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Construction of Buildings on Black Cotton Soil Case Study: Bor, Jongelei State, Republic of South Sudan

ABSTRACT
Building on black cotton soil presents numerous challenges due to its unique swelling and shrinking properties, which can lead to structural instability and failure. As Bor Town and the broader South Sudan experience rapid construction growth, it is essential to implement effective construction techniques and mitigation strategies to address the effects of black cotton soil on buildings. This study employs an interview - questionnaire format to collect data from key stakeholders, including civil engineers, construction experts, and local community members. It provides valuable insights into the difficulties associated with black cotton soil and outlines best practices for mitigating these issues. The research identifies strip and mat foundations as the preferred options for construction on black cotton soil, as they enhance stability and minimize the risk of differential settlement, making them more suitable for supporting structures in this challenging environment. Additionally, the study highlights the construction of hydraulic structures and multi -storey buildings along the River Nile as a strategy to prevent flooding in the region.

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INTRODUCTION

The black cotton soil deposits found in Bor County, characterized as alluvial soil, are highly suitable for agricultural activities. However, they pose significant challenges for construction due to their propensity to shrink and swell with changes in moisture levels. This behavior can lead to the formation of cracks in the ground surface, particularly during dry periods, while these cracks may close up during the rainy season, leaving behind an uneven terrain due to intermittent heaving and swelling. The low strength and substantial volume fluctuations of black cotton soil make it particularly problematic for building foundations. To mitigate the risks associated with shrink-swell behavior, it is common practice to replace this expansive soil with non-expansive materials like gravel and sand. While these alternatives enhance drainage and aeration, they may also reduce water retention and alter the soil's structural integrity. Black cotton soil is known for its high plasticity index, which contributes to significant changes in volume as moisture content fluctuates. This can result in ground movement that leads to structural issues in buildings, manifesting as cracks in walls, foundations, and floors. Such damage occurs as buildings settle unevenly, ultimately risking structural integrity and safety.

In the Greater Upper Nile region of South Sudan, especially in central Jonglei State, the prevalent black cotton soil presents unique challenges. This soil, a heavy clay type varying from clayey to loamy and typically dark grey, is rich in clay minerals like montmorillonite, illite, and kaolinite. Its behavior is significantly influenced by moisture: it shrinks and hardens like stone when dry, offering high load-bearing capacity. However, when wet, it swells and becomes loose, reducing its load-bearing capacity and potentially causing significant structural damage to foundations, buildings, roads, and other infrastructure. This research seeks to understand how local communities manage this soil's moisture-related volume changes and identify the most effective foundation techniques. The study also aims to determine suitable building materials that interact well with black cotton soil, focusing on soil stability and load-bearing capacity to mitigate potential issues. Furthermore, the poor drainage characteristics of black cotton soil can worsen the swelling-shrinking cycle, potentially increasing hydrostatic pressure around foundations, retaining walls, and basements.

BACKGROUND

Bor Town predominantly features clay-rich soils that expand and contract in response to changes in moisture levels. This fluctuation can lead to shifts in the foundations of residential buildings, adversely impacting local inhabitants. In various regions of South Sudan, these soils present a serious risk to the stability of lightweight structures. The swelling clays, originating from residual soils, can generate upward pressures that may inflict significant harm on lightly constructed huts.

Figure 1.1 A typically examples of Huts sinks in black cotton soil in Bor

Environment: Black cotton soil is found in semi-arid tropical regions where annual evaporation rates surpass precipitation levels. These soils undergo considerable volume fluctuations due to seasonal variations in moisture, which creates significant environmental challenges.

Environmental Degradation: Climate change, characterized by rising temperatures, increasing sea levels, and extreme weather events, can severely disrupt ecosystems and inflict substantial environmental harm. For instance, the flooding of the River Nile in the region has resulted in extended periods of inundation, leading to crop damage from oxygen deprivation in the roots, diminished nutrient availability, and heightened vulnerability to diseases. This adversely affects plant height, leaf area, and overall biomass, potentially resulting in considerable reductions in crop yields. Prolonged waterlogging can also degrade soil quality, impacting local vegetation, particularly in areas like Malou Bor Town, where trees are dying off.

Biodiversity: Flooding on black cotton soil result into destruction of forests and natural habitats reduces biodiversity, as many species depend on specific environments for survival. This loss of biodiversity can lead to the collapse of ecosystems, affecting food chains and water systems. Black Cotton Soil (BCS) In South Sudan black cotton soil is found in widespread regions of Greater Upper Nile. The Alluvial deposits of the Nile, formed from the weathering of the basement complex and heavy texture soils, with very high clay content, deep, widely cracking, calcareous, non-saline and non-sodic. This region of South Sudan experiences semi-arid climate, hot dry season and warm rainy with average rainfall of 400- 750 mm, savannah trees and long grasses. Black cotton soil is worrying for the construction on account of its volumetric changes. Such tendency of soil is due to the presence of fine clay particles which swell, when they come in contact with water, resulting in alternate swelling and shrinking of soil causing differential settlement of structures.

Figure 1.2: Characteristics of Black Cotton Soil In South Sudan, black cotton soil is primarily found along the riverbanks and throughout the Upper Nile Region. This type of soil predominantly covers areas in Jonglei, Unity, and Upper Nile States. Consequently, the riverbanks are largely composed of black cotton soil, making it a significant feature of the plateau region in South Sudan, particularly in various locations surrounding Juba.

Black Cotton Soil Location in South Sudan

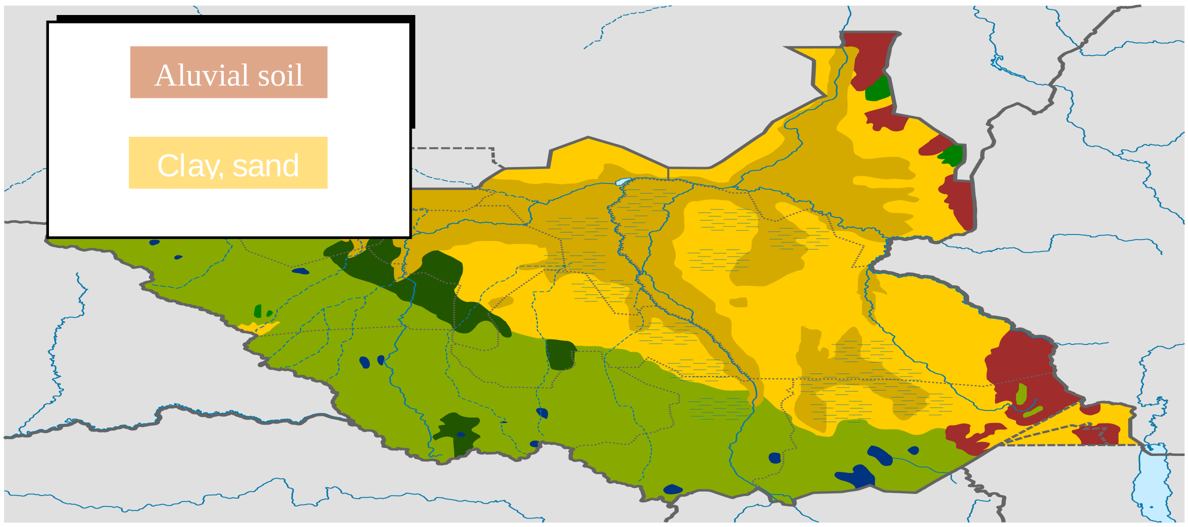

Figure 1.3 illustrates the distribution of black cotton soil and expansive soil, characterized by light brown and yellow hues. The Upper Nile region of South Sudan features plains composed of dark grey, highly plastic clayey silt, often interspersed with calcareous materials. The sediments found in this area have been deposited by the River Nile, as depicted in the accompanying map. The black cotton soil prevalent along the banks of the Nile is formed in tropical and subtropical climates, boasting a rich nutrient profile. These weathered sediments primarily consist of the clay mineral montmorillonite. The soil texture varies from loamy clay to clay, exhibiting a significant shrink-swell capacity that changes with seasonal fluctuations.

Impact of Black Cotton Soil on Structures in the Research Area Black cotton soil poses considerable challenges for buildings constructed on it, primarily due to its tendency to expand and contract in response to changes in moisture content, as illustrated in the accompanying images from the research area. Foundation Issues: The expansive nature of black cotton soil can lead to foundation damage through uplift as it absorbs moisture, resulting in uneven settlement. This differential movement can create cracks in walls, foundations, and other structural components. Notably, diagonal cracks often appear in walls, particularly at the corners of windows and doors, as a direct consequence of this uneven settlement.

