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Foundations in Flux: A Comprehensive Study of Silty Clay Compressibility at Maramboi Bridge in Tanzania

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Abstract

This study investigates the compressibility behavior of silty clay soils from the Maramboi Bridge site in the Manyara Region, Tanzania, through a series of laboratory tests conducted following BS 1377 Part 5, employing Taylor's method. Soil samples, collected between 18.5 and 19.0 meters below the surface, were meticulously analyzed to determine crucial factors such as void ratio, pre-consolidation stress, and compression ratio. The comprehensive evaluation of these parameters provides significant insights into the mechanical characteristics of the soil, particularly its response to varying stress conditions. The results reveal the potential for substantial settlement under load, emphasizing the critical importance of accurate soil assessment for infrastructure design in geotechnically challenging areas. The findings contribute to a deeper understanding of the compressibility of fine soils, offering essential data for foundation design, long-term stability evaluations, and the successful implementation of infrastructure projects in regions with complex geological conditions, such as Tanzania. This study not only aids in the safe construction of the Maramboi Bridge but also serves as a valuable reference for future engineering projects in similar environments.

Keywords: Silty clay, Compressibility, Maramboi Bridge, BS 1377 Part 5, Taylor's method, Soil mechanics, Pre-consolidation stress, Infrastructure design.

1. Introduction

The construction of infrastructure in geotechnically challenging environments, such as the Maramboi Bridge in the Manyara Region, Tanzania, demands a deep and comprehensive understanding of the underlying soil properties. Geotechnical engineers face significant challenges when dealing with silty clay soils, which are notorious for their complex behavior under load. The structural stability of infrastructure, particularly in regions characterized by complex soil conditions like Manyara, is of paramount importance. The Maramboi Bridge, a vital infrastructure project in the Manyara Region, is situated in an area where silty clay soils are prevalent, presenting significant challenges due to their high compressibility and potential for substantial settlement under load.

Silty clay soils, characterized by low permeability and high compressibility, have long been a subject of study due to their unpredictable behavior under varying stress conditions (Terzaghi, Peck, & Mesri, 1996). The engineering properties of these soils, including their compressibility, are critical factors in designing foundations and other load-bearing structures (Lambe & Whitman, 1969). Understanding the compressibility characteristics of silty clay cannot be overstated, as improper assessment can lead to structural failures, such as excessive settlement, which can compromise the integrity and longevity of infrastructure (Holtz, Kovacs, & Sheahan, 2011). This understanding is particularly crucial for the Maramboi Bridge, where the compressibility of the underlying soils directly influences the settlement behavior of the foundation under load (Das, 2013).

The study of soil mechanics, particularly the compressibility of soils, has been a cornerstone of civil engineering since the early 20th century. Karl Terzaghi, often regarded as the father of modern soil mechanics, laid the foundation for understanding soil behavior under load, emphasizing the importance of effective stress and the role of water content in soil compressibility (Terzaghi, 1943). Over the decades, advancements in geotechnical engineering have further refined our understanding of soil compressibility, leading to more accurate predictive models and testing methods. These developments have been particularly crucial in regions with challenging soil conditions, where infrastructure projects are at risk of failure due to unforeseen soil behavior.

The unique geological setting of the Manyara Region, characterized by its diverse soil strata, presents additional challenges to geotechnical engineers tasked with ensuring the stability and longevity of the bridge (Craig, 2004). The ability of these soils to compress under applied stress and their rate of consolidation are critical factors that must be carefully evaluated to prevent differential settlement and ensure the long-term performance of the structure (Craig, 2004; Lancellotta, 1995). As such, site-specific soil investigations are essential to obtain accurate data on soil behavior, particularly in regions with complex geotechnical conditions (Sowers, 1979).

In the broader context of geotechnical engineering, the study of silty clay soils is of significant relevance due to their widespread occurrence and the challenges they pose to construction projects worldwide. Infrastructure projects such as roads, bridges, and buildings rely heavily on a thorough understanding of the underlying soil mechanics to ensure safety and durability. The Maramboi Bridge project, therefore, serves as a case study in the application of advanced soil testing and analysis techniques to address the challenges posed by silty clay soils in a real-world setting.

