NWB Tools

Richard Dwyer <richard.dwyer@nwb-oen.ca>

2AM-BRP1831 2025 Winter Ice Road Technical Memo

John Roesch <JRoesch@lands.kitia.ca> Wed, Nov 19, 2025 at 9:20 AM
To: Richard Dwyer <richard.dwyer@nwb-oen.ca>

Hello Richard, KIA's geotechnical engineering consultant has reviewed the Winter Ice Road memorandum and his comments are as follows:

Hi John,

I had a look at the WIR technical memo, and I only have some editorial / clarification questions.

1. The October 22, 2024, was referring to the past season as the 2025 WIR season, which was now again the reference for the upcoming season. Not sure if this shouldn't be the 2026 season, r if they kept it is 2025 for a specific reason and will add a year as they are moving forward.
2. On page 2, Section 3 they mention that they are expecting approximately 2000 loads in the 2025 WIR season, but on page 4, section 5, they mention 3000 loads, which is similar to the October 22, 2024, report.
3. The drawing of Appendix A references the 2024 WIR, but I assume they mean 2025
4. They are referencing the 2017 Golder report on page 4 under Section 8, but I assume they mean the 2018 report that was attached.
5. In addition to the 2015 GNWT *Guidelines for Safe Ice Construction*, I would encourage B2Gold to consider and reference the new, 2024 *Guide for Building and Working Safely on Ice Covers in Alberta*, which is a revised version of the document that had been used for the 2015 GNWT guidelines. The changes aren't substantial, but things have been modernized a little bit (cf. Proskin & Salman, 2025).

Thanks,

Lukas

Lukas Arenson, Dr.Sc.Techn.ETH, P.Eng. (BC, YT, NT/NU) (he/him)

Principal Geotechnical/Permafrost Engineer, Cryology Discipline Team Co-Lead

BGC Engineering

Adjunct Professor, Department of Civil Engineering, University of Manitoba

Professeur Associé, Département des génies civil, géologique et des mines, Polytechnique Montréal

Vice-President, International Permafrost Association
Past-President, Canadian Permafrost Association

Enclosure: Technical Basis for Revisions to Alberta's Guide for Building and Working Safely on Ice Covers.

From: Richard Dwyer <richard.dwyer@nwb-oen.ca>
Sent: November 4, 2025 3:26 PM
To: Chris LeGoffe <CLeGoffe@b2gold.com>; Merle Keefe <mkeefe@b2gold.com>; Scott Morrison <Scott.Morrison@b2gold.com>
Subject: 2AM-BRP1831 2025 Winter Ice Road Technical Memo

[Quoted text hidden]

3_Proskin.pdf
743K

Technical Basis for Revisions to Alberta's Guide for Building and Working Safely on Ice Covers

Sam Proskin and Ala Salman
Thurber Engineering Ltd., Calgary, Alberta, Canada

ABSTRACT
Community re-supply and natural resource development in northern Canada often rely on temporary roads built over frozen lakes, river and frozen terrain to provide economical site access and resupply routes. These ice or winter roads offer significant socio-economic benefits to the communities (public ice roads) and industrial sites (industrial ice roads) they connect. The state of practice for determining allowable loads on ice roads has been based on empirical ice capacity equations developed in the 1970s. Canadian jurisdictional ice road construction and operations guides have combined these empirical equations with construction, operational and safety practices to promote the safe operation of public ice roads. The Guide to Building and Working Safely on Ice Covers in Alberta was updated recently to reflect changes to engineering practices. This paper discusses the technical changes made and their basis in engineering practices. The main technical changes included clarifying definitions of constructed flood ice and white ice, updating the limitations on the use of Gold's equation for certain types of vehicles, revising the text on other load capacity methods, and revising the guidance for GPR ice profiling.

RÉSUMÉ
Le réapprovisionnement des communautés et le développement des ressources naturelles dans le nord du Canada dépendent souvent de routes temporaires construites sur des lacs gelés, des rivières et des terrains gelés pour fournir un accès économique aux sites et des voies de réapprovisionnement. Ces routes de glace ou d'hiver offrent des avantages socioéconomiques importants aux communautés (routes de glace publiques) et aux sites industriels (routes de glace industrielles) qu'elles relient. L'état de la pratique pour déterminer les charges admissibles sur les routes de glace est basé sur des équations empiriques de capacité de glace développées dans les années 1970. Les guides canadiens de construction et d'exploitation des routes de glace ont combiné ces équations empiriques avec les pratiques de construction, d'exploitation et de sécurité pour promouvoir l'exploitation sécuritaire des routes de glace publiques. Le Guide pour construire et travailler en toute sécurité sur les couches de glace en Alberta a été mis à jour récemment pour refléter les changements apportés aux pratiques d'ingénierie. Cet article examine les changements techniques apportés et leur fondement dans les pratiques d'ingénierie. Les principaux changements techniques comprenaient la clarification des définitions de la glace de crue construite et de la glace blanche, la mise à jour des limitations sur l'utilisation de l'équation de Gold pour certains types de véhicules, la révision du texte sur d'autres méthodes de capacité de charge et la révision des directives pour le profilage de la glace GPR.

1 INTRODUCTION

Alberta's Ministry of Jobs, Economy and Trade (JET) requested a technical update to the office and field editions of the 2013 Best Practice for Building and Working Safely on Ice Covers in Alberta (Alberta Guide). The objective of the documents is to provide employers, supervisors and workers with up-to-date information and recommended industry practices to help ensure their health and safety when working on ice covers. Thurber's tasks were to update the Alberta Guide text (both field and office editions) to reflect current developments in engineering practices as they pertain to the building and working safely on ice covers.

The purpose of this paper is to explain the engineering basis behind the most significant changes made to the Alberta Guide. These include clarifying definitions of constructed flood ice and white ice, reducing the maximum vehicle loads from 63,500 kg to 46,500 kg when applying the load capacity charts, revising text on other load capacity methods and revising the guidance for GPR ice profiling. We also added a section on dugouts and depressions as hidden floating ice hazards.

2 DEVELOPMENT OF ICE SAFETY GUIDES

Ice bearing capacity underwent extensive theoretical and experimental research in the 20th century. Kerr (Kerr 1976) provides a bibliography of the development of ice bearing capacity analysis and cites several references mentioning analyses developed for multiple applications including those for railroads over ice, airfields for small aircraft, platforms for storage or construction, and aids to civilian and military transportation operations. Noteworthy is the extensive Soviet and American research that was published from the 1950s to the 1970s with a focus on military applications. This research explored the application of bending plate theory based on linear elasticity, visco-elasticity, and plasticity theory with closed form solutions. Solutions were developed for infinite plates and others for half-plates and quarter plates to represent different loading situations. