Comparative Hydro-Mechanical Response of Marl and Chikoko Soils from the Niger Delta to Multiple Wetting and Drying Cycles

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Abstract: This study compares how two different but common soil types—Marl and Chikoko soils—respond to various cycles of wetting and drying. In a three-level, four-factor full factorial design framework, these soils—Marl, a calcareous clay, and Chikoko, an organic-rich swampy clay—were all subjected to a rigorous experimental program using standard and modified oedometer tests. Their volumetric changes, deformation characteristics, and tensile strength properties were carefully compared in the investigation under various conditions, including changes in initial moisture content, dry density, surcharge pressure, and the number of wetting and drying cycles. The main conclusions show that although both soils are highly susceptible to cracking and show considerable volumetric instability, their specific reactions, accumulation of cumulative strain, and patterns of degradation are very different. While Chikoko soil exhibits complex, frequently larger magnitude, volumetric changes and greater susceptibility to structural degradation influenced by its organic content, Marl soil typically exhibits more classical expansive clay behavior with noticeable swell. A monolithic approach to geotechnical engineering in the Niger Delta is discouraged by the study, which emphasizes that the best design strategies for preventing moisture-induced damage in the area must be specifically tailored to the distinct hydro-mechanical profile of each soil type. This comparative understanding is essential for creating infrastructure solutions that are more sustainable and resilient.

Keywords: *Marl Soil, Chikoko Soil, Niger Delta, Comparative Study, Wetting and Drying Cycles, Volumetric Change, Deformation, Tensile Strength, Expansive Soils, Organic Soils.*

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I. INTRODUCTION

The geology and seasonal weather of Nigeria's Niger Delta region created significant geotechnical challenges. This region's soft and moisture-sensitive soils were under a lot of stress due to rapid urbanization, industrial growth, and increased infrastructure development. Several of these soils responded strongly to wet and dry cycles and demonstrated high plasticity. They swelled and grew weaker during rainy seasons. They shriveled, hardened, and frequently cracked during dry seasons. Buildings, roads, and other structures failed or deformed over time as a result of these changes, which made the ground unstable [17], [21].

The region's soils, which include clays, silts, and sands, were primarily formed by recent river deposits. Particularly in the clay-rich areas, reactive minerals such as smectite or montmorillonite were frequently found; these minerals grew considerably when wet [5, 24]. This behavior was exacerbated by the tropical climate. Constant cycles of swelling and shrinking were brought on by alternating wet and dry seasons. Uneven settlement, cracks, and other damage resulted from the repeated movement's increased stress on the pavement layers and foundations. These consequences frequently resulted in shorter lifespans and higher maintenance expenses for civil engineering structures [1], [27].

Two varieties of these troublesome soils—Marl and Chikoko—were particularly notable. Despite having different origins and characteristics, both were widespread in the Niger Delta. Marl soils were composed of a mixture of calcium carbonate and clay and had fine grains. The ratio of carbonate to clay content determined how they behaved. They exhibited moderate to high plasticity most of the time. Their strength and reaction to water were affected by the carbonate. These soils were formed under calm sedimentary conditions and were generally found in estuarine or marine environments [2], [3]. Conversely, tidal floodplain, mangrove, and swampy regions were the primary locations

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for Chikoko soils. They were very soft, very compressible, and very organic. Chikoko soils were easily deformed and provided little support under load due to their low density and high water content [4], [5].

These two soils had quite different engineering behaviors. Although both reacted to variations in moisture, Marl soils had a tendency to expand and contract as a result of mineralogical reactions, particularly those involving clay and carbonate. Chikoko soils, on the other hand, were more impacted by their organic matter and inadequate drainage, which had an impact on strength and consolidation. Additionally, Chikoko soils were more likely to decompose and lose volume over time [6], [25]. However, in geotechnical practice, these soils were frequently regarded as a single, broad category of "expansive soils." As a result, their distinct behaviors were not taken into consideration in the designs, which frequently led to expensive failures [5, 8].

There aren't many studies that directly compare how Marl and Chikoko soils behave under repeated environmental stress, despite decades of civil engineering work in the Niger Delta. The majority of research either used broad assumptions about expansive or compressible soils or concentrated on a single type of soil. Very little was known about the effects of initial moisture, dry density, and surcharge pressure on their response to cycles of wetting and drying [17], [22]. This dearth of in-depth knowledge about the soil in this area became a major issue as infrastructure continued to grow.

The goal of this study was to bridge that gap. Important characteristics like volume change, compressibility, stiffness, and tensile strength were the focus of a direct comparison between Marl and Chikoko soils. In order to simulate field conditions over time, these properties were tested under repeated wetting and drying cycles. The main effects of each variable as well as their interactions were investigated using a three-level, four-factor full factorial design. This aided in the development of improved design recommendations and provided an explanation of the mechanical causes of the soils' varying responses.

The study's conclusions were useful from an academic and practical standpoint. They offered strategies to lower construction risk, assisted engineers in predicting areas where damage was likely to occur, and backed more precise foundation and road design. In an area where such knowledge was desperately needed, the outcomes also helped to save money, increase safety, and develop more sustainable infrastructure. In addition to measuring differences, the goal of this study was to comprehend them, make a clear comparison, and apply the findings to enhance engineering practice throughout the Niger Delta.

II. LITERATURE REVIEW

In geotechnical engineering, it was essential to comprehend how soil reacts to variations in load and moisture. This section summarized previous research on organic and expansive soils, emphasizing how they behaved when wet and dry. Additionally, it prepared the way for a comparison of the Niger Delta's Marl and Chikoko soils.

A. General Principles of Expansive Soil Behaviour

When exposed to changes in moisture, expansive soils—particularly those that were high in montmorillonite—exhibited noticeable volume changes. Osmotic forces in the double layer caused the clay mineral layers to expand when water entered the soil, resulting in soil swelling. In contrast, drying caused the particles to shrink as matric suction pulled them together [15], [20]. A number of variables affected how much this expansion or contraction occurred. These included the initial water content, the dry density, the applied pressure, and the kind and proportion of clay minerals [18], [21]. These movements frequently resulted in wall distortion, pavement cracking, and even complete foundation failure in engineering practice [16]. The Niger Delta and other regions with seasonal rainfall suffered the most from recurrent cycles of swelling. and shrinkage. This could result in major structural problems if it is not adequately mitigated. The physical mechanisms underlying these soil behaviors were clarified by studies by Nelson and Miller [15] and Fredlund and Rahardjo [18], which also had an impact on how engineers evaluated and handled these soils. However, regional characteristics frequently rendered generalized solutions unreliable despite extensive global studies, particularly in geologically unique zones such as the Niger Delta.Behaviour of Calcareous Clays and Marls

Depending on their composition, marls, which are composed of both clay and calcium carbonate, displayed peculiar and diverse behaviors. The soil's response to stress and moisture was affected by the presence of calcium carbonate. For example, marls that contained a lot of carbonate tended to be more open in structure, which made it easier for water to move through them and occasionally caused them to swell more quickly [10], [11]. Because of their clay content, marls continued to behave like clays, but the carbonate may have decreased their plasticity and impacted their capacity to swell [12]. Weak bonds between carbonate particles frequently dissolved when wet, resulting in abrupt strength loss and, occasionally, collapse [11]. In dry conditions, some marls developed a degree of cementation that increased their strength and stiffness; however, as soon as water entered the soil, this strength rapidly decreased. The soil's structure became fatigued due to cyclic wetting and drying, which resulted in permanent deformation, cracks, and even chemical changes in the soil matrix [13]. Without specialized testing, these behaviors made it challenging to generalize marl performance. Marls, which varied in thickness and consistency, were frequently found in brackish water environments in the Niger Delta. Al-Homoud and associates [10] stressed that marls needed special consideration when designing a foundation, especially when they were subjected to varying moisture levels.Behaviour of Organic Clays and Peaty Soils (Chikoko-like)

