Creep properties of filtered tailings: design of a temperature-controlled uniaxial constant load testing apparatus and preliminary results

Mutaz Nujaim, Vincent Boulanger-Martel, Bruno Bussière & Weber Anselmo Dos Ramos Souza
Université du Québec en Abitibi-Témiscamingue - Research Institute on Mines and Environment (RIME-UQAT), 445 University Blvd, Rouyn-Noranda, QC, J9X 5E4, Canada
Thomas Pabst
Department of Civil, Geological, and Mining Engineering, Ecole Polytechnique de Montréal, P.O. Box 6079, Station Centre-ville, Montréal, QC, H3C 3A7, Canada

GeoCalgary 2022 October 2-5
Reflection on Resources

ABSTRACT
Filtered tailings gain popularity in the mining industry to reduce the risks associated with the physical stability of tailings storage facilities, especially for mine sites located in arctic regions. However, filtered tailings storage facilities can be heterogeneous and ground deformation can occur over time. Thus, it is imperative to gain knowledge on the geotechnical properties of frozen filtered tailings to design accordingly. In this perspective, a temperature-controlled uniaxial constant load testing apparatus was designed to obtain the creep properties of filtered tailings. This article first aims at presenting the design of the apparatus, instrumentation, and validation procedure. Then, preliminary results obtained on frozen filtered tailings from the Raglan mine are presented and discussed. The main results showed that creep increases proportionally with the increase in time, stress, and water content of the sample.

RÉSUMÉ
Les résidus filtrés gagnent en popularité auprès de l'industrie minière afin de réduire les risques associés à la stabilité physique des aires de stockage des résidus miniers, surtout pour les sites situés dans les régions arctiques. Cependant, les parcs à résidus filtrés peuvent être hétérogènes et des déformations peuvent se produire au fil du temps. Il est donc impératif d'acquérir des connaissances sur les propriétés géotechniques des résidus filtrés gelés afin de concevoir adéquatement. Dans cette perspective, un appareil d'essai uniaxial à charge constante et à température contrôlée a été conçu pour obtenir les propriétés de fluage de résidus filtrés. Cet article vise d'abord à présenter la conception de l'appareil, l'instrumentation et la procédure de validation. Ensuite, des résultats préliminaires obtenus sur des résidus filtrés gelés provenant de la mine Raglan sont donnés et discutés. Les principaux résultats ont montré que le fluage augmente proportionnellement à l'augmentation du temps, de la contrainte et de la teneur en eau de l'échantillon.

1 INTRODUCTION

The mining industry faces several hydro-geotechnical challenges associated with the storage of mine tailings. To reduce the risks associated with the physical stability of structures, it is increasingly proposed to reduce the quantity of water before deposition by filtering the tailings; filtered tailings are gaining popularity with the mining industry, particularly for northern mine sites (Bussière 2007, Davies et al. 2010). Filtered tailings are characterized by a high solid percentage (≈ 80-85% relative to the total mass) compared to typical values for pulped (25-40% solids) or thickened (50-70% solids) tailings (Davies et al. 2010). They are typically trucked to the tailings storage facility (TSF) and leveled/compacted in thin layers. From a geotechnical point of view, one of the challenges is related to the densification (mechanical compaction) of the tailings, which is usually achieved by the repeated passage of bulldozers and haul truck traffic. Also, freezing of the tailings before their compaction or an excessive presence of snow and water in the tailings can prevent adequate densification during their placement. Another geotechnical challenge is associated with building on a permafrost foundation. Several forms of interstitial ice, that can vary from small ice lenses to large inclusions, such as ice wedges and massive ice deposits can be found in permafrost foundation (Ladanyi and Andersland 2004, French 2017). The presence of such ice inclusions must be considered when choosing the location of a TSF to ensure its long-term stability (Rykaart and Hockley 2010). These phenomena associated with tailings deposition and densification as well as their foundation imply that filtered TSFs can be heterogeneous structures in terms of density and ice (or water) distribution.

The presence of such a heterogeneous system (foundation and mine tailings) of frozen and/or partially frozen materials leads to several mechanical, thermal, and hydrogeological processes that can influence the geotechnical behavior of the pile in the short- and long-term. Mechanisms such as thaw settlement, thaw consolidation, and creep can be the cause of significant ground settlement and deformation over time (Ladanyi and Andersland 2004). These characteristics generally depend on the soil type, structure, density, amount of ice and temperature, as well as the extent and type of loading (Sayles and Haines 1974). Thus, it is imperative to gain knowledge on the geotechnical properties of frozen filtered tailings to design accordingly.

