Monitoring the performance of wood blocking system for remediating timber piles in the Arctic

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ABSTRACT
Timber piles, traditionally used as the primary building foundation type in the Canadian Arctic, are vulnerable to climate change and other environmental impacts. The serviceability of timber piles is impaired by the seasonal temperature change that leads to subsidence and heave of the piles. Timber materials are being decayed by physical, chemical, and biological actions. A technique is needed to remediate damaged timber pile foundations in the Arctic. Among various methods, the wood blocking system is often adopted to replace severely damaged piles in Northwest Territories (NWT). Although this technique is common, a health monitoring program for the remedied building is rare. The present paper shows a wood blocking system for the remediation of timber piles supporting a three-story apartment building in Inuvik, NWT. The natural topsoil was removed and filled with compacted coarse gravels. The wood blockings, placed on the gravel fill, were to replace the timber piles that had been cut off or trimmed. To monitor the performance of the wood blocking system and provide early warning for excessive building movement, a field monitoring program consisting of 6 Linear Potentiometers was deployed in October 2019. In this program, building displacement data were collected and transferred with a cellular modem via the mobile network. The air and permafrost temperatures are not monitored but they can be obtained from other sources in Inuvik. By combining the measurement of displacement and the seasonal local weather of more than 6 months, the factors that dominate the performance of wood blockings and the building can be identified.

RÉSUMÉ
Les pilots en bois, traditionnellement utilisés comme matière première dans la construction de fondation dans l'Arctique canadien, sont vulnérables aux changements climatiques et à d'autres impacts environnementaux. L'efficacité des pieux de fondation en bois est altérée par le changement de température saisonnier qui conduit à l'affaissement et au soulèvement des pieux. Les matériaux en bois pourrissent par l'attaque d'agents physiques, chimiques et biologiques. Une procédé de réparation des pilots de bois est nécessaire pour rétablir les fondations de pieux en bois détériorés dans l'Arctique. Parmi diverses méthodes, le système de blocage du bois est souvent adopté pour remplacer les pieux gravement endommagés dans le Territoire du Nord-Ouest (TN-O.). Bien que cette technique soit courante, un programme de surveillance de la santé du bâtiment remédié est rare. Le présent document montre un système de blocage en bois pour l'assainissement des pieux en bois supportant un immeuble à trois étages à Inuvik, TN-O. La couche arable naturelle a été enlevée et remplie de graviers grossiers compactés. Les blocs de bois, placés sur le remblai de gravier, devaient remplacer les pieux de bois coupés ou parés. Pour surveiller les performances du système de blocage du bois et fournir une alerte précoce en cas de mouvement excessif du bâtiment, un programme de surveillance sur le terrain comprenant 6 potentiomètres linéaires a été déployé en octobre 2019. Dans ce programme, les données de déplacement du bâtiment ont été collectées et transférées avec un modem cellulaire via le réseau mobile. Les températures de l'air et du pergélisol ne sont pas surveillées, mais elles peuvent être obtenues auprès d'autres sources à Inuvik. En combinant la mesure du déplacement et la météo locale saisonnière de plus de 6 mois, les facteurs qui dominent la performance des blocs de bois et du bâtiment peuvent être identifiés.

1 INSTRUCTION

Deep foundations are nearly the sole solution for building foundations in the Canadian Arctic. Timber piles have been commonly used in the Arctic due to their cost-effectiveness and resource sufficiency since the 1950s. After 60 years of service, timber pile foundations, used for the majority of residential buildings in the Northwest Territory (NWT), have been experiencing failure or damage due to climate change, as well as decay over decades. For example, at one apartment building site in Inuvik, NWT, over 30% of timber piles are severely damaged and need urgent repair (WEC 2016; CQL 2019), because of the cost of new construction is high in NWT. These issues affect the viability of buildings, the safety of occupants, and absorbent costs. For example, Figure 1 shows that two residential houses were demolished because most of the underpinning timber piles were severely damaged.

