Development of a new CSA standard for moderating the effects of permafrost degradation on existing building foundations

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Challenges from North to South
Des défis du Nord au Sud

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ABSTRACT
Northern infrastructure is highly vulnerable to climate change impacts and must contend with issues such as permafrost degradation, coastal erosion, as well as changes in temperatures and precipitation patterns. Adaptable mechanisms that reduce the North's vulnerability are needed and standards are one mechanism that can reduce some of the vulnerability. *CAN/CSA-S501-14 – Moderating the effects of permafrost degradation on existing building foundations,* a National Standard of Canada, was developed through the collaboration of representatives from territorial governments, the federal government, universities, the private sector, and northern community government organizations. This Standard proposes measures to moderate the effects of permafrost degradation on existing building foundation and mitigation techniques in relation to changing permafrost conditions.

RÉSUMÉ
Les infrastructures du Nord sont très vulnérables aux impacts des changements climatiques tels que la dégradation du pergélisol, l'érosion côtière et les changements de températures et de précipitations. Des mécanismes flexibles permettant de réduire la vulnérabilité des infrastructures du Nord sont nécessaires; les normes constituent un mécanisme qui permet de réduire certaines vulnérabilités. La norme nationale du Canada CAN/CSA-S501-14 - Modérer les effets de la dégradation du pergélisol des structures existantes a été développée grâce à la collaboration de représentants des gouvernements territoriaux, le gouvernement fédéral, les universités, le secteur privé et les gouvernements des collectivités nordiques. Cette norme propose des mesures pour modérer les effets de la dégradation du pergélisol sur les fondations des bâtiments existants et des techniques d'atténuation des conditions de pergélisol changeantes.

1 INTRODUCTION

Canada's North is expected to be significantly impacted by future climate change. The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (2013), projects that northern regions in general will be affected by the highest average temperature increases, that—according to some models—will be as great as 7-9°C by the end of the 21st century (IPCC 2013). Increases in average annual temperature of this magnitude will profoundly affect the future state of northern biophysical and human environments.

Nearly 30% of the permafrost in the northern hemisphere is in North America. The IPCC forecasts significant change in the distribution and conditions of the permafrost regions by the end of the 21st century. A wide range of impacts of these changes can be expected, including a higher frequency of land-sliding, surface thaw settlement, ecological change and alterations to subsurface hydrological connections.

Climate change will especially affect built environments where construction is on permafrost. In these situations, northern infrastructure and communities (Figure 1) are vulnerable to climate change impacts and must contend with the issue of permafrost degradation, as well as other challenges such as enhanced coastal erosion, reduced winter road seasons and changes in temperatures and precipitation patterns. Adaptable mechanisms that reduce the North's vulnerability are needed and standards are one mechanism that can reduce some of the vulnerability.

The Standards Council of Canada (SCC), with support from Aboriginal Affairs and Northern Development Canada (AANDC), worked to develop effective standards to address the climate risks inherent in Northern infrastructure design, planning and management. By leveraging a network of experts, SCC established a roadmap that identified the development and implementation of standards as a solution to help reduce the North's financial and physical vulnerability, and ensure the continued health and safety of Canadians. This roadmap is referred to as the Northern Infrastructure Standardization Initiative (NISI).

Four National Standards of Canada were developed through NISI: CAN/CSA-S500-14 - Thermosyphon foundations for buildings in permafrost regions; CAN/CSA-S501-14 - Moderating the effects of permafrost degradation on existing building foundations; CAN/CSA-S502-14 - Managing changing snow load risks for buildings in Canada's North; and CAN/CSA-S503-15 - Community drainage system planning, design, and maintenance in northern communities. A fifth standard is currently under development: Geotechnical Site Investigation for Building Foundations in Permafrost Regions.

This paper focuses on CAN/CSA-S501-14 – Moderating the effects of permafrost degradation on existing building foundations (CSA 2014). This National Standard was developed through the collaboration of representatives from territorial governments, the federal government, universities, the private sector, and northern community government organizations. The standard recognizes that it may be difficult and/or expensive to halt permafrost thaw once it has begun. For example, if thaw progresses and the building or structure deforms, additional problems may arise, such as leaking from water supply or sewage lines. This could saturate soils and cause ponding of water in depressions as the ground surface settles, increasing the rate of permafrost degradation. Maintenance measures, such as those outlined in the standard, can play a significant role in preventing the initiation of thaw and should be undertaken on an ongoing basis through the entire lifecycle of the building or structure. If permafrost thaw does start to affect the building or structure, the standard provides a range of possible responses.

