INFLUENCE OF CLIMATE CHANGE ON SOIL SHEAR STRENGTH

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Abstract - *Climate change has introduced significant variations in temperature, rainfall intensity, and groundwater levels, which directly influence soil behaviour. Among the various geotechnical properties, the shear strength of soil plays a critical role in determining the soil bearing capacity. This study focuses on analysing the effects of climate-induced factors—such as increased precipitation, extreme drought conditions, and rising temperatures—on the shear strength and overall bearing capacity of soil. Laboratory testing methods, supported by field data and literature review, are used to evaluate changes in cohesion, internal friction angle, and soil suction under different climatic scenarios. The results indicate that higher moisture content and groundwater rise generally reduce shear strength, while temperature-related drying cycles may lead to cracking and loss of structural stability. The study highlights the need to incorporate climate- responsive soil behaviour in future foundation design and geotechnical engineering practice.*

***Key Words*: Soil, Shear strength, Climate change, Moisture content, Effective stress**

1. INTRODUCTION

Soil shear strength is a key parameter controlling the stability of foundations and earth structures. Traditional design assumes soil properties remain constant, but climate change causes variations in rainfall, temperature, and groundwater levels that alter soil behavior. Excess rainfall increases pore water pressure and reduces effective stress, leading to lower shear strength and higher failure risk. Drought conditions cause shrinkage and cracking in cohesive soils, further reducing strength. Repeated wetting–drying cycles also weaken soil structure over time. Therefore, climate-resilient geotechnical design—such as proper drainage, groundwater control, and soil stabilization—is essential to maintain long-term foundation stability.

1.1 Shear Strength of Soil and the Influence of Climate Change

Soil shear strength is a critical parameter in geotechnical engineering that determines the ability of soil to support structural stresses without failure, excessive settlement, or instability. Conventional foundation design relies on soil properties obtained from field and laboratory investigationsconducted under relatively stable environmental conditions, were parameters such as cohesion, angle of internal friction, and moisture content are assumed to remain constant over time. However, climate change has introduced significant variability in environmental conditions, including changes in rainfall patterns, temperature fluctuations, and groundwater levels, which directly affect soil behavior and shear strength.

1.2 Effect of Climate Change–Induced Soil Moisture Variations on Shear Strength and Stability

Climate change–induced variations in soil moisture content play a major role in altering soil strength and stability. Increased rainfall can lead to soil saturation, raising pore water pressure and reducing effective stress, which ultimately decreases shear strength and may cause settlement or failure. Conversely, prolonged dry periods result in shrinkage, cracking, and structural degradation of soils, particularly in clays, leading to differential settlement and reduced stress-bearing capacity. Repeated wetting– drying cycles further weaken soil fabric, making foundations more vulnerable to instability under changing climatic conditions.

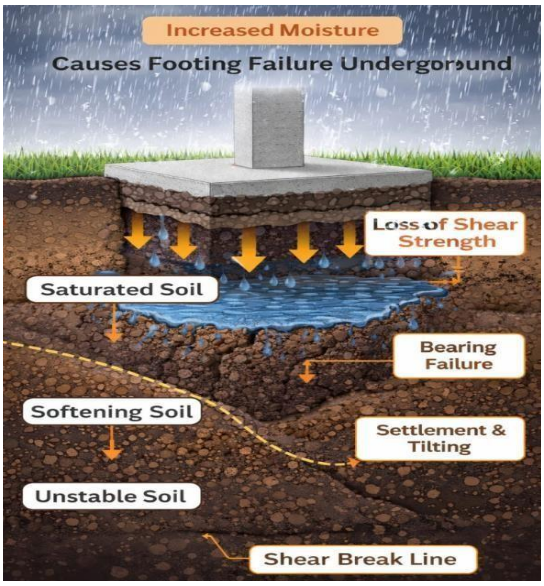


Figure 1. Shear failure of footing due to change in moisture

1.3 Need to Incorporate Climate Change Effects in Geotechnical Design

Given the growing impact of climate change on soil behavior, it is essential to incorporate these effects into geotechnical design practices. Traditional approaches based on constant soil properties are no longer sufficient, and engineers must adopt climate-resilient strategies that consider long-term variability in moisture, temperature, and groundwater conditions. This includes the use of improved drainage systems, soil stabilization techniques, enhanced site investigation methods, and adaptive safety factors to ensure the stability, durability, and reliability of structures throughout their service life.

