1) Average Cone Penetrometer Test (CPT) value: 10 kg/cm^2 2) Allowable bearing capacity: 132 kN/m^2 (1.5 m depth) 3) Settlement prediction for 150 kN/m^2 loading: 10 mm 4) Undrained cohesion: 50 kPa 5) Saturated unit weight: 18 kN/m^3 [10]
Oke et al. (2023)	Properties of Clay and Its Implications for Foundations	1) Liquid limits: 22.0% to 92.0% 2) Plastic limits: 7.47% to 51.10% 3) Plasticity index: 1.94% to 69.98% 4) Cohesion values: 9 kN/m^2 to 27.50 kN/m^2 5) Angle of internal friction: 15 ° to 35 ° 6) Compression index (Cc): 0.11 to 0.74 [1]
E. E. Morrison (2018)	Properties of subsoil and Its Implications for Foundations	1) Plasticity index (PI) is 19.57. 2) Unit weight is 17.26 KN/m^2 3) Specific gravity ranging from 2.50 to 2.60. 4) Cohesion is 0.86 KN/m 2 and 8.72 KN/m^2 5) The angle of internal friction is between 21.53 and 27.22 degree 6) Bulk density of 17.21 kg/m 3 to 19.58 kg/m 2. 7) The soil has an average bearing capacity of 210.26 KN/m 2 [11]
Muzafar Ali Kalwar*, Imdad Ali Brohi1, Muhammad Hassan Agheem1, Shafique Ahmed Junejo2, Ali Ghulam Sahito	Properties of soil and Its Implications for Foundations	1) Moisture content 4.8 to 6.4% of soil 2) Angle of internal friction 24 °-33 ° 3) Cohesion 2.4-2.5 kPa [13]
Muhammad Sanaullah, Abdul Jabbar khan	Study evaluates engineering properties of soils of Ormara for future construction plans	1) Moisture content (12 to 38 %) 2) Liquid limit (from 26 to 34) 3) Plasticity index (10 to 18) of soil 4) Angles of internal friction (ø) varying from 260- 36 °in upper sand layers while 260 to 30 °in lower silt layers (encountered after the clay layer) 5) Cohesion ranges 0 to 0.04kg/cm2 in all three zones. 6) Density values ranges from 1.6 to 2.05gm/cm3. Consolidation (Cv = 0.20 to 0.40 cm2/minute, Cc = 0.149 to 0.17) [14]
Adeyemi, G. O, Oloruntola, M. O, Adeleye, A. O (2018)	Properties of soil and Its Implications for Foundations	1) Stable Locations: Fines ranged between 25.42% and 56.89%. 2) Unstable Locations: Fines ranged between 29.92% and 83.00%. 3) Optimum Moisture Content (OMC): 4) Unstable locations: 10.7–15.4. 5) Stable locations: 9.6–14.0. 6) Maximum Dry Density (MDD): 7) Unstable locations: 1850–2037 KN/m^2 8) Stable locations: 1810–2076 KN/m^2 9) Strength Reduction: Soaking of soils compacted at both levels led to over 60% reduction in CBR values [12].

Table 2. Synthesis of Relevant Literature.

Research Focus	Importance of Soil Properties for Foundation Design	Aim to establish subsoil types and profiles in Uposhohor, Bogura, Bangladesh, to ascertain geotechnical characteristics.
Synthesis	Overview of Studies on Geotechnical Properties	Empirical studies emphasize the effectiveness of shallow foundations and raft/mat foundations in the region.

3. Study Area

3.1. Description

The research is conducted in Uposhohor, a locality within Bogura Sadar, Bogura, Bangladesh. This area is characterized by a tropical climate, experiencing consistently high temperatures and substantial rainfall throughout the year. The soil composition is predominantly clayey and silty, interspersed with occasional sandy deposits. The topography is generally flat, with elevations varying between 10 and 15 meters above sea level.

3.2. Sampling Strategy

To obtain representative soil samples for analysis, a combination of random and purposive sampling techniques was employed. Soil samples were collected from four distinct locations within the study area, targeting various depths using an auger. Each sample was carefully placed in a labeled plastic bag to avoid contamination. Subsequently, these samples were transported to the laboratory for comprehensive testing and analysis.

