In situ assesment of clay-based cover performance.

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ABSTRACT
Low saturated hydraulic conductivity covers (LSHCC) or hydraulic barriers are one of the reclamation techniques used to control the acid mine drainage generation (AMD). These covers are intended to limit the infiltration of water into reactive tailings. Compacted clays are among the materials used as LSHCC.
The performance of clay-based hydraulic barriers can be affected by their geotechnical and hydrogeological properties. Freeze-thaw cycles can increase their hydraulic conductivity. However, these effects can be minimized by adding amendments.
In order to evaluate the performance of these clay-based covers, four experimental cells were built. The first one simulates a cover composed entirely of clay, the second composed by a clay-silt mixture, the third composed by a clay-sand mixture and the last one composed by two layers of clay with an intermediate layer of silt. Each cell has been equipped with a monitoring station with continuous measurements of moisture, suction and gas concentrations. *In situ* permeability tests to assess hydraulic conductivity were also conducted.
The results of monitoring will make it possible to assess the performance of clay-based covers to enhance clay materials as building materials in mining structures.

RÉSUMÉ
Les couvertures à faible conductivité hydraulique saturée peuvent être considérées comme l'une des techniques de contrôle de la formation de drainage minier acide (DMA). Ces couvertures visent à limiter l'infiltration de l'eau vers les résidus miniers réactifs. Parmi les matériaux utilisés comme recouvrement à faible conductivité hydraulique saturée on trouve les argiles compactées.
La performance des barrières hydrauliques à base d'argile peut être affectée par leur propriétés géotechniques et hydrogéologiques. En effet, les cycles de gel-dégel peuvent engendrer une augmentation de leur conductivité hydraulique. Toutefois, ces effets peuvent être minimisés par l'ajout d'amendements.
Afin d'évaluer la performance de ces recouvrements à base d'argile, quatre cellules expérimentales ont été construites sur le terrain. La première simule une couverture composée entièrement d'argile, la deuxième composée par un mélange argile-silt, la troisième par un mélange argile-sable et la dernière composée par deux couches d'argile avec une couche intermédiaire de silt.
Chaque cellule a été équipée d'une station de mesure pour les mesures en continue des teneurs en eau volumiques, des succions ainsi que des concentrations de gaz. Également des essais de perméabilité ont été réalisés afin d'évaluer la conductivité hydraulique in situ.
Les résultats des suivis des différents paramètres vont permettre d'évaluer la performance des recouvrements à base d'argile et de valoriser des matériaux argileux comme matériaux de construction dans les ouvrages miniers.

1 INTRODUCTION

The tailings storage facilities (TSF) Quémont-2 site is located approximately 2.5 km northeast of the Osisko lake and south of Dufault lake, in Rouyn-Noranda, QC as shown in Figure 1. This TSF occupies an area of about 105 hectares and is surrounded by nine dikes. The site consists of an active, near-capacity tailings storage facility located to the east and a former TSF to the west. The deposit of tailings in this TSF began in 1949 with sulfide tailings producing acidity. Tailings were covered by a mixture of acid-free tailings, slag and treatment sludge which limit the oxidation of the underlying sulfide tailings.

Different scenarios have been suggested for the remediation of the Quemont-2 mine site. Among these scenarios, one can find the low saturated hydraulic conductivity cover (LSHCC). The purpose of this LSHCC is to limit the infiltration of water into the reactive tailings, thus preventing the oxidation reactions from sulfide minerals.
Different material can be used in the LSHCC such as geomembrane, geosynthetic clay liner and clay materials (see Maqsoud et al. 2021).

Clay materials deposit in Abitibi region cover a very large areas but they are little used in the mine site reclamation. The objective of this project is to evaluate the possibility to use the Abitibi clay material as LSHCC.

In this article, a brief description of low saturated hydraulic conductivity covers technique is presented, followed by a description of the material characterizations and the experimental cell configurations. Preliminary monitoring results are then presented with a short discussion and conclusion.

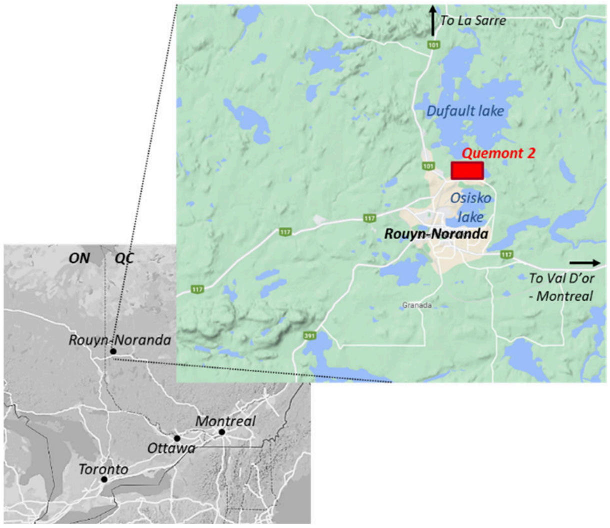

Figure 1. TSF Quémont 2 localisation (Google maps images).