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Chikoko soils had a lot of organic matter, were soft, and were very compressible. They differed greatly from inorganic clays due to these characteristics. They were easily deformed under load because of their low dry density and high natural moisture content [19], [24]. Unusual swelling patterns were frequently the result of the organic material in these soils absorbing water differently than the mineral particles. By releasing gases and changing the soil structure over time, the decomposition of organic matter made their behavior even more complex [17]. Even with low loads, these alterations led to erratic settlements. Chikoko soils displayed significant, long-term deformations known as secondary compression or creep, in contrast to marls or other inorganic clays. Additionally, they developed deep cracks as a result of matrix collapse and water loss during drying [22]. Until they were improved, their generally very low bearing capacity prevented them from being used to support heavy structures. These soils had special consolidation qualities, according to researchers like Edil and Mochtar [17]. Conventional stabilization or compaction methods frequently failed or yielded erratic results. Engineers frequently encountered issues during construction in coastal areas such as the Niger Delta, where these soils were prevalent. Understanding and appropriately treating these soils required in-depth research, particularly in areas where structures were subjected to seasonal drying and wetting.

B. Effects of Wetting and Drying Cycles on Soil Properties: A Comparative Lens

Soils, particularly those with expansive or organic components, underwent complex changes as a result of wetting and drying cycles. Repetition of these cycles typically resulted in irreversible strain, cracking, and gradual swelling for inorganic clays such as Marl. With each cycle, the fine particles moved and the soil structure loosened [4], [23]. The soil became more compressible and less rigid as a result. After a few cycles, cracks developed more readily, particularly when the initial conditions encouraged expansion. On the other hand, organic clays such as Chikoko frequently shrank as they dried, resulting in a net settlement instead of swelling. Irreversible changes resulted from the collapse of their structure, which contained loosely arranged organic particles, as water was lost [17], [24]. The soils did not regain their initial volume when they were rewetted. The organic matter occasionally broke down even more, releasing gases and creating voids. They became sensitive to changes in the environment and unstable under load as a result of these modifications. Because of the high initial moisture content and the poor particle binding, cracks in Chikoko soils were frequently wider and more asymmetrical than those in Marl [22]. These variations demonstrated that it was dangerous to treat both soil types using the same method. Before beginning any construction on such soils, thorough testing is necessary, according to studies.

C. Factorial Design and Oedometer Testing for Comparative Analysis

The behavior of soils under repeated wetting and drying was observed using modified oedometer testing. This method made it possible to measure shrinkage and swelling in a controlled setting. Comparing the Marl and Chikoko soils, which responded differently to variations in moisture, was particularly helpful. Multiple variables, including initial moisture, dry density, surcharge pressure, and number of cycles, could be statistically tested simultaneously using a factorial design approach [28]. It was helpful in determining how each factor interacted as well as its individual effects. For instance, a soil may occasionally exhibit minimal swelling at low moisture levels but react significantly when mixed with a high dry density or subjected to repeated cycles. Montgomery [28] demonstrated that complex problems with multiple influencing factors were best suited for factorial design. There were definite benefits to testing the Niger Delta soils using this method; it provided a clearer picture of the soils' behavior over time and in various scenarios. In actual projects, this degree of analysis helped lower the chance of failure. Additionally, it gave engineers the information they needed to make more informed choices regarding the type, depth, and any necessary stabilization or soil treatment of the foundation.

D. Previous Studies on Niger Delta Soils

It was established by earlier research on Niger Delta soils that the area had troublesome soils with complex water interactions, low strength, and high plasticity. Both marine and alluvial soils in the area frequently contained expansive clays and organic materials, as demonstrated by Akpokodje [7] and Etu-Efeotor [8]. Despite being instructive, these studies largely treated the soils as a single category without making a distinction between Marl and Chikoko. In order to better understand how to build on these soils, Ola [24] and Osinubi [9] looked at the effects of compaction, moisture content, and strength properties. Direct comparisons between different soil types were still lacking, though. For all clayey soils, the majority of regional designs still assumed similar responses, which frequently resulted in inaccurate predictions. The significance of soil-specific testing was emphasized by more recent studies, especially in regions with a variety of geologies. Once more, Osinubi et al. [25] did not concentrate on Chikoko or Marl when they worked on stabilizing black cotton soils with ash and other materials. How these two soils reacted to repeated wetting and drying was still unknown. By directly comparing them using statistical techniques and controlled tests, this study sought to close that gap.

III. MATERIALS AND METHODS

The extensive experimental program intended to compare the hydro-mechanical behavior of Marl and Chikoko soils under various wetting and drying cycles is described in this section. It describes the robust experimental design, the methods for carrying out the specialized oedometer tests and other pertinent measurements, as well as the origin and characteristics of the soil samples.

A. Study Area and Soil Sampling

Marl and Chikoko soil samples were collected from representative sites in Southern Nigeria's Niger Delta

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(roughly between latitudes 4°00' and 6°00' N and longitudes 5°00' and 8°00' E). Geological surveys and initial site investigations served as a guide for the sampling site selection process, ensuring that the samples were representative of the typical Marl and Chikoko deposits found in civil engineering projects within their respective geological settings. Areas with calcareous clay formations, which are commonly found in coastal plain sands or Benin Formation equivalents, were the sites from which marl samples were taken. Samples of Chikoko soil were taken from riverine floodplains or active mangrove swamps, which are features of the most recent alluvial and swamp deposits. Samples of disturbed and undisturbed soil were gathered. Thin-walled Shelby tubes were used to obtain undisturbed samples, which are necessary for tests that require preserved in-situ structure. For thorough index property testing and the creation of reconstituted specimens under carefully monitored initial conditions—both essential for the factorial experimental design—disturbed bulk samples were gathered. To reduce moisture loss and maintain their natural qualities until testing, all samples were brought to the lab in sealed containers.

B. Comparative Soil Characterization

Prior to the main experimental program, a suite of geotechnical index property tests was performed on both Marl and Chikoko soils to establish their fundamental physical and engineering characteristics. These tests adhered to relevant ASTM (American Society for Testing and Materials) or BS (British Standards) procedures, allowing for direct comparison.

➢ *Particle Size Distribution (ASTM D422):*

Hydrometer analysis determined the proportions of clay, silt, and sand. This comparison revealed the finer-grained nature of both, but potentially different distributions within the fine fraction.

➢ *Atterberg Limits (ASTM D4318):*

Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI) were determined. These are critical for assessing consistency limits and swell-shrink potential.

➢ *Specific Gravity (ASTM D854):*

The specific gravity of soil solids (Gs) provided insight into the density of the mineral and organic constituents.

➢ *Compaction Characteristics (ASTM D698, Standard Proctor):*

Optimum Moisture Content (OMC) and Maximum Dry Density (MDD) were determined for each soil type. These values were crucial for preparing specimens at controlled initial moisture contents and dry densities relevant to compaction practices.

