LABO - Axe et Equipe INSTITUT PASCAL AXE M3G, équipes Mat Inn/S2O

Thesis supervisor: Évelyne TOUSSAINT, PU, evelyne.toussaint@uca.fr
Co-supervisor : Mathilde MORVAN, McF, Mathilde.morvan@uca.fr

Title of PhD subject: Study of Clay Shrinkage and Swelling: A Coupled Approach Between Modeling and Full-Field Measurement Method for the Development of a Characterization Methodology of Swelling Clays Adapted to Individual Houses for Climate Risk Prevention

Summary :
Study of Soil Shrinkage and Swelling: A Major Geotechnical Challenge

The issue of soil shrinkage and swelling is a significant challenge in geotechnical engineering. This phenomenon is caused by the presence of swelling clays in the soil, which have the ability to retain water and expand accordingly. In France, this problem is particularly prevalent in densely populated regions, where existing buildings are already abundant, and the need for new constructions is high.
The consequences of soil shrinkage and swelling are numerous and can be severe. Buildings and infrastructure built on such soils are prone to structural damage due to repeated soil expansion and contraction. These movements are more pronounced for small structures, such as individual houses. Over the past 20 years, regulations in France have evolved considerably, requiring any seller of land located in medium- or high-risk swelling areas to conduct additional tests.
The understanding of swelling and shrinkage phenomena remains limited, as specific tests to accurately evaluate the forces at play and predict volume variations are lengthy and costly. Whether under French standards or international ones such as ASTM D 4546-90, the expenses involved are often unaffordable for individual homeowners. In France, swelling capacity is frequently assessed through correlations, despite the lack of consensus on the most appropriate test for characterizing this phenomenon.
Furthermore, recent studies indicate that generalizing soil properties is impossible due to the highly variable characteristics of swelling clays and other studied soils ([NOW 07], [CHR10]) within the ARGIC project ([VIN06], [KAZ16]). As a result, evaluating the risk of soil volume variations remains challenging and is poorly suited to standard laboratory practices. Given the evolution of regulatory requirements, it is crucial to develop reliable characterization methods for swelling soils that are accessible to homeowners with limited budgets.
The issue of soil shrinkage and swelling is linked to specific clay types that react with water, exhibiting significant volume changes. They expand when wet and contract when dry. This physic-chemical process is associated with a well-known variable in unsaturated soils: suction. Suction, present in unsaturated soils, is related to surface tension at the water-air interface. The Sécheresse 2 project, led by Cerema and IFFSTAR, revealed that the first three meters beneath the surface are the most affected [MAT15]. This shallow depth makes it relatively accessible to individual homeowners without requiring expensive machinery, necessitating the development of a simple, homeowner-friendly test for sample analysis.
To develop and validate such tests, the laboratory is equipped with advanced tools for studying unsaturated soils, enabling a comprehensive characterization of swelling soils. Additionally, stereovision cameras and image analysis techniques will be used to observe deformation distribution based on water content ([TEG18], [CHE24]) and suction in soils undergoing shrinkage and swelling.
These variations will be compared with results from complex models developed for swelling soils, such as the BBM-ex, as well as more conventional unsaturated soil models based on the effective stress theory ([MAT15]).
The results obtained through soil characterization tests, image analysis, and theoretical studies of constitutive models will contribute to the development of a reliable characterization methodology for soil shrinkage and swelling, which can be applied even for low-budget constructions.
To mitigate the risks associated with soil shrinkage and swelling, the study will also explore reinforced soils using bio-based materials and traditional stabilization techniques. Bio-based materials, besides their significant environmental benefits [BAR24], exhibit a strong response to environmental humidity variations ([KAB13], [BEK22]). They could serve as an effective solution to soil swelling and shrinkage issues, particularly under conditions of severe drought or flooding.

Societal and Environmental Impacts

The shrink-swell phenomenon poses a major societal and social challenge due to its growing economic, environmental, and human impact.

1. An Economic and Social Challenge for Homeowners and the Community

Individual houses are particularly vulnerable to soil variations, leading to cracks and structural damage that require extensive and costly repairs. These damages represent a financial burden not only for homeowners but also for public institutions. The Caisse Centrale de Réassurance (CCR) spent €12.3 billion between 1989 and 2018 to compensate for damages related to this phenomenon [GEO]. With climate change, the frequency and severity of these damages are expected to increase by 44% to 162% by 2050, making the development of financially accessible preventive solutions even more crucial.

2. A Direct Impact on Residents' Quality of Life

Progressive cracks in homes cause daily discomfort, psychological distress, and unexpected financial burdens for homeowners. Structural repairs, sometimes leading to home demolitions, disrupt family lives and create social tensions in affected areas.

3. An Environmental and Climate Challenge

This research project offers a sustainable alternative by integrating bio-based materials for soil stabilization. These materials help regulate soil moisture, thereby reducing the effects of shrink-swell cycles while lowering the environmental footprint of current solutions. This approach aligns with the vision of climate-resilient construction.

4. The Need for Public Awareness and Education

A fundamental aspect of this project is the education of the general public and construction professionals about climate risks associated with soils. The development of simple, homeowner-accessible diagnostic tests would enable effective prevention and risk anticipation. Additionally, organizing demonstration days and workshops for professionals and civil engineering students would foster collective awareness and encourage the adoption of appropriate construction practices.

Conclusion

With the increasing damages caused by soil shrinkage and swelling, it is essential to develop diagnostic and prevention methods suited to individual homeowners' financial capacities. This project represents a major breakthrough by combining economic accessibility, ecological solutions, and public awareness, ultimately aiming to protect homes and enhance territorial resilience against climate change.

Motivation for the Ph.D. Grant Application

This research, in collaboration with two themes of M3G (Mat Inn and S20), strengthens exchanges within the M3G axis of the Pascal Institute. It also highlights the involvement of multiple disciplines, including geotechnics, bio-based materials, and contactless imaging.

By combining innovative experimental approaches with material selection and constitutive modeling, the project aims to enhance understanding of shrinkage-swelling phenomena and develop solutions to mitigate the damage caused by extreme droughts and soil flooding.

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