2 LSHCC

LSHCCs, (also called water infiltration barriers or impermeable barriers) are used to avoid exchange between mine wastes and the natural environment. In this way, the main objective of LSHCCs is to control water infiltration to underlying mine wastes and thus reduce the reactions allowing acid mine drainage (AMD) production (Maqsoud et al., 2021; Mine Environment Neutral Drainage, 2004).

LSHCCs can be composed by one single low hydraulic conductivity layer, two layers including a non-compacted layer overlaying the compacted layer, or a complete structure composed by several layers each one with a particular role. In the case of two-layer covers, non-compacted layer has the store and release moisture function protecting compacted-layer of evapotranspiration effects (Mine Environment Neutral Drainage, 2004). Multilayer covers can include five soil layers (Aubertin et al., 2015; Maqsoud et al., 2021): 1) a surface layer with vegetation establishment function, 2) a protection layer providing physical stability and preventing biointrusions, 3) a drainage layer with capillary break function, 4) the hydraulic layer that correspond to the low hydraulic conductivity layer, and 5) the support layer with both bearing and capillary break function. Surface, protection and drainage layers limit the impact of wet–dry cycles and freeze–thaw cycles on the underlying layers(Maqsoud et al., 2021). Usually surface layer is made with organic soils, protection layer with cobbles size materials, drainage and support layer are made with granular (sand, gravel) soils. Impermeable barrier layer is the focus of this paper, characteristic parameters are discussed below.

Since a hydraulic barrier seeks to limit the entry of water, soil layer must have a hydraulic conductivity of 10^{-9} $m.s^{-1}$ at maximum. Hydraulic barrier layer can be made of fine-grained soils (clay or fine silt), or man-made materials such a geomembrane GM, a geosynthetic clay liner GCL, soil-bentonite mix, or a combination of these. In this paper we discuss the layer made of natural soil (clay).

Compacted clay is the most frequently used natural lining material through to its hydrogeological properties (Cossu, 2018; Maqsoud et al., 2021). Compacted clay should be characterised and placed in an appropriate way to ensure good performance as hydraulic barrier in accordance with design parameters (Cossu & Stegmann, 2018).

Clay based hydraulic barrier should be constructed using medium low plasticity clayey soils, that means a percentage of fine particles (ASTM 200 sieve, opening 0.075 mm) upper than 20 or 30 %, clay fraction (0.002 mm) upper than 15 or 25 %, plasticity index (PI) between 7 or 10% and 20 or 40%, liquid limit (LL) upper than 20 and lower than 60 or 80%, and gravel content less than 50%. Clods of soil must not exceed 25 or 50 mm. Table 1 contrast the range of values proposed bay several authors (Daniel, 1993; Maqsoud et al., 2021; Marcoen et al., 2000; Roque & Didier, 2006).

The fine particles and clay fraction percentages defines a clayed soil. The minimum value of the PI is due to achieve the required low hydraulic conductivity, whereas the maximum value of PI is related to the requirement for workable and compactable soil, with limited shrinkage and swelling properties (Favaretti & Cossu, 2018). A soil could contain up to 50-60% gravel without a detrimental impact on hydraulic conductivity. Under these gravel percentage, clay particles fill the voids between the gravel particles dominating the layer behavior (Daniel, 1993).

Table 1. Criteria for preliminary selection of soils suitable to construct compacted soil hydraulic barriers

Properties	Fines (%)	Clay (%)	PI	LL	Gravel (%)	Max Size
Maqsoud et al., 2021	> 30	>15	7<IP<20	>20	<50	--
Daniel, 1993	> 20-30	--	>7-10 <30-40	--	<30	25-50
Marcoen et al., 2000;	>30	>15	10<IP<40	<80	<10	50
Roque & Didier, 2006	--	>25	15<IP<30	15<LL<60	--	--
	>30-50	>25	>15	>30	--	--
	>20	--	10<IP<30	--	<10	--
	>30	--	>7-10 <30-40	--	<10-20	--
Benson et al., 1994	>50	>15	>7	>20	--	--

3.1 Influences on the hydrogeological properties of clay material

Based on transit time calculations, clay liners can be very effective barriers (Favaretti & Cossu, 2018). However, the properties of clays and its performance as hydraulic barrier may be affected by several factors such as field placement conditions (degree of compaction, moisture content); cracking and structural changes induced by seasonal weather cycles, such as wetting-drying and freeze-thaw cycles; root penetration, shrinkage/swelling processes and differential settlement (Council, 2007; Maqsoud et al., 2021; Wagner, 2013). These conditions and processes increase the hydraulic conductivity of the clay layers.