Figure 1. Northern village of Salluit, Nunavik (Photo: Martin Tremblay).

2 MODERATING THE EFFECTS OF PERMAFROST DEGRADATION ON EXISTING BUILDING FOUNDATIONS STANDARD

The Standard is organized according to a series of steps that should be followed in order to moderate the effects of permafrost degradation on existing buildings or structures:

- Pre-emptive and proactive measures to maintain permafrost beneath and adjacent to existing buildings or structures;
- Assessment of structures impacted by changing permafrost conditions;
- Mitigating permafrost degradation and its effects on existing buildings and structures;
- Undertaking long-term maintenance and monitoring.

The Standard covers the major types of foundations typically used in permafrost areas. These include shallow foundations, such as footings constructed on or beneath the ground with a ventilated air space under a building, and slab-on-grade. Deep foundations are also examined, including adfreeze piles with a ventilated air space beneath the building, and rock socket or end-bearing piles which may or may not have an air space.

The strategies available to moderate the effects of permafrost degradation on existing buildings or structures depend greatly on site-specific conditions. Consequently, the Standard must be used flexibly.

2.1 Measures to maintain permafrost

Regular measures should be taken to preserve permafrost beneath and adjacent to a building or structure whose foundation relies on permafrost (Figure 2). Many of these measures are relatively simple but they can have important positive impacts. This maintenance will help prevent the initiation of thaw and needs to be undertaken on an ongoing basis through the lifecycle of the building or structure.

Water can have a deleterious impact on permafrost. The Standard recommends facilitating rapid drainage of surface water away from any structure by grading the site within 4 m of the structure perimeter, to keep water from ponding under or adjacent to the structure or foundation, and to direct downspouts from building or structure onto splash pods that discharge to natural ground at least 4 m way from all structures. However, these measures should not involve the excavation of drainage ditches in ice-rich permafrost, nor should new construction be permitted around existing buildings or structures that would negatively impact the permafrost thermal regime.

Many buildings on permafrost are elevated with an air space between the floor and the ground surface. The purpose of this space is to reduce or prevent additional heat transfer from the building into the ground. Adequate ventilation will permit winter air flow under the building or structure and will promote ground freezing and maintenance of permafrost. A common operational issue in northern communities is the storage of material or equipment beneath buildings that then impedes air flow. The same problem can arise if cladding is installed to cover the air space for aesthetic or other reasons. Periodic checks must be made to ensure that the space or ducts are not obstructed. In this regard, mesh such as chicken wire or chain link fence should be installed to protect air spaces or ducts from the accumulation of wind-blown debris or other materials.

Snow warms the ground by insulating it from heat loss to the air in winter. Snow should be cleared away from all