Many methods (NEA 1999; CQL 2019) have been adopted by the local remediation activities. For piles with minor to moderate damages, the remediation techniques include: 1) wrapping pile surface with tuck tape to cut off physical contact between wood and soil; 2) inserting boron rods to the timber, preventing biological decay; and 3) bolting galvanized steel straps onto pile shaft surface as a reinforcement technique. For piles with severe damage (i.e. more than 50% loss in the cross-sectional area), wood blocking systems are a viable solution. A wood blocking is a method that replaces the failed timber piles with a stack of timber logs that are placed on the ground surface. A wood blocking system is often chosen when systems such as surface rot remediation, micro piles, among others, are not deemed feasible. A wood blocking can be placed underneath the building or outside the building edges; this makes it easy and economical to use.

Figure 1. Timber piles that were severely decayed such that the houses had to be demolished. Photo taken in Inuvik, NWT.

Wood blocking was perhaps first adopted prior to the 1990s. Although wood blocking systems are widely used in NWT to support the load when the timber piles, the performance of wood blocking systems during the era of climate change was overlooked in the past. The best practices for wood blocking remediation methods in NWT have not been proposed so far, including wood types, configuration, assembly, plus some monitoring procedures. Besides, the effects of the wood blocking system in improving the building serviceability performance in the Arctic has not been systematically monitored.

Hence, this paper is intended to apply scientific and engineering rigor to understanding the benefit of using the wood blocking remediation method in stabilizing the building structures. Wood types and other materials were beyond the scope of this paper.

A wood blocking system was deployed to remediate severely-damage pile foundations that supported the Mountain View Apartment (Mt. View) building in Inuvik, NWT. To understand the effects of this remediation method in the long term, a health monitoring program was established in October 2019 to measure the displacements of the Mt. View building across several years. In Phase I of this health monitoring program, the horizontal and vertical displacements of beams and wood blockings of the Mt. View were monitored. The displacement data were transmitted automatically via a mobile phone network to Canadian Quest Logistics Inc. (CQL) and the University of Alberta (UAlberta). Then the analysis of the displacements is conducted, to assess the efficacy of the wood blocking system and the risk of further local damage on the building where the piles are not remediated. In Phase II of the monitoring program, the permafrost temperature, air temperature, and 3-D displacement pattern of the Mt. View building will be recorded. However, the present paper will only focus on the results of Phase I of the project.

2 WOOD BLOCKING SYSTEM OVERVIEW

The Mountain View Apartment (Figure 2) is a three-story apartment building to the west of the MacKenzie Road and the east of Franklin Road in Inuvik, NWT, Canada. The building is supported on timber piles (as shown in Figure 3) and the floor beam is 1 to 2 m above the ground surface. The Mt. View is located beside a trench that stretches northwest. The Mt. View building was supported by 128 timber piles (Figure 3).

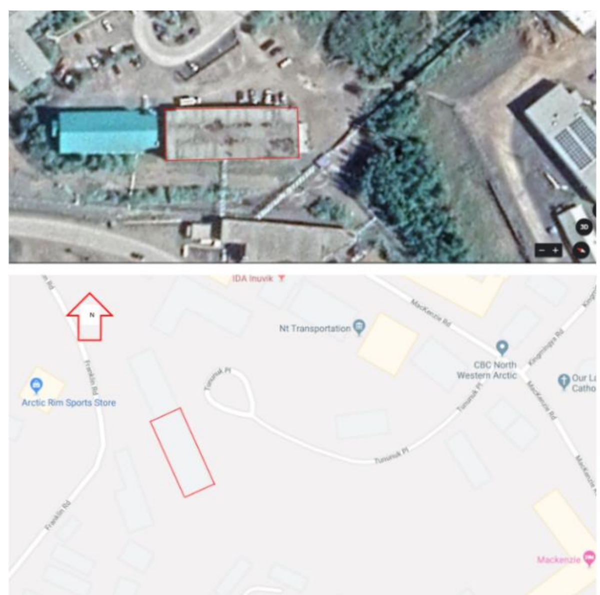


Figure 2. Plane view of the Mountain View Apartment in a rectangle. Dimensions are not to scale.

The geotechnical properties and ground temperature of several sites at Inuvik, NWT, were reported in EBA (2004). The soil layer at the present Mt. View site has not been investigated. However, according to EBA (2004) at a nearby site (Aurora College Administrative/Teaching & Residence Facility) that is several hundred meters from Mt.