3.1.1 Conditions during the construction phase

Compaction procedures and moisture content during construction strongly influence the mechanical and hydrogeological properties of clayed soils. Hydraulic conductivity is lower when the soil is compacted wet at the optimum water content with a high level of compaction energy (Benson et al., 1994; David E Daniel, 1993; David E. Daniel, 1993). The soil must be sufficiently wet to mold clods of clay, eliminating large inter-clod pores, during compaction procedure (Benson et al., 1994; David E. Daniel, 1993; Maqsoud et al., 2021). Same way, a high compaction energy can knead the soil remolding clods and eliminating large pore spaces (David E. Daniel, 1993; Eigenbrod, 2003; Maqsoud et al., 2021). This points to the need for proper control of the compaction process, that is to control moisture content and energy levels.

3.1.2 Wet/dry cycles

A clay layer acting as a low hydraulic conductivity cover can be exposed to wetting-drying cycles. The drying process causes a decrease in water content of the soil, inducing an increase in matric suction pressure. That's results in cracks as a result of a consolidation process (shrinkage) (Maqsoud et al., 2021; Rayhani et al., 2008). At the same time cracks become preferential paths for water, decreasing its hydraulic barrier capacity. A single drying cycle can generate enough damage in the cover and the loss of its capacity as a hydraulic barrier (Albrecht & Benson, 2001).

The volume changes induced by the desiccation process is directly related to the water content of the clay in the saturated state. Water content in the saturated state is a function of the soil properties (including its consistency limits) and compaction conditions (Albrecht & Benson, 2001; Ghazizade & Safari, 2017; Rayhani et al., 2008). Soil layers with a high clay content and a high plasticity index show greater water contents and subsequently significant volume changes. On the other hand, it is possible to use clay amendments with sand, silt, cement and other materials to reduce the plasticity of the clays and reduce the susceptibility of the crack formation, however, these mixtures generally increase the hydraulic conductivity of covers (Wagner, 2013).

3.1.3 Freeze-thaw cycles

Freeze-thaw cycles also cause changes in the hydrogeological properties of clays. In the freezing front a suction pressure attracts water molecules from the unfrozen zone is induced; this leads to changes in soil structure as a result of rearrange and consolidation processes affecting the hydraulic conductivity of the clays and its performance as hydraulic barrier (Konrad & Samson, 2000; Maqsoud et al., 2021; Sterpi, 2015). These effects are greater when high plasticity soils are involved. (Eigenbrod, 2003; Sterpi, 2015).

On the other hand, Chamberlain and Gow (1979) cited by Konrad and Samson (2000) explain that the increase in hydraulic conductivity after a freeze-thaw cycle, without cracking production, is due to soil structure changes at the microscopic and macroscopic level. For a silty clay, coarse grains control the structure of the soil while fine grains control hydraulic conductivity. After freeze-thaw cycle, the clay packets form denser and dispersed structures due to consolidation, occupying a smaller volume, increasing the void index and as a result the hydraulic conductivity increases (Konrad & Samson, 2000). In a clayey silt, coarse grains are not in contact. Freeze-thaw cycles in this type of soil also causes a collapse and rearrangement of the clay packets into a more dispersed structure, which leads to a reduction in void ratio. In this case, the hydraulic conductivity increases because of the shrinkage cracks that form during freezing (Konrad & Samson, 2000).

Based on laboratory tests, (Sterpi, 2015) demonstrated that the effects of freeze-thaw cycles can be reduced by using a high compaction energy. On the other hand, some non-plastic or very low plasticity soils or high expansive soils do not undergo changes in permeability, even if after the freezing cycle, zones of cracking can be observed. This behaviour can be attributed to the self-healing of these fractures during thaw and subsequent percolation (Eigenbrod, 2003).

Other processes influencing the hydraulic conductivity are discussed by several authors: root penetration (Bussière & Guittonny, 2021), and differential settlement (Council, 2007; Wagner, 2013). According to ~~(~~Wagner (2013) the effects on the clay-based covers can be minimized by using clay amendments with sand, silt or man-made substances. However, it causes an increase in hydraulic conductivity; in this paper we test in field cover amended using sand and silt in order to evaluate its performance and influences on hydraulic conductivity.

Recently Abitibi clay material were amended in lab and submitted to different freeze-thaw cycles. Results of these investigations show that the amended clay can be used as cover material (See Merzouk et al. 2022 – in this proceeding). In order to confirm these lab results the present study was started with the objective to test in an experimental scale different configuration of hydraulic barriers using amended clay material.