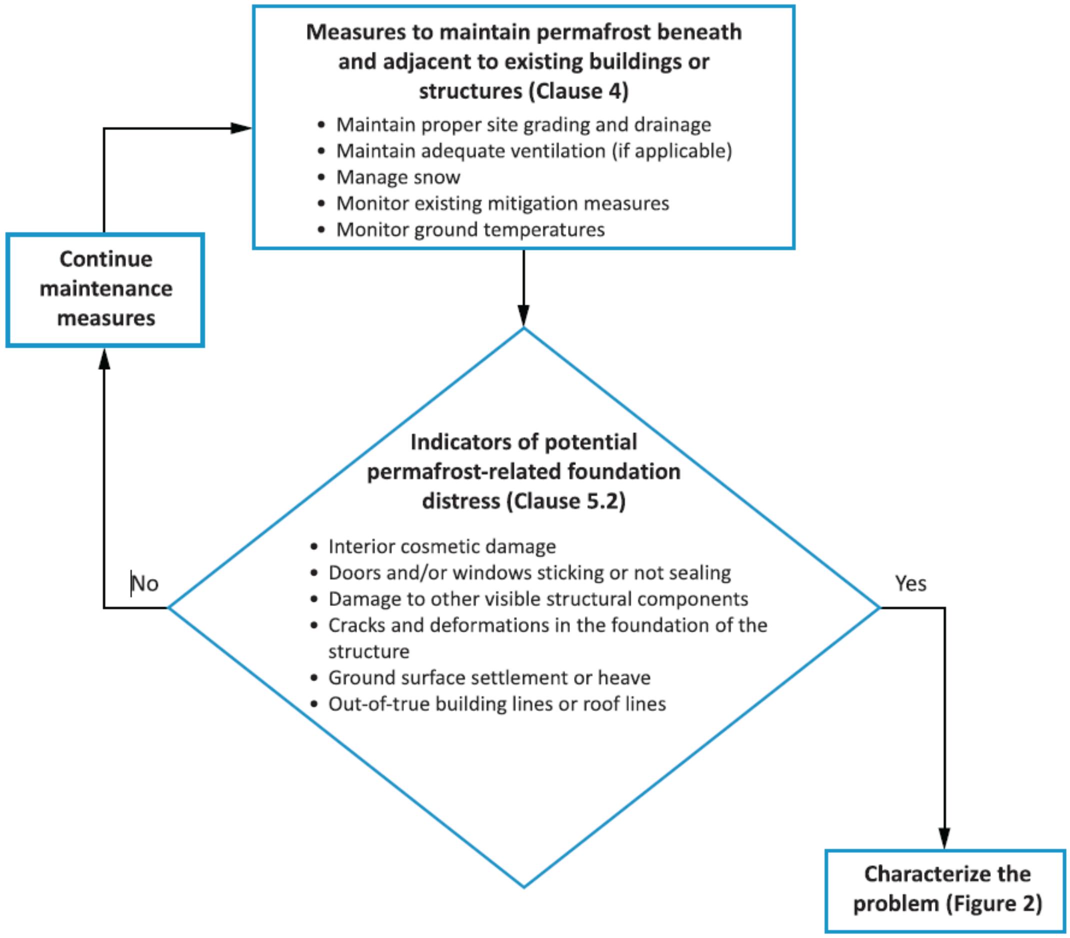

Figure 2. Measures to maintain permafrost and indicators of potential permafrost-related foundation distress. The clause and figure numbers refer to those used in the Standard. Figure 2 in the standard is Figure 3 in this paper.

structures to allow frost penetration and refreezing of the active layer in winter. This includes any snow that may accumulate due to an installed mesh acting inadvertently as a snow fence. The snow should be stored in a designated location and snowbanks must be managed so that melt water in the spring does not pond with 4 m of the building or structure.

Some building foundations depend on thermosyphons or mechanical cooling to provide building heat interception and maintain frozen ground. These must be monitored to ensure performance. Ground temperature monitoring over time can provide an early indication of changes in the permafrost thermal regime.

2.2 Assessment of structure

Notwithstanding the use of preventative maintenance, problems may still emerge. A number of indicators can provide evidence of potential permafrost degradation beneath a structure (Figure 2). These indicators can include interior cosmetic damage, such as cracks in drywall, doors and/or windows sticking or not sealing, damage to other visible structural components, cracks and deformations in the foundation of the structure, ground surface settlement or heave and out-of-true building lines or roof lines. However, some of these indicators can also be indicative of seasonal frost heave rather than permafrost problems. The mitigation objectives for seasonal frost heave and permafrost thaw problems differ so it is important that the source of the problems be correctly identified. The start of this process is a full assessment of the problems.

2.2.1 Site investigation

The first step in the assessment of existing structures for suspected permafrost related surface displacement is the initial site investigation. This investigation should include collection and documentation of existing background information such as (1) the original design information or design values used; (2) a history of the structural problems, including anecdotal information from previous or existing owners, neighbours, and contractors related to when the foundation movements were first noted; (3)

documentation of the magnitude and nature of seasonal ground deformation or surface displacement; (4) a history of building maintenance and site management, including consideration of problems concerning water supply or distribution, or sewage systems (e.g. tanks, septic fields, etc.); (5) a history of development that has occurred on adjacent lots that can affect permafrost conditions; (6) an assessment of drainage, including ice damming or water