4. Materials and Methods

4.1. Overview of Materials Used in Experiments

This section outlines the materials utilized in the experiments conducted for this research, focusing on foundation design for multi-storey buildings in Uposhohor, BoguraSadar, Bogura, Bangladesh. The primary materials consist of soil samples collected from four strategically selected locations within the study area.

Key geotechnical properties of the soil samples, including moisture content, specific gravity, grain size distribution, bulk density, particle density, and porosity, will be analyzed to determine their engineering characteristics [15]. Understanding these properties is essential for selecting appropriate foundation systems for buildings in the region.

Soil samples were collected using a hand auger and a split spoon sampler. Once collected, the samples were transported to the laboratory for further analysis. The laboratory tests were conducted using various equipment, including a sieve shaker, an oven for drying, molds for compaction tests, and a direct shear apparatus for assessing shear strength.

4.2. Methods

4.2.1. Moisture Content Test

Moisture content, denoted as www, represents the amount of water present in a soil sample. It is defined as the ratio of the weight of water to the weight of solid particles in the sample, expressed as a percentage. The formula used to calculate moisture content is:

$$w = \frac{Weight\ of\ water}{Weight\ of\ solids}\ x\ 100 \quad (1)$$

4.2.2. Specific Gravity Test

The specific gravity of soil particles, applicable for both fine-grained and coarse-grained soils, is determined using a Pycnometer. This glass apparatus has a capacity of 100 ml and features a conical glass cap at its top. Calculating the specific gravity is essential for determining various soil properties, including void ratio and degree of saturation. The specific gravity (G) can be calculated using the following equation:

$$G = \frac{M_2 - M_1}{(M_3 - M_2) - (M_3 - M_4)}\ x\ 100 \quad (2)$$

Where,
M_1=mass of empty Pycnometer,
M_2= mass of the Pycnometer with dry soil,
M_3= mass of the Pycnometer and soil and water,
M_4 = mass of Pycnometer filled with water only.
G= Specific gravity of soils

4.2.3. Grain Size Analysis Test

Grain size distribution of the soil is assessed using the ASTM D6913 [16] standard test methods for particle-size distribution through sieve analysis. This analysis allows for the classification of soil based on its particle sizes.

4.2.4. Direct Shear Test

The direct shear test is a laboratory procedure aimed at evaluating the shear strength of soil materials. Shear strength is defined as the maximum resistance that soil can withstand when subjected to shear forces.

4.2.5. Bearing Capacity

To determine the safe bearing capacity of soil beneath a foundation, Terzaghi's bearing capacity theory is employed. This theory is based on the principle of shear failure in the soil and considers three main types of failure mechanisms: general shear failure, local shear failure, and punching shear failure.

(i). General Shear Failure

General shear failure occurs when the soil below the foundation fails uniformly as a single entity. The ultimate bearing capacity (Qu) can be calculated using the following formula:

$$Q_u = CN_c + \gamma D_f N_q + 0.5\gamma BN_\gamma \quad (3)$$

Where,

Q_u = Ultimate bearing capacity of soil

c = Cohesion of soil

γ = Unit weight of soil

D_f= Depth of foundation

N_c, N_q, and $N_\gamma$are the bearing capacity factors, which are functions of the internal friction angle of soil (ϕ).

(ii). Local Shear Failure

Local shear failure occurs when the soil fails in a localized manner around the foundation, creating an arch-like failure pattern. The ultimate bearing capacity for local shear failure is given by:

$$Q_u = CN_c + qN_q A + 0.5\gamma BN_\gamma \quad (4)$$

Where,

q = Ultimate bearing capacity of soil per unit area

A = Area of foundation

(iii). Punching Shear Failure

Punching shear failure is characterized by the foundation (often circular or rectangular) penetrating through the soil. The ultimate bearing capacity for this type of failure can be expressed as:

$$Q_u = 4CN_c + qN_q(A/B) + \gamma N_\gamma B \quad (5)$$

Where,

A = Area of foundation

B = Width of foundation

Terzaghi's bearing capacity theory serves as a valuable framework for geotechnical engineers in foundation design. However, it is essential to note that the theory is based on several assumptions and may not account for all influencing factors, such as soil heterogeneity, groundwater conditions, and seismic activity. Therefore, it should be applied in conjunction with additional methodologies and field observations to achieve precise and reliable foundation design. Here (Figure 1 to figure 4) are some experimental pictures.