Creep can have a significant impact on ground settlement and movement over time. Vialov and Tsytovich (1955) attribute creep in frozen soil to: pressure melting of the ice in the soil at points of soil grain contact, migration of unfrozen water to regions of lower stress, breakdown of the ice and structural bonds to the soil grain, plastic deformation of pore ice, and a readjustment in particle arrangement. Creep laboratory tests (one-dimensional and triaxial creep tests) are used to investigate the creep characteristics of soils and to predict the creep behaviour of soil in the long term (Sayles 1974; Sayles and Haines 1974; Eckardt 1982; Nixon and Lem 1984; Yuanlin and Carbee 1987; Wijeweera and Joshi 1991; Fish 1994). In traditional creep testing, a soil sample is loaded to predetermined effective stress and then allowed to creep under constant effective stress (Sayles 1968; Wijeweera and Joshi 1991; ASTM-D5520 2001, 2018). Long-duration creep tests can be required to capture the long-term creep behaviour of soil.

In this perspective, it is important to gain knowledge on the strength and deformation characteristics of filtered tailings. The first objective of this article is to present the design, instrumentation and validation of a temperature-controlled, uniaxial constant load testing apparatus that can be used to obtain the creep properties of frozen filtered tailings. Preliminary creep curves were obtained for Raglan mine's filtered tailings at a temperature of -8°C and for several degrees of saturation and loading conditions.

2 MATERIALS AND METHODS

2.1 Materials

The Raglan mine produces filtered tailings that are at approximately 85% solids (wt%/wt%). For this study, fresh filtered tailings were sampled directly from the Raglan mine's TSF. The filtered tailings were stored in plastic buckets and immersed with water to prevent the tailings from oxidation. The tailings were then sent to the laboratory for testing.

The mineralogical, chemical, physical, hydrogeological and thermal properties of the Raglan mine tailings were characterized by several authors (e.g., Coulombe 2012; Lessard et al. 2018; Larochelle et al. 2021). Table 1 provides a summary of the main geotechnical properties of the Raglan tailings.

The tailings' grain size distribution (GSD) is typically a low plasticity silty sand (80% passing 80 µm; Coulombe 2012). The GSD of the tested Raglan tailings was determined on a homogenized sample using a Malvern Mastersizer S 2000® (Malvern Panalytical, Malvern, UK) laser particle. The GSD of the tested tailings is presented in Figure 1. The GSD shows that about 50% of the tailings are finer than 20 µm and that the average percentage of fine particles (passing 80 µm) is about 80% (Table 1). Coefficients of curvature (C_c) and uniformity (C_u) of 0.77 and 12.5 were calculated, respectively. Similar results were obtained by Coulombe (2012). For the Raglan tailings, the values of C_c and C_u typically vary between 0.9 and 1.1, and 14.8 and 16.5, respectively. A specific gravity (G_s) of 3.07 was obtained for the tailings using a helium pycnometer (AccuPyc 1330, MicroMeritics, Norcross, GA, USA). Such G_s is slightly higher than those obtained by Coulombe (2012), which varied from 2.86 to 2.94. Coulombe (2012) measured a saturated hydraulic conductivity (k_{sat}) of 3.5×10^{-5} cm/s, an air entry value (AEV) air entry value (AEV) is of 300 cm as well as a residual suction (ψ_r) of 10000 cm at a residual volumetric water content (θ_r) of 0.05 m³/m³.

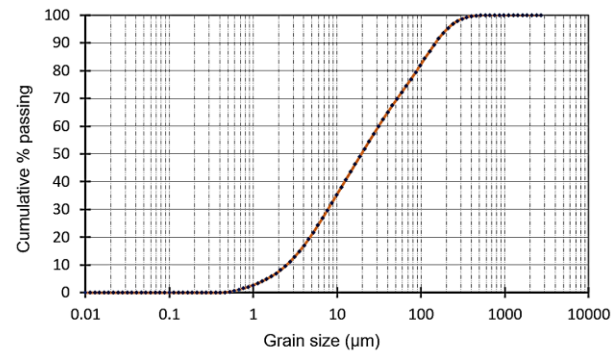

Figure 1. Grain size distribution of the tested Raglan tailings.

Table 1. Main geotechnical properties of the Raglan tailings

Parameter	Units	Value
$Cu = D_{60}/D_{10}$	(-)	12.50
$Cc = D_{30}^2/(D_{60}*D_{10})$	(-)	0.77
$U = (D_{90}-D_{10})/D_{50}$	(-)	7.49
D_{10}[1]	(µm)	2.2
D_{30}[1]	(µm)	6.8
D_{50}[1]	(µm)	17.2
D_{60}[1]	(µm)	27.5
D_{90}[1]	(µm)	131.0
Gs	(-)	3.07
k_{sat}[2]	cm/s	3.5×10^{-5}
AEV[2]	cm	300
ψ_r[2]	cm	10000
θ_r[2]	m³/m³	0

[1]D_x: diameter corresponding to x w/w % passing on the cumulative grain-size distribution curve
[2]: data from Coulombe (2012)

2.2 Experimental setup

For the purpose of this study, a temperature-controlled constant-load creep apparatus was designed to determine the creep properties of frozen filtered tailings (Figure 2).

