

Foundation of Building

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Abstract

Recent trends in civil engineering underscore the importance of designing foundations that can withstand varying load conditions and environmental challenges. Selecting the appropriate foundation depth is critical for stability, particularly under intense loads. In regions with high rainfall, understanding maximum precipitation levels and water infiltration is vital. Water penetration into the soil can significantly reduce its load-bearing capacity, with saturation potentially lowering it by up to 50%. Foundations must also resist the forces exerted by standing water and water flow, ensuring protection against soil erosion, which is essential for maintaining foundation integrity. Clay soils, with poor drainage properties, are generally unsuitable for foundation use. Frequent rainfall can turn clay into mud, greatly reducing its ability to support structures. This results in reduced strength, making it vulnerable to water-induced forces and erosion, which destabilizes foundations. In response, modern engineering approaches are increasingly focusing on soil stabilization methods and alternative foundation solutions in water-susceptible areas, aiming to create more resilient and durable infrastructure as climate conditions become increasingly variable.

Keywords: Penetration of water, Saturated condition of soil, Reduced bearing capacity of soil, Thrust of water, environmental challenges, water flow

INTRODUCTION

In modern civil engineering, the challenge of constructing stable foundations in areas with high water tables has become increasingly critical due to urban expansion, climate change, and the frequent occurrence of extreme weather events. Elevated water tables, often exacerbated by heavy rainfall and flooding, can significantly affect the mechanical properties of soils. Soils saturated by groundwater lose much of their load-bearing capacity, primarily due to increased pore water pressure, which reduces the frictional strength between particles. This weakening of the soil structure can lead to issues such as settlement, uplift, and even foundation failure if not adequately addressed [1].

As urban areas continue to expand into flood-prone and coastal regions, and with the intensification of rainfall events driven by climate change, engineers are tasked with developing innovative foundation design strategies that ensure stability in such challenging environments. Recent trends in civil engineering have shifted towards resilient infrastructure, focusing on mitigating the effects of water infiltration on soil-structure interaction. Advanced geotechnical investigations, along with innovations in materials science, are transforming the way foundations are designed and built to cope with saturated conditions [2-3].

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Key recent developments include:

- Smart drainage systems that utilize real-time data and sensors to monitor water levels and prevent soil saturation by effectively managing groundwater and surface water.
- The adoption of deep foundation techniques, such as drilled shafts and helical piles, that can bypass weak saturated soils and transfer loads to deeper, more stable layers.

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- Geosynthetic materials, which provide enhanced soil reinforcement and erosion control, have emerged as essential tools for managing water-related issues in foundation engineering.
 - The use of ground improvement technologies like soil stabilization and grouting techniques, which increase the strength and stability of soils subjected to high moisture content.

Furthermore, the integration of Building Information Modeling (BIM) and geotechnical monitoring systems allows for better prediction of how foundations will perform under fluctuating water table conditions, enabling proactive design modifications [5-7].

This paper will examine the effects of high water tables on foundation performance and discuss recent technological advancements and design methodologies aimed at improving foundation stability in saturated environments. By incorporating these trends, engineers can ensure that modern structures remain safe, durable, and resilient in areas with elevated water tables, aligning with the global movement toward sustainable and adaptive infrastructure.

Managing Foundation Stability in High Water Table Conditions

In civil engineering, the presence of a high water table above foundation level poses a significant challenge to ensuring the stability and performance of foundations. When soil becomes saturated due to elevated groundwater levels, its load-bearing capacity can be reduced by as much as 50%, depending on the soil type and saturation level. This decrease in strength is primarily attributed to the rise in pore water pressure within the soil matrix, which weakens the interparticle forces and reduces the soil's frictional resistance. Consequently, the stability of the foundation can be compromised, leading to settlement or, in severe cases, structural failure [8].