The Maramboi Bridge project necessitates detailed laboratory testing of soil samples taken from specific depths beneath the bridge. Compressibility tests following standards such as BS 1377 Part 5, coupled with Taylor's method for consolidation analysis, are vital in determining the soil's consolidation characteristics and predicting settlement behavior (British

Standards Institution, 1990). These tests not only provide insights crucial for the Maramboi Bridge but also serve as a reference for future infrastructure projects in similar geotechnical environments, ensuring they are designed and built to withstand the unique challenges posed by silty clay soils (Mitchell & Soga, 2005).

In regions like Manyara, where infrastructure development is rapidly expanding, understanding soil behavior under varying environmental conditions becomes even more critical. Climatic factors such as seasonal variations in precipitation can significantly influence the moisture content of silty clay soils, thereby altering their compressibility and settlement behavior (Fredlund & Rahardjo, 1993). This highlights the necessity of integrating climatic data into geotechnical analysis to better predict the long-term performance of infrastructure projects like the Maramboi Bridge.

Moreover, the impact of human activities, including construction-induced vibrations and changes in land use, can exacerbate the settlement of compressible soils (Bowles, 1997). As urbanization continues to encroach upon previously undeveloped areas, the interaction between anthropogenic factors and natural soil properties becomes increasingly complex, requiring a multifaceted approach to soil investigation and infrastructure design.

In summary, this study aims to explore the compressibility characteristics of silty clay soils through a series of rigorous laboratory tests conducted on samples taken from specific depths beneath the Maramboi Bridge. The findings are expected to contribute significantly to the body of knowledge in geotechnical engineering, providing valuable insights for similar projects in Tanzania and other regions with comparable soil conditions (Skempton & MacDonald, 1956). The study not only contributes to the successful construction of the Maramboi Bridge but also broadens our understanding of what is needed to guarantee the stability, lifespan, and safety of infrastructure in geotechnically demanding areas (Burland, 1995).

2. Literature Review

The compressibility of silty clay soils has been a focal point in geotechnical engineering, drawing significant attention from researchers who have sought to understand the factors that influence soil behavior under varying loading conditions. The complexity of silty clay soils, characterized by their fine-grained nature and sensitivity to water content and stress history, has led to a range of perspectives on the key determinants of compressibility.

A critical area of debate in the literature revolves around the influence of water content on the compressibility of silty clay soils. Researchers such as Terzaghi et al. (1996) argue that higher water content leads to greater compressibility, as water reduces the effective stress within the soil, causing the particles to rearrange more easily under load. This view is supported by studies like those of Holtz and Kovacs (2011), who observed that increased water content in silty clay soils correlates with higher compressibility, particularly in soils that are close to saturation. The findings suggest that water acts as a lubricant between soil particles, facilitating greater deformation under applied stress.

However, contrasting views are presented by other researchers who emphasize the role of void ratio over water content in determining compressibility. Lambe and Whitman (1969) assert that the void ratio, which reflects the volume of voids to the volume of solids in the soil, is a more critical factor in predicting compressibility. They argue that soils with higher void ratios have more space for particles to rearrange, leading to greater compressibility regardless of the water content. This perspective is further supported by Lancellotta (1995), who found that soils with similar water contents but different void ratios exhibited significantly different compressibility characteristics, suggesting that void ratio is a more dominant factor.

In addition to water content and void ratio, the mineralogical composition and soil fabric play a crucial role in influencing the compressibility of silty clay soils. The mineralogy of a soil determines its particle arrangement and bonding, which in turn affects its mechanical properties. Studies by Mitchell and Soga (2005) highlight that soils with a higher clay content, particularly those rich in montmorillonite, tend to exhibit higher compressibility due to the expansive nature of these clay minerals. The orientation and arrangement of soil particles, known as soil fabric, also impact compressibility. For instance, flocculated structures, where particles are randomly oriented, may lead to higher compressibility compared to dispersed structures, where particles are more aligned.