View, the topsoil was fill material consisting of gravel, clay, including some minor sands. The peat layer was found underneath the filling on some arbitrary locations. A thick layer of sand and gravel underlies the unevenly distributed peat. Shale bedrock was reported at some locations at depths ranging from 3 m to 11 m. There were many ice lenses in the soils. The active layer was reported to be 3 m deep in this region. The average ground temperature was approximate – 2.7 °C below 5 m depth (EBA 2004).

Visual inspection suggested that many piles have suffered partial or full deterioration caused by physical, chemical, or biological actions of the ambient environment. The damaged piles need to be replaced or supported for the safety of the building and tenants. The wood blocking system was adopted by the owner to fix the failed piles and to assure the long-term service of the timber pile foundation. The wood blocking system was built in September 2019 to retrofit selected piles (29 piles in total, shown in Figure 3).

The Mt. View project's wood blocking system was particularly challenging given the sloped terrain on which the piles were located and hence, the building's super-structure is located. Before the construction of the wood blocking system, the natural topsoil will be removed and refilled with compacted coarse gravels (gravel pad, Figure 4). To ensure the gravel pad remained in place, an extensive wood retaining wall (Figure 5) system beneath the building was designed and constructed. The wood retaining walls allowed for the adequate compaction of the placed gravel, on which the blocking and wedge system would be installed. The wood blockings (Figure 6) are located on the top of the gravel pad. These layered wood pieces consist of a typical wood blocking for one pile. If there is a gap between the building floor beam and the wood blocking, wedges will be placed in between and can be hammered in if a gap forms in the future.

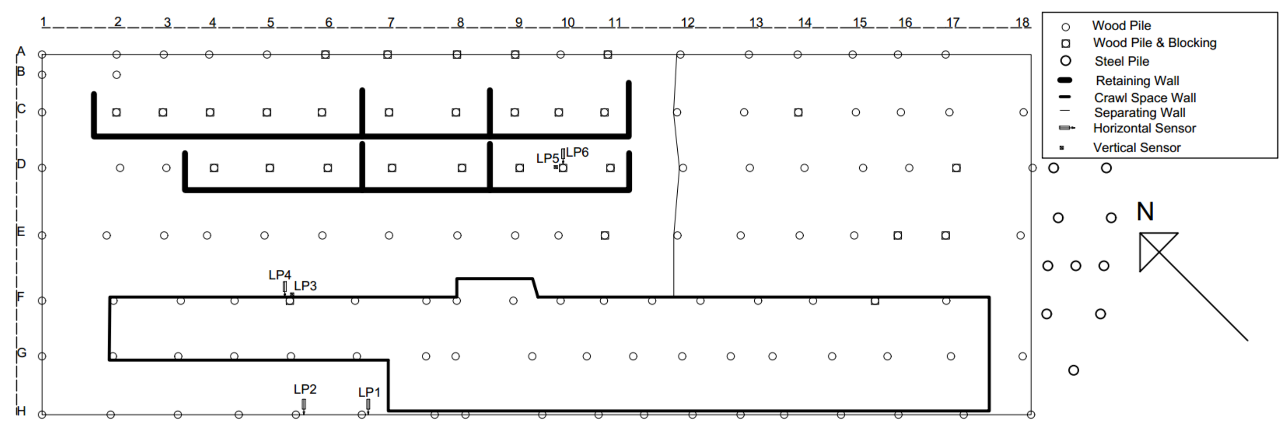


Figure 3. Layout of timber piles, wood blockings, retaining walls, and LPs

3 MEASURING SYSTEM

The objective of the present program is to monitor the movement of the building to foundations and thus to inspect the effects of the wood blocking systems in timber pile remediation.

Figure 3 shows the layout of timber piles and wood blocking systems. A field inspection of the pile quality conducted in 2019 suggests that the building might have a trend to slip toward the backside (or toward the Northeast direction) of the building, perhaps because the building is seated on a high terrace.

To monitor the performance of the building after the remediation, a monitoring system was established in the field, consisting of 6 Linear Potentiometers (LP), a Campbell Scientific CR1000X data logger, and a cellular modem. The LPs were mounted on piles or wood blocking on October 29, 2019, to measure the relative displacement between the floor beam and piles (or blocking). The data logger, which is powered by both 110 V AC and a battery, measures the data at a 5-s interval and logs the data at the interval of an hour. The cellular modem transmits the data to a remote server, from which the data can be downloaded via the internet.