4 EXPERIMENTAL CELLS

In this context, the objective of the project is to test the performance of clay-based covers on an experimental scale. To achieve this, four experimental cells simulating low hydraulic conductivity covers were built to monitor their hydrogeological properties and their response to meteorological conditions.

The first one simulates a cover composed entirely of clay, the second composed by a clay-silt amendment, the third composed by a clay-sand amendment and the last one composed by two layers of clay with an intermediate layer of silt. Each cell has been equipped with a monitoring station with continuous measurements of volumetric water content, temperature, suction and gas concentrations.

4.1 Configuration and instrumentation of experimental cells

Experimental cells have an inverted truncated pyramid shape with a base of 1m x 1m with 2H:1V slopes. External slopes are made with rockfill to give support to the cell. The first cell is the control cell and simulates a cover composed entirely of clay, with a thickness of 0.8 m, for a total volume of 13 m^3 (see Figure 2).

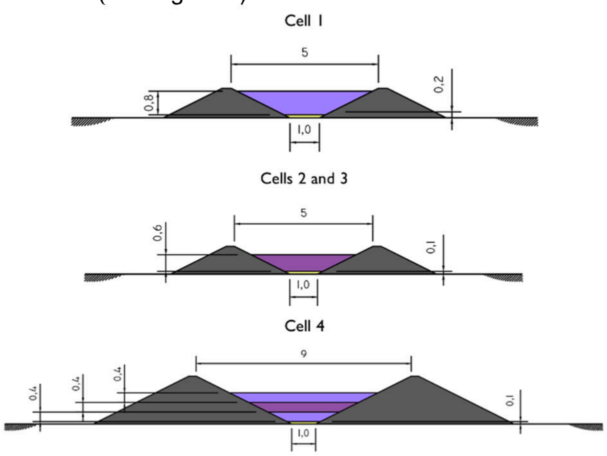

Figure 2. Configuration of experimental cells.

The monitoring system is composed of three levels equipped with volumetric water content probes, temperature sensors (thermistors), and suction sensors (watermark) and a level with oxygen sensors as it's show in the Figure 3.

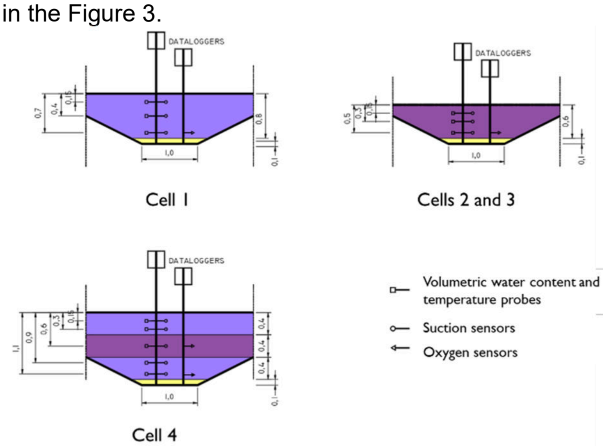

Figure 3. Instrumentation of experimental cells.

The second cell is composed of a clay-sand mixture, with a ratio of 5:1, a thickness of 0,6 m and a total volume of 5,8 m^3. The third one has the same geometry of cell 2 (see Figure 2) but composed of a mixture of clay and silt, also having a ratio of 5:1, a thickness of 0,6 m and a volume of 5,8 m^3. The monitoring system in both cases are identical and consist of three levels with moisture, temperature and suction sensors and a level with oxygen sensor (see Figure 3).

Finally, cell 4 is made up of two layers of clay with a thickness of 0.4 m and an intermediate layer of silt with a thickness of 0.4 m, as we can see in the Figure 2. This cell occupies a volume of 35,5 m^3. The monitoring system is composed of five levels with moisture, temperature and suction sensors and two levels with oxygen sensor as shown in Figure 3.

The construction process included excavation, geomembrane installation, installation of the outlet drains (consisting of a perforated pipe and a sand filter), backfilling and compaction. Compaction was made with a plate compactor using 20 cm layers. The mixture of materials was made at the site. Density and moisture content have controlled by using nuclear density gauge and a sample ring.

The monitoring system is completed with periodic tests to be performed throughout the year. Hydrogeological parameters are then measured in the laboratory (water retention curve, hydraulic conductivity) and in the field (hydraulic conductivity).

Hydraulic conductivity tests (Guelph permeameter) and outlet flow measurements will be carried out periodically in field. Filed water retention curve will be determined by means of instruments placed in the experimental cells (volumetric water content and suction sensors). This approach allows to compare lab, and field-measured data to identify the influence of construction factors, and to evaluate the evolution of hydrogeological parameters with meteorological conditions.