2. AIM AND OBJECTIVES

1. To examine the impact of climate change on Shear strength of the soil.
2. To compare the shear strength behavior of Black Cotton Soil and Medium Stiff Soil.
3. To determine the physical properties of soil.

3. LITERATURE REVIEW

Bo Wang et al. (2025) has investigated the shear behavior of frozen soil–structure interfaces using high-pressure direct shear tests under varying normal stresses and freeze–thaw conditions. The study found that higher normal stress increases peak shear strength, while higher thawing temperatures reduce interfacial bonding and shear resistance, shifting behavior from strain-softening to strain- hardening.

Ming Lu et al. (2024) has investigated the nanoscale shear behavior of kaolinite clay using molecular dynamics simulations. The study found that the presence of water films interparticle significantly friction (up reduces to 98%), changing soil behavior from brittle to ductile. Wettability and water content strongly influence shear resistance and clay failure mechanisms.

Joris Eekhout et al. (2022) has conducted a global review of soil erosion models and found that climate change is likely to increase soil erosion, especially in semi-arid regions. However, land management practices such as reforestation and soil conservation can effectively reduce these impacts.

Sudeshna Mondal et al. (2021) has reviewed the effects of climate change on soil fertility and properties. Rising temperatures and changing rainfall patterns were found to alter soil structure, organic matter, and moisture conditions, potentially leading to long-term soil degradation if not properly managed.

Maurizio Barbieri et al. (2021) has emphasized that climate change, land use, and human activities are major factors affecting groundwater and surface water quality. The studyhighlights increasing problems such as chemical pollution, eutrophication, and microbial contamination. It also stresses the need for more research, long-term monitoring, and better groundwater management to address climate change impacts.

4. SYSTEM DEVELOPMENT

The present study involves a systematic experimental investigation of the physical, index, and shear strength properties of two commonly encountered soils—Black Cotton Soil and Medium Stiff Soil—selected due to their contrasting engineering behavior, particularly in terms of moisture sensitivity, strength variation, and volume change characteristics. Black cotton soil, known for its expansive nature and shrink–swell behavior, poses significant challenges for foundation stability, whereas medium stiff soil exhibits relatively moderate compressibility and better stress- bearing characteristics. Disturbed soil samples were carefully collected from identified locations, processed to remove impurities, and prepared under controlled laboratory conditions. All experimental procedures were conducted in accordance with IS 2720 standards to ensure reliability and consistency of results.

A comprehensive laboratory testing program was carried out, including determination of moisture content by (oven drying method), in-situ density (core cutter method), specific gravity (pycnometer method), and shear strength (direct shear test). The evaluated properties included moisture content, bulk and dry density, void ratio, porosity, degree of saturation, and shear strength parameters under varying moisture conditions and normal stresses. The results indicate that Black Cotton Soil has lower moisture content and higher dry density compared to Medium Stiff Soil, while both soils exhibit significant variation in shear strength with changes in moisture. These findings provide a detailed understanding of soil behavior and form the basis for analyzing the influence of environmental factors, particularly climate-induced moisture variations, on soil stability and foundation performance.