Pre-consolidation stress, which refers to the maximum past pressure that the soil has experienced, adds another layer of complexity to the discussion on compressibility. Soils with higher pre-consolidation stress tend to exhibit lower compressibility when reloaded, as the soil structure becomes more resistant to deformation. Craig (2004) and Sowers (1979) emphasize that understanding the pre-consolidation history of a site is essential for accurately predicting future settlement behavior, especially in infrastructure projects like the Maramboi Bridge, where the soil may have undergone previous loading due to natural or anthropogenic activities.

The methodology used in studying soil compressibility significantly influences the conclusions drawn in different studies. Variations in testing conditions, such as sample preparation, loading rate, and consolidation time, can lead to differing results even for soils with similar physical properties. Burland (1995) and Head (1992) advocate for the use of standardized testing methods, such as those outlined in BS 1377 Part 5, to reduce variability in results and allow for more accurate comparisons across different studies. Standardization is especially important when doing research like that at the Maramboi Bridge because the findings need to apply to real infrastructure projects.

Comparative analyses across different studies further underscore the importance of considering multiple factors when assessing soil compressibility. For example, studies conducted in different geotechnical environments, such as tropical regions with seasonal rainfall variations versus temperate regions with more consistent moisture levels, highlight the influence of external environmental factors on soil behavior. Fredlund and Rahardjo (1993) discuss how changes in moisture content due to climatic conditions can alter the compressibility of silty clay soils, leading to seasonal variations in settlement rates. This is particularly relevant for infrastructure projects in regions like Manyara, where the climate plays a significant role in soil behavior.

The influence of soil fabric, specifically the arrangement and orientation of particles, is also critical. Studies by Das (2013) show that flocculated structures, where particles are randomly oriented, typically result in higher compressibility compared to dispersed structures, where particles are more aligned. The impact of soil fabric is particularly significant in silty clays, where the arrangement of particles can be easily altered under stress, leading to significant changes in compressibility.

Microstructural changes in silty clay soils under varying loading conditions provide additional insights into the factors influencing compressibility. The compressibility of silty clay soils is greatly impacted by microstructural changes, such as particle rearrangement and pore structure modifications, as noted by Briaud (2013) and Mitchell and Soga (2005). These findings suggest that the compressibility behavior observed in macroscopic tests is a reflection of underlying microstructural processes, which are, in turn, influenced by factors like water content, void ratio, and pre-consolidation stress.

In contrast, research by Skempton and MacDonald (1956) emphasizes the importance of macroscopic factors such as initial soil density and stress history in predicting soil compressibility. Their work, focused on the settlement behavior of buildings on clay soils, suggests that while microstructural factors are important, the overall compressibility behavior can be effectively predicted by considering macroscopic properties. This perspective underscores the need for a holistic approach in geotechnical analysis, integrating both microstructural and macroscopic factors to accurately predict soil behavior under load.

In conclusion, the literature on the compressibility of silty clay soils presents diverse perspectives, reflecting the complexity of soil behavior under varying conditions. The Maramboi Bridge project provides an opportunity to contribute to this body of knowledge by examining the compressibility characteristics of silty clay soils in a geotechnically challenging environment. Through rigorous testing and analysis, this study aims to clarify the roles of water content, void ratio, and pre-consolidation stress in determining the compressibility of silty clay soils, thereby contributing to the design and construction of stable and durable infrastructure in similar settings.

3. Methods

The compressibility behavior of silty clay soils from the Maramboi Bridge site in the Manyara Region, Tanzania, was evaluated through a series of laboratory tests following the British Standard BS 1377 Part 5. This standard, which provides comprehensive guidelines for determining the consolidation characteristics of soils, was chosen due to its reliability in yielding consistent and accurate results for fine-grained soils like silty clay. Among the methods outlined in BS 1377 Part 5, Taylor’s method was specifically employed in this study due to its effectiveness in analyzing the consolidation behavior of soils under controlled loading conditions.