Figure 1.4 illustrates examples of structures constructed on black cotton soil that have experienced foundation failures. The foundation may suffer from cracking or other problems as a result of soil movement, which can cause heaving or upward pressure during the swelling phase. This can lead to cracks in walls and floors, and in extreme cases, may even result in the collapse of the entire building. Differential settlement occurs when the soil beneath the structure exhibits shrink-swell behavior, causing various parts of the building to settle unevenly. This uneven settling can lead to structural damage, including misaligned doors and windows, ultimately jeopardizing the architectural integrity of the structure.

Figure 1.5 illustrates multiple cracks on a structure caused by uneven settlement. Tilted Structures: The characteristics of black cotton soil, which experiences irregular ground movement, can lead to buildings leaning and becoming hazardous. Additionally, unforeseen geological faults or fissures in the earth may contribute to this tilting. The instability of the weak black cotton soil beneath the building is a significant factor in this issue. Fluctuations in groundwater levels can further compromise soil stability.

Figure 1.6 depicts a washroom at Greenbelt Academy in Bor Town. Structural Damage: The ongoing cycle of expansion and contraction can result in visible cracks appearing in the walls, floors, and ceilings of structures. Over time, this deterioration can jeopardize the building's structural integrity, potentially necessitating extensive repairs or, in some cases, complete demolition and reconstruction.

Fig 1.7 Typical black cotton soils structural damage, school buildings in Bor Town Road Pavements and Damage: the swelling and shrinking of black cotton soil can cause potholes, cracks, and other damage to roads and pavements. Due to very low CBR values of black cotton soil, excessive pavement thickness is required for designing for flexible pavement. The constant stress and strain from loaded transport vehicles are most liable to damage as a result of the volume changes in the soil. Dampness: moisture issues it's crucial causes building materials to deterioration, corrode, and weaken, reducing their lifespan. General Site Descriptions: The Studied Area is located in the capital city of Jonglei State, Bor Town, where area lies is seen as extensive plain clay that is associated with the White Nile. The area is part of the semi- arid climate, which is hot and dry with summer rain and a cold dry winter season. The study area is composed mainly of superficial clay deposits and alluvium of the White Nile the clay mineralogy of the study area is strongly dominated by Smectitic clay minerals mainly montmorillonite type, which is an expanding clay mineral. Topography: The land form of the study area is almost flat and hence flooding usually stances for a lengthy time after rainfall. Therefore, surface drainage is necessary to be considered. The major kind of land use includes rain fed agriculture such as traditional and mechanized farms of sorghum and irrigated agriculture such as fruits and vegetables. White Nile River and its flood plain and rain water constitute the main sources of flooding in the area, since the study area lies on the western bank of the White Nile. Drainage Patterns: Black cotton soils in Bor, Jonglei, and some areas of South Sudan in general, exhibit impeded drainage due to their high clay content and low permeability. This makes them prone to waterlogging and can hinder the construction of buildings and other infrastructure. The poor drainage of black cotton soils can lead to waterlogging, which can affect the growth of crops and cause issues with sanitation, hygiene, and pose significant challenges for construction, making it difficult to build stable foundations and infrastructures.

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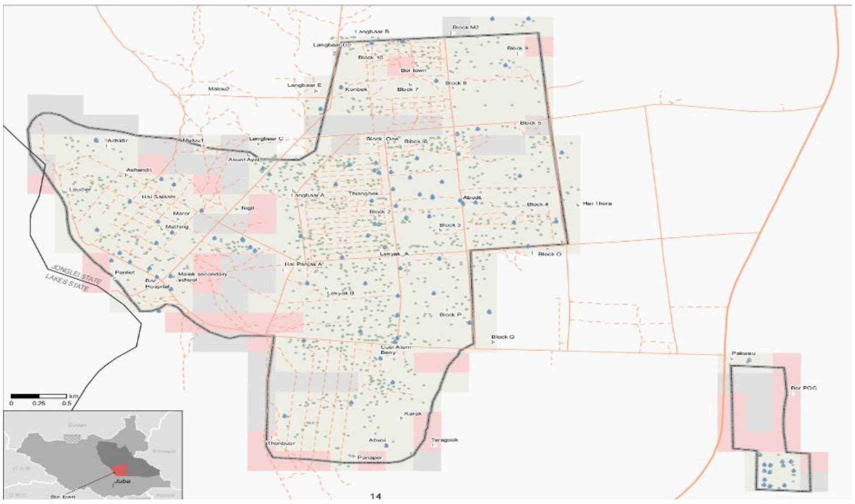
South Sudan - Jonglei State, Bor Town



Bor's Water and Land: A Summary of Bor heavily relies on groundwater, but its usability is complicated. While one aquifer shows low salinity, elevated nitrate levels pose a concern. Seasonal changes also play a role; the rainy season can flood and cut off water sources. Beyond water quality, Bor struggles with flood control and developing water infrastructure. The area's alluvial aquifers mean groundwater levels fluctuate, with some areas having deeper water than others.

Seasonal Patterns in Jonglei**:** Jonglei's climate, with its wet and dry seasons, strongly dictates seasonal changes. These shifts affect farming, livestock, water, and people's lives. These regular yearly changes are driven by factors like temperature, rainfall, and the White Nile's flooding. Soil moisture also varies seasonally, with more moisture during the wet season, impacting plant life, soil processes, and the overall ecosystem.

Building in Bor: Soil Considerations**,** Bor's soil is rich in clay, known as black cotton soil. This means any construction in Bor Town must account for the soil's limited ability to support weight when designing foundations and other structural components.

Mitigation Strategies**:** The impacts of black cotton soil on buildings can be mitigating with several strategies considered on areas of black cotton soils. Soil Stabilization: improvement of geotechnical properties of soil, making it more suitable for several engineering tenders like roads, foundations, and embankments. These techniques can be broadly categorized into mechanical, hydraulic modification, physical and chemical modification, and modification by inclusion and confinement each with its own set of applications. These methods will reduce shrink-swell behaviors of black cotton soil. Foundation Design: proper foundation designs for structure built on black cotton soil to resist the movement of the soil and provide a stable foundation. Exceeding the active zone for foundation area, where swelling and shrinkage occur can minimize the impact of soil movement. Utilizing foundations types likes deep foundations such as pile foundations that extend to stable soil strata, reducing the influence of soil behavior. Also using raft and strips foundations, raft distribute load over large area as well strip footings are more stable and minimize the effects of soil expansion and contracting. Moisture Construction Management: using materials of moisture control during construction to keep soil moisture level under control. Likes of bitumen waterproof paints in footings and DPC (Damp Proof Course) and DPM (Damp Proof Membrane) are both used to prevent moisture from entering a building, but with their different applications. Drainage and water management: developing proper site grading to facilitate runoff away from the foundation with invest effective drainage system to prevent water accumulation around buildings. There is need for regularly monitoring groundwater levels to understand changes in soil moisture that could affect stability.

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Construction Practices: It is essential to utilize materials capable of withstanding soil movement without resulting in cracks, such as the Expanded Polystyrene (EPS) core panel system.

Problem Statement

This study addresses a significant issue: buildings that suffer damage due to their inability to withstand the variability of black cotton soil. The rapid infrastructure development in Bor Town has highlighted the urgent need for research aimed at creating effective and sustainable construction solutions tailored to the unique climatic conditions of the area. The rationale behind this research is grounded in a comprehensive understanding of soil characteristics, innovative engineering approaches, and environmental factors. Ongoing studies continue to yield valuable insights that can enhance construction practices, making them safer, more efficient, and more viable. By tackling the challenges posed by black cotton soil, it becomes feasible to design structures that positively impact the community. The research will concentrate on advancing techniques to stabilize black cotton soil, addressing construction challenges related to its strength, and mitigating issues of swelling and shrinkage, while also investigating methods to improve poor drainage.

OBJECTIVES

This research aimed to achieve the following specific goals:

Primary Objectives

i. To investigate the most appropriate foundation types for structures based on the stability and load-bearing characteristics of the underlying soil.
ii. ii. To evaluate methods for managing volumetric changes (such as swelling or shrinkage) in response to fluctuations in moisture levels.

Secondary Objectives:

i. To identify suitable construction materials and methods that positively interacts with black cotton soil.
ii. ii. To enhance the load-bearing capacity of black cotton soil.

Hypothesis

The study posits that effective solutions exist for stabilizing the variability of black cotton soil. A robust strategy for controlling shrinkage and swelling behavior is essential for achieving high strength in black cotton soil.

LITERATURE REVIEW

Introduction Black cotton soil with its high shrinkage and swelling characteristics, it has become crucial and common in recent decades to find out satisfactory techniques in varying moisture content that can lead to potential settlement issues in buildings. Numerous studies have been carryout in search for the best mitigation strategy for problematic black cotton soil. Broadly speaking soil stabilization encompasses every physical, physio-chemical and chemical method developed and used to make a soil perform better its desired engineering purpose. Black cotton is unsuited soil which needs careful understanding and appropriate method of construction of structures on it.

General Literature Review on Black Cotton According to (Shailendra Singh et al, 2013), detailed generally the observed characteristics of black cotton soils as per studies. Problem associated with Black Cotton soil: Black cotton soils are problematic for engineers everywhere in the world, and more so in tropical country like South Sudan because of wide temperature variations and because of distinct dry and wet seasons, leading to wide variations in moisture content of soils. The following problems generally occur in black cotton soil. High Compressibility: black cotton soils are highly plastic and compressible, when they are saturated. Footing, resting on such soils under goes consolidation settlements of high magnitude. Swelling: a structure built in a dry season, when the natural water content is low shows differential movement as result of soils during subsequent wet season. This causes structures supported by such swelling soils to lift up and crack. Restriction on having developed swelling pressures making the structure suitable and Shrinkage: a structure built at the end of the wet season when the natural water content is high, shows settlement and shrinkage cracks.

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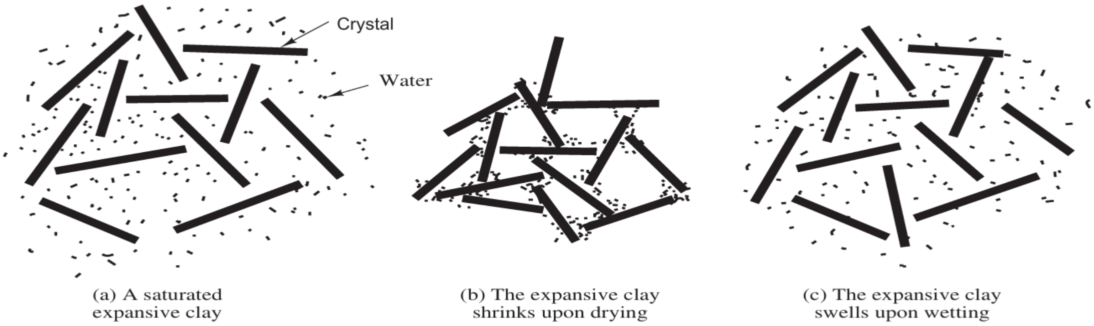

Fig 2.1 Sources, (Donald P et al, Foundation Design Principles and Practices, Third Edition) Chemical Composition of Black Cotton Soil: Mineralogy of black cotton soil clay is majorly, montmorrilonite, illite and kaolinite. Its chemically, categorized by high concentrations of silica, lime, iron, magnesia, alumina and also contains calcium carbonate in the form of kankars, as well as iron oxide and organic matter. The clay fraction is particularly rich in silica, sometimes up to 60-70%, with iron and alumina making up the remainder. Montmorrilonite is the predominant mineral (are hydrous silicates of aluminium and magnesium) of black cotton soils mainly responsible of swelling and shrinkage behaviour. Engineering Properties of Black Cotton Soil The Engineering properties of black cotton soil are permeability, plasticity, compaction, compressibility and shear strength. High Plasticity: is the property of a soil which allows it to be deformed rapidly, without elastic reflection, without volume change, thus Back Cotton soil has high plasticity due to the presence of high clay content. Low Permeability: is a porous material which permits the passage or seepage of water through its interconnecting voids. black cotton soil has low permeability, which makes it difficult for water to penetrate and drain through the soil. Compaction: compaction is a process by which the soil particles artificially rearrange and packed together into a closer state of contact by mechanical means in order to decrease the porosity of the soil and thus increase its dry density. Low Bearing Capacity: the soil has poor bearing capacity, making it unsuitable for the construction of foundations withstand suitable intervention High Compressibility: the property of soil mass pertaining to its susceptibility to decrease in volume under pressure in which black cotton soil is highly compressible, making it easy to settle. Low Shear Strength: is the resistance to deformation by continuous shear displacement of soil particles or on masses upon the action of a shear stress where black cotton soil has low shear strength, making it susceptible to angled failure and instability. Shrink-swell Behaviour: the soil swell and shrink are a major concern for engineers. Its expands when wet and shrinks when dry, causing cracking and instability in structures foundations. This exerts significant uplift pressure, and the shrinkage can lead to cracks in slabs and walls.

Index Properties of Black Cotton Soil properties are not of primary interest to the geotechnical engineering, but are symbolic of the engineering properties. Index properties of black cotton are characterized by high clay content, exhibits and influence its engineering behavior. These include high liquid limit, low plastic limit, and a significant plasticity index, leading to high swelling and shrinkage potential. The soil is typically classified as clay of high plasticity (CH). Liquid limit: is the minimum water content at which the soil is still in liquid state but has a small strength against flowing which can be measured range from 50%-60% and 82.6%. Plastic limit: is minimum water content at which soil will just begin to crumble water rolled into a thread approximately 3mm in diameter, its plastic limit is typically ranging from 30-40% and recommended value of 29%. Plasticity index determine by LL-PL. The shrinkage limit: is the minimum water content at which a soil mass will still be in a saturated condition and will not reduce in volume if continue to dry. Plasticity Index: the plasticity index, which is the difference between the liquid and plastic limits, falls within the range of 30%-35% and 53.4%. Bearing Capacity The California Bearing Ratio (CBR) test is often used to assess the strength and bearing capacity of black cotton soil for engineering designs. This a type of clay soil that is known for its high shrink-swell potential. This means it expands and contracts significantly with changes in moisture content, which can be problematic for construction. Black cotton soil's swelling and shrinkage characteristics significantly impact its bearing capacity. When wet, it swells and loses strength, while drying causes it to shrink and crack, further reducing its ability to support loads. Stabilization techniques are often used to improve the CBR value of black cotton soil. This can involve adding materials like lime, cement, or fly ash to the soil, or by using other methods like geotextiles or reinforcement techniques. CBR values for black cotton soil, study found that the original CBR of black cotton soil was 1.31%, and after stabilization its ranges from 1.97% up to 6.18 % according to the research records. Black cotton soil has a high plasticity index, meaning it is easily moulded and deformed, further reducing its bearing capacity. Compaction can improve the bearing capacity of black cotton soil, but it's important to note that it can also lead to excessive swelling and shrinkage if moisture levels change significantly. Structures built on black cotton soil require specialized foundation designs to accommodate the soil's swelling and shrinkage behaviors and avoiding structural damage. (IJSR,2013)

Specific Mitigation Measures Internationally General Sight The search for mitigations of black cotton soil problematics, (B. Vinod, et al 2016) said, these soils passed high strength in summer and decreased rapidly in winter. The soil has a swelling property due to the presence of montmorillonite mineral. Though various constructions techniques are utilized, the cracking (Minor Cracking) is seen in the buildings. For the site investigations, the behaviour of soil is important. (B. Vinod, et al., 2016) An attempt was made for improvement of the properties of black cotton soil by Ahmad Muhammad with his associate, by blended with ordinary Portland cement (OPC) and bone ash (BA) for soil stabilization. and the determination of the optimum quantity that could be used as road construction material at minimal cost. Therefore, recommended that a 50% replacement of cement by the bone ash can be made to achieve a desired material for sub-base pavement construction at a reduced cost. (MAT Journals, 2019). Owing to such soil of poor shear strength and high swelling & shrinkage, has been acknowledged widely. Kavish S. et al, 2014 ….a great diversity of ground improvement techniques such as soil stabilization and reinforcement are employed to improve mechanical behaviour of soil, thereby enhancing the reliability of construction. Stabilization occurs when lime is added to black cotton soil and a pozzolanic reaction takes place. The hydrated lime reacts with the clay particles and permanently transforms them into a strong cementation's matrix. Black cotton soil showing low to medium swelling potential from Rajkot Gujarat was used for determining the basic properties of the soil. (Miss K S. et al 2014) The black cotton soils are considered "problematic" according to Gidigasu S. et al, the black cotton soils around the world and the geomechanically challenges they pose to structures founded on them, we need to understand the peculiar characteristics and behaviours to enable effective utilization of these soils for engineering purposes. The first step "there is a need to assemble, correlate and integrate useful information on the genesis, nature and distribution as well as some basic geotechnical characteristics of the black cotton soils useful for civil engineering purposes scattered in various journal papers, proceedings of conferences, symposia, workshops, etc". Secondly, "there is also the need to add value to existing knowledge in terms of technical information relating to geology and geomechanics of the black cotton soils occurring in Ghana through laboratory and field studies. The paper attempts to review the literature on the state of the art. The review relates to the raw soils and has not discussed improvement and stabilisation aspects". (Gidigasu S. S. R et al 2013) (Kochi, 2022) supplement that, "Working on reinforcing black cotton soil to check its ability to serve as subgrade material but enhancement of drainage characteristics of black cotton soil requires more attention''. (IGC, 2022)

(joy. Jyothi, 2024) Assessment "One of the most significant challenges that geotechnical engineers encounter is building any form of foundation over weak or soft soil. Because high-rise buildings could suffer severe damage, it is imperative to enhance the load bearing capacity of black cotton soils by addition of layered stone Dust.'' SVSNDL Prasanna E3S Web of Conferences (04002ICSTCE, page 559). (Terzaghi, 1951) view on, the Influence of Modern Soil Studies on the Design and Construction of foundations commented on foundations as "foundations can appropriately be described as a necessary evil. If a building is to be constructed on an outcrop of sound rock, no foundation is required. Hence, in contrast to the building itself, which satisfies specific needs, appeals to the aesthetic sense, and fills its matters with pride, the foundations merely serve as a remedy for the deficiencies of whatever whimsical nature has provided for the support of the structure at the site which has been selected. On account of the fact that there is no glory attached to the foundations, and that the sources of success or failures are hidden deep in the ground, building foundations have always been treated as step children; and their acts of revenge for the lack of attention can be very embarrassing''. (Fulzele et al, 2016) describe, "civil Engineering aspects Black cotton soil is very troublesome and problematic and hazardous due to its characteristics. Because of its high swelling and shrinkage characteristics, the black cotton soil has been a challenge to the Engineers. The black cotton soil is very hard when dry but loses its strength completely when in wet condition''. International Journal of Advances in Science Engineering and Technology Vol-4. (Arun Paul, 2020), Among the clayey soil the black cotton soil is considered as the most problematic as it has tendency to swell and shrink due to seasonal moisture variation. In India about one-fifth of the area is covered by expansive soil. The soil behaves like a soft soil under wet/saturated condition. As a result of wetting and drying process, vertical movement takes place in the soil mass leading to failure of structure, in the form of settlement, heavy depression, cracking and unevenness.

Other type of clay which is considered problematic is dispersive clay. These are mostly found as alluvial clays in the form of slow wash, lake bed deposits and are easily erodible. They are not generally identified by standard laboratory tests such as index, grain size analysis etc. It is therefore concluded that nearly are types of soils may pose problem depending on different combination of working conditions and therefore may need improvement. The soil properties related to strength, settlement, drainage etc. need to be tailored to suit the situation in the field. A wide range of soil improvement techniques are available which may be suitable to a particular type of soil or working condition. Determination of bearing capacity of black cotton soil reinforced with granular pile using plaxis. (ACNT, 1984), Foundation movements are a major cause of distress to established buildings. The main cause of such movements in Australia is the swelling and shrinking of expansive clays resulting from soil moisture changes. There are two aspects to this problem. Firstly, buildings must be managed in a manner that reduces the possibility of damage. Secondly, if foundation movements do occur, the damage should be repaired and measure taken to stabilize the footing system.

To achieve these aims, a sound knowledge of foundation behaviour is required. For example, unless the cause of the distress is clearly identified and appropriate remedial measures selected, there is a danger of further failure.

This report is concerned mostly with the damage that may be caused to existing buildings by movements of expansive clays resulting from soil moisture changes. However, in order to give this particular problem its proper perspective, some discussion of other forms of foundation behaviour is appropriate. In order to discuss soil moisture changes, it is necessary to introduce the following basic technical concepts: Soil moisture content. The moisture content of soil is defined as the ratio of the weights of soil moisture and dry soil, expressed as a percentage. The significance of this moisture content value depends upon the type of clay. For example, at 25% moisture content, one clay may seem dry but another clay may be in a very moist state. Soil suction. A more useful concept is that of soil suction, which is a measure of the internal stress caused by the small amounts of water at the particle-to-particle interfaces. The common unit of suction is the P_F unit. Generally, soil suctions can vary from P_F =2.5 to P_F =5 under natural climatic conditions. High suction values are associated with dry soils and low suctions with wet soils. Over the normal range of suctions, moisture content is approximately linearly proportional to suction for a particular soil suctions are commonly determined from measurements of the relative humidity of the air within the soil. Generally, good temperature control is necessary for reliable readings and measurements of suction are conducted in a laboratory rather than on site. Damage to Buildings on Clay Soil, Technical Bulletin 5.1 Mustapha Mohammed Alhajia and Musa Alhassan; Black cotton soil is one of those problematic clay soils found in many parts of the world. Large deposits of black cotton soil exist in the north-eastern part of Nigeria and also have the problem of causing serious damages to road pavement structures and light building structures founded on them. These soils cannot also be borrowed for use in any component of road pavement structure or fill of any sort because of their soft and swelling characteristics. A lot of researches have been carried out to evaluate the swelling characteristics of clays including black cotton soil. Other similar researches attempted to correlate swelling characteristics with consistency limits to ease the process of evaluating swelling properties and reduce the time required to conduct the real swelling tests.

In order to avert these damages, a lot of research has been conducted to modify or stabilize black cotton soil using various additives to improve its swelling-shrinkage characteristics, physical, and geotechnical properties. Free Swelling and Modulus of Elasticity of Compacted Black Cotton Soil Treated with Reclaimed Asphalt Pavement, The Egyptian International Journal of Engineering Sciences and Technology, (P 60–61, Vol. 25 2018). (Guru, et al, 2020), Black cotton soil is highly expansive in nature when gets in contact with water, thus making it unsuitable for construction. The unsuitability of black cotton soil can be changed by making the soil water repellent and exhibiting high bond strength. This can be achieved by application of Terrasil and Zycobond (A Zydex product) when added to soil mixed with water. It improves the bond strength between the soil particles and creates a protective layer by permanently changing the soil properties. It increases the California Bearing ratio of the soil mass exponentially over a period of time thus, making it suitable for infrastructure projects and high chances to be used as non-expansive BC soil in infrastructure development. The structures on black cotton soil bases develop undulations at the road surface due to loss of strength of the sub-grade through softening during monsoon. The physical properties of black cotton soil vary from place to place, 40 % to 60% of the BC soil has particle size less than 0.001 mm. At the liquid limit, the volume change is of the order of 200 % to 300% and results in swelling pressure as high as 8 kg/cm2 to 10 kg/cm2[1]. laboratory soaked CBR values of black cotton soils are generally found in the range of 2 to 4%. Due to very low CBR values of black cotton soil excessive pavement thickness is required for designing flexible pavement. Research & Development (R&D) efforts have been made to improve the strength characteristics of black cotton soil with new technologies. Black Cotton Soil in Highway Construction, (Helix, 2020)

(Cyrus, et al, 2022); In areas covered by black cotton soils, the constructions and performance of roads have been found by several researchers such Ola (1978) to possess a major problem. The reason being that in Black Cotton soils, the predominant Black Cotton mineral in the Black Cotton fraction is montmorillonite. This causes the soil to pose a high-volume change with fluctuation in moisture content severe cracking when dry and high swelling potential with low bearing value when wet. Building on unstable black cotton soil presents significant challenges for engineering projects. This type of soil, known for its susceptibility to uneven settling, low strength, and compressibility, poses a considerable risk to infrastructure like roads. In nations like Ethiopia, where transportation is crucial for progress, this is a particularly pressing issue. A large portion of Ethiopia's landscape is composed of expansive soil, and many existing and planned roads and railways traverse these areas. Roads built on this soil often fail prematurely, sometimes within months of completion. For example, in 2004, the Addis Ababa City Roads Authority spent a substantial amount, approximately 300 million Ethiopian Birr, on road construction and upkeep, with over 30 million Birr allocated to routine maintenance, highlighting the scale of the problem. Furthermore, roads in tropical and subtropical regions experience unique deterioration patterns compared to those in temperate climates. This is due to factors such as severe weather, inadequate design and quality control, heavy traffic, and insufficient assessment of damage causes before repairs are undertaken.

Evaluation of Distress on Ethiopian Roadways

Fig 2.2 Slippage crack Swelling- upward displacement of a pavement Sag in asphalt pavement Expansive soils are clayey soils, mudstones or shales that are characterized by their potential for volume change on drying and/or wetting. Usually, the clay content is relatively high and the clay mineral montmorillonite dominates. They are characterized by their high strength when dry; very low strength when wet; wide and deep shrinkage cracks in the dry season; high plasticity and very poor traffic ability when welled. Whenever insufficient attention is given to the deleterious properties of expansive soils, the results will be premature pavement failure evidenced by undulations, cracks, potholes and heave. The fact that expansive soils are a major engineering problem makes their study an important research aspect due to the accruing cost involved in terms of economic loss when construction is undertaken without due consideration to the probability of their presence. Like in Ethiopia, the destructive effects caused by these soils have been reported in many countries around the world, including USA, Australia, South Africa, India, Canada, Israel, Sudan, and China, but are generally most serious in arid and semiarid regions. Life time, performance and environmental compatibility of lightweight engineering infrastructures are detrimentally influenced (in terms of time, and money both at the construction and maintenance stages). The effects on buildings constructed on reactive soils with inadequate footings can be dramatic. Road subgrades can be viewed as the footings/ foundations for road pavements, and if these footings are not adequate, structural damage can occur. Cracking of foundations, walls, driveways, swimming pools, and roads costs millions of dollars each year in repairs. For example, Ethiopian Roads Authority (ERA) was forced to decrease the maximum speed limits below the original design speeds at many localities for instance on the main road connecting Addis Ababa and Jimma town.

Black cotton soils are very difficult to use for building because of their low strength and propensity for significant volume fluctuations. To lower the possibility of shrink-swell, expansive soil is often replaced with non-expansive material. The entire layer may be eliminated if the expanding soil or stratum is thin. Nevertheless, the soil or layers are frequently excessively deep, rendering this process economically inefficient. Controlling the swelling potential of clayey soil is one of the most difficult difficulties that foundation engineers confront because swelling stresses on the foundation cause catastrophic damage to structures. The swelling can be monitored by adding various components including stone dust, cement, and fly ash. Assessment of Engineering Characteristics for Black Cotton Soil with Addition of Layered Stone Dust. (ICSTCE, 2024). (Kavish, et al, 2014) also write that; The expansive soils occur all over the world. India has large tracks of expansive soil known as Black Cotton soil (BC soil), covering an area of

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0.8 million square kilometre, which is about 20% of total land area. The major areas of their occurrence are states of Maharashtra, Gujarat, southern parts of Uttar Pradesh, eastern parts of Madhya Pradesh, parts of Andhra Pradesh and Karnataka. This type of soil is available up to a depth of 3.7 meters on an average in the above parts of India. Expansive soils occurring above water table undergo volumetric changes with change in moisture content. Increase in water content causes the swelling of the soils and loss of strength and decrease in moisture content brings about soil shrinkage. Swelling and shrinkage of expansive soil cause differential settlements resulting in severe damage to the foundations, buildings, roads, retaining structures, canal linings, etc. The construction of foundation for structure on black cotton soils poses a challenge to the civil engineers.

(Gaikwad, et al, 2024) statement; In the construction industry, black cotton soil is a troublesome soil because of its expansive nature and shrink-swell behaviour. This tendency causes cracking and differential settling in buildings and roads, which can be problematic. Stabilizing black cotton soil is necessary to improve its engineering properties and suitability. Construction on expansive soils, such as highways and railways, faces difficulties and suitable materials may not be readily available. Increases in strength and durability, as well as reductions in consistency limitations and shrinking-swelling behaviour, are all essential components of the expansion of expansive soils. With their susceptibility to moisture-induced volume fluctuations, expansive soils provide issues in the field of geotechnical applications and civil engineering. Improving Shear Strength and Microstructural Behaviour of Black Cotton Soil Treated with Construction Demolished Waste (Gaikwad, et al 2024) (Yohanna, et al, 2021) stated; Black cotton soil is known to expand, swell or shrink in excess when there is variation in amount of moisture (Ola 1983). When civil infrastructures are built with or on these soils, it experiences the shrinkage or swell property depending on the level of stress it is exposed to. It is therefore quite tasking to carry out design and construction involving the use of this soil due to its un-usual behaviour. Black cotton soil in Nigeria is estimated to cover an area of about 104,000 km2, usually with little or no amount of organic content in the soil, and its black colouration is probably due to titanium or iron (Jha and Sinha, 1993). Osinubi (1995) reported that in regions where black cotton soil are located, most deposits have been found to cover large expanse areas that by-passing or avoiding them is not always feasible. Experimental and Statistical Study on Black Cotton Soil Modified with Cement–Iron Ore Tailings (FUOYEJET, 2021) (Ingabire, 2023); black cotton soil expansive soil found in several regions, including India, Australia, South-West of the United States, South Africa, and Israel. This soil is also found in semi-arid tropical regions where evaporation exceeds precipitation. Black cotton soil is not suitable for building houses or roads due to its construction difficulties. Black cotton soil, commonly found in tropical and subtropical regions, is one such problematic soil that presents a challenge in construction due to its high plasticity and low strength. These characteristics make it unsuitable for use in various engineering projects, as it is prone to deformations and settlements. This has prompted many studies to look for ways to improve the soil's subgrade by stabilizing it and enhancing its engineering properties. The failure of some buildings in the Adamawa state of Nigeria has been attributed to the shrink swell behaviour of black cotton soil, causing differential settlement and resulting in cracks in the walls and foundation. Enhancement of Engineering Properties of Black Cotton Soil Using rice husk and sawdust ash. (ICMED-ICMPC, 2023) (Argu, 2017); Subgrade soils are essential components of any pavement structures. The long-term performance of any construction project depends on the soundness of the underlying soils. Unstable soils can create significant problems for pavements or structures. In order to avoid most of the problems that has been appearing on the upper layer of any pavement it is better to treat the subgrade soil. Soil that are highly susceptible to volume and strength changes can cause severe roughness and accelerate the deterioration of the pavement structure in the form of increased cracking and decreased riding quality in combined with truck traffic. Subgrade soils are an essential component of pavement structures, and poor performance of subgrade soil is the cause of pavement failures.

Most of the subgrade material of the city of Addis Ababa is heavy clay and silty clay in nature; and a substantial area of the city subsoil is being occupied by black cotton soil. Black cotton and clay soils have higher plasticity index, swelling and shrinkage characteristics by these they have lower load bearing capacity and stiffness. These soils are not at all useful for any kind of road construction work, otherwise needs treatment. The application of stabilizers in a subgrade soil will result in increased the load bearing capacity or strength, stiffness, improve durability, reduce plasticity of the soil, reduce the swelling potential of the soil, facilitate compaction process, reduce the overlying pavement thickness and enhance long term structural stability. Subgrade Soil Stabilization Practice of AACRA. (Hussain, 2019); Construction on expansive clay is the most critical problem faced by the civil engineers due to the volume change either in the presence or in the absence of moisture. In the same way, soils which have high clay content tend to swell when their moisture content is allowed to increase. In civil engineering works most problems occur when the sub-structure is found to be expansive clay. The low strength is the most critical situation of construction on expansive soil and this may also lead to poor construction of buildings over those soils, the tendency to enhance their volume when they come in contact with moisture and to shrink if moisture is eradicated from them. Those soils which possess more clay particles have the behavior of swelling when their moisture content is allowed to increase (Neeladharan et al., 2018). Volume change behaviours in swelling type of soils presence or absence of moisture are the origin of a lot of troubles in structures such as bridges, roads, building etc.; which are being constructed over those soils (Patel et al., 2015). Clay has the property of low strength and high compressibility. Many of the clayey soils are very sensitive, in the sense that their strength is reduced by mechanical disturbance. The problematic expansive clay material used for road and building construction needs its properties to be improved (stabilized) to avoid failure. The idea of soil replacement with good engineering properties by cut and fill is highly expensive and time consuming (Thomas et al 2016). Stabilization of expansive soil using sodium hydroxide. (Hussain, 2019).

(Babu, et al, 2016); All construction should rest on the soil. So, the soil bearing capacity plays a vital role in constructions. All soils will not have good strength and bearing capacity. So, there is a need to increase the soil strength and bearing capacity. The black cotton soils pose many problems in construction. So, in this present work, the black soil collected from chintakommadinne mandal has been stabilized by using sand and cement. All the black soils are not expansive soils and all the expansive soils are not black in colour. These soils passed high strength in summer and decreased rapidly in winter. The soil has a swelling property due to the presence of montmorillonite mineral. Blackcotton soils which has high expansive characteristics. These soils are low shrinkage limit and with high optimum moisture content. It is highly sensitive to moisture changes. Stabilization of Black Cotton Soil with Sand and Cement as A Subgrade Pavement, (IJET, 2016) (Ameratunga, et al, 2006) Soft clays are very different to other weak geomaterials such as loose sands that require ground improvement. Soft clays and ground improvement have become major geotechnical challenges in civil engineering during the last three decades. Not only civil engineers, but planners, architects, consultants, and contractors are now aware of the behaviour of soft clays and the risks associated with developments in such areas. Soft clays are encountered in many large cities, including coastal regions and reclaimed lands. They occur naturally in the geological process of transportation and deposition or due to man-made activities such as reclamation. There are two main concerns related to soft clays, viz., strength and compressibility. Such materials could lead to excessive settlements and instability under development loads if not properly designed. Soft clay is a term that could be misleading. In general, the term is associated with the consistency when describing a clay. The classification of clays is generally based on the undrained shear strength, C_u, and this is what is adopted by almost all Standards (e.g. Canadian Geotechnical Society 2006). Soft Clay Engineering and Ground Improvement. (Reddy, et al, 2023); Swelling behaviour is the prime hindrance for effective utilization of expansive soils as a geomaterial. To alleviate such behaviour, stabilization with a suitable additive is essential. However, the current practice of additive and stabilization selection technique to treat the expansive soils predominantly relies on geotechnical properties, in particular on consistency limits. Expansive soils have continued to attract the attention of the research fraternity for their inherent ability to undergo significant volume change due to drying and wetting cycles (Shahsavani et al. 2020). When lightweight and earthen structures such as single storey buildings, tunnels, buried pipelines, roads, embankments, etc., are built on/in these soils, they might experience non-uniform or differential settlements, eventually undergoing failure (Chen 1975; Uzundurukan et al. 2014; Sharma and Sivapullaiah 2016). Expansive soils are spread almost all over the world. Understanding the Role of Ca 2+, Na+ on Swelling Behaviour of Natural Expansive Soils: A field Application Perspective.

Black cotton soil, known for its expansive nature, presents significant challenges due to its pronounced swelling and shrinking characteristics. This soil is exceptionally hard when dry but becomes highly unstable when wet, leading to surface cracking upon drying. These expansive soils experience substantial volume changes with moisture fluctuations, causing considerable damage to infrastructure like canals, roads, buildings, and other structures built on or with this soil type. The stabilization of black cotton soil using fly ash has been explored (Muawia et al., 2012). In semi-arid regions, the behavior of expansive soils is a major concern for geotechnical engineers. Understanding the range and variations in soil properties is crucial for effective design. Saudi Arabia, a semi-arid region, has been a focal point for research and engineering efforts over the past three decades due to rapid urbanization. The country is significantly impacted by issues related to expansive soils, situated within a climate zone where high summer temperatures dry out subsurface soils, creating dry to semi-dry conditions near the surface (RRJEES, 2012).

In the heart of the bustling city, a small café offered a tranquil escape from the chaos outside. The hum of conversations blended with the soothing notes of a jazz melody playing softly in the background. Patrons sipped their lattes and cappuccinos, savoring the rich, aromatic flavors. The barista, with practiced ease, crafted intricate designs on the foam of each cup, adding a personal touch to every order. Outside, the city moved at a frenetic pace, but within the café's cozy walls, time seemed to slow down. It was a haven for writers, artists, and dreamers, a place where inspiration flowed as freely as the coffee. Fig 2.3 Typical boundary wall crack-Tabuk (Al Rowda) Deserted two storey building-Tabuk (Al Masif) (Thang, 2021); Expansive soil is regarded as a kind of problematic soil that has a low bearing capacity and excessive volume change (shrinkage or swelling) under climate change or changes of ambient moisture. These characteristics are seen as pivotal factors that pose a threat to the foundations of civil structures, such as pavements, highways, light buildings, and canal linings and beds. Hence, it has a necessity of reducing the shrinkage-swelling potential of expansive soil and enhancing its strength so that the improvement can minimise adverse impacts of soil. Characterisation of Expansive Soils Treated with Hydrated Lime, Bottom Ash and Bagasse As (El-Waheda, et al, 2022); However, most of the soil in these cities is problematic. This type of soils, which may pose engineering challenges when uncovered beneath pavements or foundations, have sparked worldwide interest in recent years. New Sohag city highways' sub-grade soils are found in expansive soils like shale, clay-stone, mudstone, or Nile deposits like silt and clay. These expansive soils cause a variety of issues, including road uplift, especially when they come into touch with water, which causes a rise in volume, producing pavement uplift. These expansive soils must be improved using different enhancing materials such as lime, fly ash, cement dust, or polymer to avoid these difficulties. Dust shield polymer was employed as a stabilized agent in stabilized sub-grade soil of local roads in New Sohag city to improve the swelling of expansive soils. Enhancement of Polymer on Road Problematic Soil Stabilization, (SEJ, 2022). (LINDH, et al, 2022); Safety, stability and geotechnical performance of civil constructions (roads, building foundations or railways) are highly dependent on properties of soil, such as strength, permeability, compactness, porosity and resistance to traffic load and climate effects (e.g., freeze-thaw cycles, temperature extremes). Therefore, improving the physiochemical and mechanical parameters of soil is aimed to increase its bearing capacity, which has a crucial importance in industrial engineering. Improving mechanical and geotechnical properties of soils is possible by stabilization methods, which are used to increase the Uniaxial Compressive Strength (UCS), bearing capacity, stability and resistance to deformation from traffic. Impact of Strength-enhancing Admixtures on Stabilization of Expansive Soil by Addition of Alternative Binders.

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Black cotton soils, rich in clay minerals, have a unique relationship with water, as described by Deshmukh et al. (2024). These soils readily absorb water, causing them to swell significantly. This expansion can exert considerable force, potentially damaging buildings and other structures. Conversely, when the soil dries, it shrinks, which can also lead to structural problems, even causing collapses or the formation of cracks in the ground. These fissures then facilitate water penetration during rainfall or runoff, exacerbating the cycle of swelling and shrinking, which repeatedly stresses the soil. The high water retention capacity of these soils is due to the small size of the clay particles and the presence of specific ions. Briaud et al. (2013) discuss various methods for predicting this shrink-swell behavior. These include the potential vertical rise (PVR) method (McDowell, 1956), the suction method, and the water content method. The PVR method involves collecting soil samples, determining their water content and Atterberg limits, and using established charts to estimate the maximum vertical movement possible, assuming prolonged water saturation.

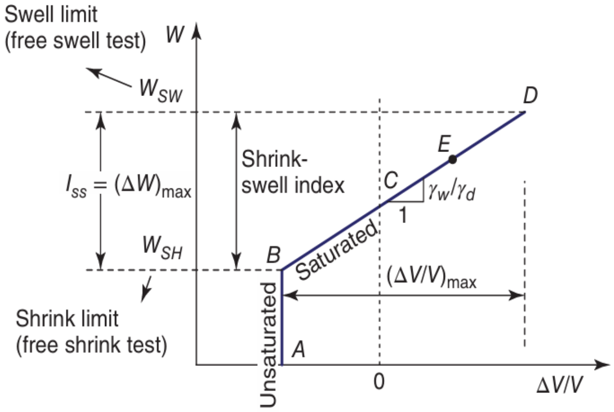

Fig 2.4 Water content vs. relative volume change. The suction method (Lytton, 1994) relates the settlement the log of the water tension. Lytton includes the settlement due to the change in mechanical stress in addition to the movement due to the change in water tension and proposes the following equation. Geotechnical Engineering: Unsaturated and Saturated Soils, Second Edition (V.N.S Murthy) Swelling soils, which are clayey soils, are also called expansive soils. When these soils are partially saturated, they increase in volume with the addition of water. They shrink greatly on drying and develop cracks on the surface. These soils possess a high plasticity index. Black cotton soils found in many parts of India belong to this category. Their colour varies from dark grey to black. It is easy to recognize these soils in the field during either dry or wet seasons. Shrinkage cracks are visible on the ground surface during dry seasons. The maximum width of these cracks may be up to 20 mm or more and they travel deep into the ground. A lump of dry black cotton soil requires a hammer to break. During rainy seasons, these soils become very sticky and very difficult to traverse. The depths of these soils in some regions may be up to 6 m or more. Normally the water table is met at great depths in these regions. As such the soils become wet only during rainy seasons and are dry or partially saturated during the dry seasons. In regions which have well-defined, alternately wet and dry seasons, these soils swell and shrink in regular cycles. Since moisture change in the soils bring about severe movements of the mass, any structure built on such soil experiences recurring cracking and progressive damage. Principles and practices of Soil Mechanistic and Foundation Engineering. (Moles, et al 2006). To dig trenches to build the foundation will allow the water to penetrate faster (between the existing soil and the substructure) to the base of the foundation. As a consequence, the soil between 90 and 100 cm beneath the base of the foundation will be subject to expansion and shrinkage movement

SPECIFIC, ESPECIAL FOR NETHERLANDS

Black cotton characteristics make it unsuitable for engineering projects, as it is prone to deformations and settlements as a result of being soft under wet/saturation condition. It is a well-known fact that water is the worst enemy of all structures, particularly in black cotton soil areas. Therefore, let look at the experience of Netherlands in controlling flooding which has clearly an excellent reputation in water management, flood safety and land reclamation, building on eight centuries of knowledge and experience. We are countries that need to look at the experience of Netherlands for our future. Prevention and mitigation of flooding in Upper Nile States is at the heart of our water policy, and our thorough approach to pay off. The Netherlands Flooding Strategies: How the Netherlands manages water risks and the level of risk considered has significant bearing on the financial, ecological and social sustainability of the system then and the future. The Delta Programme: The Delta Programme is a national planning instrument that aims to achieve two priority goals for a country "safe now and in the future": protect the Netherlands against flooding and ensure freshwater supply. (Mao, et al, 2020). This feat was largely possible through poldering, a process that involves progressively reclaiming land, building dykes to hold back seawater, or draining wetlands through windmills or other technological means to keep low-lying lands inhabitable and usable for agriculture. (OECD 2014), The idea that "the dykes make up the state" has long shaped Dutch water policy, and managing water affairs remains essentially a core public activity. This is in part due to the highly specific challenge of maintaining water levels at desired levels in extensive reclaimed areas. However, private enterprise has a role in actually implementing many water management activities, such as dredging and the construction of dykes, pumping stations and wastewater treatment plants. Water Governance in the Netherlands: Fit for the Future, OECD Studies on Water, OECD Publishing. (Slomp, et al, 2016) In 1958 the flood risk standards for coastal areas were formally laid down in law (Deltawet,1958) after a cost benefit analysis [van Dantzig, 1956] for the largest population centre of the Netherlands protected by a single continuous line of flood defences. This is the largest part of the urban circular agglomeration called the Randstad. Amsterdam, Leiden, Delft, The Hague, Rotterdam and the new western part of the city of Utrecht (Leidsche Rijn) are included in this flood prone area, another name for the area is dyke's ring. A dyke's ring has a continuous line of flood defences consisting of dunes, structures and dikes. Implementing risk-based flood defence standards. (Stive, et al, 2011). The Delta committee introduced a concept of plausible high-end sea-level rise scenarios, thereby testing the feasibility of maintaining the defence strategy of the 53 dyke rings, which turned out positive both in technical and in economic terms.

(Hiltrud Pötz, 2014). Building with Multiple storeys and skylights (vertical evacuation) In polders where water can remain for a long time after a flood due to a break in the dike, making sure that buildings have multiple storeys and skylights is useful for purposes of vertical evacuation. Roads become impassable and dangerous, causing horizontal evacuation to be difficult. Multi-level safety: water resilient urban and building design (Verwof, 2017). Protective hydraulic structures are installed to safeguard another function that intersects the flood defence. They include such structures as locks (IJmuiden) and storm surge barriers (Nieuwe Waterweg, Hollandsche IJssel) for shipping, pumping stations (Katwijk), sluices (Haringvliet) and storm surge barriers (Eastern Scheldt) to provide drainage, and cuts (Lobith) for traffic. Research methodology This research methodology outlines a descriptive qualitative study designed to assess the impact of black cotton soil on various structures in Bor Town, including buildings, roads, and local huts. The study's primary objective is to understand the consequences of this soil type on structural integrity, foundation stability, and overall performance. A target population of 24 individuals was identified in Bor Town, comprising practicing civil engineers, builders, technicians, and residents (especially those living in flood-prone areas or buildings constructed on black cotton soil). A purposive sampling technique was employed to ensure diverse representation across occupations, dividing the sample into ten residents, five builders, five technicians, and four civil engineers to mitigate bias and achieve a comprehensive understanding. Data collection was primarily conducted through structured interview questionnaires, which were developed to gather qualitative insights. These questions focused on participants' knowledge and awareness of black cotton soil properties, their past experiences with affected buildings (including observed structural damage and overall impact), the specific effects of flooding on the environment and structures, and current mitigation strategies, particularly foundation techniques used in the area. Interviews were conducted in person at construction sites and relevant institutions in Bor Town, with notes taken and recordings made with interviewee consent. A robust follow-up procedure was implemented to encourage participation and achieve a target sample size of 19-24 respondents, aligning with the Taro Yamane formula for sample size estimation.

The findings reveal that shallow foundations, such as strip and mat foundations for lightweight buildings, have significantly improved effects of black cotton on buildings, whereas considering measures of ground improvement at the site in controlling flooding/water. These findings suggest that the adoption of these foundation techniques, materials and floods mitigation can significantly enhance structural efficiency and sustainability in the construction industry. In essence, the summary to the results and findings section serves as a concise yet impactful summary of the study's key outcomes, highlighting their significance and contribution to the field of construction research. The findings from this research provided valued insights into the challenges posed by black cotton soil and floodings on buildings, as well as effective practices for mitigating these impacts. The outcomes subsidize to improved construction practices and inform stakeholders about possible risks related with black cotton soil. Such as Strip foundations with stabilization of BC soil by replacement the top soil and blending with stabilizers such as sand and marram on foundation depth below the active zone of swelling and shrinking, to prevent damage. Ground improvement by backfilling and paving the site around buildings with marram, sand mix compacted in layers enhance the runoff. Building houses with Expanded Polystyrene (EPS) core Panel system in areas of BC soil. EPS is new technology recommended with its strength and durability - used extruded polystyrene virtually inert and does not absorb moisture, is durable and resistant to decay. Local house hut common materials used for huts in Bor particularly Jonglei state might comprise of, reeds, Tek, and Leng (Dink Language) as poles for structural elements poles and roofs. Foundation with burnt bricks good at drainage and powder acts as a stabilizer Some of factors are inadequate design or construction, unanticipated loads, deterioration of materials, compressibility of the supporting soils, landscaping practices, leaking plumbing, and slope instability, but most thought-provoking in the area is effect of black cotton soil.

Presentation and Interpretation of Data

Fig 5.1 A dyke that was overtaken by Nile River waters in Bor. Waterlogged: Flooding reduced bearing capacity of black cotton soils. When dry, its strong but lose their strength when saturated. Waterlogging can weaken the soil's bearing capacity and increase the risk of foundation failure making them unsuitable for supporting structures, especially in flood zones. Soil Swelling: Black cotton soil is acknowledged for its expansive nature. When it absorbs water during flooding, it tends to swell, increasing in volume. This Impact on Buildings leading to ground heave and settlement, causing structural damage, cracking in walls and foundations, and even potential collapse in many cases.Increased Saturation: Flooding causes the soil to become saturated, leading to an increased risk of hydraulic conductivity issues, the drainage becomes very slow. Saturated soil can lead to shallow foundations instability due to hydrostatic pressure on foundation walls can also increase, potentially leading to structural failure. Erosion soil: Floodwater can cause soil erosion, especially on slopes or near stream beds. This impact on Buildings, leading to settling or tilting of buildings. Over time, erosion can significantly challenge the structural integrity of buildings. Drainage Issues: Black cotton soil has poor drainage properties, meaning it retains water for longer periods. Poor drainage aggravates the effects of flooding, increasing the duration of water sitting around or under the structure, leading to prolonged periods of risk for flooding-related damage.

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Figure 5.2 showing one of the affected schools by flood in Bor Town

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Fig 6.1 Current safety standards by dyke ring area Source: Muralt wall near the Oosterlandpolder, 2008 (Image Bank Rijkswaterstaat, photo Jan van den Broeke) The Netherlands initiated approximately 40 infrastructure projects along rivers and waterways. The objective of this project was to ease flooding by giving waterways space to move and flood naturally,34 through excavating and deepening existing floodplains, moving dikes farther back from river. These infrastructures projects are along rivers and sea are Hydraulic structures and multi-storey buildings. (Amersfoort, 2014) Multi-storey Buildings: 'Buildings can be realized at a raised level. They can be positioned on piles on raised ground, such as traditional dwelling mounds. Alternatively, the ground floor can be designed to fulfill a function such as storage space or garage, using the water-resistant construction methods described above. After a flood, and once it has been cleaned, the ground level is ready for use once more. Using raised construction methods on piles, space becomes available at the ground level for other, less vulnerable or temporary functions, such as parking or storage. Where buildings are realized on a raised area (a dwelling mound or dyke), the raised area might be part of the flood protection. In the Netherlands, it is currently not permitted to build on top of floodwalls. However, it is permitted to realise a raised area against a floodwall or dyke''. Multi-level safety: water resilient urban and building design (STOWA)

Fig 6.2 The Netherlands Multi-storey Buildings along water bodies.

