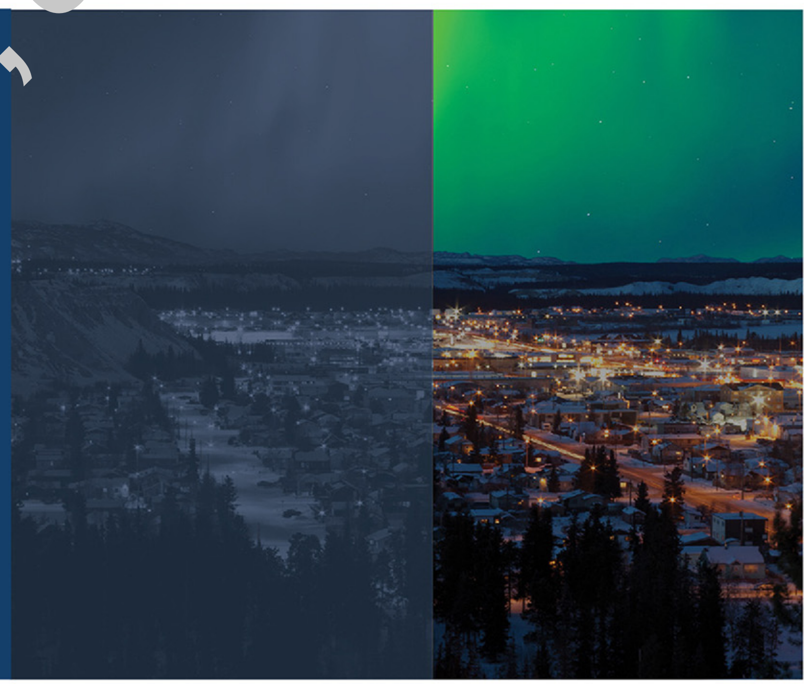
CSA PLUS 4011:19

Technical Guide: Infrastructure in permafrost: A guideline for climate change adaptation



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Contents

Preface

This is the second edition of CSA PLUS 4011, *Technical Guide: Infrastructure in permafrost: A guideline for climate change adaptation*. It supersedes the previous edition published in 2010.

Updates to the new edition are as follows:

a) Current climate change projections recommended for use in northern Canada are presented (Chapter 4);

b) Up-to-date information on ground temperature trends in permafrost throughout northern Canada are presented (Chapter 2);

c) Permafrost conditions critical for infrastructure foundations have been summarized, revised, and consolidated into a single chapter (Chapter 2);

d) Description and explanation of foundations used in northern Canada for buildings constructed on permafrost have been revised to improve readability (Chapter 3);

e) Current trends in climate (temperature and precipitation) throughout the North are presented (Chapter 4);

f) A range of climate projections available for northern Canada are presented graphically to allow assessment of current uncertainty in future climate projections (Chapter 4 and Annex C);

g) Minor revisions to the screening process have been made for clarity (Chapter 5).

CSA Group received funding for the development of this Guideline from the Standards Council of Canada, as part of the Northern Infrastructure Standardization Initiative with input from the Northern Advisory Committee (NAC).

This Guideline was prepared by the Technical Subcommittee on Climate Change Adaptation for Infrastructure in Permafrost, under the jurisdiction of the Technical Committee on Northern Built Infrastructure and the Strategic Steering Committee on Construction and Civil Infrastructure, and has been formally approved by the Technical Committee.

Notes:

1) *Use of the singular does not exclude the plural (and vice versa) when the sense allows.*

2) *Although the intended primary application of this Guideline is stated in its Scope, it is important to note that it remains the responsibility of the users of the Standard to judge its suitability for their particular purpose.*

3) *This Guideline was developed by consensus, which is defined by* CSA Policy governing standardization — Code of good practice for standardization *as "substantial agreement. Consensus implies much more than a simple majority, but not necessarily unanimity". It is consistent with this definition that a member may be included in the Technical Committee list and yet not be in full agreement with all clauses of this Guideline.*

4) *To submit a request for interpretation of this Guideline, please send the following information to* ***inquiries@csagroup.org*** *and include "Request for interpretation" in the subject line:*
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   Committee interpretations are processed in accordance with the CSA Directives and guidelines governing standardization *and are available on the* Current Standards Activities *page at* ***standardsactivities.csa.ca****.*

