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Influence of Soil Water Content on Filter Cake Formation During Drilling Fluid Injection

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Abstract

Bentonite support fluid plays a crucial role in the temporary stabilization of excavation walls during the construction of deep foundations or underground structures, primarily through the formation of a filter cake that limits fluid loss and transfers lateral pressure to the surrounding soil. While the effects of fluid properties and soil permeability have been widely studied, the impact of the initial water content of the host soil remains underreported. Thus, the results of a preliminary experimental study concerning the effects of soil water content on bentonite fluid filtration are presented here. Tests were conducted in a laboratory cell filled with sand in which a bentonite fluid was injected under a constant pressure of 100 kPa. Two initial water contents were tested: 2% and 8%, corresponding to degrees of saturation of 6% and 26%, respectively. Results revealed a three-phase filtration process: rapid infiltration, clogging and internal cake formation, and progressive filtration (external cake formation and thickening). At a water content of 2%, no filtrate was collected, indicating immediate pore clogging. At a water content of 8%, more than 3.2 L of filtrate was recovered. At the end of the bentonite injection, the final water content profiles in the soil (sand + retained bentonite fluid) were more uniform in the drier soil (water content = 2%) than for the wetter one (8%). Bentonite retention was uniform throughout the sand depth at 2%, while at 8%, the retention was greater across the soil depth. The filter cake was thicker in the drier soil than in wetter one. These results demonstrate that the initial water content of the studied soil influences filtration behavior and cake formation. Ongoing studies aim to further quantify this effect and support field practices adapted to site-specific moisture conditions.

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Introduction

Bentonite fluid has been used to temporarily support civil engineering excavations. This thixotropic clay suspension forms an internal and/or external impermeable filter layer on trench walls that transfers hydrostatic pressure to the surrounding soil and prevents cave-ins [1-3]. This technique enables the construction of deep foundations and underground structures below the water table, while minimizing ground movements [4-6].

Inadequate fluid control can compromise excavation stability and is reported to influence defects, occurence such as shadowing – the imprint of reinforcement cages in hardened concrete – or the inclusion of bentonite fluid, observed at panel joints [7]. Chemical contamination of bentonite by ions (Ca^{2+}, Mg^{2+}, sulfates) or acidic pH can affect the fluid rheological profile and lead to a more permeable filter cake, destabilizing the excavation [8-12]. Filtrate flow into the soil first creates an internal cake by pore clogging, then an external cake at the surface – a quasi-impermeable layer limiting fluid loss and ensuring trench wall stability [4,9,13-15]. Optimal cake thickness is critical: if too thin, it leads to instability and fluid losses if too thick, it may affect fresh concrete flow, causing shadowing [7,16,17].

Filter cake quality (thickness, permeability, continuity) depends on several factors. Drilling conditions (overpressure, flow rate) influence filtration dynamics: higher pressure increases fluid penetration and cake growth [18]. The physicochemical properties of the fluid – bentonite type and concentration – also play a role: higher clay content leads to thicker, less permeable cakes [19,20]. Electrolytes and contaminants (e.g., salt water) inhibit bentonite swelling and increase cake porosity [21,22]. Weighting agents (barite, hematite, ilmenite) affect grain size and cake thickness, while soil hydraulic properties (permeability, porosity) govern filtrate flow and cake formation [23,24]. However, in-situ uncertainties remain due to complex couplings (fluid-structure interaction, subsurface moisture), which make prediction difficult.

A key parameter remains insufficiently studied: the initial water content of soils. While fluid formulation can be adjusted on-site, initial soil moisture is a fixed geological constraint that likely influences filtrate initiation, pore clogging, and cake structuring. This study seeks to isolate the effect of soil water content on bentonite fluid filtration. Founded by FNTP (National Federation of Public Works (France)) and the Normandy Region, this preliminary investigation aims to improve understanding of bentonite support systems in unsaturated or partially saturated soils.

Materials and Methods

Materials

Soil

The soil used is a sand with a grain size range of (160-1000) µm, a median diameter (d_{50}) of 600 µm, a dry density of 1.45 g/cm³, and a specific unit weight of solid particles of 2.58 g/cm³. Its hydraulic conductivity was experimentally measured by means of a constant-head test and found to be $(3.5 \pm 0.3) \times 10^{-4}$ m/s, with a porosity of 40%.