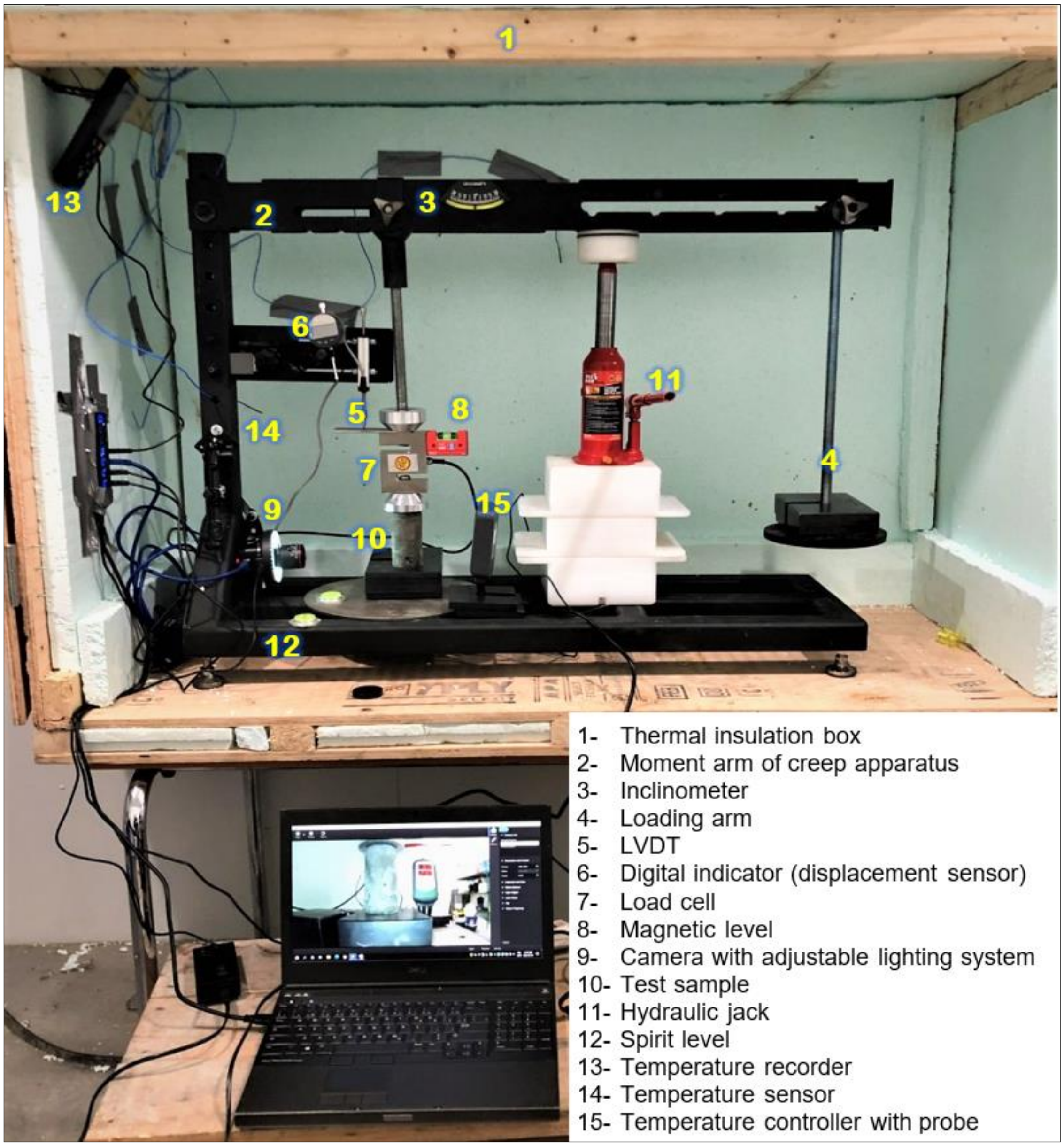

Figure 2. Uniaxial creep test apparatus

The structure of the creep load frame was made of rectangular steel tubing (5 cm-wide), and is overall 110 cm-long, 80 cm-high and 35 cm-wide. The base of the set-up contains four threaded adjustable leveling feet to ensure that the base can be leveled prior to performing a creep test. The loading platen is 7.62 cm wide (3-in diameter). Because specimen diameter increases during a creep test, the platen must be wide enough to contain the sample during deformation. Therefore, the loading platen is wide enough to allow testing samples up to 7.62 cm in diameter.

