PhD position

Modeling soil-atmosphere interactions to study the clay shrink-swell hazard in a context of climate change.

General context:

The cycles of clay shrink-swell (CSS) are linked to the cycles of soil moisture fluctuations, themselves governed by the alternation of precipitation and drought periods. In France, 54% of constructions are located in areas characterized by a medium to high hazard of CSS. Structural damages to constructions caused by CSS are estimated at several hundred million euros annually, making CSS the second largest category for natural disaster compensation. Managing the risk associated with CSS thus constitutes a considerable economic challenge. In the context of climate change, the increasing occurrences of extreme meteorological events (in intensity and frequency) are likely to exacerbate the vulnerability of constructions to CSS. Therefore, it is essential to take into account these climatic changes to understand the risk of CSS during the next decades.

Scientific issues and objective:

In such a context, the study of interactions between the atmosphere and clayey soil faces several scientific challenges. Firstly, although climate projections exist at the regional scale, they are still characterized by low spatial (a few km^2) and temporal (daily) resolutions, making their utilization challenging for targeted impact studies. To address this shortcoming, downscaling methods are often proposed, but they generally rely on stationarity assumptions and struggle to represent extreme values, which are particularly useful in risk management. Lastly, there is a notable lack of knowledge regarding the influence of this local hydrometeorological context on the control of the stresses to which the soil is and will be subjected (and any potential treatment it may receive).

This PhD project will therefore focus on proposing a model to determine local meteorological scenarios (mainly precipitation and temperature) characterized by high spatial and temporal resolutions, as well as a soil-atmosphere interaction model that takes into account local geotechnical and climatic characteristics. These will aim to accurately represent the extreme values of the involved hydrometeorological processes, essential for understanding periods of drought and/or saturation linked to CSS risks. Finally, this work will make it possible to study the consequences of climate change on this CSS risk, as well as the relevancy of possible remediation solutions in such a context.

Workplan:

This PhD project will be structured in 4 parts.

1- State of the art and data collection

The first step will consist of conducting a state-of-the-art review of scientific research on the hydrological impact of climate change, focusing specifically on the climatic scenarios used for this purpose (assumptions, spatial and temporal resolutions). This work will focus on downscaling methods that adapt outputs from regional climate models (daily data on grids of several km²) to higher resolutions (Vogel et al., 2023). Various methods will be analyzed and compared, with particular attention given to the added value provided by multifractal methods (Schertzer and Lovejoy, 2011). Concurrently, a prospective study will be conducted to identify and collect datasets that have measured the phenomenon of clay shrink-swell in the past (possible sources: BRGM, INRAE, SNCF…), as well as the associated meteorological data.

2- Spatio-temporal characterization of hydrometeorological processes

In order to understand and characterize the hydrometeorological processes underlying clay shrink-swell phenomena, the collected data (displacement measurements, meteorological data, climate scenarios, etc.) will be analyzed. The use of multi-scale tools based on (multi)fractals will allow for their characterization from a geostatistical perspective (Ramanathan et al., 2022): spatiotemporal variability, scale break, estimation of extreme values, etc. Additionally, efforts will be made to determine the required hydrometeorological input data for modeling soil behavior (precipitation, temperature, infiltrated flux, water content, etc.), as well as their spatial and temporal resolutions (daily, hourly, sub-hourly, etc.) using scientific literature.

3- Development of high-resolution climate scenarios

In order to obtain meteorological scenarios characterized by high spatial and temporal resolutions capable of accurately representing extreme values, a downscaling model will be developed and implemented. It will be capable of: (i) adapting selected climate scenarios to the spatiotemporal scales required to study the phenomenon of clay shrink-swell, (ii) representing the extreme values necessary for understanding the periods of drought and/or saturation that lead to significant consequences of clay shrink-swell. To achieve this, a model based on universal multifractals will be favored. This stochastic approach will enable the production of a set of plausible scenarios compatible with risk characterization.

4- Soil-Atmosphere interaction model

Finally, the aim will be to develop a soil-atmosphere interaction model that can generate the required input data for a numerical behavior model. This model should take into account both soil heterogeneity and the variability of climate scenarios. Special attention will be given to modeling evapotranspiration and infiltration processes using local climatic, geotechnical, and pedological data (soil type, permeability). To achieve this, it is proposed to study the heterogeneity of this porous medium to characterize both its granular structure and the distribution and evolution of fluxes using (multi)fractal-based tools (Stanic et al., 2020).

Context of the project:

This PhD subject is part of a research project funded by ADEME (French Agency for Ecological Transition), coordinated by two research laboratories, ESTP and Ecole des Ponts ParisTech (ENPC). The project aims to develop an in-situ soil treatment solution, which will inhibit volume change of clayey soils during seasonal wetting-drying cycles. Various actions are planned: laboratory tests, field-scale experiments, and predictive numerical simulations, to propose a treatment protocol considering local geological, geotechnical, and meteorological conditions. This PhD proposal aims to benefit from measurements made during the project and to contribute to the final predictive behavior model.

Profile of the candidate:

The candidate should be graduated in (fluid or geo) mechanics or environmental physics, have capabilities in computer simulations, and be of interest for the experimental follow-up and multi-scale analysis.

Administrative information:

The PhD candidate will be supervised by Dr. Pierre-Antoine Versini (ENPC), and Dr. Benjamin Dardé (ESTP). Starting on October 2024 for a duration of 3 years, this PhD will take place at Ecole des Ponts ParisTech in the Hydrology, Meteorology and Complexity laboratory (HM&Co – ENPC, 6-8 avenue Blaise Pascal, 77455 Champs-sur-Marne, France; see http://www.enpc.fr/hydrologie- meteorologie-et-complexite).

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Deadline for submitting applications: April 30, 2024

References:

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