Two water contents were tested: 2% and 8%, corresponding respectively to degrees of saturation of 6% and 26%. Notice that the water content at full saturation of the used sand is 30%.

Support Fluid

The bentonite used is a sodium bentonite of type CM10t (Clariant (Le Treport, France)). prepared at a concentration of 45 g/L using moderately hard to hard water (an average hardness of 26 °F and a pH of 7). Its yield stress was 1.1 Pa, and its dynamic viscosity is 0.021 Pa.s. The pH of the prepared fluid is (9.5 ± 0.5). Preparation was carried out at a constant temperature of (16 ± 1) °C, resulting in a Marsh viscosity of (46 ± 2).

Filtration Cell

To investigate the influence of the initial water content of the soil on bentonite fluid filtration, laboratory experiments were conducted using a stainless-steel filtration cell (Figure 1) with a diameter of 29 cm and a height of 30 cm. Frontal filtration technique is used to inject the bentonite fluid across the soil under a constant injection pressure (Cf. Figure 1).

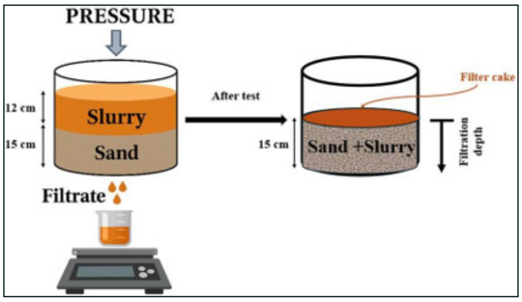

Figure 1: Schematic representation of the experimental setup

Methods

Filtration tests were conducted under controlled and identical conditions to ensure reproducibility. A constant pressure of 100 kPa was applied for 7 hours. An identical measurement protocol was used for all tests. The recorded parameters include filtrate volume as a function of time, cake thickness, water content profile, and retention(R) profile (Cf. Eq. (1)).

$$R = \frac{M_{fp}}{M_{sand}} \times 100\ (\%) \qquad (1)$$

With M_{fp} (g) is the mass of deposited bentonite fine particles in the sand and M_{sand} (g) is the sand mass.

Cake thickness measurements were taken at multiple locations using a Fann-standard ruler to ensure accuracy and consistency, enabling the determination of a representative average cake thickness.

Also, at the end of each test, the equivalent hydraulic conductivity of the complex (cake + fluid-impregnated sand) was derived from the change in filtrate volume over time.

Results and Discussions

Filtrate Volume

The experimental filtrate volume curves plotted against the square root of time (Cf. Fig. 2) show a typical three-stage filtration pattern: an initial rapid filtration phase, followed by clogging and internal cake formation, and then a progressive filtration phase (external cake formation and thickening). Figure 2 indicates that the initial water content of the soil is a critical controlling factor. After 7 hours of injection, no filtrate was collected throughout the soil in the 2% water content test, whereas at 8%, the cumulative filtrate volume exceeded 3.2 L. This pronounced difference is attributed to effective permeability in soil with 2 % water content, where strong capillary suction and high intergranular mechanical resistance greatly limit the infiltration of the fluid [25]. In contrast, for 8 % water content soil, pre-existing water in pores acts as a lubricant, reducing interparticle friction and enabling the bentonite fluid to penetrate more easily into the granular matrix [25].

Clogging onset time, identified by the inflection point in the 8% filtrate curve, occurs approximately 2 minutes after the start of the injection test. In the 2% water content soil, however, no distinct filtration phase is initiated, suggesting that pore clogging by capillary retention and particle deposition occurs almost immediately, without significant fluid migration [25]. These findings highlight the role of initial water content in controlling bentonite fluid filtration dynamics, particularly in relation to fluid mobility, and the advancement of the infiltration front.

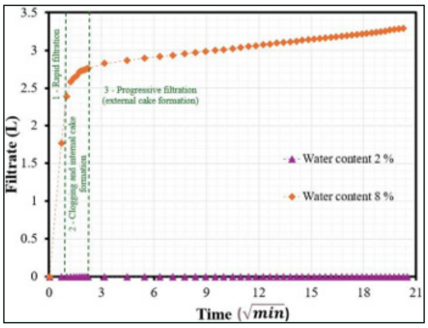

Figure 2: Filtrate volume as a function of the square root of time

Final Water Content and Retention

The final water content profiles as a function of the soil depth after testing is presented in Figure 3. It clearly highlights the influence of the initial water content of the soil. For the soil with 2% water content, the water content reaches 31.6% for the first centimeter of the soil (0 to –1 cm) and 24% at the bottom of the cell (–14 to –15 cm). In contrast, for an initial water content of 8%, the water content decreases from 31.3% for the first centimeter of the soil (0 to –1 cm) and 22% at the bottom of the cell (–14 to –15 cm). This behavior is explained by the greater mechanical resistance of the sand at 2% water content. This resistance slows bentonite fluid flow and promotes the retention of water and fine particles at various depths [26]. In contrast, in the soil with 8% water content, the pre-existing water acts as a lubricant, reducing friction and thus promoting faster infiltration [27].

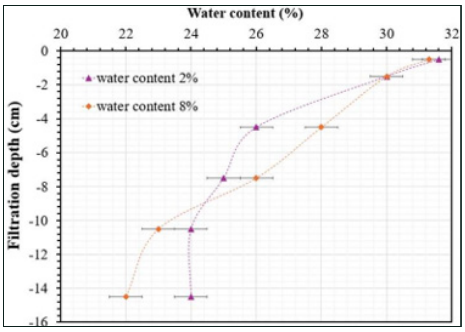

Figure 3: Final soil water-content profile, after the test

The fine particle retention profile measured at the end of the bentonite fluid injection is shown in Figure 4 for the depths ranging from -1 to -15 cm. The results indicate the influence of the soil's initial water content on the particle retention: At all depths, retention is higher in 2% water content soil than 8% water content soil. For 2% water-content soil, retention reaches 1.7% for the depths ranging between -1 and -2 cm, then decreases to 1.5% at a depth of -7 cm, reaching 1.1% at the bottom of the cell. Conversely, for a soil with an initial water content of 8%, retention reaches 1.3% at depths between -1 and -2 cm, then decreases to 1 % at a depth of -7 cm, reaching to 0.8% at the bottom of the cell., As discussed before, these behaviors could be attributed to the high mechanical resistance resulting from the lack of lubrication in the 2% water-content soil, which promotes the trapping of bentonite particles throughout the infiltration path [28,29].

Regarding the first centimeter (0 to -1 cm) of soil, an average retention of 3.6 % was measured in the 2% water-content soil, whereas it was 3.3 % in the 8% water-content soil.

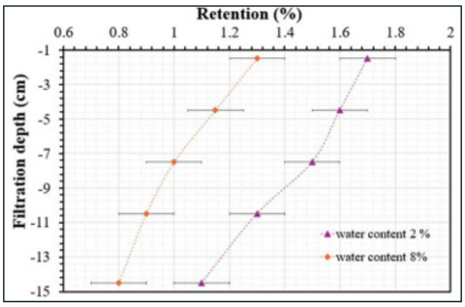

Figure 4: Retention profile of fine particles after the test

Filter Cake

In Table 1 is presented the average cake thickness measured after the injection of the bentonite fluid for the two-water content studied.

Table 1: Cake thickness measured for soil at 2% and 8% water content at the end (after 7h) of bentonite fluid injection

Water content	2%	8%
Average cake thickness (mm)	2.2	1.8

The results indicate that the initial water content affects the surface filter cake, thickness. As mentioned above, this behavior results from the previously described mechanisms: in the soil with 2% water content, mechanical resistance and capillary interfaces promote a rapid trapping of fine particles, leading to a thicker surface deposit (external cake); conversely, in 8% water content soil, this effect is reduced.

Concerning the hydraulic conductivity of the complex (clogged soil + surface filter cake (Cf. Fig. 5), at 8% water content, the hydraulic conductivity average was 8.4×10^{-9} m/s. Notice that the initial hydraulic conductivity of the soil was 3.5×10^{-4} m/s. Thus, a complete loss of soil hydraulic conductivity is obtained. For the soil with a water content of 2%, as noted earlier, no filtrate was collected, which prevented us from determining its hydraulic conductivity. This suggests that the deposit formed in the 2% water content soil is not only thicker but also impermeable.

Figure 5: Photo of the surface cake and the internal deposition of the bentonite fluid particles

These results confirm that the initial water content of the soil governs not only the initiation of the filtration process but also the structuring and performance of the filter cake – a key parameter for maintaining lateral pressure on excavation walls during fluid-supported geotechnical works.

Conclusions

This preliminary study shows that the initial water content of the soil influences the filtration mechanisms. The tests carried out at 2% and 8% water content demonstrate that moisture affects bentonite fluid infiltration, fine-particle retention, and filter-cake formation.

For the soil with 2% water content, capillary suction and mechanical resistance are observed to induce rapid clogging, high particle retention, and the development of a thick filter cake that inhibits filtrate passage. Conversely, for the soil with 8% water content, the presence of water within the pores enhances fluid mobility, promoting deeper infiltration, lower retention, and the formation of a thinner external cake.

Additional experiments are currently in progress to sharpen the quantification of this phenomenon, determine a potential threshold in initial water content, and explore how it may interact with factors like applied pressure or fluid concentration.

Acknowledgements

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References

1. Comodromos EM, Papadopoulou MC, Konstantinidis GK (2013) Effects from diaphragm wall installation to surrounding soil and adjacent buildings. Computers and Geotechnics. http://dx.doi.org/10.1016/j.compgeo.2013.05.003
2. Vipulanandan C, Mohammed A (2020) Effect of drilling mud bentonite contents on the fluid loss and filter cake formation on a field clay soil formation compared to the API fluid loss method and characterized using Vipulanandan models. Journal of Petroleum Science and Engineering. https://doi.org/10.1016/j.petrol.2020.107029
3. Qin S, Cheng Y, Zhou W (2023a) State-of-the-art review on pressure infiltration behavior of bentonite slurry into saturated sand for TBM tunneling. Smart Constr Sustain Cities 1.
4. Xu T, Bezuijen A (2019) Experimental study on the mechanisms of bentonite slurry penetration in front of a slurry TBM. Tunnelling and Underground Space Technology. https://doi.org/10.1016/j.tust.2019.103052
5. Yin X, Chen R, Meng F, Ding Z, Cui Y, et al. (2021) Face stability of slurry-driven shield with permeable filter cake. Tunnelling and Underground Space Technology. https://doi.org/10.1016/j.tust.2021.103841
6. Jin D, Shen Z, Song X, Yuan D, Mao J, et al. (2023) Numerical analysis of slurry penetration and filter cake formation in front of tunnel face. Tunnelling and Underground Space Technology. https://doi.org/10.1016/j.tust.2023.105303.
7. Kmeid M, Casaux-Ginestet G, Escadeillas G, Armengaud J, Robit P (2023) Shadowing pathology on diaphragm walls investigation. Construction and Building Materials https://doi.org/10.1016/j.conbuildmat.2023.133719.
8. Choo KY, Bai K (2015) Effects of bentonite concentration and solution pH on the rheological properties and long-term stabilities of bentonite suspensions. Applied Clay Science https://doi.org/10.1016/j.clay.2015.02.023.
9. Min F, Du J, Zhang N, Chen X, Lv H, et al. (2019) Experimental study on property change of slurry and filter cake of slurry shield under seawater intrusion. Tunnelling and Underground Space Technology https://doi.org/10.1016/j.tust.2019.03.006.
10. Choo H, Choi Y, Lee W, Lee C (2020) Effect of pH Variations on the Yield Stress of Calcium Bentonite Slurry Treated with pH-Responsive Polymer. Materials https://doi.org/10.3390/ma13112525.
11. Abed MA, Rasaei MR (2024) Experimental study of hydrophilic additives on filter cake permeability and filtrate losses. Canadian Journal of Chemical Engineering 102: 1825-1841.
12. Wang K, Zhang Y (2025) Evaluation of the Service Performance of Soil–Bentonite Vertical Cut-Off Walls at Heavy Metal Contaminated Sites: A Review. Applied Sciences https://doi.org/10.3390/app15095215.
13. Nguyen TB, Lee C, Lim J, Choi H (2012) Hydraulic Characteristics of Bentonite Cake Fabricated on Cutoff Walls. Clays and Clay Minerals 60: 40-51.
14. Lee D, Kim K, Lee H, Lim J, Lee I, et al. (2016) Measurement of hydraulic properties of bentonite cake formation deposited on base soil medium. Applied Clay Science http://dx.doi.org/10.1016/j.clay.2016.01.037.