5. RESULTS AND DISCUSSION

5.1 Black cotton soil

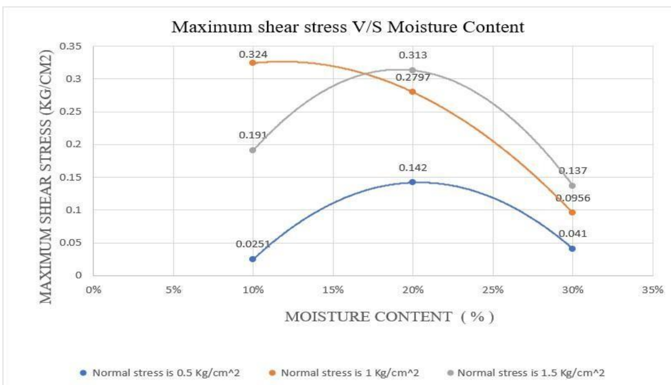
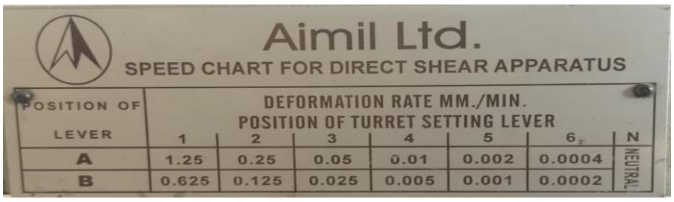


Chart 1: Maximum shear stress v/s Moisture content tested on 1st gear of Direct shear test apparatus

The graph indicates that the shear strength of Black Cotton Soil varies significantly with moisture content under different normal stresses. For all stressings, shear stress increases with water content and reaches a maximum at about 20% moisture content. The peak shear strength increases as the normal stress increases from 0.5 kg /cm^2 to

1.5 kg/cm^2. Beyond the optimum moisture content, shear strength decreases due to excess water and loss of soil interlocking. Overall, Black Cotton Soil shows maximum shear strength near optimum moisture content, and higher normal stresses result in higher shear strength.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SPEED CHART FOR DIRECT SHEAR APPARATUS

POSITION OF LEVER	DEFORMATION RATE MM./MIN. POSITION OF TURRET SETTING LEVER						
	1	2	3	4	5	6	N
A	1.25	0.25	0.05	0.01	0.002	0.0004	NEUTRAL
B	0.625	0.125	0.025	0.005	0.001	0.0002	

Figure 2. Speed Chart for Direct Shear Test Apparatus

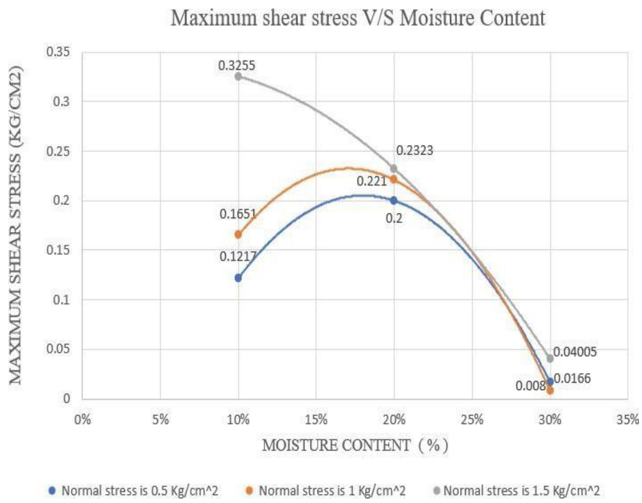

Chart 2. Maximum shear stress v/s Moisture content tested on 2nd gear of Direct shear test apparatus

The graph shows that the shear strength of Black Cotton Soil increases with moisture content up to an optimum value of about 18–20% for all normal stresses. The maximum shear stress increases as the normal stress increases from 0.5 kg/cm² to 1.5 kg/cm². Beyond the optimum moisture content, shear strength decreases sharply due to excess water and reduced soil friction. Overall, Black Cotton Soil exhibits maximum shear strength near its optimum moisture content, and higher normal stresses result in higher shear strength.