➢ *Natural Moisture Content (ASTM D2216):*

The moisture content of the as-received samples provided a baseline for their in-situ state.

➢ *Organic Content (ASTM D2974, Loss-on-ignition):*

This test specifically quantified the organic matter content in Chikoko soil, which is a critical distinguishing feature from Marl.

Table 1 Comparative Summary of Basic Geotechnical Properties of Marl and Chikoko Soils

Property	**Marl Soil (Typical Range/Value)**	**Chikoko Soil (Typical Range/Value)**	**Standard (ASTM/BS)**
Natural Moisture Content (%)	40 - 60	80 - 150 (Significantly Higher)	ASTM D2216
Liquid Limit (LL, %)	60 - 90	90 - 150 (Significantly Higher)	ASTM D4318
Plastic Limit (PL, %)	25 - 40	50 - 80	ASTM D4318
Plasticity Index (PI, %)	35 - 50	40 - 70	ASTM D4318
Clay Content (%)	30 - 50	40 - 60	ASTM D422
Silt Content (%)	30 - 40	30 - 40	ASTM D422
Sand Content (%)	10 - 30	5 - 20	ASTM D422
Specific Gravity (Gs)	2.65 - 2.75	2.50 - 2.60 (Slightly Lower)	ASTM D854
Organic Content (%)	< 5	15 - 30 (Significantly Higher)	ASTM D2974
Optimum Moisture Content (OMC)	28 - 35	35 - 45 (Higher)	ASTM D698
Maximum Dry Density (MDD) (g/cm³)	1.45 - 1.60	1.20 - 1.35 (Lower)	ASTM D698

C. Experimental Design: Three-Level Four-Factor Full Factorial Design for Comparative Analysis

To facilitate a robust comparative analysis, a three-level four-factor full factorial experimental design was implemented *for each soil type*. This approach ensured that the influence of each factor and their interactions could be separately assessed for Marl and Chikoko soils, allowing for direct comparison of their responses under identical experimental factor combinations.

The four factors (independent variables) chosen for their significant influence on soil behaviour and environmental relevance were:

➢ *Initial Moisture Content (wi):*

- Chikoko Soil: Low (14%), Medium (15.25%), High (16.5%). These levels were selected to span a range relative to Chikoko's OMC.
- Marl Soil: Low (47%), Medium (49.25%), High (51.5%). These levels were chosen relative to Marl's distinct OMC.

➢ *Initial Dry Density (γd):*

- Chikoko Soil: Low (1.70 g/cm³), Medium (1.83 g/cm³), High (1.96 g/cm³).

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- Marl Soil: Low (1.00 g/cm³), Medium (1.14 g/cm³), High (1.28 g/cm³).

- *Surcharge Pressure (Psur):*

Low (1 kN/m²), Medium (5.5 kN/m²), High (10 kN/m²). These pressures simulate varying loads or overburden conditions.

- *Number of Wetting and Drying Cycles (N):*

Low (1 cycle), Medium (e.g., 3 cycles), High (e.g., 5 cycles). These cycles represent accumulated environmental stress.

With 3 levels for each of the 4 factors, a total of 34=81 distinct experimental runs were performed for each soil type, leading to a grand total of 162 specimens tested. This comprehensive design enabled the use of Analysis of Variance (ANOVA) to statistically compare the main and interaction effects on the response variables for Marl and Chikoko soils.

E. Experimental Procedures

The core of the experimental program involved a combination of conventional and modified oedometer tests, complemented by assessments of tensile strength and visual observations of cracking. The procedures were standardized and applied consistently to both Marl and Chikoko soil specimens to ensure a fair comparative basis.

- *Specimen Preparation*

Bulk soil samples (Marl and Chikoko) were air-dried and pulverized to pass a 2 mm sieve. The processed soil was then mixed with calculated amounts of distilled water to achieve the target initial moisture contents (wi) as per the experimental design for each specific soil type. The moistened soil was sealed in plastic bags and allowed to mellow for a minimum of 24 hours to ensure uniform moisture distribution.

For each experimental run, a precise quantity of moist soil was dynamically compacted into a rigid oedometer ring (typically 63.5 mm diameter and 20 mm height). Compaction was performed in multiple layers using a miniature rammer to achieve the target initial dry density (γd) for that specific test condition. After compaction, the specimen, still within the oedometer ring, was carefully trimmed, and its mass was determined to verify the achieved initial moisture content and dry density.

- *Conventional Oedometer Test (Initial Swell/Consolidation)*

A subset of specimens for both Marl and Chikoko soils underwent conventional incremental loading oedometer tests (ASTM D2435) to establish their initial consolidation and swelling characteristics before any cyclic loading. This involved:

- Placing the prepared specimen in the oedometer cell between saturated porous stones under a minimal seating load (e.g., 1 kN/m²).
- Applying a series of incremental vertical loads (e.g., 10, 20, 40, 80, 160, 320 kN/m²) and monitoring vertical deformation over time until primary consolidation was completed for each load increment.
- Unloading the specimen incrementally to determine swelling properties. This data provided a baseline for comparing the virgin behaviour of Marl and Chikoko soils.

- *Modified Oedometer Test for Cyclic Wetting and Drying*

A custom-fabricated modified oedometer apparatus was utilized to facilitate the controlled application of multiple wetting and drying cycles while continuously monitoring volumetric changes under constant surcharge pressure.

- *The Procedure for Each Cycle was as Follows for Both Soil Types:*

- *Initial Setup:*

Compacted specimens were placed in the modified oedometer cell under the specified constant surcharge pressure (Psur).

- *Wetting Phase:*

Distilled water was introduced at the bottom of the porous stone. The specimen was allowed to absorb water, and the resulting vertical swelling was continuously monitored using a high-precision Linear Variable Differential Transformer (LVDT) connected to a data acquisition system. The wetting phase continued until volumetric changes stabilized (typically 24-48 hours).

- *Drying Phase:*

After the wetting phase, the free water was drained from the cell. The specimen was then subjected to controlled drying. This was achieved by exposing the specimen to controlled laboratory temperature (e.g., 25°C) and relative humidity, or by placing the entire oedometer cell in a temperature-controlled oven (e.g., 60°C) to accelerate drying while minimizing sudden desiccation cracking artifacts. Volumetric shrinkage was continuously monitored. Drying continued until volumetric changes ceased or a target moisture content was reached.

- *Cyclic Repetition:*

Steps 2 and 3 were repeated for the specified number of cycles (1, 3, or 5 cycles). For each cycle, the cumulative volumetric changes (swell and shrinkage) were recorded. The specimen's mass was measured at the start and end of each wetting and drying phase to track moisture content changes.

Tensile Strength Test and Cracking Observations (Comparative) After the completion of the specified number of wetting and drying cycles, and for companion specimens dried fully, the tensile strength and cracking characteristics were assessed comparatively for both Marl and Chikoko soils.

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➢ *Indirect Tensile Strength (Brazilian Test):*

Cylindrical specimens (if their integrity allowed) were prepared to match the dimensions of the oedometer samples or were prepared from the larger bulk samples. These were subjected to the Brazilian test (ASTM D3967, adapted for soils) by applying a diametral compressive load until failure. The indirect tensile strength (Ts) was calculated as: Ts =πLD2P Where P is the failure load, L is the specimen length, and D is the specimen diameter. This allowed for a direct quantitative comparison of their tensile strength.