4.2 Material characterization

Throughout the backfilling process, samples of both installed (large volume) and compacted (ring) soils were collected. Samples were used to characterise soils placed in the cells. Characterization includes physical, mineralogical and hydrogeological testing in laboratory. Physical characterization involves particle size, specific gravity, Atterberg limits and proctor test. Mineralogical characterization is based on X-ray Diffraction (XRD) and X-ray Fluorescence (XRF) Analysis. Hydrogeological characterization involves saturated hydraulic conductivity. In this section, results of characterization testing are presented.

4.2.1 Physical characterization

Figure 4 shows the particles size distribution of materials used in cells construction. Based on it, placed soils can be classified as low plasticity clay (CL) for clayey soil (see Figure 5), and silty sand (SM) and fine sand (SP) for the soils used in amendments. Both mixtures were classified as low plasticity clay (CL) as shown in Figure 5. Table 2 resumes the results of physical characterization. Clay content varies between 16 and 18% for clay material and amendments, for sand materials is only 1%. Fine content varies from 91 to 97 % for clay material and amendments.

Clayed soils show a low – medium plasticity with IP values between 10 and 13.

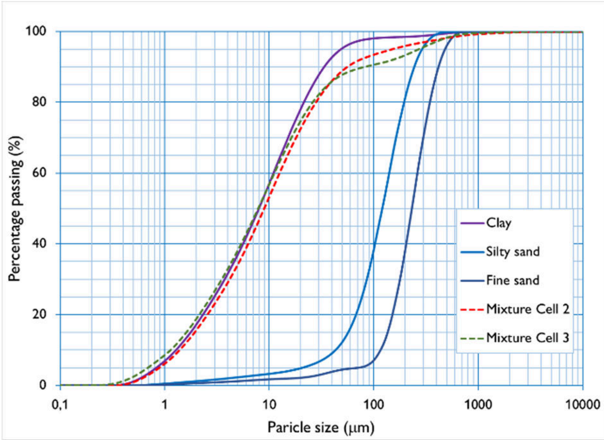

Figure 4. Particle size distribution of materials.

a)

b)

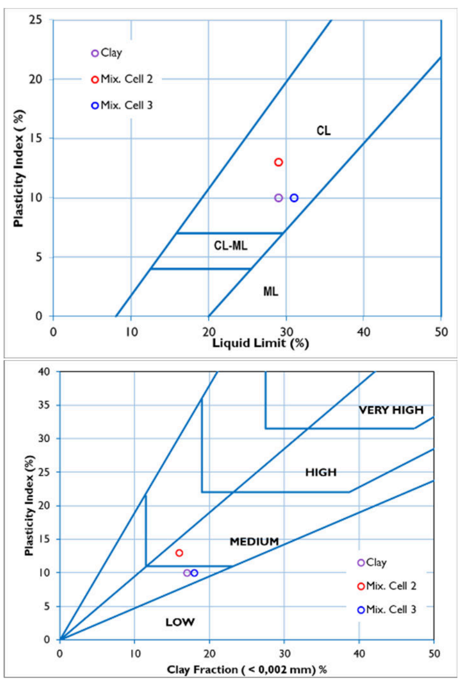

Figure 5. Plasticity chart (a) and Clay activity chart (b)

Table 2. Results of physical characterization

Properties	Clay	Silty Sand	Sand	Mix. Cell 2	Mix. Cell 3
Fines (%)	97	27	6	92	91
Clay (%)	17	1	1	16	18
IP	10	NP	NP	13	10
LL	29	NL	NL	29	31
D_{10} (mm)	1	43	116	1	1
D_{60} (mm)	12	140	262	14	12
SG	2,67	2,69	2,72	2,66	2,66
g_{opt} (kN/m^3)	17,5	18,9	17,6	--	--
w_{opt} (%)	4	11	15	--	--

Figure 5 presents the plasticity and clay activity charts for the clayey soil and the mixtures of cell 2 and cell 3. Plasticity chart based allows to determine low plasticity behavior in all the three samples. Clay activity chart shows low and medium swelling potential for the clay and mixture samples.

4.3 Mineralogical characterization

Table 3 and Table 4 illustrate the mineral species and chemical composition of clay sample. Mineral analysis made with XRD method, reveal a dominant composition of tectosilicates (albite, quartz, feldspar) and a minimal content of phyllosilicates (illite/muscovite, chlorite). Only 4% may be a clay mineral (illite). Analysis reports that may contain a small amount (not measurable) of vermiculite or smectite minerals. XRD analysis on sands reveals that these are composed by around 55% of quartz, 30% albite and other silicates to a smaller degree.