15. S, Xu T, Zhou W, Bezuijen A (2023b) Infiltration behavior and microstructure of filter cake from sand-modified bentonite slurry. Transportation Geotechnics https://doi.org/10.1016/j.trgeo.2023.100963.
16. Dong H, Wang D, Li Z, Zhang Q, Li Y Zhang, et al. (2024) Experimental Study on Infiltration of Seawater Bentonite Slurry. Buildings https://doi.org/10.3390/buildings14092609.
17. Zhang C, Bezuijen A (2025) Experimental study and mechanistic understanding on the airtightness of the bentonite filter cake. Construction and Building Materials https://doi.org/10.1016/j.conbuildmat.2024.139634.
18. Ramadan AM, Osman A, Mehanna A, Shehata AI, Shehadeh M (2024) Simulation of Filter-Cake Formations on Vertical and Inclined Wells Under Elevated Temperature and Pressure. SPE Production & Operations https://doi.org/10.2118/219446-PA.
19. Benna M, Kbir-Ariguib N, Clinard C, Bergaya F (2001) Static filtration of purified sodium bentonite clay suspensions. Effect of clay content. Applied Clay Science https://doi.org/10.1016/S0169-1317(01)00050-3.
20. Wang Z, Wang Y, Feng D, Zhang J, Liu S (2021) Effects of slurry viscosity and particle additive size on filter cake formation in highly permeable sand. Underground Space https://doi.org/10.1016/j.undsp.2021.06.002.
21. Qin S, Zhou W, Xu T (2023c) Effects of seawater on the infiltration behavior of bentonite slurry into sand. Construction and Building Materials https://doi.org/10.1016/j.conbuildmat.2023.130759.
22. Zhang C, Bezuijen A (2024) Pressure infiltration characteristics of bentonite slurry affected by the salty water: experimental study and mechanistic understanding. Ghent University Institutional Repository. http://hdl.handle.net/1854/LU-01J0TYY7E1XCHWXN3B38PHSS4D.
23. Bageri BS, Gamal H, Elkatatny S, Patil S (2021) Effect of Different Weighting Agents on Drilling Fluids and Filter Cake Properties in Sandstone Formations. ACS Omega https://doi.org/10.1021/acsomega.1c02129.
24. Lin Y, Fang Y, He C (2022) Numerical study on clogging mechanism of slurry infiltration in porous media based on coupled CFD-DEM method. Tunnelling and Underground Space Technology https://doi.org/10.1016/j.tust.2022.104622.
25. Sharma P (2012) Geological Disposal of Nuclear Waste: Fate and Transport of Radioactive Materials. InTechOpen http://dx.doi.org/10.5772/50391.
26. Fredlund DD, Xing A, Fredlund MD, Barbour SL (1996) The relationship of the unsaturated soil shear strength to the soil-water characteristic curve. Canadian Geotechnical Journal http://dx.doi.org/10.1139/t96-065.
27. Berilgen S, Kılıç H, Ozaydın (2007) Determination of Undrained Shear Strength for Dredged Golden Horn Marine Clay with Laboratory Tests. In: Sri Lankan Geotechnical Society's First International Conference on Soil & Rock Engineering.
28. Dong Q, Liu T, Wang Y, Liu S, Wen L (2024) Study on the Influence of Walnut Shell Coarse Particles on the Slurry Permeation and the Air Tightness of Filter Cake. Materials https://doi.org/10.3390/ma17215186.
29. Talmon AM, Mastbergen DR, Huisman M (2013) Invasion of pressurized clay suspensions into granular soil. Journal of Porous Media 16: 351-365.