➢ *Visual and Digital Image Analysis for Cracking:*

For specimens that exhibited surface cracking, particularly those dried unconfined after cyclic loading, high-resolution digital photographs were taken at critical drying stages. Image processing software (e.g., ImageJ) was utilized to quantify comparative crack parameters such as:

- Crack Area Ratio: Total cracked area divided by total surface area.
- Crack Intensity Factor: Total crack length per unit area.
- Average Crack Width and Depth: Measured if possible. These parameters provided quantitative data to compare the extent and nature of desiccation cracking in Marl versus Chikoko soils (Yesiller et al., 2000; Tang et al., 2015).

F. Data Acquisition and Comparative Analysis

All deformation and load measurements from the oedometer tests were acquired automatically using LVDTs and load cells connected to a computerized data acquisition system. Manual checks were performed for verification.

The collected data for both Marl and Chikoko soils were processed and analyzed using statistical software packages (XLSTAT). The analysis focused heavily on comparative metrics:

➢ *Comparative Calculation of Volumetric Strain:*

Direct comparison of swelling/shrinkage magnitudes for each soil type under identical conditions.

➢ *Comparative Void Ratio and Saturation:*

Tracking changes in these parameters for both soils throughout cycles.

➢ *ANOVA (Analysis of Variance):*

Used to determine the statistical significance of main effects and interaction effects *for each soil type separately*, and then to perform multi-factor ANOVA to identify statistically significant *differences in response* between Marl and Chikoko soils to the various factors.

➢ *Regression Analysis:*

To develop empirical relationships describing the behaviour of each soil type and to compare these models.

➢ *Comparative Graphical Representation:*

Plots and charts were designed to clearly illustrate the differences in trends between Marl and Chikoko soils for volumetric changes, deformation, and tensile strength (e.g., overlaying curves, side-by-side bar charts).

This rigorous and comparative experimental and analytical framework enabled a precise differentiation of the hydro-mechanical responses of Marl and Chikoko soils, providing a foundation for tailored geotechnical design recommendations.

IV. RESULTS

A. Comparative Geotechnical Properties

The initial characterization tests (as summarized in Table 1) provided a clear basis for understanding the key differences between Marl and Chikoko soils. These tests revealed distinct variations in their plasticity, moisture behaviour, and organic content, which are critical to predicting how each soil responds under changing environmental conditions.

In terms of plasticity, Chikoko soil had much higher liquid limits (LL) and plasticity indices (PI) than Marl soil. This meant it could absorb and retain more water and displayed a broader plastic range. These traits aligned with its higher organic content and finer particles [24]. Marl soil, although still plastic, showed lower LL and PI values. This behaviour was typical of clays with an inorganic makeup, particularly those with some carbonate content.

The natural moisture content and compaction behaviour further highlighted their differences. Chikoko soil consistently recorded higher moisture contents and lower maximum dry densities (MDD), alongside higher optimum moisture contents (OMC). These results reflected the soft, spongy nature of organic-rich soils with high void ratios [17]. In contrast, Marl showed MDD and OMC values closer to those expected of more stable, inorganic clayey soils.

A direct measurement of organic matter showed that Chikoko contained about 15–30% organic content, while Marl had less than 5% shown in Fig. 1. This large difference explained much of their contrasting behaviour. High organic matter in Chikoko made it more compressible and sensitive to environmental changes. Marl, being low in organic matter, behaved more predictably under stress and moisture changes.

These baseline properties confirmed that both soils posed engineering challenges but for different reasons. While Marl responded like a traditional expansive clay, Chikoko's high organic content and low strength made it behave more like a peaty or fibrous soil. This fundamental difference helped frame the rest of the study, particularly in comparing their reactions to wetting and drying cycles.

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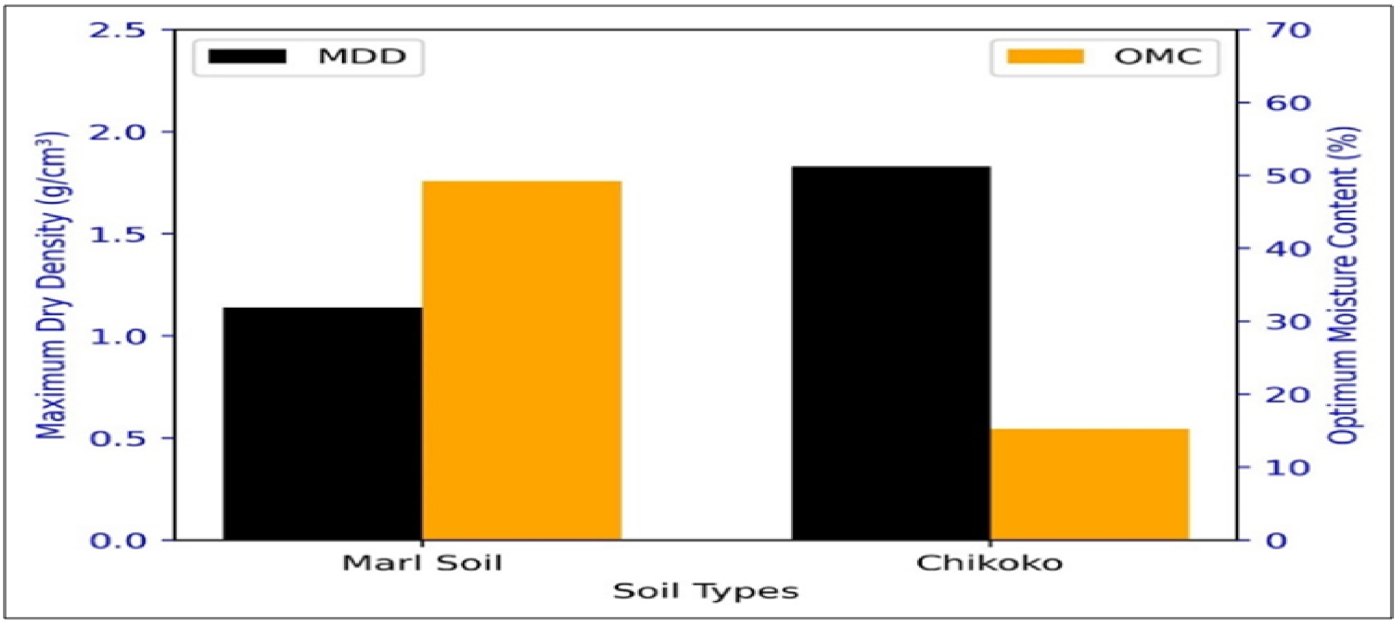


Fig 1 Maximum dry Density and Optimum Moisture Content of Marl and Chikoko Soils

B. Comparative Volumetric Change Behaviour

The modified oedometer tests offered detailed insight into how Marl and Chikoko soils responded to repeated wetting and drying. Both soils showed notable volume changes, but the magnitude and direction of these changes differed significantly between the two.

Marl soil generally swelled when wetted and shrank when dried seen from Fig. 2. The amount of swelling was higher when the soil started off drier and was reduced when more pressure was applied. As wetting and drying continued, Marl often experienced a net increase in volume over time. This behaviour, sometimes called "ratcheting," was more pronounced under lighter surcharge loads. The soil gradually expanded beyond its original state after each cycle, building up residual strain [5].