Fig 6.3 Apartments on stilts, Hoek van Holland by Herman de Kovel

Protective hydraulic structures are designed to serve multiple functions that overlap with flood defense systems. These include locks, such as those at IJmuiden, and storm surge barriers like those at Nieuwe Waterweg and Hollandsche IJssel, which facilitate shipping. Additionally, there are pumping stations in Katwijk, sluices at Haringvliet, and storm surge barriers in the Eastern Scheldt that aid in drainage, as well as cuts at Lobith for traffic management. To ensure these various functions can operate effectively, hydraulic structures typically incorporate one or more movable closure mechanisms. When these mechanisms are engaged, they transfer the forces acting upon them to the more rigid components of the structure. For instance, the storm surge barrier in the Eastern Scheldt not only protects the land behind it but also permits tidal movements to continue.

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Figure 6.4 illustrates the hydraulic structures in the Netherlands situated along various water bodies, specifically highlighting the Algerakering storm surge barrier in Krimpen aan den Ijssel. Analyzing the Netherlands' experiences with hydraulic engineering and multi-story construction is crucial for addressing the flood protection and water management challenges faced in Bor Town and throughout Jonglei State. The Netherlands' distinct geographical and demographic characteristics require a strategic blend of strong hydraulic systems and the efficient utilization of space through high-rise buildings to create a safe, sustainable, and livable environment. This approach can be adapted for the low-lying regions of South Sudan, serving both flood mitigation and developmental needs. Given the potential for investment, it would be beneficial to attract investors to undertake significant projects along the River Nile. The increasing demand for housing in densely populated urban areas further fuels the need for multi-story developments.

CONCLUSION

Research offers crucial insights into constructing buildings on black cotton soil in Bor Town, aiming to address the specific problems this soil type presents. The study's outcomes will help establish superior building methods and educate stakeholders about the potential hazards linked to black cotton soil. A key recommendation is the use of raft/mat foundations for multi-story buildings. This approach ensures sufficient safety against base failure and minimizes settlement, thereby enhancing structural integrity. The research highlights the significant impact of black cotton soil on buildings in Bor Town, revealing a high prevalence rate that warrants serious public attention, particularly in the Upper Nile regions of South Sudan. The soil's expansive properties, coupled with frequent flooding, create considerable challenges for building stability. Flooding intensifies these issues by saturating the soil, leading to increased swelling and weakening of structures. The persistent flooding, caused by heavy rainfall and the overflow of the River Nile in this low-lying area, further complicates construction efforts. In essence, the study underscores the urgent need for effective mitigation strategies to manage the soil and flooding in the region. Implementing these measures is essential to prevent water accumulation and stabilize the soil, which is critical for the safety and durability of buildings in these areas.

Recommendations: There is need to adopt the construction practices of strip foundation for low -rise buildings and Mat for midrise buildings and applying waterproof paint in substructure to prevent effect of moisture. There is need to adopt use of Expanded Polystyrene (EPS) core panel system is a modern technology, efficient, light weight, environmentally friendly and economic construction system for the construction of buildings. (GEM-24, 2017) The Geotechnical Engineering Bureau (GEB) provides earthwork and foundation engineering services for the design and construction of Departmental projects statewide. When subsurface explorations reveal that a project's underlying soils are soft or unstable, the GEB may utilize specialized treatment options to allow completion of the desired final product. Expanded Polystyrene Fill (EPS) is one such option. It is a lightweight fill used to reduce vertical stresses beneath embankments, or to reduce lateral stresses on retaining walls, abutments or foundations. EPS has been used in highway construction in Europe since the early 1970's and was first used in New York in 1996. Advantages to using EPS include: EPS has a density that is less than 1% of typical soil fills. By using this extremely lightweight material in an embankment section over a deep, soft organic or clay soil deposit, significant time and cost savings may be achieved as compared to other foundation stabilization and settlement mitigation techniques. When properly designed as backfill, EPS blocks exert little to no lateral load on retaining structures. Geotechnical Engineering Manual: Guidelines for design and construction of expanded polystyrene fill as a lightweight soil replacement. Adopting the use of Damp Proof Course (DPC) is a critical component of any construction project, offering a wide range of benefits for both residential and commercial buildings. For protecting against moisture damage to ensuring a healthy indoor environment and promoting energy efficiency, DPC plays a vital role in preserving the structural integrity and longevity of buildings. The local hut needs a deep excavation of poles footing to strata level using some good variety locally named by Dinka language as Reeds, Teak and Leng are highly recommended as strong and durable from decay. There is need to applied bitumen paint and treatment of anti-termite. Therefore, there is need for government to have body constituted for both flooding and construction practices in the regions of black cotton soil and flooding. The best example for Netherlands can be adopted. The Netherlands, Delta Programme for managing flooding. This project consist of varies department in different part of Netherlands, as flood defence strategies by constructing 54 ring dykes preventing flood. This can be an ideal solution for Bor Town and other cities of Upper Nile Region. The region faced significant challenges related to flooding due to its low-lying geography. The county must have committee for managing the effects of flooding by developing a strategy for creating ring - dykes, as an experience of Netherlands approach of water management.

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Excavation and Earthwork: Excavation depth should be carried out below the active zone, usually1.5 to 2.0 meters below the natural ground surface and the excavated soil should be properly managed to prevent moisture damage and carried away to avoid others issues. Backfilling with stable materials like gravel, redbrick dust and hardcore is recommended to avoid further issues with the foundation. Excavation before the rainy season, as the zone beneath the foundation may be affected by the soil's expansion/ shrinkage and considering using moisture barriers and protective layers like gravel or sand to prevent direct contact between the soil and foundation walls during rainy seasons. Strategic Recommendations by others Countries Experience There are many different methods used to deal with black cotton soil. Options include removal of the black cotton soil during grading operations, soil stabilization, deep foundation systems, and post tensioned slab-on-grade foundations. In countries such as the United States, Australia, South Africa, Thailand, and India, they have adopted Posttensioned slab on grade foundations, for both residential and commercial buildings. It is particularly recommended in regions with black cotton soils. There can be many different types of posttensioned designs. In Texas and Louisiana, the early posttensioned foundations consisted of a uniform thickness slab with stiffening beams in both directions, which became known as the ribbed foundation.

Soil Treatment or Stabilization: There are many different soil treatment or stabilization methods that are used in practice across the world. It depends on advantages and disadvantages of each method. Some of the more commonly used methods are as follows: Removal and replacement: During the grading of a project, it may be possible to remove the expansive soil and replace it with non-expansive or less expansive soil.

Surcharge loading: This method basically consists of applying sufficient pressure to the expansive soil in order to reduce the amount of swell. Remolding and compaction: This method is also commonly known as compaction control. This process is based on the observation that by compacting a clay at a water content that is wet of the optimum moisture content, the initial percent swell will be less than for the same soil compacted dry of optimum (Holtz and Gibbs, 1956b; Holtz, 1959). Thus, by compacting a clay wet of optimum, the swell potential of the soil will be reduced and Barriers. Horizontal and vertical barriers can be constructed around the perimeter of the foundation in order to reduce the potential for cyclic heave and shrinkage.

Deep Foundations: such as pier and grade beam support. The basic principle is to construct the piers such that they are below the depth of seasonal moisture change. The piers can be belled at the bottom in order to increase their uplift resistance. Grade beams and structural floor systems, that are free of the ground, are supported by the piers. These are some of methods adopted internationally with countries experiencing effects of black cotton soil. They analyse their advantages and disadvantages of each method. In the Netherlands, it mainly flood/water management which is the main factor for black cotton soil characteristics. The Netherlands have a long history of managing water and protecting their land from flooding, they initiate projects like the Afsluitdijk and the Maeslant Barrier, as well as the extensive Delta Works. These engineering feats demonstrate the Netherlands' commitment to flood protection and their proactive approach to managing water resources. The area is protected by system of dikes, dunes and other water defences. The Netherlands flood defence system is divided into 53 dykes ring areas, each with its own safety standards and designated water authority responsible for its management. As we mentioned early, the areas of Upper Nile region are low-lying area I would advise to adopt the Netherlands flood defences mechanism that will also lead to our infrastructure’s development in Bor Town and entirely region.

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