Figure 3 also shows the location and orientation of all LPs. Locations and objectives of all LPs are described as follows in Table 1. Piles in Row A, C, and D have been modified with retaining walls and wood blocking.


Figure 4. Gravel pad to support the wood blocking system


Figure 5. Wood retaining wall to hold the gravel pad


Figure 6. A typical configuration of a wood blocking

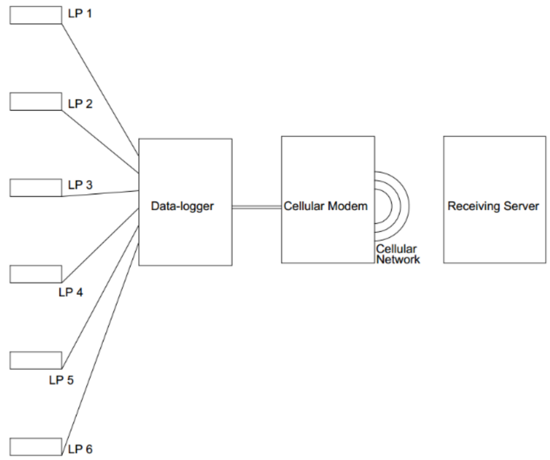


Figure 7. System of data logging and transmission

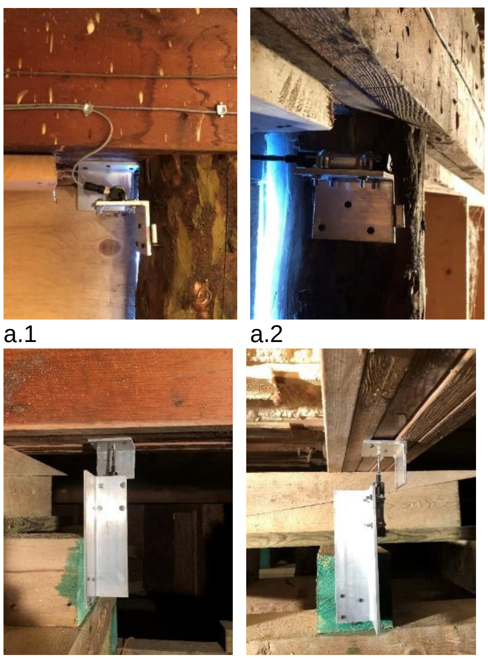

Figure 8. Cellular modem, data-logger, and battery (left to right)

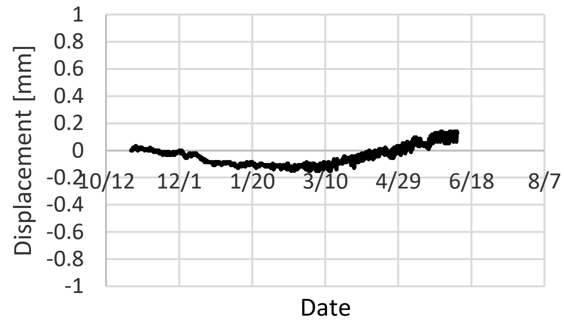
LP 1,2, 4, and 6 measures the horizontal movement of the beam to the assumed unmoving piles. LP 3 represents the vertical movement of the beam to the pile. And LP 5 indicates the vertical displacement of the wood blocking to the pile. All the LPs were mounted to an aluminum plate firstly, and then the plate was fixed to the beam (Figure 9). All readings are in mm scale and the typical recording was shown in Figures 10 and 11.