Chikoko soil, however, reacted differently. It showed much larger volume changes than Marl, especially when prepared at its naturally high moisture levels. The organic matter in Chikoko absorbed water easily, which caused swelling, but also made the soil prone to collapse as the cycles continued. Over time, this soil often settled rather than swelled, showing a net volume loss. Repeated cycles likely broke down its internal structure and organic content, leading to irreversible shrinkage [17].

Initial moisture and density had a strong effect on both soils shown on Fig. 3. For Chikoko, even small changes in these conditions led to dramatic shifts in swelling or shrinkage.

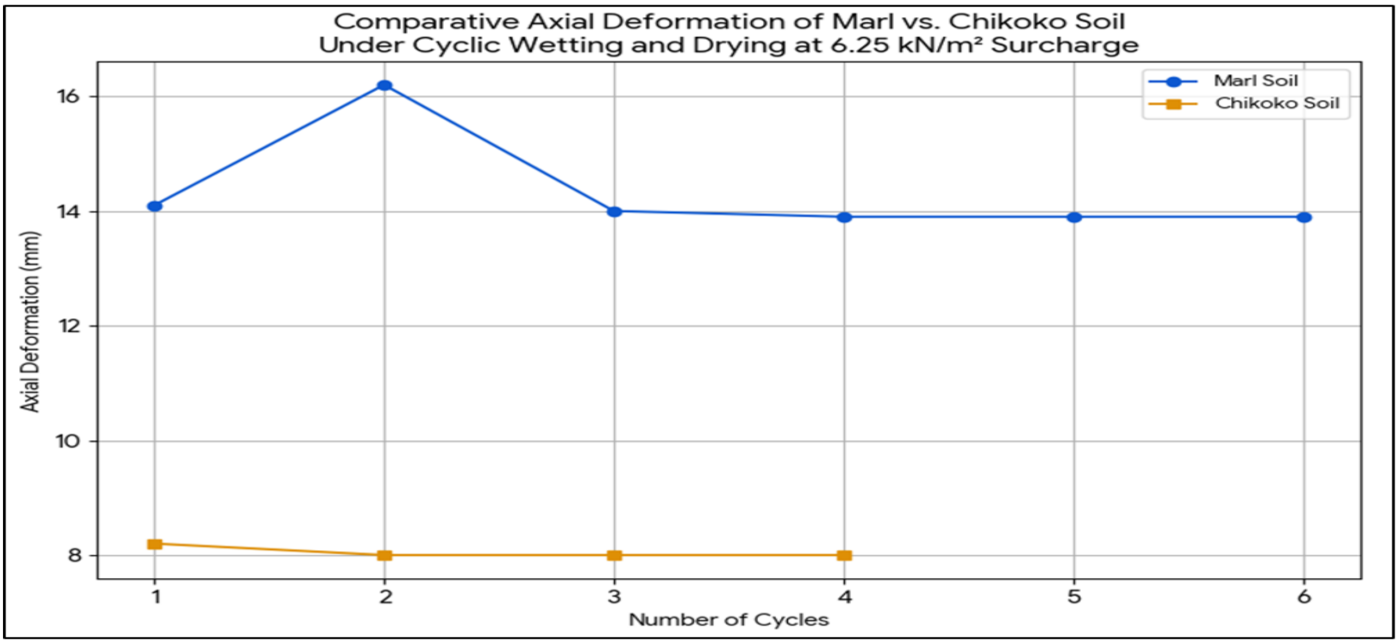


Fig 2 Comparative Cumulative Volumetric Strain of Marl vs. Chikoko Soil Under Multiple Wetting and Drying Cycles at 6.25 kN/m² Surcharge

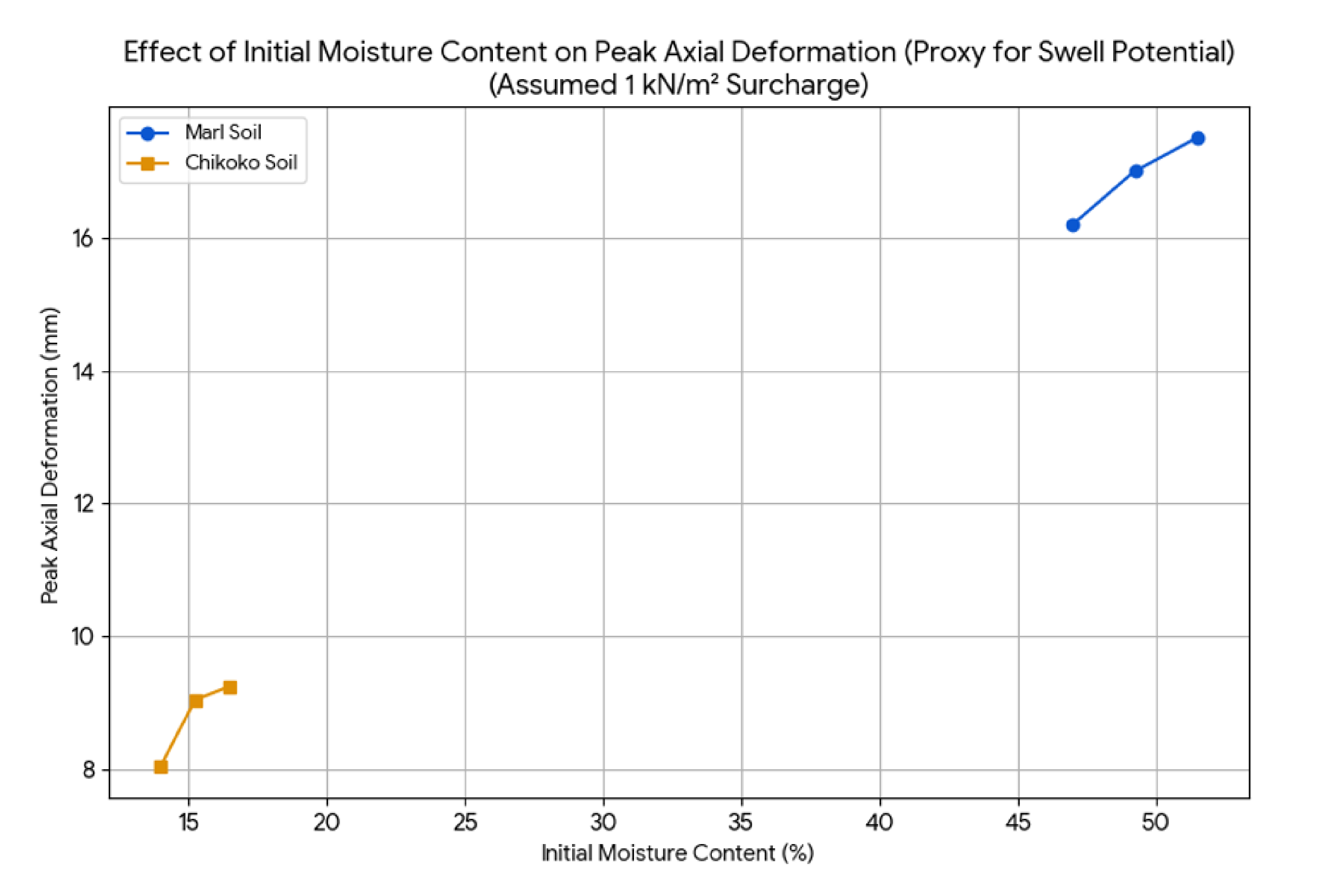


Fig 3 Effect of Initial Moisture Content on Maximum Swell Potential: Marl vs. Chikoko Soil at 1 kN/m² Surcharge

C. Comparative Tensile Strength Properties and Cracking Behaviour

The evaluation of tensile strength and cracking behaviour revealed clear distinctions between Marl and Chikoko soils, mainly driven by differences in their internal structure and material composition seen on Fig. 4.