The moment arm (no. 2; Figure 2) is adjustable at five positions (10 cm spacing) so that the applied load to the sample can be increased or decreased. The selected load is applied to the moment arm by steel dead weights added to the loading arm (no. 4; Figure 2). A hydraulic jack (no. 11; Figure 2) is used to keep the moment arm horizontal before the tests. The hydraulic jack also gradually transfers the load from the loading arm to the sample. The inclination of the moment arm can be validated with an inclinometer (no. 3; Figure 2) installed along the moment arm.

The apparatus is equipped with a RAS1-05KS-S (Loadstar-sensors) load cell (no. 7; Figure 2) and a LVDT-050M-V (Loadstar-sensors) linear variable differential transformer (LVDT) displacement sensor (no. 5; Figure 2). The load cell has a capacity of 2068 kg, and the displacement sensor can measure a maximum displacement of 50 mm. A magnetic level (no. 8; Figure 2) is also attached to the load cell to verify the verticality of the bar that transmits the load to the sample. The load cell and LVDT sensor are connected to DI-1000U and DI-1000U-5V resistive interfaces (Loadstar-sensors), respectively. Such interfaces are used for data acquisition and logging. Another digital indicator for displacement measurements (no. 6; Figure 2) is also used to compare accuracy, calibration, and to continuously measure strain in the event of a power failure. A full-frame 16MP-camera (Mokose) equipped with an adjustable illumination system is used to record images for the sample during the test at predetermined time intervals (no. 9; Figure 2).

This creep apparatus was installed in a temperature-controlled chamber (cold room) and housed in an insulating box (no. 1; Figure 2) to reduce potential fluctuations in air temperature. Also, several types of accurate temperature sensors were used to check the stability of the sample temperature during the test, as a slight fluctuation could spoil the time-consuming creep results. The temperature measurements inside and outside the insulating box in the cold room (temperature-controlled chamber) were recorded to check the stability of the temperature in the room. Four type-K thermocouples (accuracy of ±0.5°C) were placed at different locations inside the insulating box (no. 14; Figure 2) to monitor the surrounding air temperature. The thermocouples were connected to a Perfect-Prime TC0521 data logger. The temperature measurements were verified by comparing the four K type-thermocouple sensors (two exposed tips and two metal head 3x30mm) to a platinum ultra-accurate digital traceable thermometer equipped with a 316 stainless-steel probe (±0.05°C of accuracy).

2.3 Calibration process

The sensors used with this apparatus have been calibrated by the manufacturers according to their calibration process. In addition, the calibrations of most measurement tools were validated in the laboratory prior to testing. The load cell measurements (loading/unloading) were compared to the load applied by standard dead weights placed on the loading arm (Figure 3a). The LVDT measurements were also compared to an accurate digital indicator and the results indicated high accuracy of the displacements measured by the LVDT sensors (Figure 3b). Before calibration and testing, the bubble levels and inclinometer are used to check the horizontality of the base and the verticality of the load arm.

The temperatures measured by the thermocouples inside and outside the insulated box were calibrated by the ultra-accurate traceable digital platinum thermometer fitted with a 316 stainless steel probe (±0.05°C accuracy). Figure 3c shows that the temperature measured in the controlled atmosphere room (outside; Figure 3c) is slightly lower than that inside the insulated box. Overall, temperature monitoring indicates that the temperatures inside the insulated box are maintained stable and dampens the temperature variations of the controlled atmosphere rooms. The maximum temperature variation inside the insulated box is ±0.5°C, which is within the typical maximum tolerance for tests performed at such temperatures (ASTM-D5220 2018).

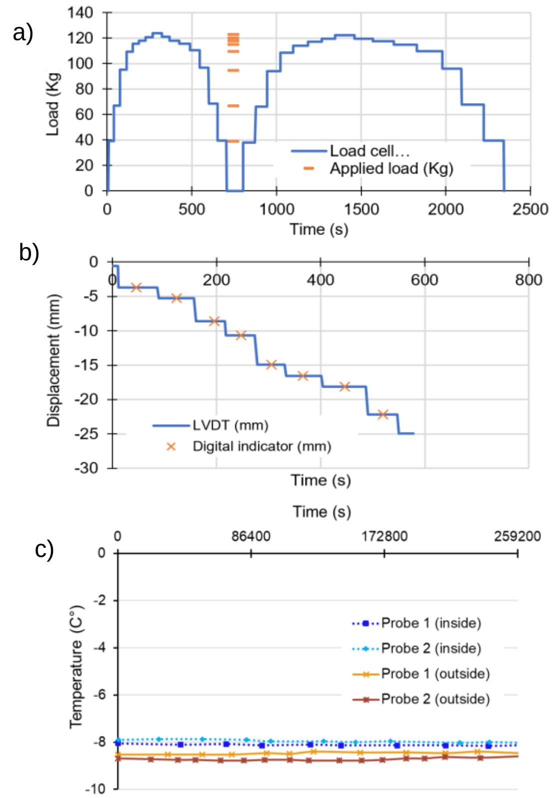

Figure 3. Calibration process and results for (a) the load cell during loading and unloading, (b) the LVDT and digital indicator measurements, and (c) the temperature recorded inside and outside the insulated box.