5) *This Guideline is subject to review within five years from the date of publication. Suggestions for its improvement will be referred to the appropriate committee. To submit a proposal for change, please send the following information to **inquiries@csagroup.org** and include "Proposal for change" in the subject line:*
   a) *Standard designation (number);*
   b) *relevant clause, table, and/or figure number;*
   c) *wording of the proposed change; and*
   d) *rationale for the change.*

EXECUTIVE SUMMARY

This Guideline outlines methods to estimate the sustainability of engineered structures on permafrost foundations over their service lives in northern Canada. The objective is to mitigate climate-change-induced risk of system failure at the design stage. The intent is to accommodate climate change effects anticipated throughout the Canadian North. This Guideline was developed initially in 2010 for community decision makers so that the impacts of climate change on permafrost are considered during the siting, design, and management of new community infrastructure. This updated version is more general and is applicable to all new infrastructure in permafrost regions, including those for resource development. The guideline will assist engineering design of new infrastructure to be built on permafrost.

Change in the climate is demonstrated by increases in mean annual air temperatures since the 1970s in the western Arctic and since the 1990s in the eastern Arctic, including northern Quebec and Labrador. At Inuvik, NT, for instance, the mean annual air temperature in 1961–70 was -9.7 °C but by 2009–18 it had increased to -6.3 °C. The temperature in 1998 (-4.6 °C) was considered an extreme value, with a return period estimated at 300 years, but the annual means in 2016–18 were -5.7, -4.8 and -6.1 °C suggesting such conditions are no longer unusual. These specific values all demonstrate warming, and in the last 15 years there have also been increases in precipitation, especially rainfall.

Warming and/or thawing of permafrost due to climate change have been recorded throughout the North. The most comprehensive Canadian data on ground temperatures in permafrost are available from the Mackenzie River valley and the western Arctic coastlands. Increases of about 3 °C in the uppermost 10 m of the ground have occurred since 1970 near the western Arctic coast and absolute change has been measured to depths of more than 50 m. In places, ground warming has further increased due to other consequences of climate change, such as growth of vegetation and a deeper snow cover.

At many locations in the southern part of the permafrost zone, the perennially frozen ground is discontinuous and its temperature is above -2 °C. This temperature approximates a threshold above which the permafrost in these regions is not resilient to the effects of climate change and may be susceptible to long-term thaw. Further north, the permafrost may be cooler and spatially continuous, but the prospect of continuing climate change means that commissioning and design of infrastructure throughout the permafrost regions must now consider the changes in ground temperature anticipated over the intended service life of structures. This involves determination of permafrost conditions and the consequences of climate change at sites proposed for development, and selection of an appropriate foundation design to mitigate warming of the ground beneath the structure. The consideration must also establish the consequences of foundation system failure and the likelihood of this occurring. It may lead to investigation of alternative sites for the infrastructure.

The guideline describes important aspects of permafrost terrain that contribute to its sensitivity following construction, especially the organic surface cover, the ground-ice content and near-surface temperature regime. The guideline also describes foundation types currently used in northern Canada: 1) to prevent heat from buildings compromising the integrity of permafrost by using gravel pads and ventilated crawl spaces; 2) to prevent frost heave or thaw settlement altering the structural integrity of the building by using pile foundations; and 3) to prevent thaw of permafrost foundation soils by installation of passive heat exchangers such as thermosyphons.

The guideline describes trends in climate observed in northern Canada and presents the most recent authoritative projections of climate for the 21st century available from global simulations used by the IPCC. These projections provide a range of potential adjustments to seasonal temperatures anticipated following continuing increases in greenhouse gas concentrations under increasing unrestricted future emission scenarios (Representative Concentration Pathway 8.5, RCP8.5) and with policy action taken to reduce emissions (RCP4.5). The rate of increase or decrease in greenhouse gas concentrations will depend upon societal behaviour, but regardless of this action, increases in air temperature are expected throughout the 21st century due to the residence time of gases in the atmosphere. RCP8.5 and RCP4.5 do not differ greatly in terms of CO_2 and N_2O concentrations over the next 20 years or in terms of radiative forcing of climate. The guide recommends that engineering design is based upon projected climate change over the next 20 years or for the projected life of the structure accompanied by effective monitoring to inform owners about performance of the infrastructure during its operating period.