➢ *Tensile Strength Values:*

- Both soils showed low tensile strength, typical of cohesive materials.
- Chikoko soil generally recorded lower values than Marl under similar moisture and density conditions.
- This was due to Chikoko's high organic matter, loose fabric, and higher void ratio, which reduced inter-particle bonding strength [22].

➢ *Tensile Strength Degradation:*

- Repeated wetting and drying cycles led to noticeable reductions in tensile strength for both soils.
- The rate of degradation appeared faster in Chikoko soil, likely caused by structural weakening from organic decomposition and repeated moisture fluctuations [17].

➢ *Crack Pattern Observations:*

- *Marl Soil:*

Formed polygonal, evenly spaced surface cracks. Cracks widened gradually over successive cycles. This pattern resembled typical expansive clay desiccation features [43].

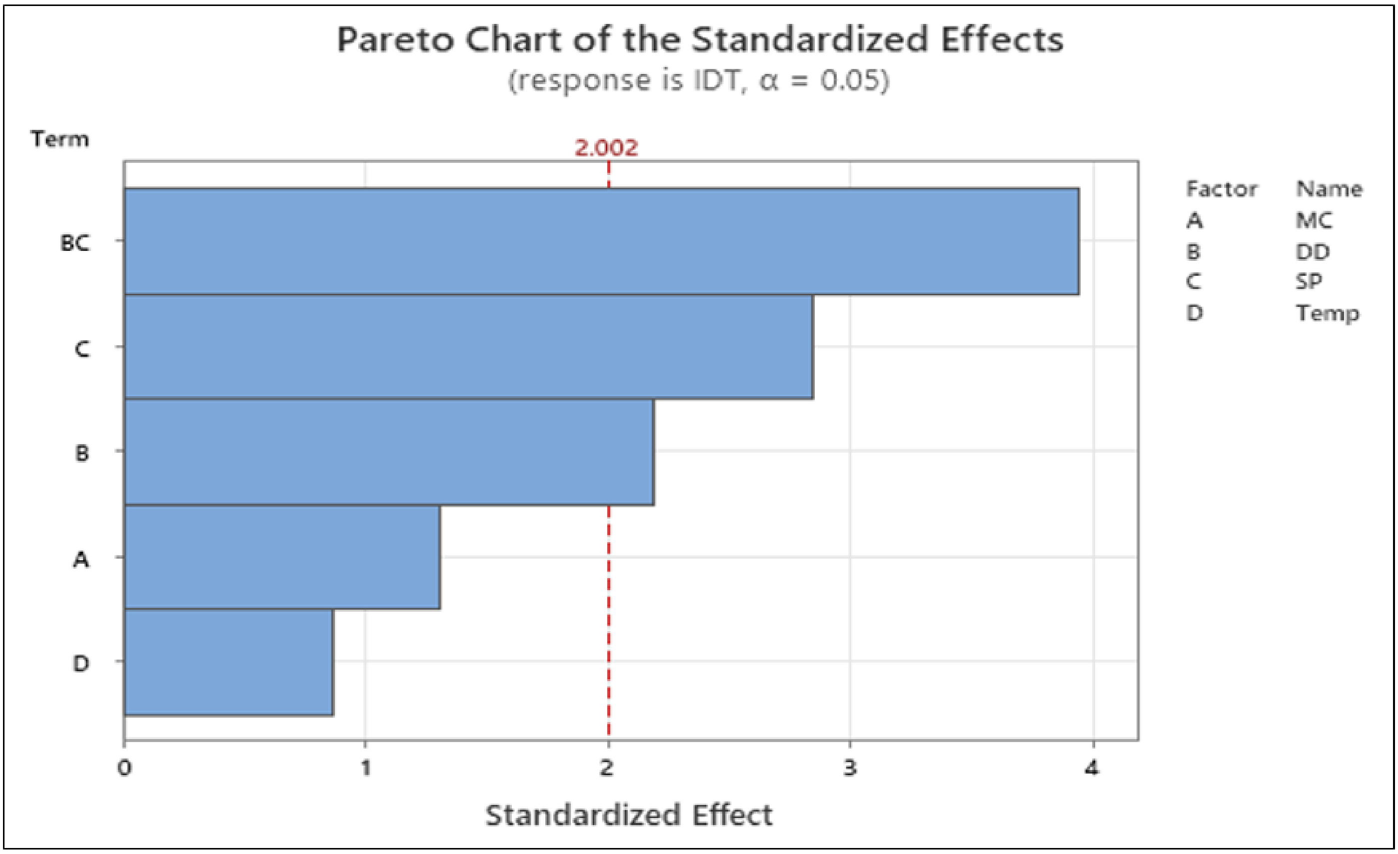
- *Chikoko Soil:*

Developed wider, deeper, and more irregular cracks. Cracks often interconnected, forming larger fissures due to rapid water loss and collapse of organic components [44].