2.4 Experimental approach

2.4.1 Specimen preparation

The tailings sample preparation was done in three main steps (Figure 4). First, the tailings were homogenized at a selected water content (Figure 4a). Second, the homogenized tailings were placed in 10.16 cm high (4 in) by 5.08 cm-diameter (2 in) plastic molds (Figure 4b). Silicon grease was added to the inner surface of the molds to reduce friction during the ejection of the samples from the mold. Depending on the water content of the tailings, samples were compacted with a compaction hammer (low water contents) or compacted by vibration (by tapping the sides of the mold) during filling to remove air bubbles. Third, the sample molds were placed in a temperature-controlled chamber (cold room) at a temperature of -8C°. The specimens were frozen in an open system by removing the top cover of the mold. The soil specimens were frozen rapidly in an attempt to minimize ice lensing (Sayles and Haines 1974). After ejection from the mold, each test specimen was inspected for imperfections and cut to the right length (Figure 4c). The nominal size of the specimens after trimming was 50 mm in diameter by 100 mm in height. Handling of the frozen tailings samples was done in the cold room at freezing/testing temperature. It is important to mention that the tailings were placed in a closed mold after preparation. A small hole was made on the top lid of the mold to allow the material to freeze without loss of moisture. After the samples were frozen, the holes in the top lids were sealed with grease to prevent moisture loss due to the long period of storage in the cold room. The water contents of the filtered tailings samples were verified before freezing as well as before and after the tests.

(a) (b) (c)

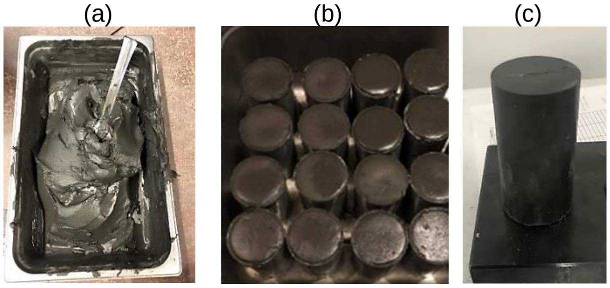

Figure 4. (a) Homogenization of tailings and preparation of samples at different water contents; (b) molds filled with tailings after compaction; (c) trimmed sample before testing.

2.4.2 Experimental program

A creep testing program is usually designed to provide a relationship between the creep strength and the magnitudes of factors such as time to failure, steady-state or minimum creep rate, strain at failure, and temperature (ASTM-D5520 2001; 2018). For a given frozen soil and a constant temperature, the relationship between the creep strength and the minimum creep rate can be obtained from a series of constant-stress creep tests at different stress levels and can be represented in a log (stress) versus log (minimum creep rate) plot (ASTM-D5520 2001; 2018).

The preliminary tests performed in this study were carried out at a fixed temperature of approximately -8C°. The first three tests were carried out at water contents of 20%, 28% and 35%. A fourth test sample was prepared at a water content of 32.8% with silicon grease applied to the outer surface) to limit sample's mass loss to evaporation. Samples were submitted to stepped-loading creep tests as described by ASTM-D5520 (2001; 20108). Each load increment was maintained for 72 hours. Samples were incrementally loaded every 3 days using loads of 72, 107, 142 and 172 Kg. In terms of stress, these load increments correspond to values of 360, 535, 710 and 860 kPa, respectively.

3 PRELIMINARY RESULTS

This section presents the results and interpretation of four creep tests performed at -8C° on frozen filtered tailings. Three samples were prepared at water contents of 20%, 28% and 35% without grease on the outer surface. The fourth sample was prepared at a water content of 32% and was covered with silicon grease to prevent the loss of water content. The temperature inside the insulated box was recorded throughout the tests to monitor any change in testing temperature. Overall, the temperature inside the insulated box was maintained stable at -8°C ±0.3°C for all tests (Figure 5a).

The main results show that creep increases proportionally with the increase in time, stress, and water content of the sample (Figure 5b; c). When the first load was applied (360 kPa), samples recorded an initial displacement mostly attributed to pre-loading conditions and platen-to-sample contact. This initial displacement can be relatively important because the platen must make full contact with the sample until the end of the load transfer (displacement typically observed during the first 30 seconds after loading). This instantaneous displacement resulting from the initial load has been removed from the results presented in Figure 5.