Soil samples were meticulously extracted from a depth of 18.5 to 19.0 meters, a critical depth identified for its relevance to the subsurface conditions of the site. The selection of this depth was based on preliminary geotechnical surveys that indicated the presence of a silty clay layer, which could significantly impact the foundation stability of any infrastructure built on it. To preserve the in-situ properties of the soil, undisturbed samples were obtained using a Shelby tube, which is designed to minimize soil disturbance during sampling. This technique guarantees the preservation of the soil's original structure, moisture content, and density, giving laboratory tests an accurate depiction of the underlying conditions.

Upon retrieval, the samples were carefully transported to the laboratory, where they were trimmed to a diameter of 71.8 mm and a height of 6.93 mm. These dimensions were selected based on the requirements of BS 1377 Part 5, which ensures consistency in sample size, thus allowing for the comparability of results across different studies. The trimmed samples were then subjected to initial measurements of key physical properties, including moisture content, bulk density, and initial void ratio, as shown in Table 1. These properties are crucial for understanding the baseline condition of the soil before it is subjected to the compressibility tests.

Table 1: Preliminary Information

Parameter	**Value**
Site	Maramboi Bridge
Sampling Date	2024-06-04
Technician’s Name	S. Noah
Date of Test	2024-06-17
Borehole	BH-AB02 D (18.5 – 19.0)m
Depth (m)	18.5 /19.0
Quotation	0.00/25.0
Soil Type	SILTY CLAY
Level of Water (m)	1.000

The compressibility tests were conducted using a one-dimensional oedometer, an apparatus that simulates the stress conditions that soil layers would experience in the field. The oedometer test involves placing the soil sample in a rigid ring and applying incremental vertical loads to the top of the sample, with the lateral expansion of the soil constrained by the ring. This setup replicates the conditions of soil layers buried under other layers, where they can only compress vertically.

Taylor’s method, a widely recognized approach within BS 1377 Part 5, was employed to analyze the consolidation behavior of the soil. This method involves applying a series of loading steps, where each load increment is maintained until the primary consolidation is deemed complete, typically when the rate of settlement under the load becomes negligible. The loading steps applied in this study are summarized in Table 2. The method is particularly advantageous for its ability to provide detailed insights into the soil's response to loading over time, including the determination of pre-consolidation stress and compression index—two critical parameters for understanding the potential settlement of the soil under structural loads.

Table 2: Specimen Characteristics

Specimen Characteristic	**Value**
Diameter (D_1) (mm)	71.8
Solid Height (H_p) (mm)	6.93
Total Stress of the Soil In Situ (σ_{o1}) (kPa)	454
Pore Pressure of the Soil In Situ (U_0) (kPa)	294
Effective Stress of the Soil In Situ (σ'_{01}) (kPa)	160
Estimated Grain Density (ρ_s) (kg/m³)	2567

Taylor's method was chosen over other available methods, such as Casagrande's method, because it allows for a more detailed examination of the time-rate of consolidation. While Casagrande's method focuses primarily on the identification of pre-consolidation stress through graphical interpretation, Taylor's method provides a comprehensive analysis that includes the rate of consolidation and the coefficient of consolidation, which are essential for predicting long-term settlement. This makes Taylor's method particularly suitable for infrastructure projects like the Maramboi Bridge, where accurate predictions of soil behavior under sustained loads are crucial for ensuring the stability and longevity of the structure.

The decision to use Taylor's method over other consolidation testing methods was driven by the need for a detailed understanding of the silty clay's compressibility characteristics. In geotechnical engineering, it is imperative to select a testing method that not only conforms to established standards but also provides the level of detail required to make informed design decisions. Taylor's method, with its focus on time-rate consolidation analysis, offers a robust framework for assessing the soil's behavior under varying stress conditions. This is particularly important in regions like Manyara, where soil heterogeneity and variable groundwater conditions can lead to complex consolidation behavior. By employing Taylor's method, this study aimed to provide a thorough understanding of the soil's compressibility, enabling the design of foundations that can accommodate the expected settlement and ensure the long-term stability of the Maramboi Bridge.