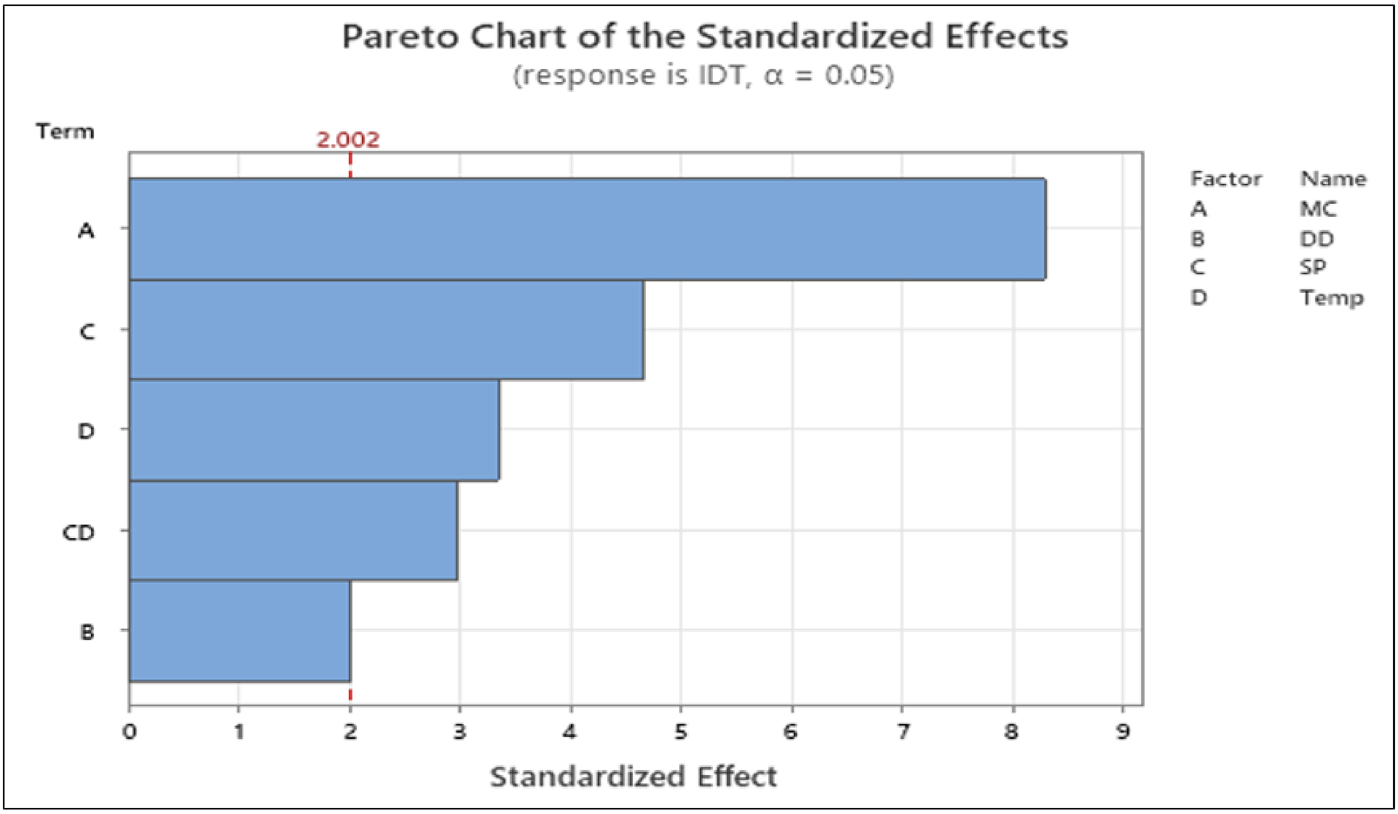
➢ *Shrinkage–Crack Correlation:*

- Both soils showed strong correlation between volumetric shrinkage and crack development.
- Greater shrinkage typically resulted in longer, wider, and more numerous cracks.

These differences underscore the distinct tensile behaviours and crack risks associated with each soil type.



(a) Pareto effect chart for Significant factor responsible for indirect tensile strength in Marl soil



(b) Pareto effect chart for Significant factor responsible for indirect tensile strength in Chikoko soil

Fig 4 Comparative effect of significant of Marl vs. Chikoko Soil with Increasing Wetting-Drying Cycles

D. Comparative Statistical Analysis of Experimental Data

The ANOVA results from the full factorial design were instrumental in quantitatively distinguishing the responses of Marl and Chikoko soils.

➢ *Main Effects:*

All four factors (initial moisture content, initial dry density, surcharge pressure, and number of wetting and drying cycles) exerted statistically significant main effects on volumetric changes, deformation, and tensile strength *for both soils.*

➢ *Comparative Significance of Factors:*

The *relative significance* of these factors often varied between the two soils. For instance, the impact of initial moisture content on swelling might be even more pronounced for Chikoko due to its higher water absorption capacity and the vast range of water content changes it undergoes.

➢ *Interaction Effects:*

Significant two-way and higher-order interaction effects were observed for both soils, but the *nature* of these interactions differed. For example, the interaction between surcharge pressure and the number of cycles might show that while high surcharge effectively mitigates swell in Marl, its long-term effectiveness in Chikoko might be compromised by structural degradation related to organic matter, leading to sustained cumulative settlement even under load. The factorial analysis confirmed that the "best" initial conditions or design approaches for one soil were not necessarily optimal for the other due to these distinct interactive behaviours.

The statistical analysis clearly demonstrated that while both soils are reactive to moisture changes, their underlying mechanisms and consequently their hydro-mechanical responses are sufficiently different to warrant distinct consideration in geotechnical engineering.

V. DISCUSSION

A. Interpretation of Comparative Volumetric Behaviour

The most critical comparative difference between Marl and Chikoko soils emerged in their volumetric responses during cyclic wetting and drying. Chikoko soil consistently experienced much larger magnitudes of swelling and shrinkage than Marl soil as seen in Fig.2 and Fig.3. This distinction was strongly linked to its very high organic matter content, which contributed to greater water retention and more extreme structural changes upon moisture fluctuations [23].

➢ *Magnitude of Swelling and Shrinkage:*

- Chikoko soil recorded significantly higher swell percentages under wetting, often exceeding 12% in early cycles, especially when compacted at low dry density and high initial moisture content.
- Upon drying, the same specimens exhibited substantial shrinkage, sometimes over 10%, creating large volume changes across cycles.
- Marl soil, in comparison, showed moderate swell (around 4–6%) and less shrinkage (2–4%), consistent with typical expansive clays with moderate plasticity and low organic content.
- The expansive behaviour of Marl was mainly attributed to the swelling of clay minerals like montmorillonite, while Chikoko's behaviour was influenced more by the hygroscopic nature of organic matter and high initial voids [17], [20].

➢ *Cumulative Volumetric Strain Trends:*

- *Marl Soil:*

Displayed net cumulative swelling (positive strain accumulation) after multiple wetting-drying cycles.

✓ The clay fabric gradually opened with each wetting, producing residual swell even as drying induced some shrinkage.
✓ This "ratcheting" behaviour led to gradual elevation in volume over time, especially at lower surcharge pressures [17].

- *Chikoko Soil:*

Showed a different trend.

✓ After initial swelling in early cycles, repeated desiccation caused structural collapse that was not fully recovered in subsequent wettings.
✓ This led to a cumulative net settlement or shrinkage across cycles.
✓ Permanent volume loss occurred due to breakage or softening of the organic matrix [23].

➢ *Key Factors Contributing to Cumulative Shrinkage in Chikoko Soil:*

- *Structural Collapse:*

✓ Desiccation triggered the collapse of loosely bonded organic and silty structures.
✓ These internal collapses were often irreversible.

- *Degradation of Organic Matter:*

✓ Even though the test duration was short, limited biochemical breakdown might have occurred, contributing to long-term loss in structure.
✓ Longer exposure would likely increase this effect under natural field conditions [23].

- *Inherent Compressibility:*

✓ Chikoko's high compressibility meant that small strains translated into large volume losses under constant pressure or repeated cycles.

- ✓ This response contrasted sharply with Marl, whose denser, inorganic composition resisted such rapid structural changes.

- *Influence of Initial Conditions:*

- ✓ Initial dry density and moisture content had a strong effect on both soils.
- ✓ However, Chikoko soil reacted more drastically.
- ✓ Even small reductions in moisture led to excessive shrinkage.
- ✓ Marl showed more predictable and limited swelling/shrinkage within its plastic range.
- ✓ This emphasized the extreme moisture sensitivity and fragile structure of Chikoko compared to the more stable Marl.

B. Comparative Mechanisms of Deformation

The observed differences in the compression index (Cc) and swelling index (Cs) between Marl and Chikoko soils clearly reflected their distinct material characteristics. Chikoko soil showed a much higher Cc than Marl shown in Fig.4, indicating a significantly greater compressibility. This was expected, considering its high organic content and loose structure. Organic soils like Chikoko typically contain a large amount of water and air-filled pores within their matrix. These features make them soft, weak, and highly deformable under applied loads. As a result, when subjected to static loading, Chikoko soil compressed more and settled faster and deeper than Marl soil. Marl, by contrast, showed lower compressibility due to its denser structure and lower water content. Its behavior under load was more typical of inorganic clays with moderate to high plasticity.

The effect of repeated wetting and drying cycles further emphasized these differences. Marl soil, although sensitive to moisture changes, responded in a more stable and predictable way. With each cycle, its structure became slightly more open, allowing more compression under load. This led to small increases in both Cc and Cs, as the soil's capacity to hold and release water evolved with changes in its internal arrangement. These changes were gradual and remained within the expected range for expansive clays.