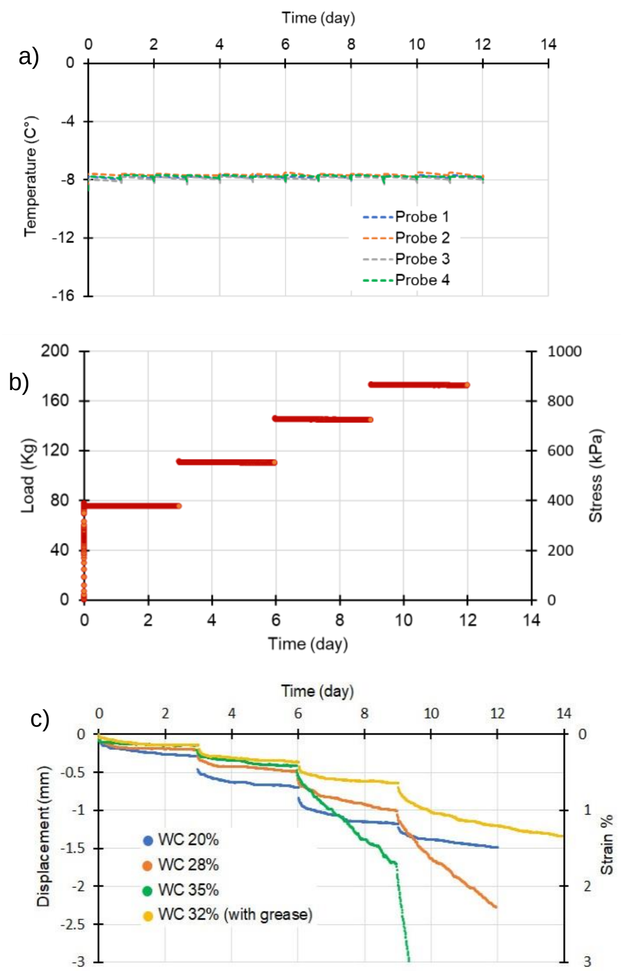

Figure 5. Creep test results of specimens: (a) temperature recorded during the first test (similar results for following tests), (b) applied load, and (c) measured displacements.

The water content for the samples prepared with no grease was slightly affected during freezing and storage and largely during testing. For the samples at water contents of 28% and 35% lost approximately 22% of their water content during the freezing-storage stage and testing. These samples reached creep failure at 710 kPa. The sample prepared at a water content of 20% desaturated during preparation and testing down to a water content of 10%. The sample did not fail at 860 kPa although it showed large axial strain. Figure 6 shows images for the first three samples (no grease) before and after of the test.

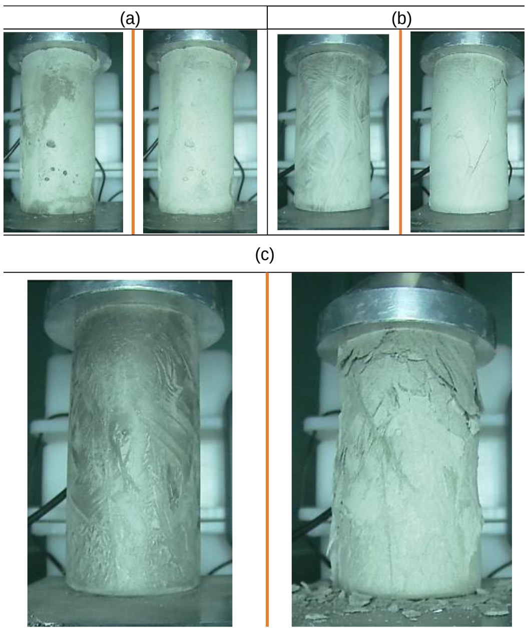

Figure 6. Images recorded before and after testing for the samples at a water content of: a) 20%, b) 28%, and c) 35% (animated photo).

The fourth test was for a sample prepared at a water content of 32% of water content and covered with silicon grease to prevent its desaturation during the test (Figure 7). The water content of the sample after the test was approximately 31% and the sample did not reach failure after 860 kPa of loading (Figure 5c).

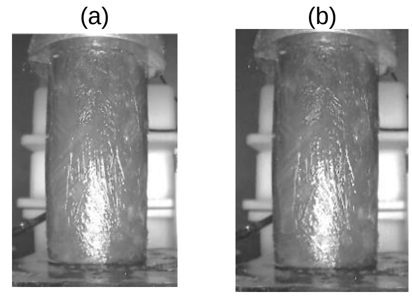

Figure 7. Images recorded for the greased sample: (a) before the test; (b) after the test.

