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Tensile strength and crack pattern during desiccation of compacted clayey soils

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Summary

This study presents desiccation tests performed on a constrained desiccation box, designed to measure tensile strength and investigate crack formation during desiccation in compacted clayey soils. Tests were conducted on three clayey soils of varying plasticity, under two sets of boundary conditions: one rigid condition and one unrestrained condition. On the other hand, hydro-mechanical properties of the soils are characterized in terms of compression and tensile strengths at various suctions, water retention properties and free shrinkage curves. The soil behavior in the desiccation box is analyzed in the light of unsaturated soil mechanics concepts. Results demonstrate that the development of crack pattern depends on the kinetics of drying, and the shrinkage potential of the soil. The high plasticity soil exhibits a distributed crack pattern due to the internal constrained induced by the suction gradient along the 3 cm thickness of the soil, independently of the constrained conditions at both ends of the box. On the contrary, for lower plasticity soils, a single crack occurs approximately in the middle of the specimen when the conditions are constrained, while no crack occurs upon free shrinkage conditions.

1 Introduction

Desiccation cracking of clayey soils is an important issue in environmental geomechanics. For instance, when clay is used as an engineered barrier in waste disposal, desiccation cracking may have a substantial detrimental impact on its confinement capability. Desiccation cracking occurs when tensile stresses exceed the tensile strength of the soil. The tensile strength of unsaturated soils plays an important role in the occurrence and growth of desiccation cracks. While many studies have explored soil desiccation and tensile strength (Omidi et al. 1996; Yesiller et al. 2000; Albrecht and Benson 2001; Tang et al. 2011; Poncelet et al. 2022; Ighil Ameur and Hattab 2022), few have focused on experimentally measuring tensile strength as desiccation occurs. In most previous research, tensile strength was tested under nearly constant water content and suction, using external tensile loads to cause failure. The work in this paper is based on the idea that soil behavior and strength may depend on the stress and suction path followed during drying.

The current study uses a novel device to measure the tensile strength of the soil during desiccation drying (Varsei et al. 2016). In contrast to earlier approaches, the device introduced and employed in this study enables direct measurement of soil tensile strength during the desiccation process. This condition simulates the natural drying condition where tensile stresses develop by decreasing water content, and cracks develop at a water content lower than the initial water content. In addition to the monitoring of tensile stress developed during desiccation, a camera allows to follow the development of crack pattern all along the

desiccation process. .

2 Materials and methods

2.1 Material Properties

Three types of soils are studied in this research. They are called “Soignies”, “Kruibeke” and “Tournai”, corresponding to the location where they have been extracted in Belgium. These three soils exhibit different characteristics to cover a range of soil behaviour from silt to clay. Particle size analysis, Atterberg limits, and the standard Proctor tests were performed to characterise the materials. A large portion of the grains has a diameter smaller than 80 μm . This fraction represents 85.6% for the Soignies soil, 83.7% for the Kruibeke soil, and 88.5% for the Tournai soil. In particular, Tournai soil is very plastic. According to the Unified Soil Classification System (USCS), the soil from Soignies ($I_p = 17.8\%$) corresponds to low plasticity clay (CL), while the soils from Kruibeke ($I_p = 26.3\%$) and Tournai ($I_p = 98.3\%$) correspond to high plasticity clay (CH).

2.2 Desiccation box

The concept of the constrained desiccation box is inspired from (Varsei et al. 2016). The box is designed to measure tensile strength and investigate crack formation during desiccation in compacted clayey soils. The apparatus consists of an aluminum box (22 cm in length and 30.3 cm in width) divided into two halves: one mobile part and one fixed part. Both halves are connected through two force sensors to record tensile forces sustained by the soil during drying.

For the soil specimen preparation, the soil is first mixed with the amount of water required to achieve the optimum water content. Then, the wet soil is left to rest for at least 24 hours in a plastic bucket to ensure that the water is evenly distributed throughout the soil. Finally, the soil with a thickness of 3 cm is compacted into the desiccation box. The mass of soil inserted in the box is adjusted to correspond to the optimum standard Proctor density.

To provide a constraining condition, screws are placed at the end walls of the box and embedded in the soil within. This prevents the soil at the boundaries from pulling away from the ends during shrinkage and causes the desiccation crack to form at the midsection of the box in which the maximum tensile stress is expected to occur.



Figure 1: Desiccation Test Setup

3 Results

Desiccation tests were conducted on three clayey soils of varying plasticity, under two sets of boundary conditions: one rigid condition (for which the soil is fixed at both ends of the box, leading to constrained shrinkage) and one unrestrained condition (for which the soil is free to shrink). The experiments are described in Table 2. Two tests for each soil have been conducted for each boundary condition. Totally 4 desiccation tests have been performed for each soil.