Table 3. Minerals species detected with XRD analysis

Mineral	Clay	Silty Sand	Sand
Quartz	21,9	55,4	46,8
Albite	26,7	30,1	31,1
K feldspar	8,2	4,9	3,0
Amphibole	7,0	4,5	2,9
Muscovite/Illite	3,6	3,0	3,8
Chlorite	4,6	2,1	3,2
Amorphous	28,0	n.d.	9,2

Table 4. Chemical composition, XRF analysis.

Mineral	Clay	Silty Sand	Sand
SiO2	61,2	73,6	75,0
Al2O3	15,7	11,3	11,8
Fe2O3	5,9	3,7	4,1
MgO	2,8	1,0	1,3
Na2O	3,1	3,4	3,5
CaO	2,5	2,6	2,7
K2O	2,6	1,5	1,3

XRF analysis allows to confirm the non-existence of expansive clay minerals. Analysis shows a composition of 61% of SiO_2 and 16% of Al_2O_3, other components (like CaO, MgO, Na_2O) are presents in a small proportion. In sands samples SiO_2 component is over 70%.

4.3.1 Hydrogeological characterization

As part of hydrogeological characterization, saturated hydraulic conductivity tests were conducted. Saturated hydraulic conductivity has measured through flexible wall permeameters for clayey soils and rigid wall for sandy soils.

Table 5. Results of laboratory hydraulic conductivity test

Material	Hydraulic Conductivity (m/s)
Clay	$2{,}2 \times 10^{-10}$
Silty sand	$6{,}7 \times 10^{-6}$
Sand	$8{,}5 \times 10^{-4}$
Mixture Cell 2	$1{,}8 \times 10^{-10}$
Mixture Cell 3	$1{,}8 \times 10^{-9}$

Table 5 resumes measured values of hydraulic conductivity. Measured values for cell materials (clay in Cells 1 and 4 and mixtures in Cell 2) are lower than maximum allowable value (10^{-9} m.s^{-1}). Measured value in Cell 3 is on the limit of acceptance criteria.

5 HYDROGEOLOGICAL BEHAVIOR OF THE EXPERIMENTAL CELLS

5.1 *In situ* permeability tests

Hydraulic conductivity tests were conducted in field using Guelph permeameter a week after cells construction. Two tests were realized in cells 1 and 3 and one test in each cell 2 and 4. Table 6 resumes the results of field testing.

Table 6. Results of *in situ* hydraulic conductivity test

Characteristics	Hydraulic Conductivity (m/s)
Cell 1	$8{,}9 \times 10^{-9}$
	$4{,}3 \times 10^{-7}$
Cell 2	$1{,}4 \times 10^{-9}$
Cell 3	$1{,}0 \times 10^{-7}$
	$1{,}1 \times 10^{-7}$
Cell 4	$3{,}7 \times 10^{-7}$

In general, in situ measured values are higher than laboratory values, even higher than literature criteria. More details are show in discussion section.

5.2 Volumetric water content measurements

As described in section 4.1, monitoring system includes continuous volumetric water content measures. Figure 6 shows the evolution of volumetric water content data from moisture sensors in the observation period (from 28 October 2021 to 30 April 2022). Superficial monitoring levels (15 cm deep) are traced in green, medium levels are traced in blue (30 - 40 cm deep) and orange (50 – 60 cm deep) and finally deep levels (70 - 110 cm) are traced in red. As the air temperature decreases, superficial monitoring levels record a decrease in the volumetric water content due to the freezing of water and lose of sensibility of sensors. Reduction takes place from 20 to 27 November. Same behavior has observed in medium levels later all through December. Depth levels shows decrease in the volumetric water content through January and February when the temperature is lower. the decrease is lower in the deep levels. Sensor located at -90 cm in Cell 4 don't shows decrease in volumetric water content due to low temperature. After second week of March sensors stars to record the data correctly, at the end of the observed period it's possible to read the volumetric water content between 0,34 and 0,46.

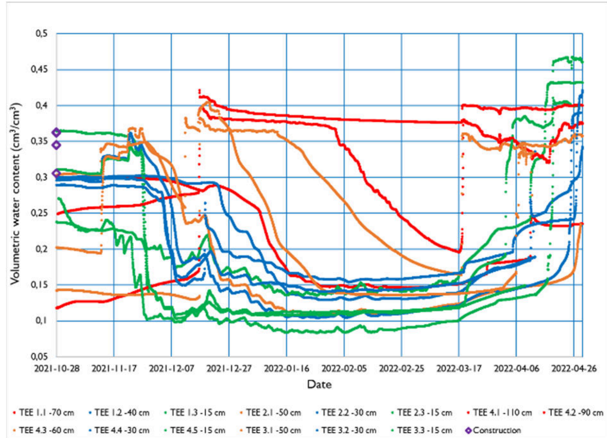

Figure 6. Volumetric water content monitoring data.