4 DISCUSSION ON FUTURE IMPROVEMENTS

The actual laboratory setup can be used to obtain the creep properties of frozen materials at different temperatures – the temperature of a sample is controlled by the temperature of the cold room. In this context, the precision and degree of control on the testing temperature is limited to about ±1-2 °C. However, for most frozen soils/geomaterials applications, it is important to control well the testing temperature. Therefore, future improvements on the experimental setup described in this article involve adding a precise temperature-control system attached to the top and base of the loading platens (Figure 8). To do so, two aluminum heat exchange plates were designed to allow the circulation of a heat transfer fluid (ethylene glycol) and control the temperature of the top and base of the tested sample. The heat exchange plates are connected in closed system to a VWR® refrigerated circulating bath (-40° to 200°C) which allows to precisely control the testing temperature.

With this approach, the temperature of the cold room should first be set close to the targeted testing temperature. Then, the testing temperature can be micro-adjusted using the circulating bath and the heat exchange plates.

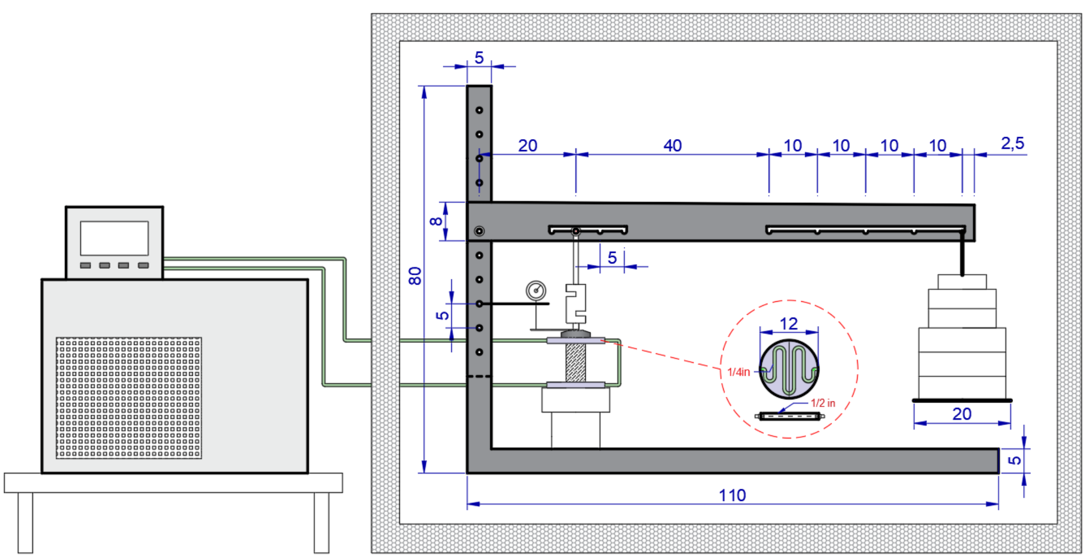

Figure 8. Proposed improvements for the uniaxial constant-load temperature-controlled creep test (dimensions in cm).

5 CONCLUSION

This study aimed at designing of a temperature-controlled, uniaxial constant load testing apparatus that was used to obtain preliminary creep properties of frozen filtered tailings from the Raglan mine. The instrumentation used to monitor temperature, displacement and load was calibrated and validated in the laboratory. A methodology for testing the creep properties of filtered tailings using a stepped-loading approach was developed. The results obtained for grease-less samples were affected by evaporation/desaturation Losses of moisture reduces the cohesion between soil particles and affects the strength and creep behavior of geomaterials. The grease-coated sample provided a typical creep behavior. Therefore, it is recommended to apply grease to the surface of the samples to reduce evaporation induced drying. The developed apparatus will be further validated by performing creep tests on known frozen materials (ice, clay, silt, etc.). As a part of the validation process, the obtained results will be compared to previous studies on frozen soil (e.g., Mellor and Smith 1966, Sayles 1968, Sayles and Haines 1974, Yuanlin and Carbee 1987, Joshi and Wijeweera 1990, Wijeweera and Joshi 1991). The work on filtered tailings will also be pushed further to obtain the creep properties of the Raglan tailings at different water contents, density, temperatures, and pore-water salinity. The results will be used to create a constitutive model and predict the long-term creep of filtered tailings from the Raglan mine.

6 ACKNOWLEDGMENTS

This study was funded by the FRQNT as a part of the -*Développement durable du secteur minier* program and by the Research Institute on Mines and the Environment (RIME UQAT-Polytechnique; http://www.irme.ca). The personnel from the Raglan mine's environment department is thanked for their collaboration.

7 REFERENCES

ASTM-D5520. 2001. Standard test method for laboratory determination of creep properties of frozen soil samples by uniaxial compression (D 5520). In: Annual Book of ASTM Standards. ASTM, Philadelphia (Reapproved 2001).