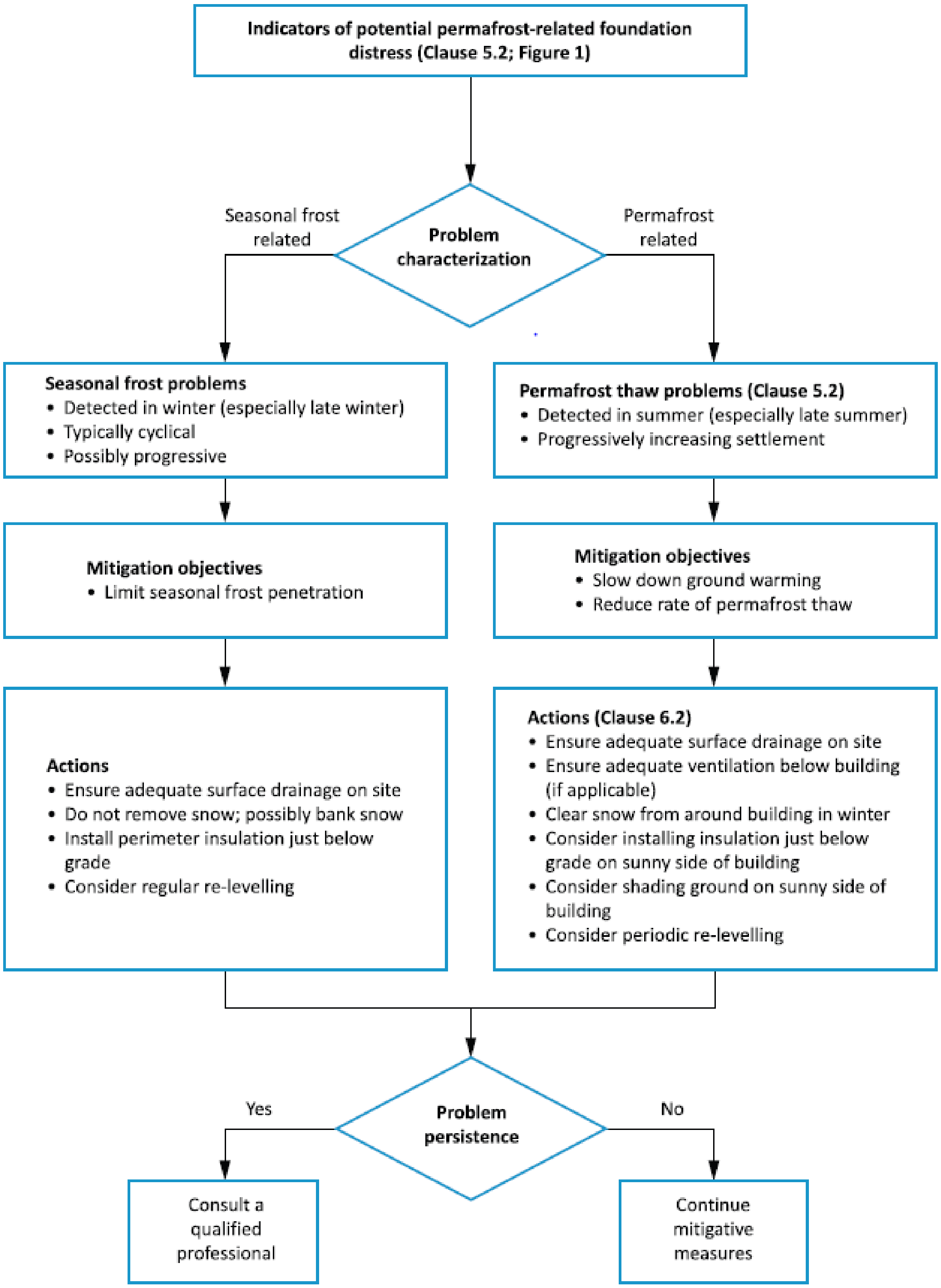

Figure 3. Steps in a typical investigation to characterize the causes of potential permafrost-related foundation distress and mitigation measures that can be applied to the site. The clause and figure numbers refer to those used in the Standard. Figure 1 in the standard is Figure 2 in this paper.

dripping from roof, ponding, snow accumulation, and vegetation conditions at the building or structure; and (7) an assessment of any extreme short-term weather events, and long-term climate change effects.

The second step is a complete inspection of structure and site to assess damage. This inspection should document the following: (1) deviations from issued for construction design; (2) interior cosmetic damage; (3)cracks and deformations in the foundation of the structure; (4) out-of-true building lines or roof lines; (5) ground-surface settlement or heave; (6) any damage to structural components; (7) damage to any water supply/distribution or sewage systems (e.g., tanks, septic fields, etc.) that could lead to permafrost degradation; (8) surface drainage characteristics around the site, including any ice damming or water dripping from the roof; (9) observed changes in adjacent development, vegetation or similar conditions around the site; (10) a review of maintenance and operations procedures and records of the facility, including interviews with facility operators and maintenance staff; and (11) monitoring of any in-situ instrumentation present on the site.