5.3 Suction measurements

Coupling moisture data, monitoring system includes suction sensors. Figure 7 plots suction measure data. Shallow monitoring levels are traced in green and deeper levels in red as in volumetric water content graph.

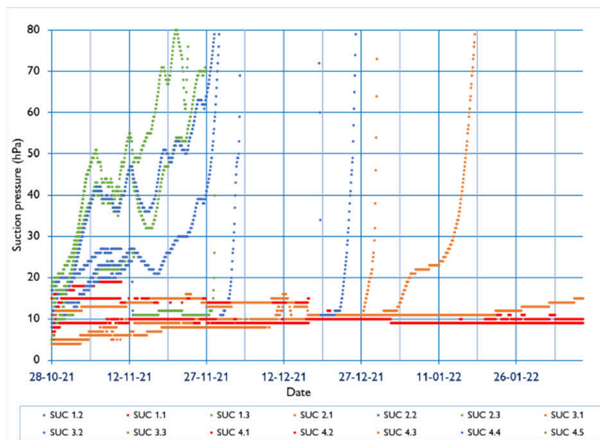

Figure 7. Suction monitoring data

Figure 7 allows to see dysfunction of suction sensors with the freezing. As the volumetric water content, shallow levels stop record good values (between 23 and 28 November) and then medium depth levels (from 28 November to 16 January). Depth levels don't show changes in suction levels with temperature decrease showing no influences of external temperature at these levels.

5.4 Temperature measurements

Similarly, Figure 8 presents the collected data from thermistors placed in the cells. Colors was chosen as above. Monitoring in soil temperature shows a low feedback on shallow levels and marginal changes in deeper instruments. More details are presented in discussion section.

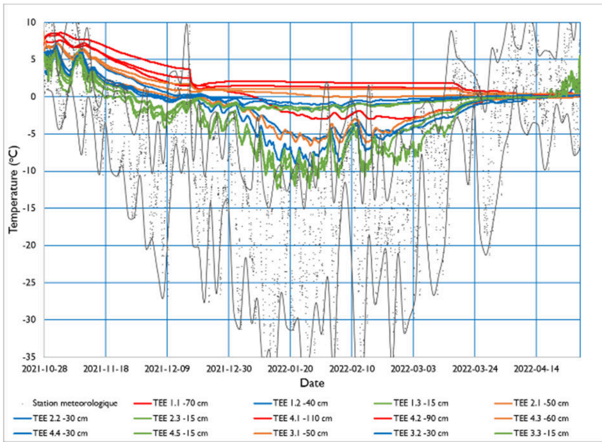

Figure 8. Soil temperature and regional temperature data

6 DISCUSSION

In this section we discuss preliminary results and collected data from monitoring system. In order to preliminary evaluate pertinence of selected materials, Table 1 and Table 2, can be contrasted. Chosen materials satisfy Table 1 criteria; only the clay content is not completely satisfying. Two of five criteria for clay content request at least 25% of clay, clayey soil of cell 1 and cell 4 has a clay content of 17%, cell 2 and 3 mixtures have 16 and 18% respectively. The other properties criteria (%F, LL, IP) are successful.

Figure 9 compares hydraulic conductivity measured from laboratory and field tests and estimate with prediction methods. Graph evidences that laboratory test ever results lower values of hydraulic conductivity than in situ tests.

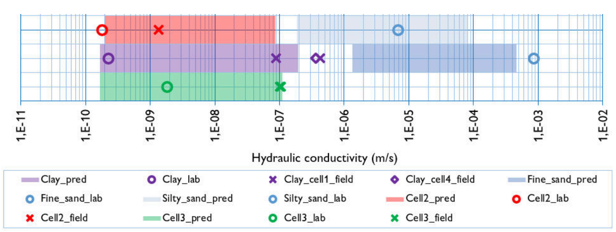

Figure 9. Hydraulic conductivity measured in laboratory and field

This fact evidences the influence of construction conditions, thus, Figure 10 compares field density, measured by nuclear gage and ring sampler. That reveals water content upper than optimal, as effect of construction under light rain conditions, and a density under 85% of optimal density due to both high water content and low compaction energy: compaction has made with a plate compactor. In situ values can be influenced by shortcomings in the equipment used for carrying out the tests.