Table 1. Summary of LP locations and measurements

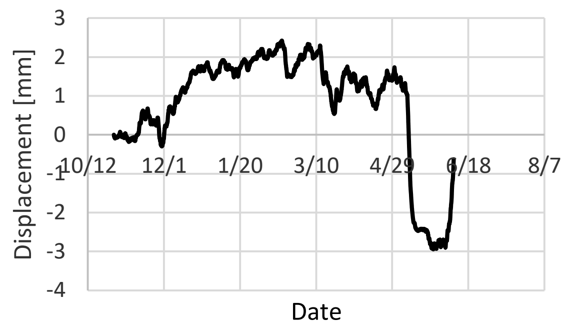
LP	Location	Measurement	The direction of positive displacement
LP1	Pile, Row H	Horizontal movement of beam to pile	Beam moves towards the Southwest

LP2	Pile, Row H	Horizontal movement of beam to pile	Beam moves towards the Southwest
LP3	Pile, Row F	Vertical movement of beam to pile	Beam detaches vertically from the pile
LP4	Pile, Row F	Horizontal movement of beam to pile	Beam moves towards the Southwest
LP5	Wood blocking wedge, Row D	Gap between beam and wedge	Gap forms between floor beam and wedge
LP6	Pile, Row D	Horizontal movement of beam to pile	Beam moves towards the Southwest


a.1 a.2
b.1 b.2
Figure 9. Configuration of the mounted LPs



a



b

Figure 10. Some typical data represented by the LPs: (a) LP 1; (b) LP 5

4 RESULTS

Measured displacements as of today show that the magnitude of most LP data is within 1 mm, which implies that the building is currently at a steady-state during this period.

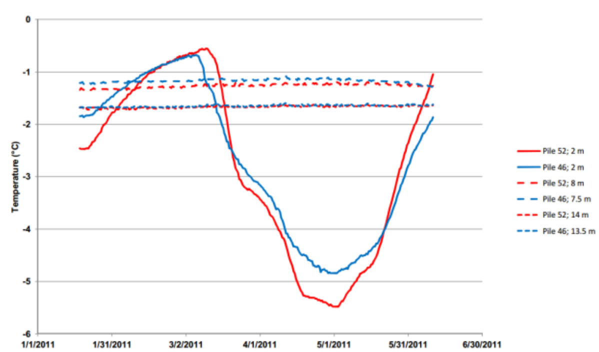


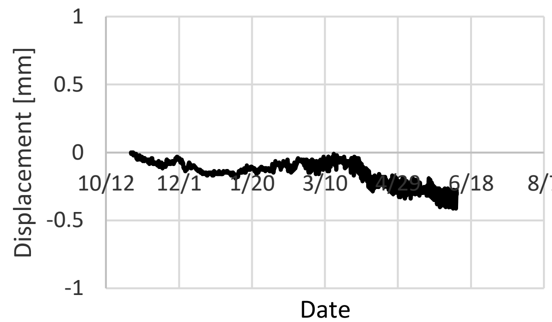
Figure 11. Comparison of Ground Temperatures Under another building at a nearby site in Inuvik, NWT (EBA 2011)

Figure 11 shows a temperature change of the ground at the Western Arctic Center through a year-long time. The temperature deeper than 2 m was stable which indicated that the active layer of this site was around 2 m. The temperature of the shallow surface implied a seasonal change that during winter and the early spring (January to April) it was under freezing point and it increased dramatically after May. In winter the heat from the upper structure would warm the ground and when the heat shuts down the temperature is more like the real air temperature. The warm summer will thaw the ground substantially.