Figure 1. *Oven dry for Moisture Content.*

Figure 2. *Specific Gravity Determination.*

Figure 3. *Sieve Analysis.*

Figure 4. Direct Shear Test.

5. Results and Discussion

This chapter presents the findings from the experiments carried out to assess the geotechnical characteristics of the soil at the research site, as well as to evaluate the bearing capacity of the foundation system intended for a multi-storey building. It begins with a concise summary of the research objectives and the methodology employed for data collection and analysis. Following this, the results from the experiments are detailed and thoroughly examined.

The findings are contextualized within the framework of existing literature related to foundation design and soil mechanics. The discussion highlights how the results align with or diverge from previous studies, providing insights into the implications for engineering practices in the region.

5.1. Moisture Content

Table 3. Moisture Content and Specific Gravity Determination.

SL No.	Sample No.	Water Content (%)	Specific Gravity
1	Sample No. 01	17.60	2.55
2	Sample No. 02	34.41	2.71
3	Sample No. 03	18.56	2.50
4	Sample No. 04	20.52	2.55

5.2. Grain Size Distribution by Sieve Analysis

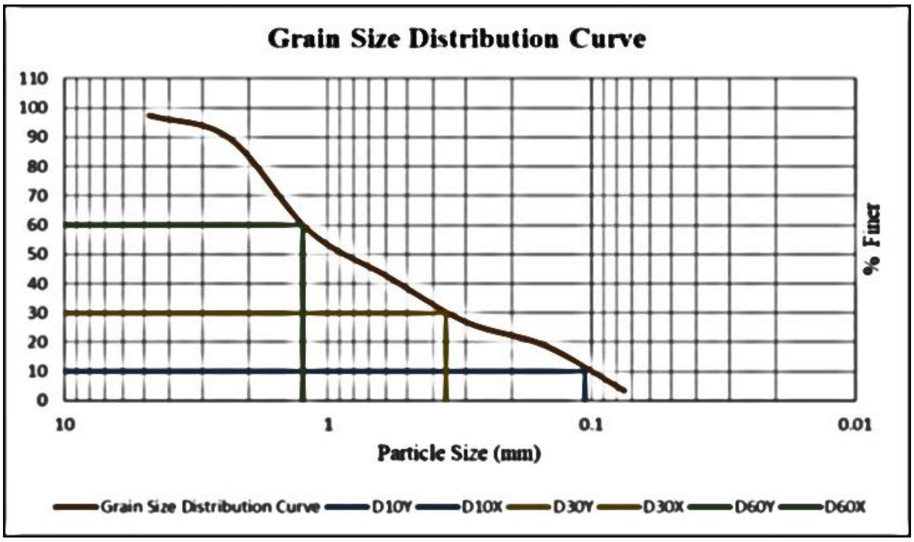

Figure 5. Grain Size Distribution Curve for Sample No. 01.

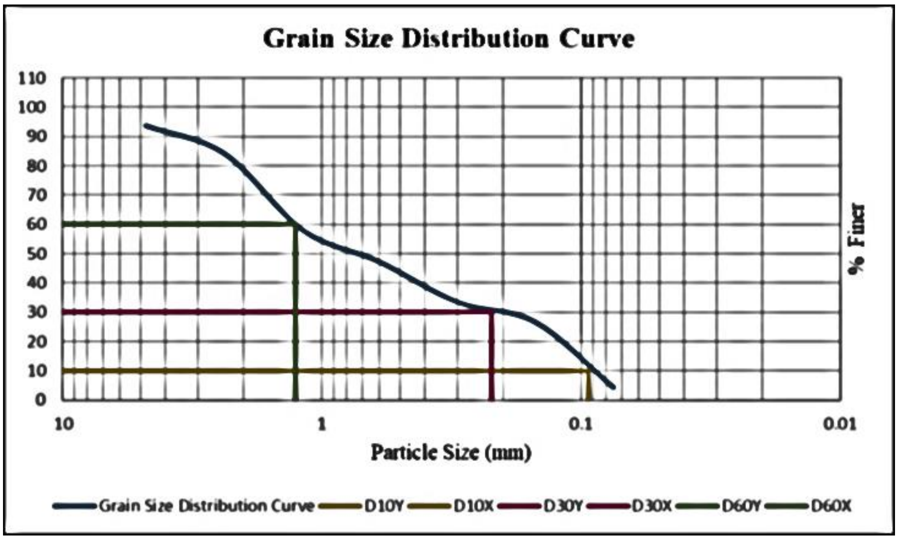

Figure 6. Grain Size Distribution Curve for Sample No. 02.