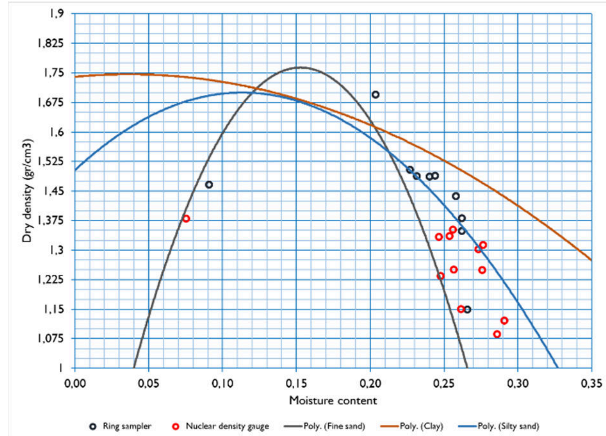

Figure 10. Proctor curves and placement density.

Although laboratory tests result adequate values of hydraulic conductivity (less than $1x10^{-9}$ $m.s^{-1}$) for clay and cell 2 mixture, in situ tests result in values greater than the established limit. Figure 9 also shows than cell 2 (clay - sand) has the lower values in both laboratory and field tests. Workability as result of sand amendment can explain this fact. Figure 11 reveals that porosity in cell 2 is lower, meaning a more efficient compaction. Workability of cell 2 mixture has been pointed out in laboratory sample reconstruction. Workability is portrayed in clods reduction and easy compaction by vibrations effects.

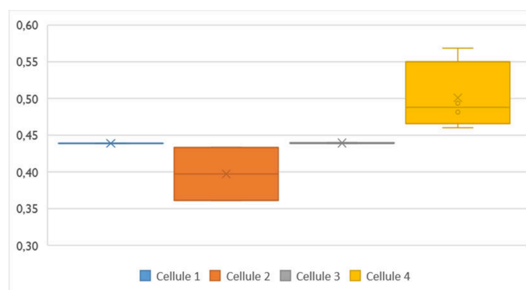

Figure 11. Ring sampler measured porosity

Volumetric water content data, showed in Figure 6, cannot be properly measured in freezing conditions due to the effect freezing water; at the end of the observed period we can to note a saturated conditions of soils layers. More observations allow to construct the in-situ WRC as the soil has been desaturated by drainage and meteorological conditions.

Results of suction measurements are presented in Figure 7. This figure allows to see an influence of the atmospheric temperature in suction values measured in the more superficial monitoring levels, placed 15 cm deep, in cells 1, 3 and 4, and 30 cm deep in cell 4. An attenuated variation is also seeing in medium deep levels.

Similar behavior is evidenced in Figure 8 for soil temperature, in this case soil temperature descends with atmosphere temperature but in a reduced proportion. While atmospheric temperature descends 47 °C (between 13 and -34 °C), soil temperature only descends 9 °C (between 6 and -3 °C) in the critical case (Cell 4 at -15 cm). the influence of atmosphere temperature decreasing with depth, the deeper monitoring levels (70 – 110 cm) temperature is ever upper 0 °C allowing to conclude that material are not affected by freeze and thaw effect.

Figure 12. Experimental cells aspect after snow melting.

During the early days of May, after snow melting, a field visit was carried out. Aspect of cells on this day are show in Figure 12: Cell 1 was saturated with a very plastic behavior and a very low bearing capacity; drain was clear of water. Cell 2 was flooded with 6 to 10 cm of water and the drain was empty, evidencing a good performance and a very low hydraulic conductivity. In contrast, Cell 3 was a consistent aspect with dry zones and a normal bearing capacity. Several cracks and deformations are observed and drain was dropping. Finally, Cell 4 shows a plastic aspect in a saturated condition, nevertheless drain shows dropping.

Finally, data from gas concentrations doesn't has analyzed for this paper.

7 CONCLUSION

Observation time is too short for make conclusions about a hydraulic barrier performance of clayey soils in Abitibi, Quebec. However, several aspects of clay hydrogeological behavior can be pointed. First, Abitibian clay deposit can be preliminary selected as material with hydraulic barrier function because of their basic physical properties (% Fines, % Clay, IP, LL, % Gravel) matched with revised criteria.

Density test, in situ and laboratory permeability tests, and observations carry out after snow melting, preliminary indicated that Cell 2 are the most performant. This is because of the workability and best conditions for compacting clay by adding sand.

Hydraulic conductivity measured in laboratory test is lower than values measured in situ. Construction conditions like water content and compaction energy can influence the resulting hydraulic conductivity. Measure methods can influence measured values: for example, the saturation phase of the laboratory test may take many weeks instead of a few hours of in situ testing in the saturation phase.

Hydraulic conductivity is affected by amendments. Atmosphere temperature influences soil temperature and suction measured in cells. The effect of temperature is higher on superficial monitoring levels and dissipate with depth. In the observation period soil temperature don't come under 0 °C for deeper levels.

It's necessary to continue monitoring cells behavior to adequately evaluate clay-based hydraulic barriers performance.

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