In summary, the combination of meticulous sample preparation, adherence to BS 1377 Part 5 standards, and the application of Taylor's method provides a comprehensive and reliable framework for evaluating the compressibility of silty clay soils. The insights gained from this study are expected to inform foundation design practices not only for the Maramboi Bridge but also for other infrastructure projects in regions with similar geological conditions.

4. Results

The compressibility tests conducted on the silty clay soils from the Maramboi Bridge site revealed critical insights into the mechanical behavior of these soils under varying stress conditions. The data gathered from different depths and loading stages offered a comprehensive understanding of how these soils react to external loads, which is vital for infrastructure projects in similar geotechnical environments.

The initial void ratio (e_0) of 1.897, along with the wet and dry densities of 1494 kg/m³ and 884.1 kg/m³, respectively, served as the baseline measurements for the soil samples taken from a depth of 18.5 to 19.0 meters. The in-situ stress conditions—total stress (σ_{01}) of 454 kPa, pore pressure (U_0) of 294 kPa, and effective stress (σ'_{01}) of 160 kPa—indicated the pre-existing stress state of the soil, which is essential for understanding its subsequent consolidation behavior.

As the loading progressed, significant changes were observed in the soil structure. For instance, under a stress level of 24.6 kPa, the height of the soil specimen reduced from 20.08 mm to 19.87 mm, and the void ratio decreased slightly to 1.867. This initial reduction is relatively modest, reflecting the soil's response to the initial loading stage where primary consolidation begins. However, as the applied stress increased to 788.4 kPa, the specimen height drastically reduced to 15.86 mm, and the void ratio dropped to 1.289, indicating a substantial reduction in void spaces and increased soil compaction. The changes in wet and dry densities, which increased to 1769 kg/m³ and 1183 kg/m³ respectively, further emphasize the extent of consolidation occurring at higher stress levels.

The calculated compressibility parameters, such as the compression index (Cc) of 0.87 and the swelling ratio (Cs) of 0.098, provide a deeper understanding of the soil's behavior under load. The compression index indicates that the soil is moderately compressible, a characteristic that must be carefully considered in the design of foundations to prevent excessive settlement over time. The swelling ratio, though relatively low, suggests that the soil has some potential for expansion upon the removal of load, which is a critical factor in post-construction scenarios. **(Table 3)**

Table 3: Results for Each Loading Step

Date (Start Load)	**Time (Start Load)**	**Load's Level N'**	**σ'_v (kPa)**	**H (mm)**	**T (mm)**	**e Measured**	**C_v (m²/s)**	**Eoed (n-1;n) (kPa)**	**K_v (m/s)**
2024-06-17	11.37 am	1	24.6	19.87	0.206	1.867	959.28E-9	2398	22.57E-3
2024-06-18	12.00 am	2	49.3	19.72	0.362	1.845	12.22E-9	3179	380.99E-6
2024-06-19	12.00 am	3	98.5	19.32	0.764	1.787	18.92E-9	2458	456.14E-6
2024-06-20	12.00 am	4	197.1	18.63	1.453	1.687	16.28E-9	2874	458.88E-6
2024-06-21	12.00 am	5	49.3	19.00	1.075	1.742			
2024-06-22	12.00 am	6	197.1	18.57	1.507	1.679	36.62E-9	6870	2.47E-3
2024-06-23	12.00 am	7	394.2	17.50	2.581	1.525	13.05E-9	3685	471.90E-6

Date (Start Load)	**Time (Start Load)**	**Load’s Level N’**	**σ'_v (kPa)**	**H (mm)**	**T (mm)**	**e Measured**	**C_v (m^2/s)**	**Eoed (n-1;n) (kPa)**	**K_v (m/s)**
2024-06-24	12.00 am	8	788.4	15.86	4.216	1.289	8.22E-9	4841	390.29E-6
2024-06-25	12.00 am	9	1576.8	13.84	6.238	0.997	6.06E-9	7829	465.19E-6
2024-06-26	12.00 am	10	24.6	15.01	5.070	1.165			