ASTM-D5520. 2018. Standard test method for laboratory determination of creep properties of frozen soil samples by uniaxial compression (D 5520). ASTM: West Conshohocken, PA, USA.

Boulanger-Martel, V. 2019. Évaluation de la performance de recouvrements miniers pour contrôler le drainage minier acide en climat arctique. Polytechnique Montréal.

Boulanger-Martel, V., Bussière, B., Côté, J., and Mbonimpa, M. 2016. Influence of freeze–thaw cycles on the performance of covers with capillary barrier effects made of crushed rock–bentonite mixtures to control oxygen migration. Canadian Geotechnical Journal, 53(5): 753-764.

Bussière, B. 2007. Colloquium 2004: Hydrogeotechnical properties of hard rock tailings from metal mines and emerging geoenvironmental disposal approaches. Canadian Geotechnical Journal, 44(9): 1019-1052.

Coulombe, V. 2012. Performance de recouvrements isolants partiels pour contrôler l'oxydation de résidus miniers sulfureux. Université du Québec en Abitibi-Témiscamingue.

Côté, J., and Konrad, J.-M. 2009. Assessment of structure effects on the thermal conductivity of two-phase porous geomaterials. International Journal of Heat and Mass Transfer, 52(3-4): 796-804.

Davies, M., Lupo, J., Martin, T., McRoberts, E., Musse, M., and Ritchie, D. Dewatered tailings practice–trends and observations. *In* proceedings of Tailings and Mine Waste. 2010.

Eckardt, H. Creep tests with frozen soils under uniaxial tension and uniaxial compression. In Proceedings of the 4th Canadian Permafrost Conference, Calgary, Alberta, National Research Council of Canada. 1982. pp. 365-373.

Fish, A.M. 1994. Creep and Strength of Frozen Soil Under Triaxial Compression. Cold Regions Research and Engineering Lab Hanover NH.

French, H.M. 2017. The periglacial environment. John Wiley & Sons.

Joshi, R.C., and Wijeweera, H. Post peak axial compressive strength and deformation behavior of fine-grained frozen soils. *In* Proc. Proceedings of the Fifth Canadian Permafrost Conference. 1990. Citeseer. pp. 317-325.

Ladanyi, B., and Andersland, O. 2004. Frozen ground engineering. Wiley.

Larochelle, C.G., Bussière, B., Boulanger-Martel, V., Wilson, W., and Rivest, É. In situ thermal behavior of an insulation cover for mine site reclamation in arctic climate.

Kyhn, C., and Elberling, B. 2001. Frozen cover actions limiting AMD from mine waste deposited on land in Arctic Canada. Cold Regions Science and Technology, 32(2-3): 133-142.

Ladanyi, B., and Andersland, O. 2004. Frozen ground engineering. Wiley.

Lessard, F. 2018. Évaluation des couvertures isolantes avec effets de barrière capillaire faites de résidus désulfurés afin de contrôler le drainage minier acide en conditions nordiques. Ecole Polytechnique, Montreal (Canada).

Mellor, M., and Smith, J.H. 1966. Creep of snow and ice.

Nixon, J., and Lem, G. 1984. Creep and strength testing of frozen saline fine-grained soils. Canadian Geotechnical Journal, 21(3): 518-529.

Qualitas. 2013. Factual report. Campagne d'investigation géotechnique. Forages réfrigérés.Projet de rehabilitation du parc à résidus de Mine Raglan, Nunavik. File 3301201. 16 October 2013.

Rykaart, M., and Hockley, D. 2010. Cold Regions Cover Research–Phase 2. Mine Environment Neutral Drainage (MEND). Rapports. Prévision, 1: 72p.

Sayles, F.H. 1968. Creep of frozen sands. COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER NH.

Sayles, F.H. 1974. Triaxial constant strain rate tests and triaxial creep tests on frozen Ottawa sand. No. 253. Corps of Engineers, US Army Cold Regions Research and Engineering Laboratory.

Sayles, F.H., and Haines, D. 1974. Creep of frozen silt and clay. No. 252. Corps of Engineers, US Army, Cold Regions Research and Engineering Laboratory.

SNC Lavalin. 2009. Caractérisation du parc à résidus miniers de la mine Raglan - Rapport final

SNC Lavalin. 2014. Tailings storage facility deformation study - final report, file 507215-8000-4GER-0001.

Wijeweera, H., and Joshi, R. 1991. Creep behavior of fine-grained frozen soils. Canadian Geotechnical Journal, 28(4): 489-502.

Yuanlin, Z., and Carbee, D.L. 1987. Creep and strength behavior of frozen silt in uniaxial compression.