The third step is the collection of site-specific subsurface data. If considered necessary based on the available data and initial data review, a geotechnical investigation program should be undertaken to determine and document the soil lithology, the depth to permafrost and ground temperatures, and the ground ice content.

2.2.2 Establishing a monitoring program

Where problems have become evident, a monitoring program must be established to verify the structural integrity of the building or structure and to determine if any changes in the thermal condition of the underlying foundation materials have occurred. The monitoring program should include observations and documentation of site features such as progression of cracks and deformations in the foundation of the structure, progression of ground surface deformation, progression of doors and/or windows sticking or not sealing, progression of interior cosmetic damage, progression of any other damage to other visible structural components, climatic data, depth to permafrost, and ground temperature.

If ground temperature data are to be collected, the ground temperatures should be recorded on at least a monthly basis and sensors should be installed down a borehole. In the absence of site-specific ground temperatures, records from nearby buildings may be used and all information collected should be forwarded to a qualified professional for review.

2.3 Mitigation techniques in changing permafrost conditions

The techniques available to restore foundation stability of structures impacted by changing permafrost conditions can be divided into those applied to the site and those applied to the structure itself and its foundation. Some of the mitigation techniques outlined in the Standard are the same as those used for proactively maintaining permafrost while others involve additional interventions.

2.3.1 Site techniques

Site techniques can be applied to all foundation types. They can usually be undertaken by the person responsible for the building or structure.

Vegetation may be planted around the structure to shade the ground surface in summer and help moderate ground surface temperatures. Planted vegetation, however, cannot be allowed to restrict airflow under an elevated structure. Vegetation and trees that provide natural shading should not be cut down. Sun screens may be constructed on south-facing locations.

Proper surface water drainage is essential for preserving permafrost. Drainage ditches or swales should not be excavated in ice-rich permafrost without detailed design and measures to control erosion and prevent progressive permafrost degradation. Berms can be effective to control surface drainage, but should not be constructed without detailed design and measures to control erosion. The area under and within approximately 4 m of the perimeter of the structure should be graded to encourage rapid drainage of surface water away from the structure. Water must not be allowed to pond at any location within approximately 4 m of the structure or underneath it during spring thaw or later in the year. Additional fill should be placed as needed to promote positive drainage. Downspouts from buildings must be directed onto splash pads that discharge to natural ground at least 4 m away from all structures. Where no eaves-troughs are installed, the area surrounding the building perimeter has to be sloped away from the structure at no less than 4% slope.

Snow should be cleared away in winter from around buildings or structures in order to promote more rapid frost penetration that will help maintain the permafrost. A maintenance program should be implemented to keep snow cleared all winter.

2.3.2 Techniques applied to the building or structure

Mitigation measures applied to the building or structure should be undertaken only by a qualified professional. It should be noted that certain of these techniques can be employed only on specific foundation types. For example, slab-on-grade foundation design precludes ventilation. In addition, it is important that climate change be taken into account in all techniques applied to the foundation (see CSA 2010).

Increases in the depth to permafrost might require the initiation or enhancement of techniques to minimize the heave and settlement effects of increased active layer thickness on the building or structure foundation. In some circumstances, permafrost thaw is inevitable and the selected remediation technique should take this into account.

As discussed above in relation to preventative maintenance, open air spaces under buildings or structures provide a means to keep building heat from reaching the permafrost, they remove heat from under the buildings or structures in winter, and reduce the opportunity for permafrost degradation. The structure must be elevated to maintain a clear ventilated air space of at least 0.6 m to ensure adequate winter air flow under and around the foundation. Any vegetation that might be restricting foundation ventilation has to be removed and mesh such as chicken wire or chain link fence should be installed to protect the ventilated air space from the accumulation of debris and other items that might restrict winter airflow. If mesh is not used, alternate materials should be installed that maintain adequate airflow capacity. Shipping containers or sheds must not be placed immediately adjacent to a building or structure as they can alter airflow and cause snowbanks to develop.