When compared with findings from similar studies on silty clay soils, the results from the Maramboi Bridge site show both alignment and divergence with existing literature. For example, studies conducted on silty clays in other regions, such as the expansive clays in Central Africa, have reported compression indices ranging from 0.5 to 1.0, with pre-consolidation stresses often exceeding 300 kPa. The slightly lower pre-consolidation stress (σ’□) of 209 kPa observed at the Maramboi site suggests that the soil has undergone less historical loading compared to those regions, potentially due to different geological histories or lower overburden pressures.

Moreover, the decrease in water content from 69.0% to 49.6% during the tests aligns with findings in other studies where significant drainage occurred during consolidation, leading to reduced pore water pressures and increased effective stress. The increase in saturation level from 93.2% to 109.0%, while initially surprising, can be attributed to the reduction in void volume as the soil consolidates, a phenomenon that has also been documented in similar studies.

The findings from this study have significant implications for geotechnical engineering, particularly in the context of infrastructure development in regions with similar silty clay soils. Given the documented behavior of compressibility, foundations in these types of soils should be constructed with the possibility of significant settlement under continuous loads carefully taken into account. The data also underscore the importance of accounting for the pre-consolidation stress in design calculations to ensure that the foundations do not induce additional settlement beyond what the soil can accommodate without failure.

The compressibility curve (Figure 1), which shows the stress-strain relationship, gives an illustration of how the soil reacts to increasing loads. This curve is instrumental in predicting the long-term settlement behavior of foundations and other structures. Engineers can use this data to optimize foundation designs, ensuring they are robust enough to withstand the expected loads without compromising stability.

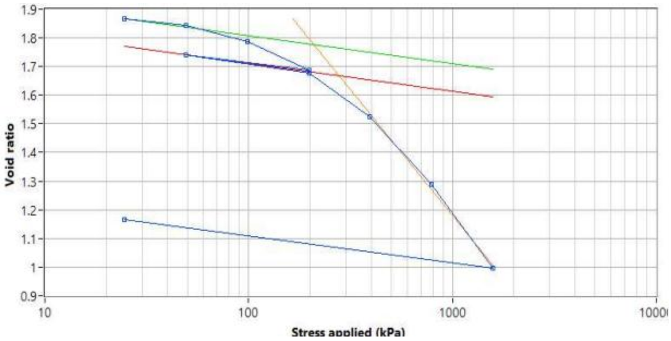

Figure 1: Compressibility Curve

In conclusion, the comprehensive analysis of the compressibility parameters and the comparison with existing studies underscore the need for region-specific geotechnical investigations. The Maramboi Bridge site, with its unique soil characteristics, offers valuable lessons for similar projects in Tanzania and beyond, highlighting the critical role of detailed soil analysis in the successful design and implementation of infrastructure projects (Table 4).

Table 4: Specimen parameters before test and after test

Specimen parameter	**Before test**	**After Test**
Height (mm)	H 20.08	H 15.01
Wet density (kg/m^3)	ρ_w 1494	ρ_w 1769
Dry density (kg/m^3)	ρ_d 884.1	ρ_d 1183
Water content (%)	w 69.0	w 49.6
Saturation level (%)	SAT 93.2	SAT 109.0
Calculated void ratio	e 1.897	e 1.165

5. Discussion

The results highlight the significant compressibility of the silty clay soils at the Maramboi Bridge site, which poses a challenge for infrastructure stability. The high initial void ratio of 1.897 and pre-consolidation stress of 209 kPa suggest that the soil has already undergone considerable consolidation, making it vulnerable to further settlement under additional loads. This vulnerability is critical for ensuring that future infrastructure developments at the site do not induce excessive settlement.