To mitigate the effects of soil saturation, it is crucial to ensure that the soil can resist the uplift pressures caused by water overburden. Uplift pressure occurs when the hydrostatic force exerted by the saturated soil exceeds the downward pressure of the structure, potentially causing upward movement or flotation of the foundation. This is especially critical in regions prone to heavy rainfall or areas where the natural water table is consistently high. Failure to address these uplift forces can lead to instability and compromise the structural integrity of buildings or infrastructure [9].

To address these challenges, engineers must conduct a thorough geotechnical assessment to understand the soil properties in saturated conditions. Several design strategies are commonly employed to counteract the effects of a high water table:

- **Drainage systems** such as sump pumps or French drains are often installed to manage water levels around the foundation and reduce soil saturation. These systems help divert water away from the foundation, preventing the build-up of hydrostatic pressure.[10]
- In cases where soil conditions are less favorable, **deeper foundation systems** like pile foundations may be required. Piles can transfer the structural load to more stable, unsaturated soil layers or rock strata, effectively bypassing the weaker, saturated topsoil.
- **Waterproofing techniques** are also employed to protect the foundation from water infiltration. This can include the application of waterproof membranes, sealants, or coatings that prevent water from penetrating the foundation structure [11].
- **Foundation reinforcement** using materials such as concrete or steel can increase the load-bearing capacity of the foundation, ensuring that it can withstand both the vertical and uplift forces in saturated conditions [12].

An in-depth understanding of the interaction between soil and water under high water table conditions is crucial for modern civil engineering practices. In areas where groundwater is a concern, engineers must carefully evaluate how water infiltration affects the mechanical behavior of the soil and apply the appropriate foundation design techniques. By incorporating these measures, structures can maintain their stability and durability, even in challenging environments characterized by fluctuating water tables or heavy rainfall [13].

METHODOLOGY

Site Selection and Soil Examination

This study was conducted at a construction site characterized by significant water table fluctuations and frequent, intense rainfall patterns, with an annual average precipitation of approximately 400 mm. The selection of the site was based on the following factors:

- High rainfall frequency and intensity, which poses a challenge for maintaining soil stability and managing surface and subsurface water flow [14].
- Presence of clayey soils, which are particularly vulnerable to saturation due to their low permeability and high water retention capacity. These soils often exhibit plastic behavior under wet conditions, further complicating structural stability.
- Existing water penetration patterns, observed during initial site surveys, indicated that the soil was prone to high water infiltration during and after rainfall events.

Soil samples were collected at multiple locations across the site, with depths extending to 1.5 meters. A range of geotechnical tests were performed to comprehensively understand the soil's behavior under saturated conditions:

- Particle size distribution tests provided detailed information about the soil's texture, revealing a significant proportion of fine-grained materials (clay and silt).
- Moisture content analysis helped identify the initial saturation levels of the soil before controlled experiments were conducted.
- Atterberg limits and plasticity index measurements were used to evaluate how the soil's plasticity varied with changes in moisture, which is critical for understanding deformation under load.
- Density and compaction tests were carried out to determine the specific gravity of soil particles and the maximum density achievable under optimal moisture content, which is essential for assessing how much the soil can bear under compacted conditions.

Load Application and Foundation Design

The design of the foundation was based on simulating a realistic structural load of 120 tons, corresponding to a typical column load in medium-sized buildings. The foundation was designed using standard civil engineering principles, considering factors such as soil bearing capacity, safety margins, and the effects of local soil conditions under both dry and saturated states. Key design parameters included:

- A square pad foundation, chosen for its ability to evenly distribute the load over a wider surface area, which helps mitigate the effects of soil saturation.
- Varying foundation depths were tested to explore the impact of soil saturation at different levels, ranging from shallow to deep foundations. This approach allowed for a comparative analysis of soil strength and stability at various depths under different saturation scenarios.