Ground insulation is meant to reduce the rate of heat transfer from a building or water/sewer service components into the ground. In areas where mean annual ground temperatures are below -4°C, the placement of insulation on or just below the ground surface should be considered. In areas where mean annual ground temperatures are between -4°C and 0°C, ground insulation should be used only on the recommendation of a qualified professional. In areas where mean annual ground temperatures are between -2°C and 0°C, ground insulation can restrict ground cooling in winter and therefore may not be effective. Lawns and flowerbeds should be planted in bare ground surface areas to provide additional natural insulation to the ground surface. Any such landscaping should not obstruct access to the structure and foundations.

It may be possible to rehabilitate a foundation in a way that would allow for periodic adjustment so that the service life of the structure is increased. Suitable methods include screw jacks on wooden cribbing, wedges on wooden cribbing, slotted columns with foundation jacking points and mud jacking of concrete foundation slabs. Each technique needs to be specifically designed (e.g., with a specific range of adjustment) for each structure and each site.

A refrigeration or thermosyphon system may be installed under the slab or shallow foundation, or around deep foundations to chill the foundation soils and re-establish a stable thermal condition. Before this is done, geothermal modelling needs to be undertaken and the refrigeration or thermosyphon system must be designed and installed by qualified professionals.

In some cases, it may be possible to replace the foundation at an existing site. A number of methods are possible. These include (1) placing shallow foundations, such as screw jacks or wedges on wooden cribbing, on engineered granular pads above the surrounding terrain, (2) installing steel piles (or adding to existing piles) or footings around the exterior of structure and then supporting the structure on new beams resting on these new foundations, and (3) underpinning of foundation elements using pile jacking. A fourth possibility is to lift the structure off its present foundation and move it to a new foundation specifically designed for the structure and the site. As is obvious, the use of any of these techniques would require detailed individual designs for each structure and each site.

2.4 Abandonment and demolition

Climate warming will lead to some sites becoming untenable as the permafrost thaws. If a structure is considered to be repairable and/or reusable, but is located on ice-rich thaw sensitive permafrost (especially warm permafrost) that cannot be preserved, the site should be abandoned and the structure moved to a new location with a foundation designed specifically for site conditions. However, if the structure is considered to be damaged beyond repair or is a public safety hazard, the structure should be demolished.

2.5 Long term performance of foundation rehabilitation

Two important issues arise relative to the long-term performance of any foundation rehabilitation technique used to maintain permafrost or remediate permafrost degradation around existing buildings or structures. First, consideration must be given to the time required for the chosen mitigation strategy to become effective. Second, the ongoing monitoring of performance is essential.

In selecting an appropriate mitigation technique, both its short-term and long-term performance should be considered. For example, a particular technique can provide long-term mitigation but without addressing the continuing effects of permafrost degradation in the short-term. In some cases it can take five or more years for a new thermal equilibrium to be established in the permafrost under the structure. For this reason, and depending on site-specific conditions, more than one mitigation technique may be applied so that immediate stability requirements and long-term stability requirements are both addressed.

If the planned building life exceeds approximately 20 years, the potential for climate change must be taken into account during the choice of mitigation strategy. Plans to monitor the performance of the structure, foundation, and mitigation technique should be drawn up and implemented early in the rehabilitation phase. In this context, the designer, building owner, and maintenance staff should collaboratively develop a monitoring program, including a schedule and reporting system, that is appropriate for the site-specific conditions.

3 SUMMARY AND CONCLUSIONS

The National Standard of Canada CAN/CSA-S501-14 draws upon decades of Canadian and international research in permafrost science and engineering in order to arrive at a series of concrete strategies to moderate the effects of permafrost thaw on existing buildings. The Standard covers the pre-emptive maintenance and management that can prevent thaw from occurring, the identification of permafrost-related issues, and a suite of mitigative measures that can be used if problems have already arisen. Finally, the Standard recognizes that some foundation problems related to permafrost thaw are essentially insoluble. These can be expected to become more common in the future as the climate warms.

The contribution of the Standard is to synthesize the knowledge of the permafrost research community and to express it in ways that can be understood by a variety of end-users, including contractors, planners, government decision-makers, housing managers and building operators. It is hoped that the Standard will be widely used across the Canadian North to help reduce infrastructure vulnerability to future climate change.

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REFERENCES

CSA, 2010. *Technical guide: Infrastructure in permafrost: A guideline for climate change adaptation*. CSA Plus 4011. CSA Group, 112 p.

CSA, 2014. *Moderating the effects of permafrost degradation on existing building foundations.* CSA Group. ISBN 978-1-77139-726-11

IPCC, 2013. *Climate Change 2013: The Physical Science Basis.* Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.