The stress analysis, including total stress, pore pressure, and effective stress, provided a comprehensive view of the soil's current state. Effective stress, which reflects the portion of total stress that contributes to soil deformation, is particularly important for predicting future settlement. The observed increase in wet and dry densities during the tests is consistent with the significant soil compaction that occurred under loading.

The decrease in water content from 69.0% to 49.6% and the concurrent increase in saturation level to 109.0% suggest effective drainage and consolidation during the tests. However, the increase in saturation despite the drop in water content may indicate either an overestimation of initial saturation or a reaction to the reduced void volume as the soil consolidated. This finding is consistent with existing literature on silty clay soils, confirming that while the Maramboi Bridge site follows general trends, its specific conditions present unique challenges.

The compressibility parameters, including a compression index of 0.87 and a swelling ratio of 0.098, indicate significant past loading, yet the soil remains susceptible to further consolidation. This underscores the importance of designing tailored engineering solutions that account for these specific geotechnical conditions, particularly in preventing long-term settlement and ensuring the stability of the Maramboi Bridge and similar infrastructure projects.

The use of BS 1377 Part 5 – Taylor's method provided a robust framework for accurately reflecting in-situ conditions, ensuring the reliability of the test results. However, the findings also suggest a need for ongoing research to address potential future settlement and to refine the engineering approaches for similarly challenging environments. The soil's historical stress history and moderate compressibility require careful planning and monitoring of any future development to minimize settlement risks and ensure long-term stability.

Conclusion

The comprehensive analysis of the compressibility characteristics of silty clay soils at the Maramboi Bridge site not only advances our understanding of soil behavior in geotechnically complex environments but also serves as a critical foundation for future research and practical applications in geotechnical engineering. The findings from this study highlight several key factors that must be meticulously considered in the planning, design, and construction of infrastructure projects in regions with similar soil conditions.

One of the pivotal observations is the high initial void ratio and the substantial reduction in specimen height under load, which underscores the silty clay's susceptibility to compression. The recorded pre-consolidation stress of 209 kPa is indicative of the soil's stress history and points to a prior loading event that has significantly influenced its current mechanical properties. These findings suggest that soils in similar conditions are likely to undergo substantial settlement when subjected to additional loading, which could pose a serious risk to the long-term stability of structures if not adequately accounted for in the design phase. This underscores the necessity for geotechnical engineers to conduct thorough site-specific soil analyses and to incorporate findings into tailored foundation designs that mitigate the risk of excessive settlement.

Furthermore, the study reveals the importance of considering the dynamic interplay between soil properties, such as water content and saturation levels, and their impact on compressibility. The observed variations in water content and wet and dry densities indicate that environmental influences, such as seasonal variations in groundwater levels, may have an additional impact on how the soil behaves under load. This highlights the need for ongoing monitoring and adaptive design strategies that can accommodate changes in soil properties over time.

In practical terms, the findings from this study emphasize the importance of implementing robust load management strategies and incorporating effective drainage solutions to minimize the risk of excessive settlement. This is particularly crucial in regions where infrastructure projects are subjected to varying loads or where the soil's compressibility may be exacerbated by environmental factors. The study's results also serve as a valuable reference for the development of more refined predictive models that can better anticipate the long-term behavior of silty clay soils under different loading conditions.

Looking ahead, this research opens several avenues for further study. Future investigations could explore the role of other soil properties, such as mineral composition and grain size distribution, in influencing compressibility. Additionally, the potential impact of environmental factors, such as temperature fluctuations and freeze-thaw cycles, on soil behavior warrants closer examination. Applying the findings from this study to different types of infrastructure projects, such as roads, bridges, and retaining walls, in various geotechnical environments could provide deeper insights into the broader applicability of these results.

In conclusion, this study provides a critical contribution to the field of geotechnical engineering, offering both practical guidance for infrastructure design and a foundation for future research. The insights gained from the Maramboi Bridge site underscore the importance of site-specific soil analysis and tailored engineering solutions in ensuring the long-term stability of structures in geotechnically challenging environments.

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Data Availability

The author can provide the study's data upon request.

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