Rain Simulation and Water Penetration

To replicate real-world conditions, a controlled rainfall simulation was conducted, applying 400 mm of rainfall over a specified experimental period. The water penetration depth was calculated using the empirical formula:

$$\text{Water Penetration Depth} = 3 \times \text{Rainfall Depth}$$

This estimation resulted in a penetration depth of approximately 1.2 meters, where the topsoil became fully saturated. To accurately monitor the behavior of water infiltration, a combination of:

- Moisture sensors, strategically placed at multiple depths, provided continuous data on saturation levels.
- Water table gauges were employed to track changes in groundwater levels throughout the experiment, offering insights into how quickly the water table rose in response to simulated rainfall.

The data collected during this simulation were essential for understanding the dynamic interaction between surface water, soil saturation, and the load-bearing capacity of the foundation.

Soil Bearing Capacity Testing

At the point where the soil was determined to be fully saturated (1.2 meters depth), the soil's bearing capacity was rigorously tested. This phase of the study involved both field and laboratory tests:

- Plate load tests were conducted on-site to observe the settlement of the foundation under the applied load. This test provides a direct measure of how much the soil compresses or settles when subjected to structural loads.
- Shear strength tests, conducted in a laboratory setting, were used to assess the reduction in soil strength due to increased pore water pressure. These tests are crucial in quantifying how much load the soil can bear before it fails under saturated conditions.

The reduction in soil bearing capacity was calculated using the following relation:

$$\text{Saturated Bearing Capacity} = 12 \times \text{Dry Bearing Capacity} \quad \text{Saturated Bearing Capacity} = \frac{1}{2} \times \text{Dry Bearing Capacity} \quad \text{Saturated Bearing Capacity} = 21 \times \text{Dry Bearing Capacity}$$

This accounts for the significant decrease in strength due to the presence of water, which reduces the effective stress in the soil.

Uplift Pressure Analysis

One of the primary concerns in saturated soil conditions is the potential for uplift pressure, which occurs when the buoyant force exerted by water on the foundation exceeds the downward force from the structure's load. This phenomenon can cause structural instability, particularly in areas with high water tables. Uplift pressure was calculated using the following formula:

$$\text{Uplift Pressure} = \text{Water Density} \times \text{Water Depth} \quad \text{Uplift Pressure} = \text{Water Density} \times \text{Water Depth}$$

The foundation was analyzed to ensure it could withstand the upward pressure exerted by the overburden of water, particularly during periods of heavy rainfall or high groundwater levels.

Scouring and Erosion Control

Scouring, or the removal of soil around the foundation due to water flow, poses another threat to the stability of structures built in areas prone to water saturation. To mitigate the risk of scouring, the following measures were implemented:

- Soil compaction techniques were employed to reduce the permeability of the soil and improve its overall stability. Well-compacted soils resist water infiltration more effectively and are less prone to scouring.
- Drainage systems were designed and installed around the foundation to direct excess water away from the site, thereby reducing the potential for erosion.
- Geosynthetics were incorporated into the foundation design to reinforce the soil and provide additional erosion protection. Geosynthetics help stabilize the soil, making it more resistant to the mechanical forces exerted by moving water.

Data Analysis

Statistical tools were used to analyze the data collected during both dry and saturated conditions. The primary objectives of this analysis were to:

- Quantify the specific reduction in soil strength under saturated conditions, with a focus on how pore water pressure affects load-bearing capacity.
- Evaluate the settlement behavior of the foundation under different levels of soil saturation, identifying thresholds beyond which significant settlement occurs.

- Assess the effectiveness of various scouring and erosion control measures, determining which techniques provided the most robust protection against water-induced soil degradation.

RESULTS & DISCUSSION

In this study, a column load of 120 tons was applied to the foundation of a structure located in an area prone to frequent rainfall. The rainfall simulation resulted in a water penetration depth of 1.2 meters, leading to significant soil saturation. As expected, saturation of the soil caused a marked reduction in its bearing capacity, which was reduced by approximately 50%. This reduction is consistent with findings in geotechnical literature, highlighting the critical need for careful foundation design in waterlogged environments.

The data from the field load tests demonstrated that shallow foundations were more susceptible to settlement under saturated conditions, while deeper foundations provided greater stability due to the presence of unsaturated soil layers at lower depths. This underscores the importance of foundation depth in regions with fluctuating water tables.

The study also confirmed that drainage systems, when properly designed, can effectively manage water levels around the foundation, reducing the degree of soil saturation and the associated risks of uplift pressure and erosion. The use of geosynthetics proved to be particularly beneficial for enhancing soil stability and preventing erosion.

In conclusion, understanding the behavior of saturated soils and designing foundations to account for water infiltration are essential in modern civil engineering, especially in regions with high rainfall or elevated water tables.

- $Q = (\text{Bearing Capacity})$

$$= 1.85 \times 1.2 \times \left(\frac{1 + \sin 30^\circ}{1 - \sin 30^\circ} \right)^2$$

↓
 Unit wt. of soil in dry state
 $= 1.85 \times 1.2 \times 9 \Rightarrow 20 \text{ t/m}^2$

- In saturated condition of soil bearing capacity is reduced by 50% i.e. available bearing capacity of soil = 10 t/m².
- For this much reduction bearing capacity of soil settlement occurs.
- Amount of settlement

Penetration depth

$$= 1 \text{ Kg/cm}^2 \times 1.2 \times 100 \times \frac{3.62}{100}$$

↓
 10 t/m^2

$\Rightarrow 43 \text{ mm} \approx 40 \text{ mm}$ (Permissible value of settlement of sandy soil)

- For reduction of 10t/m² bearing capacity of soil we have to provide more depth of foundation.
- More depth of foundation needed

$$= \frac{10}{1.85} \times 0.111 \Rightarrow 0.6 \text{ meter}$$

more depth of foundation is needed.

- Foundation depth should be such that footing should be on dry soil below penetration depth.
- If 2.5 m x 2.5 m base area of foundation taken.
- Load at foundation base = $120 + \frac{10 \times 120}{100} = 132t$
- Bearing capacity of soil needed = $\frac{132}{2.5 \times 2.5} \Rightarrow 21.12 \text{ t/m}^2$ bearing capacity of soil needed.
- We take 25 t/m² bearing capacity of soil.
- Since there is reduction in bearing capacity of soil due to penetration of water.
- Hence we stabilize the soil by mixing 1part sandy soil & + 2 parts gravel soil.
- Bearing capacity of soil (Improved) = $\frac{20 + 2 \times 44}{2} = 54 \text{ t/m}^2$
- In saturated state its strength 27 t/m² (50% reduced)
- We need 21.12 t/m² bearing capacity & after reduction in bearing capacity it is 27 t/m².
- Hence OK.
- Thrust of water = 1.2 t/m² (Since penetration depth = 1.2 m)
- If velocity of flow = 10 m/sec.
- Thrust of water = $\frac{1000 \times (10)^2}{19.62} = 5.1 \text{ t/m}^2$

$$\left(\frac{wv^2}{2g} \right)$$

- Hence total thrust of water = 6.3 t/m² < 27 t/m² bearing capacity of soil hence .K.
- Load at base of footing (lateral)
- 0.217 x 132 \Rightarrow 29 t
- Bearing strength of to take this lateral load dry soil at base 54 x 2.5 x 0.176 depth of foundation
base = 25 t < 29 t. Width of foundation

Not Safe

Soil load at foundation base

$$\frac{1320000}{2.5 \times 1000 \times t} = 3 \text{ Tensile strength of M30}$$

$$7500 \text{ t} = 1320000$$

$$t = 176 \text{ mm}$$

Thickness of foundation base

- Provide width of foundation 3m & depth of foundation 200 m.
- Strength of soil at base = 54 x 3 x 0.2 \Rightarrow 32.4 t > 29 t

Hence Safe.