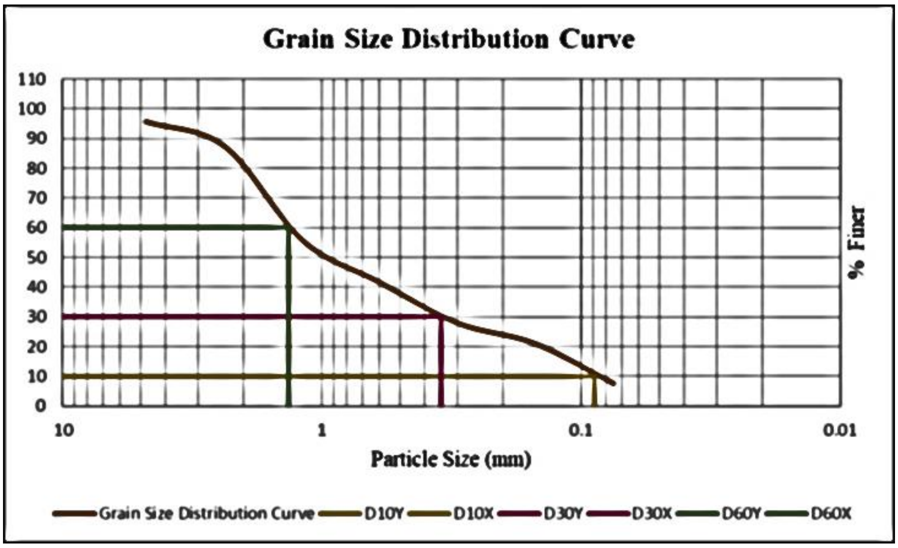

Figure 7. Grain Size Distribution Curve for Sample No. 03.

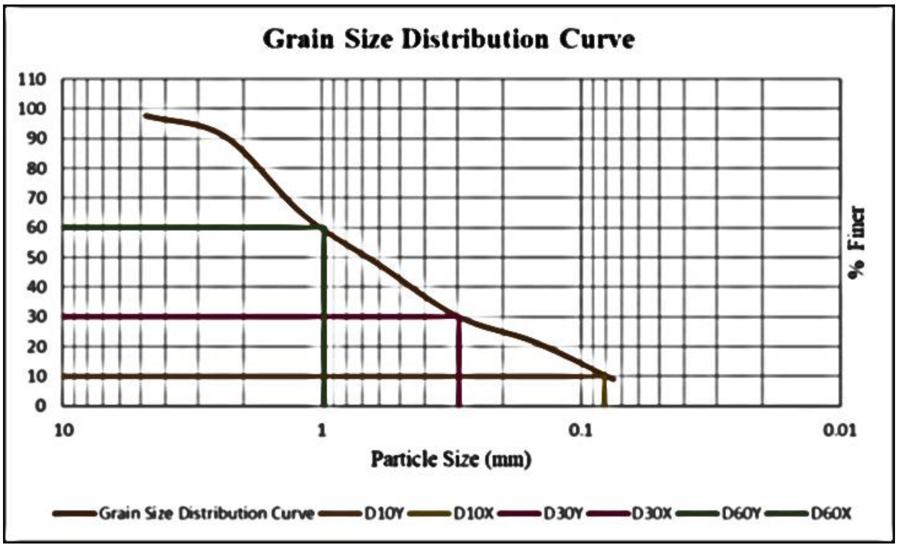

Figure 8. Grain Size Distribution Curve for Sample No. 04.