The projected increases in temperature vary geographically across the Canadian Arctic, so the guideline presents tables for 11 sectors of northern Canada divided by latitude at approximately 60, 65, 70, and 75 °N and by longitude at approximately 59, 86, 114, and 141 °W. The projections are presented as the mean increases in seasonal and annual air temperatures in each sector for the periods 2011–40, 2041–70, and 2071–2100. Box plots indicate the range of increases projected for each sector and time period. The mean increases in annual air temperature projected for 2011–40 under an unrestricted increasing emissions scenario (RCP8.5) range from 1.2 to 2.0 °C, and from 2041–70 from 3.1 to 5.3 °C. The total ranges in projections from all climate simulations are greater than the ranges in means listed here, but almost all indicate climate warming throughout the 21st century. The increases are consistently highest in winter and lowest in summer. This is an important consideration that must be addressed during foundation design. These projected increases suggest considerable changes to permafrost conditions are likely over the 40- to 50-year service lives of structures to be designed and built in the next decade.

The guideline describes screening and design processes to determine the scope of site investigation and engineering design services required for effective adaptation of structures to climate uncertainty and warming. The screening process establishes the potential sensitivity of proposed structures to the effects of climate change on permafrost and assesses the associated risks. The process requires information on ground temperatures, ground materials, and ground ice contents at the proposed site. Screening also involves estimating ground temperatures at the end of the service life using extrapolation of recent temperature trends and/or evaluation of climate projections. In combination, these data are used to estimate the sensitivity of permafrost at the site to climate change. This sensitivity is combined with an assessment of the consequences of foundation system failure to determine the risk presented by the project.

Projects of low or moderate risk may proceed easily from preliminary to final design, while projects of high risk require more detailed quantitative assessment. This usually involves geothermal modelling of the foundation system throughout its service life, including the potential benefits of heat exchangers installed to cool the ground if the permafrost must be preserved. These complex foundation systems require that a detailed design basis report be prepared and approved by the Engineer of Record, then submitted to the owner. In addition, a monitoring and maintenance program must be developed, documented, and approved by the owner.

The key elements of the process presented in this Guideline are: 1) field assessment of permafrost materials and temperatures; 2) projection of foundation ground temperatures over the service life of the proposed structures; 3) determination of climate-induced risk presented by the project; 4) geothermal modelling of the proposed foundation over its service life; and 5) development of a comprehensive monitoring and maintenance plan.

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1 INTRODUCTION

CHAPTER AT A GLANCE

This Chapter introduces the second edition of a guideline for community decision makers and geotechnical engineers with roles in planning, designing, developing, or managing community infrastructure and development projects in permafrost regions. It concerns structures that require foundations. It is not a design textbook for building in permafrost regions. It is intended to equip community decision makers with the ability to ensure that the impacts of climate change on permafrost are considered during the siting, design, and management of new community infrastructure. The text has been revised to reflect changes in scenarios of future climate and new building standards that have become available since the first edition was published in 2010.

1.1 Need for this Guideline

Engineering projects in northern Canada often encounter permafrost in their foundation environment. The ability of frozen ground to support these structures depends mostly on local climatic conditions, ground temperatures, soil/rock material properties, and ground ice conditions.

Geographic range of permafrost in Canada

This Guideline is relevant to communities and development projects wherever permafrost occurs in the territories and the northern portions of most provinces (see Figure 2.1, p. 17).

Significant climate warming is occurring in the North. Community infrastructure should be located and foundations should be designed with careful consideration of the potential for **significantly different foundation environments** over the service lives of structures as permafrost warms and thaws. The analyses required to address permafrost and climate-change-related factors will vary between projects, depending upon the type of infrastructure, its design, location, intended service life, and purpose.

Infrastructure covered by this Guideline

The guideline relates to *structures that require foundations*, whether buildings, utilidors, water treatment plants, towers or tank farms, and bridges. Community water supply facilities (containment structures) require special design considerations, but climate change effects should also be considered for these structures. The Transportation Association of Canada (TAC) publication, *Guidelines for Development and Management of Transportation Infrastructure in Permafrost Regions* should also be consulted for specific guidance with respect to roads and permafrost (TAC, 2010, www.tac-atc.ca).

The guideline supports the appropriate consideration of climate-change-related factors during the