On the other hand, Chikoko soil responded in a much more complex and less stable manner. The cyclic exposure to wetting and drying caused its internal structure, which relied on organic bonding and weak particle contacts, to gradually weaken. This breakdown was not simply reversible. As the organic matter began to lose its cohesion, the overall stiffness of the soil decreased. At the same time, its compressibility increased. In practical terms, this meant that each time the soil went through a drying phase followed by re-wetting, it became softer and more prone to deformation. The stress-strain curves obtained from laboratory testing confirmed this trend. Chikoko soil consistently showed lower stiffness, more curvature in the loading phase, and a more ductile response than Marl soil.

Over multiple cycles, Chikoko's resistance to deformation reduced further, pointing to possible long-term structural collapse. The loss of structure, combined with the gradual decomposition of organic matter, reduced its ability to resist settlement. This was evident in the sustained increase in Cc and the inconsistent recovery of volume after re-wetting. Marl soil, while affected by cycles, maintained a better capacity to recover and retained some of its stiffness. It deformed less and retained more of its original strength across the cycles.

C. Comparison with Broader Literature

The findings for Marl soil aligned closely with established knowledge on expansive calcareous clays. It responded to wetting and drying cycles with notable swelling, especially when prepared at low initial moisture content or subjected to low surcharge pressures. This pattern of behaviour confirmed what earlier researchers had observed—that expansive soils tend to take in water, expand, and retain part of the volume increase across cycles. This progressive accumulation of strain, often called "ratcheting," is typical of unsaturated clays and has been reported in many studies focused on volume change under environmental cycling. The data also showed that Marl soil's response was highly influenced by its initial conditions. Dry specimens swelled more than moist ones, while higher surcharge reduced both swell and shrinkage. These effects matched observations in other expansive clay studies, particularly those involving calcium-rich clays where carbonate particles influence fabric and moisture movement. The swelling index also increased slightly over time, suggesting an opening of the soil structure as cycles progressed, likely due to weakening of interparticle bonds.

In contrast, the results for Chikoko soil pointed strongly toward behaviours usually associated with organic or peaty soils. High natural moisture content, large void ratios, and very low dry densities marked its initial condition. These characteristics made it highly compressible and extremely responsive to external loads and moisture changes. Upon drying, it shrank significantly, and unlike Marl, did not fully regain its original volume when re-wetted. This irreversible volume change was more severe over multiple cycles. Chikoko soil's behaviour also revealed a tendency for cumulative settlement, rather than swelling. The organic content, which played a major role in this response, possibly degraded or collapsed structurally after repeated wetting and drying. The test results showed a clear reduction in stiffness and a higher compressibility with each cycle, indicating ongoing breakdown of the soil fabric. Such findings have been supported by earlier studies on peaty soils and soft organics, especially under fluctuating moisture conditions. The large shrinkage, coupled with cracking and loss of tensile strength, also confirmed the vulnerability of organic soils to surface instability when exposed to drying phases.

The most important contribution of this study came from the side-by-side comparison of Marl and Chikoko soils under exactly the same testing conditions. Unlike most studies that examine only one type of problematic soil, this

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approach allowed for a direct contrast of their behaviours. It became clear that although both soils posed engineering challenges, the source of those challenges was fundamentally different. Marl soil behaved as expected for an inorganic expansive clay, with issues linked to moisture sensitivity and swelling. Chikoko, on the other hand, posed risks related to compressibility, collapse, and permanent volume loss due to its organic makeup. Recognizing these differences is essential for accurate geotechnical design. It showed that region-specific, soil-specific strategies must be used, rather than applying a one-size-fits-all solution for all soft or clayey soils in the Niger Delta.

D. Limitations

While this comparative study provides valuable insights, it is important to acknowledge certain limitations:

- *Laboratory Scale:*

Laboratory tests, by nature, cannot fully replicate the complex heterogeneous field conditions, including variations in temperature, groundwater fluctuations, vegetation effects, and non-uniform moisture profiles.

- *Limited Number of Cycles:*

The study used up to 5 wetting and drying cycles. Real-world structures are exposed to many more cycles over their design life, and extrapolation beyond the tested range should be done cautiously.

- *Indirect Tensile Strength:*

The Brazilian test provides an indirect measure of tensile strength. Direct tensile tests are challenging for soils but could offer more fundamental insights into tensile fracture.

- *Organic Degradation:*

The study duration may not be sufficient to capture the full long-term effects of biochemical degradation of organic matter in Chikoko soil.

- *Sample Specificity:*

While representative, the specific properties of Marl and Chikoko soils can vary geographically within the Niger Delta. The findings provide general trends but should be validated with site-specific investigations.

These limitations serve as avenues for future research to further refine the understanding and predictive capabilities for these critical soil types.

VI. CONCLUSION AND RECOMMENDATIONS

- *The Salient Comparative Conclusions are:*

- *Distinct Compositional Properties:*

Marl soil is characterized as a calcareous clay with moderate to high plasticity, while Chikoko soil is a highly organic, very high plasticity clay with exceptionally high natural moisture content and low dry density. These fundamental differences dictate their subsequent engineering behaviour.

- *Divergent Volumetric Changes:*

Chikoko soil exhibits larger magnitudes of both swelling and shrinkage compared to Marl soil. Critically, while Marl typically shows a *net cumulative swelling* over cycles, Chikoko often demonstrates a *net cumulative shrinkage or settlement*, driven by organic matter characteristics and structural collapse.

- *Varied Deformation Characteristics:*

Chikoko soil is significantly more compressible than Marl soil, with higher compression indices. Cyclic wetting and drying can alter the stiffness and compressibility of both, but Chikoko's long-term deformation is further influenced by potential organic degradation and structural breakdown, leading to sustained settlement risk.

- *Differential Tensile Strength and Cracking:*

Both soils have low tensile strengths and are prone to desiccation cracking. However, Chikoko soil generally has lower tensile strength and develops wider, deeper, and more interconnected crack networks compared to the finer, more uniform cracking in Marl soil. This implies a greater risk of rapid water ingress and subgrade degradation for Chikoko.

- *Factor-Interaction Differences:*

The influence of initial moisture content, dry density, and surcharge pressure, while significant for both, manifest differently. The response of Chikoko soil is often more extreme and sensitive to initial conditions compared to Marl soil.

- *Necessity of Soil-Specific Design:*

The study unequivocally demonstrates that despite both being problematic, Marl and Chikoko soils respond in fundamentally different ways to environmental moisture fluctuations. A generic approach to geotechnical design is insufficient; distinct, tailored strategies are essential for each.

- *Contribution to Knowledge*

This research makes a substantial contribution to geotechnical engineering, particularly for challenging environments like the Niger Delta. It fills a critical gap by providing the first systematic and statistically robust *comparative analysis* of two of the region's most problematic and compositionally distinct soil types. By delineating their unique hydro-mechanical responses under cyclic environmental loading, the study moves beyond generalized problematic soil behaviour to offer granular, soil-specific insights that are vital for informed decision-making in infrastructure development. The detailed characterization of their differing volumetric changes, deformation, and tensile strength degradation patterns under a controlled factorial design provides a valuable dataset and a deeper mechanistic understanding specific to Marl and Chikoko soils.

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