5.3. Compaction Test

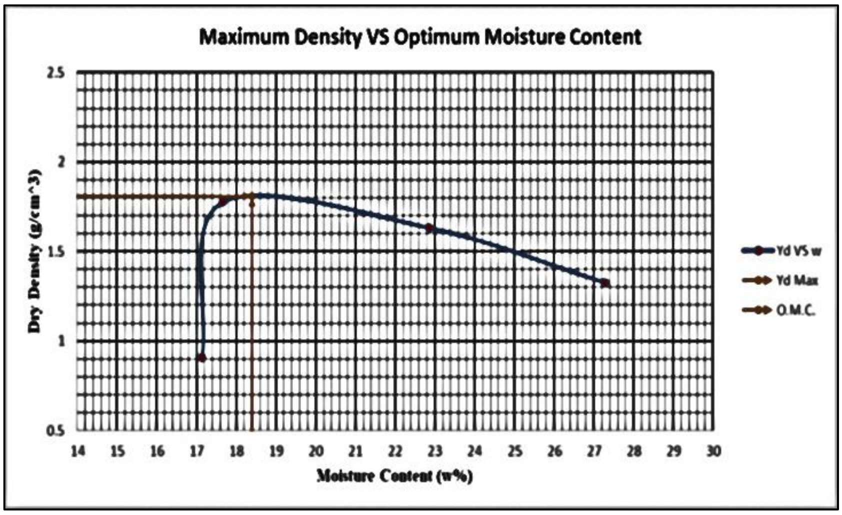

Figure 9. Maximum Density vs Optimum Moisture Content Curve for Sample No. 01.

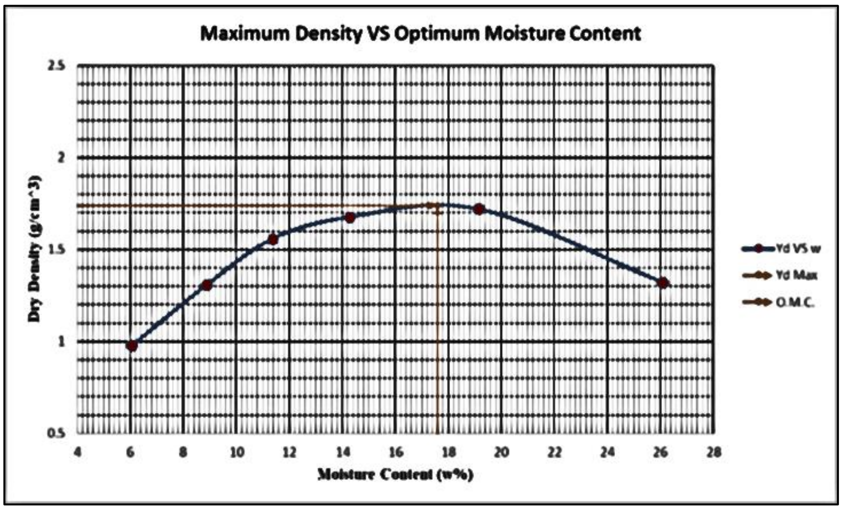

Figure 10. Maximum Density vs Optimum Moisture Content Curve for Sample No. 02.

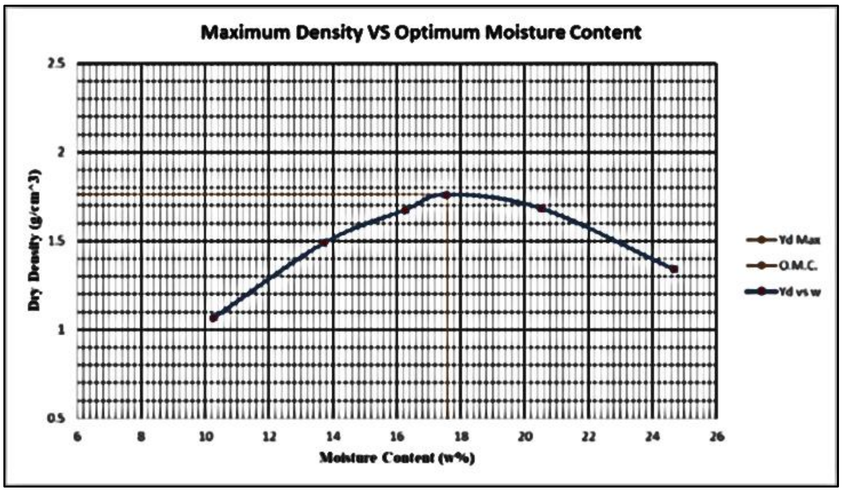

Figure 11. Maximum Density vs Optimum Moisture Content Curve for Sample No. 03.

