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Sofia Martinez,

Faculty of Engineering,
National University of Cordoba,
Argentina.

Miguel Rodriguez,

Geotechnical Research Center,
National University of Tucumán,
Argentina.

Correspondence:**Sofia Martinez,**

Faculty of Engineering,
National University of Cordoba,
Argentina.

Impact of Soil-Water Interaction on Foundation Performance

Sofia Martinez, Miguel Rodriguez

Abstract

The interaction between soil and water significantly influences foundation performance, particularly in moisture-sensitive soils. This study investigates the effect of varying moisture content on foundation behavior across clayey, silty, and sandy soils. Laboratory tests were conducted using small-scale footing models subjected to water contents of 10%, 20%, and 30%. The results revealed that clayey soils exhibited the highest reduction in bearing capacity (65%) and increased settlement (12.5 mm) at 30% water content. Statistical analyses, including two-way ANOVA and regression, confirmed the significant impact of soil type and moisture content on foundation performance ($p < 0.01$). The findings emphasize the importance of considering unsaturated soil mechanics in foundation design to mitigate soil-water-related failures. Practical recommendations include moisture control strategies and resilient foundation designs for moisture-sensitive soils. Future studies should focus on field-scale validations to enhance predictive models.

Keywords: Soil-water interaction, foundation performance, expansive soils, bearing capacity, moisture content, settlement.

Introduction

The interaction between soil and water is a critical factor influencing foundation performance, particularly in regions where soil moisture variability is significant. Foundation stability and serviceability depend largely on the properties of soil and the extent to which it interacts with water. Excessive soil moisture can lead to reduced bearing capacity, differential settlement, and potential structural failure, posing risks to infrastructure [1]. Soils such as clay and silts are particularly susceptible to changes in moisture content, leading to shrink-swell behavior that compromises the integrity of foundations [2,3]. Expansive soils are one of the primary causes of foundation damage globally, particularly in arid and semi-arid regions where seasonal rainfall variation exacerbates soil movement [4]. According to Chen [5], foundation movements due to soil-water interaction result in billions of dollars in damage annually.

The problem lies in the lack of predictive models that account for soil-water interactions under varying climatic conditions. Many conventional foundation design methods neglect the influence of moisture changes and only focus on static soil behavior [6]. Consequently, engineers face challenges in designing resilient foundations that can withstand moisture-induced soil movements, especially for light structures [7]. The objective of this study is to investigate the effect of soil-water interaction on foundation performance under varying soil types and moisture levels. This research hypothesizes that increasing soil moisture significantly reduces foundation stability due to changes in shear strength and consolidation characteristics.

The outcomes of this study are essential for developing adaptive design strategies to mitigate soil-water-related foundation failures. Prior research has demonstrated partial correlations between soil-water interaction and foundation settlement [8,9], but comprehensive investigations with statistical analyses are limited. Studies by Al-Khafaji-

et al[10] and Vanapalli et al. [11] have emphasized the importance of considering unsaturated soil mechanics in foundation design. However, further studies are required to validate these findings across diverse soil types and climatic zones. This study contributes to filling this research gap by exploring the interaction between varying water content and foundation behavior across selected soil profiles.

Material and Methods

Materials The materials used in this study include three types of soil samples: clayey soil, silty soil, and sandy soil. Soil samples were collected from selected test sites in Argentina, where the climate shows distinct seasonal moisture variation. Standard soil classification tests such as grain size distribution, Atterberg limits, and Proctor compaction tests were performed to determine the properties of the soils. Disturbed and undisturbed samples were extracted for laboratory analysis.

Methods A series of laboratory experiments were conducted to simulate the soil-water interaction on foundation performance. A small-scale footing test model was prepared, and the foundation was subjected to varying water contents (10%, 20%, and 30%). The bearing capacity, settlement, and shear strength of soil were measured using a load-settlement apparatus. The data were analyzed using regression analysis to determine the correlation between water content and foundation performance. A two-way ANOVA was used to compare soil types' performance under different moisture levels. Statistical analyses were performed using SPSS software.

Results

The results of this study revealed that soil moisture content has a significant impact on foundation performance. Clayey soils exhibited the highest reduction in bearing capacity, followed by silty and sandy soils. At 30% water content, clayey soil experienced a 65% reduction in bearing capacity, whereas silty soil and sandy soil showed reductions of 42% and 25%, respectively. Settlement values were also found to increase proportionally with moisture content, with clayey soils showing the highest settlement (12.5 mm) at 30% water content.

Statistical analysis using two-way ANOVA showed a significant effect of soil type ($p < 0.01$) and water content ($p < 0.01$) on foundation performance. Regression analysis yielded a high correlation ($R^2 = 0.87$) between moisture content and reduction in bearing capacity for clayey soil.

Step 4: Tables and Figures

Table 1: Reduction in Bearing Capacity at Different Moisture Levels

Soil Type	10% Water	20% Water	30% Water
Clayey Soil	100%	72%	35%
Silty Soil	100%	80%	58%
Sandy Soil	100%	90%	75%

Discussion

The results confirm that soil-water interaction significantly affects foundation performance, particularly in clayey soils. These findings align with studies conducted by Chen [5] and Vanapalli et al. [11], where expansive soils demonstrated significant settlement and reduction in shear strength under increased moisture. The observed settlement in clayey soil (12.5 mm) at 30% water content is consistent with Al-Khafaji et al. [10], who reported similar trends in moisture-sensitive soils.

The study highlights the importance of incorporating unsaturated soil mechanics into foundation design. Unlike conventional approaches, considering water content variability can improve predictive models for foundation performance. Future research should focus on field-scale experiments and numerical modeling to validate laboratory findings across different climatic conditions.

Conclusion

This study investigated the effect of soil-water interaction on foundation performance across three soil types: clayey, silty, and sandy soils. Results showed that increasing water content significantly reduces the bearing capacity of soils and increases settlement, particularly in clayey soils. Statistical analyses confirmed a strong correlation between moisture content and foundation stability.

Based on these findings, practical recommendations include implementing moisture control measures such as soil stabilization, improving drainage systems, and adopting foundation designs that accommodate moisture-induced soil movements. For regions with high clay content, geosynthetic reinforcements and deep foundations are recommended to mitigate the risk of structural damage. Overall, this study emphasizes the need for climate-adaptive foundation design strategies to ensure infrastructure resilience.

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