Table 1: Constrained and Unconstrained Desiccation Tests

Test Name	Boundary Condition	Bulk density (g/cm ³)	Max tensile Stress (kPa)	Crack Pattern
Kruikeke 2	Constrained	1.84	23.96	Localized Crack
Kruikeke 3	Constrained	1.84	32.76	Localized Crack
Kruikeke 4	Unconstrained	1.84	18.46	No Crack
Kruikeke 5	Unconstrained	1.84	18.24	No Crack
Soignies 2	Constrained	2.03	29	Localized Crack
Soignies 3	Constrained	2.03	34.70	Localized Crack
Soignies 4	Unconstrained	2.03	23.13	No Crack
Soignies 5	Unconstrained	2.03	20.12	No Crack
Tournai1	Constrained	1.54	10.88	Distributed Crack
Tournai2	Constrained	1.54	12.89	Distributed Crack
Tournai3	Unconstrained	1.54	10.35	Distributed Crack
Tournai4	Unconstrained	1.54	10.95	Distributed Crack

The results reveal that Soignies and Kruikeke soils do not develop any crack when the tests are performed under unconstrained conditions. Actually, even if some tensile stresses are developed due to friction at the base between soil and bottom plate of the box, this tensile stress does not overpass tensile strength such that no crack occurs. On the contrary, for Tournai soil, a distributed crack pattern is observed during desiccation even in absence of external constraints (Figure 2d). This cracking process is due to internal constraints induced by suction gradient in the thickness of the soil. Top part tends to shrink due to high suction while bottom part remains more wet and constraints the shrinkage, inducing tensile stress at the top part that leads to cracking.

For desiccation upon constrained conditions, the three soils exhibits cracking but the pattern of cracks differ. Kruikeke and Soignies soils show a localized crack transversally to the constrained direction (Figures 2a and 2b) while Tournai soil shows a distributed patterns without real preferential direction (Figure 2c). Again, this difference is due to different constraint mechanisms: the cracks occurring in Soignies and Kruikeke soils are due to external constraints (effect of the screw at the boundary) while the cracks in Tournai soil are induced by internal constrained (due to suction gradient within the thickness of the soil).



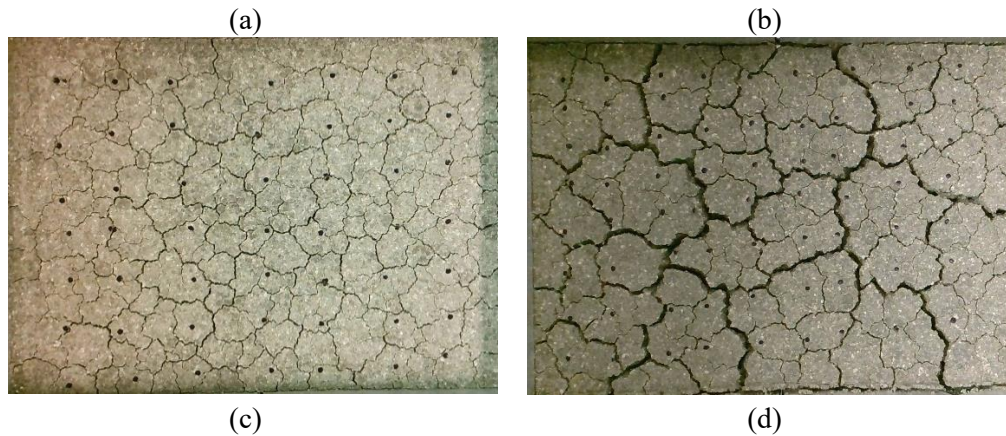


Figure 2: Crack pattern obtained from (a) Soignies Constrained condition (b) Kruikebeke Constrained Condition (c) Tournai Constrained Condition (d) Tournai Unconstrained Condition

4 Conclusion

This study highlights the key role of soil plasticity, water retention behavior, and drying kinetics in the development of desiccation cracks. The results confirm that the formation and evolution of desiccation cracks are influenced not only by mechanical boundary conditions but also by the soil's drying rate, which is closely related to its water retention properties. For the high-plasticity soil, a distributed cracking pattern was observed, attributed to internal constraints from suction gradients across the soil thickness, regardless of external boundary conditions. In contrast, lower plasticity soils tended to develop a single central crack under constrained conditions and remained crack-free when allowed to shrink freely.

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