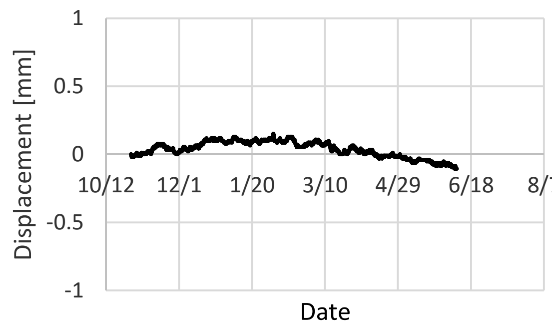
LP 1 (Figure 10a) is less than 0.2 mm, which means this part of the building is stable and the beam is well supported by the timber pile. LP 2 (Figure 12-a) indicates a bigger movement than LP 1. As these two sensors were located in the same row which has no wood blocking, it possibly implies that the beam on the timber pile mounted with LP 2 shifts a little to the slope though it is very marginal. LP 3 (Figure 12-b) has the same trend as LP1. LP 4 (Figure 12-c) shows a negative displacement of 0.6 mm right now, while it kept decreasing in winter months and bounced back as the spring came. It seemed that the freezing of the ground in winter made the horizontal movement of the pile as big as -1.3 mm while the ground temperature went up in spring it became stable around -0.6 mm. LP5 (Figure 10-b) shows a fluctuation from 0.6 mm to 2.5 mm in winter. Its value was positive in this period which means there was a gap between the blocking and the beam. The ground was frozen in winter. Ice lens formed in the soils around the wood blocking and the water beneath the wood blocking might have been absorbed by the ice, which caused the shrinkage of the natural soil under the gravel pad. Thus the gravel pad around the wood blocking subsided. When spring came, the ice melted and water refilled the voids in the natural soil so that the gap was becoming smaller. Figure 12-b shows a quite big change in May that the LP was -3 mm. It could be due to the reconstitution of the voids in the natural soil. After the freezing and thawing, the voids in the natural soil increase. These extra voids were filled with melting water and thus the soil expanded. As the summertime comes, the water in these voids decreases so that the vertical movement gets to -1 mm. LP 6 (Figure 12-d) shows a fluctuation between -0.5 mm and 0.5 mm. In winter the beam moved towards the northeast and in spring it moved towards the opposite (the trench).

The performance of LP5 and LP6 are of significance as they represent the movement of the blocking. If the displacement of LP5 and LP6 continue to change, a visual inspection of the pile or wood blocking needs to be done to eliminate any potential risk.

The data measured between October 2019 and June 2020 show that the vertical and lateral movement of the building is at a magnitude of 1 mm, which is considerably small for such a large building structure. The settlement measured at one wood blocking is alarmingly 3 mm; this value implies that a gap may be formed between the wood blocking wedge and the building floor beam underpinned by the wedge. As the inspection system went through winter and spring, it strongly suggested that the temperature change in the ground had a significant impact on the behaviour of the sensors. The gap may be caused by the settlement or sliding of the wood blocking due to the freezing and thawing of the ground; however, the actual reason may be discovered by a site visit.



(a)



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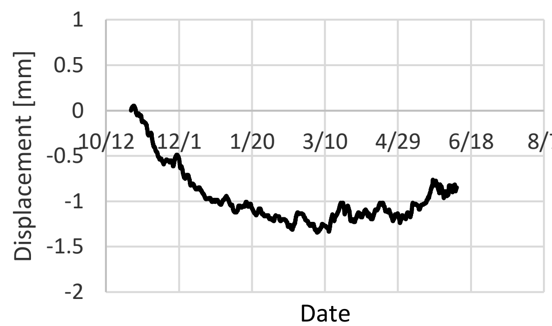
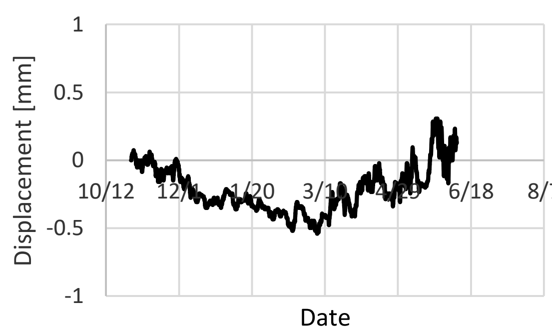


(c)



(d)

Figure 12. LP readings in various locations: (a) LP 2; (b) LP 3; (c) LP 4; and (d) LP 6

5 CONCLUSIONS

As climate change affects the integrity of timber pile foundations in the Canadian Arctic, it is urgent to repair damaged piles or replace failed timber piles to continue supporting the prosper of Arctic communities. The wood blocking technique is often adopted as it involves reasonable efficiency and cost. To demonstrate the performance of the wood blocking system in the long term, a health monitoring program was established in October 2019 for an apartment building in Inuvik, NWT. The program consists of six displacement transducers, a data logger, and automatic data transmission via a mobile network. Based on the recorded data as of today, the following observations are made.

1) Most of the movement was in a small magnitude. When the displacement of the wood blocking reaches 3 mm and fluctuates, the wood blocking may need more attention. A manual adjustment of the wood blocking wedges may be required.

2) The seasonal temperature change in the natural soil underlying the gravel pad perhaps is the cause of this fluctuating displacement.

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