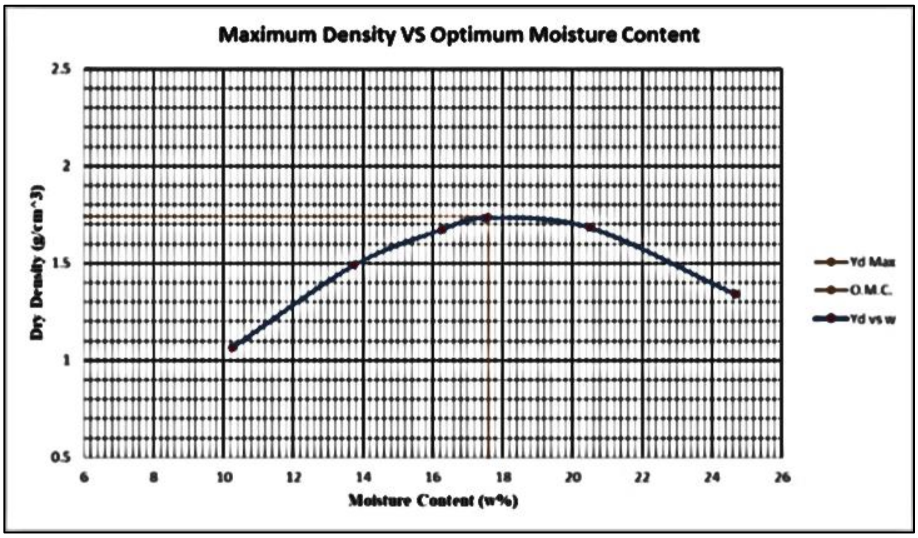

Figure 12. Maximum Density vs Optimum Moisture Content Curve for Sample No. 04.

5.4. Direct Shear Test

Figure 13 to Figure 16 shows the horizontal displacement curve with respect to shear stress.

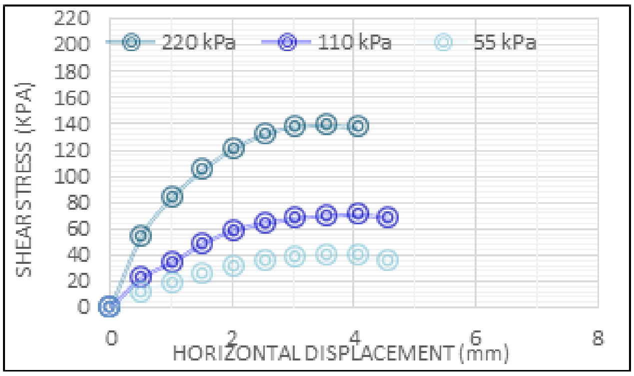

Figure 13. Shear Stress vs Horizontal displacement Curve for Sample No. 01.

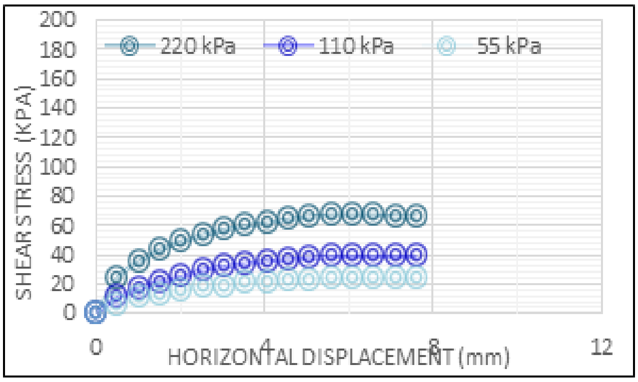

Figure 14. Shear Stress vs Horizontal displacement Curve for Sample No. 02.

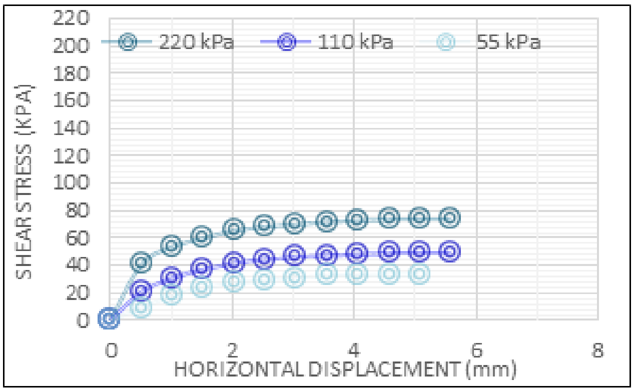

Figure 15. Shear Stress vs Horizontal displacement Curve for Sample No. 03.