5.2 Medium stiff soil

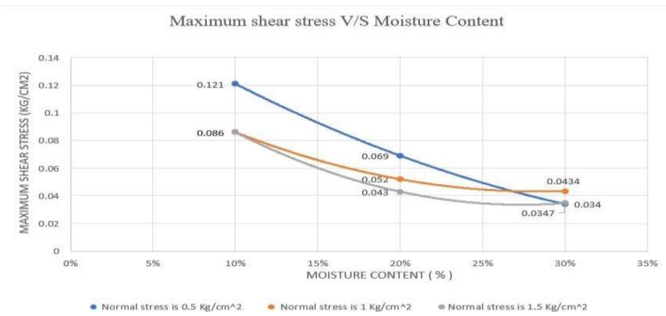

Chart 3 Maximum shear stress v/s Moisture content tested on 1st gear of Direct shear test apparatus

The graph indicates that for medium stiff soil, shear strength decreases with increase in moisture content for all normal stresses. Higher shear stress is observed at lower moisture content, and it reduces steadily as moisture increases due to loss of interparticle friction. Shear strength increases with increase in normal stress, but moisture content has a dominant weakening effect. Overall, medium stiff soil shows better shear strength under drier conditions.

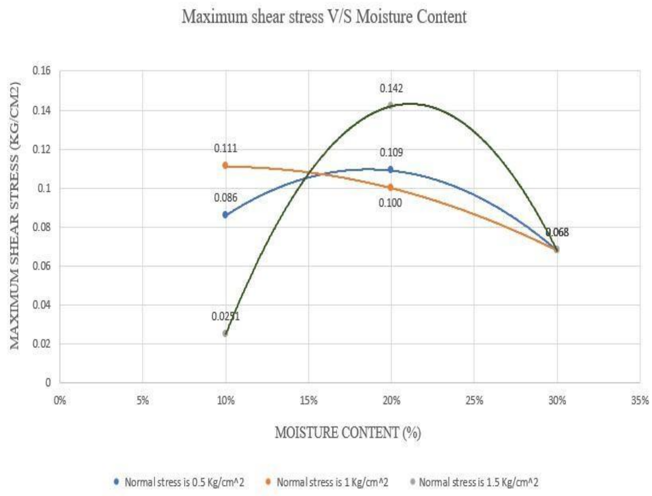

Chart 4 Maximum shear stress v/s Moisture content tested on 2nd gear of Direct shear test apparatus

The graph shows that for medium stiff soil; shear strength increases with moisture content up to an optimum value of about 20% for all normal stresses. The maximum shear stress increases as the normal stress increases from 0.5 kg/cm^2 to 1.5 kg/cm^2. Beyond the optimum moisture content, shear strength decreases due to excess water reducing soil friction. Overall, medium stiff soil exhibits maximum shear strength near its optimum moisture content under higher normal stresses.

4. CONCLUSIONS

The results and graphs show how the shear strength of soil changes with both Moisture content and Normal stress. In case of Black cotton soil, shear strength first increases with moisture content and then decreases after a certain limit. Higher normal stress generally gives higher shear stress. In case of Medium stiff soil, shear strength gradually decreases when moisture content increases. Therefore, soil is strongest at an optimum moisture level, and too much water reduces its strength.

REFERENCES

1. **Bo Wang et al.**, Direct shear testing of frozen soil– structure interface under high normal stress and frozen–thawing conditions, Soils and Foundations, Volume 65, 2025, Article No. 101660, pp. 1–7.
2. **Ming Lu et al.**, Nanoscale shear behavior of hydrated kaolinite: Effects of water content and surface wettability, Applied Clay Science, Volume 65, 2024, Article No. 106087, pp. 2843–2854.
3. **Joris Eekhout et al.**, Global impact of climate change on soil erosion and potential for adaptation through soil conversation, Earth-Science Reviews, Volume 226, 2022, Article No. 103921, pp. 01–12.
4. **Sudeshna Mondal et al.**, Impact of Climate Change on Soil Fertility, Journal of Soil Science, Vol. 63 , 2021, pp. 551–569.
5. **Maurizio Barbieri et al.**, Climate change and its effect on ground water quality, Environmental Geochemistry and Health, Vol. 45, 2021, pp. 1133–1144.

BIOGRAPHIES

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