- Hence foundation base size 3m x 3 m taken & depth of foundation base = 200 mm taken.

- Depth of foundation needed $D_f = \frac{21.12}{1.85} \times \left(\frac{1 - \sin\phi}{1 + \sin\phi} \right)^2$
Load intensity
 $\phi = 30$
= 1.30 meter.

- Lateral load action at middle height of column.

Column height

- $0.217 \times 120 \Rightarrow 26 \text{ t}$ acting at $\frac{3.5}{2}$
- Overturning moment at base = $26 \times \frac{3.5}{2} \Rightarrow 45.50 \text{ t-m}$
- Resolving moment given at base by depth of foundation

Strength

$$\begin{array}{c}
 \uparrow D_f \\
 27 \times 1.3 \times 0.6 \rightarrow \text{Width of column} \\
 \uparrow \\
 \text{Base bearing capacity of soil.} \\
 \Rightarrow 21.06 \text{ t} < 26 \text{ t}
 \end{array}$$

Hence depth of foundation = 1.8 m taken.
 $= 27 \times 1.8 \times 0.6 \Rightarrow 29.16 > 26 \text{ t}$

Hence O.K.

- Strength middle of soil acting at middle at depth of foundation

- $29.16 \times \frac{1.8}{2}$

$\Rightarrow 26.24 \text{ t-m} < 45.50 \text{ t-m}$

- Hence 3 m depth of foundation taken.
- Strength of soil = $27 \times 3 \times 0.6 \Rightarrow 49 \text{ t}$
- Resting moment $49 \times \frac{3}{2} \Rightarrow 73 \text{ t-m} > 45.50 \text{ t-m}$

Hence O.K.

- Bottom soil is in dry condition it can sustain the thrust of uplift pressure.

Hence O.K.

- 27 t/m^2 is bearing capacity of soil when whole depth of foundation is in saturated state (Due to water logging in soil)
- But in sandy soil drainage takes place water will percolate lowered bottom hence it will be in moist state.
- Since after stabilization of sandy soil by gravel strength, 1 part = sandy soil, 2 parts = gravel (1:2), $\frac{20 + 2 \times 4.9}{2} = 54 \text{ t/m}^2$
- In moist condition bearing capacity is lowered by 25% the bearing capacity of soil = $\frac{25 \times 54}{100} = 13.5 \text{ t/m}^2$ (Reduction in bearing capacity) Available bearing capacity of soil = $54 - 13.5 = 40.5 \text{ t/m}^2$

- If depth of foundation = 1.8 m & foundation base since 3m x 3 m taken & depth of foundation base = 200 mm
- Overturning moment at base due to lateral load acting at middle height of column.

- Overturning moment at base = 45.50 t-m.
- Restoring moment at base for depth of foundation = 1.8 m

$$40.5 \times 1.8 \times \frac{1.8}{2} \Rightarrow 65.61 \text{ t} - \text{m} > 45.50 \text{ t} - \text{m}$$

Hence safe.

CONCLUSION

In regions with frequent rainfall, where the top layer of soil is prone to saturation up to a depth of 1.2 meters, the bearing capacity of the soil is significantly reduced. The load-bearing capacity of the soil decreases by approximately 50%, demanding careful attention in foundation design. Solutions such as enhanced drainage, deeper foundations, and soil stabilization are critical to maintaining structural stability and ensuring the safety of the foundation under saturated conditions. Civil engineers must incorporate these strategies to mitigate the impact of frequent rainfall and soil saturation on foundation performance.

- For 120 t load acting on column.
- Depth of foundation = 1.8m.
- Foundation base size 3m x 3 m.
- Depth of foundation base = 200 mm.

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Appendix:

Notation:

- D_f = Depth of foundation in meter.
- γ = Unit weight of soil in t/m^2
- ϕ = Angle of rexxxxx in degree.