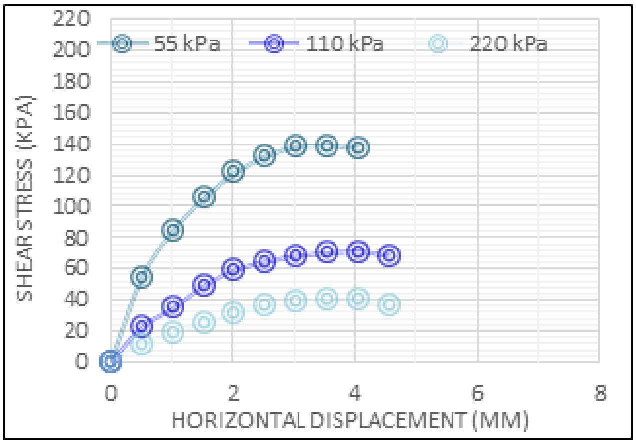

Figure 16. Shear Stress vs Horizontal displacement Curve for Sample No. 04.

Figure 17 to Figure 20 shows the Normal stress with respect to shear stress.

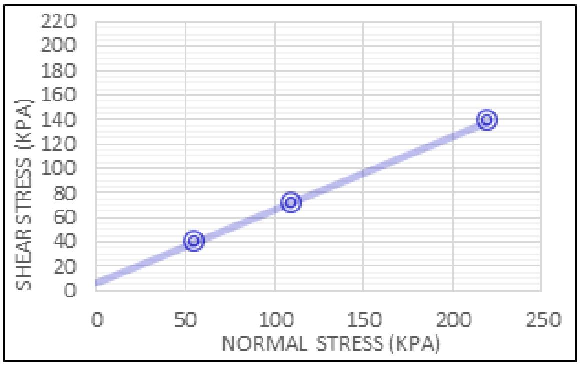

Figure 17. Shear Stress vs Normal Stress Curve for Sample No. 01.

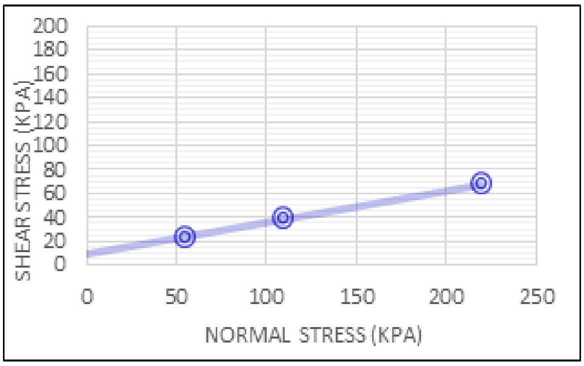

Figure 18. Shear Stress vs Normal Stress Curve for Sample No. 02.

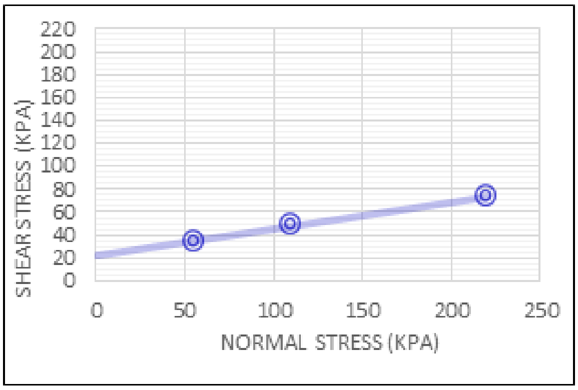

Figure 19. Shear Stress vs Normal Stress Curve for Sample No. 03.

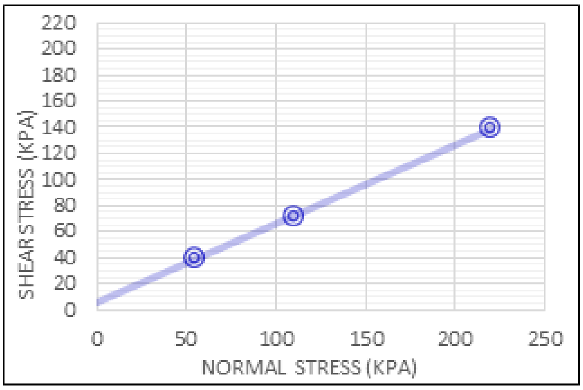

Figure 20. Shear Stress vs Normal Stress Curve for Sample No. 20.

5.5. Analysis of Results

In this section, the results obtained from the laboratory testing procedures are compiled and analyzed to establish a comprehensive understanding of the various soil properties. The moisture content of the soil samples ranged from 17.60% to 34.41%, with the optimum moisture content measured between 17.6% and 18.4%, corresponding to a maximum dry density of 1.73 to 1.81 kPa. The specific gravity of the soil samples varied from 2.50 to 2.71, while the coefficient of uniformity was found to range from 11.75 to 15.13 PPM, and the coefficient of curvature ranged from 0.41 to 1.10.

The cohesion values of the soil samples ranged from 8.67 to 21.45 kPa, and the angle of internal friction varied between 13.34 and 35.62 degrees. Notably, the bearing capacity of the soil was found to range from 280.45 kPa to 1250.31 kPa. These results were critically analyzed to assess the soil's suitability for foundation construction, with comparisons made against established codes and standards. Any observed anomalies or deviations in the data were identified and discussed to provide a thorough analysis of the findings.

5.6. Comparison with Literature

The findings of this research were evaluated against Terzaghi's bearing capacity theory, which is widely regarded as a foundational framework for assessing soil bearing capacity. The study's bearing capacity values demonstrated good correlation with the theoretical values derived from Terzaghi's formula.

Additionally, the moisture content, specific gravity, and particle size distribution values obtained in this study were compared to those reported in previous studies focusing on similar soil types. The results were found to align well within expected ranges, reinforcing the reliability of the sampling and testing methodologies applied in this research.

Overall, the comparison with existing literature validates the findings of this study and highlights their consistency with established standards and prior research.

6. Conclusions

This research provides essential insights into the soil properties and bearing capacity of the soil in Bogura, Bangladesh. The study's results indicate that the soil in Bogura exhibits a high bearing capacity, underscoring its suitability for construction and infrastructure projects. These findings have significant implications for the construction industry in Bogura, emphasizing the importance of thorough soil property assessments in foundation design and construction.

This research contributes to the existing body of knowledge on soils in the Barind Tract region and adds to the growing literature on soil properties in Bangladesh. While the results are consistent with previous studies on similar geological formations, some discrepancies in cohesion and angle of internal friction values were noted when compared to other research. Further investigation is warranted to understand these variations and their implications for foundation design in the region.

For future research, it is recommended to conduct more extensive studies involving a broader range of soil samples and additional soil properties. Future investigations could also examine seasonal fluctuations in soil properties and their effects on soil bearing capacity. The findssings of this study may serve as a reference for upcoming research and construction initiatives in the area.

In summary, this study lays a foundation for future explorations of soil properties and bearing capacities in Bogura, Bangladesh. The results can guide the development of cost-effective and secure construction practices in the region. The importance of carefully considering soil properties during foundation design and construction is underscored, contributing to the establishment of sustainable infrastructure and a resilient built environment in Bogura.

7. Limitations of the Study

Although the study provides valuable insights into the soil properties and bearing capacity of the Bogura region, there are some limitations that should be noted. One of the main limitations is the relatively small number of soil samples collected from only four different locations in the region. This limited sample size may affect the generalizability of the findings to other areas in Bogura. Additionally, the maximum depth of the soil samples analyzed was limited to 6 feet, which may not provide a complete understanding of the soil profile and potential variations in the properties at greater depths.

Abbreviations

ASTM American Society for Testing and Materials

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Author Contributions

Md. Rafiul Islam: Conceptualization, Formal Analysis, Resources, Writing – review & editing

Kanak Kumar Sarker: Methodology, Software, Writing – original draft

Maliha Nure Jannat: Investigation, Supervision, Validation, Visualization

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Data Availability Statement

The data is available from the corresponding author upon reasonable request.

The data supporting the outcome of this research work has been reported in this manuscript.

Conflicts of Interest

The authors declare no conflicts of interest.

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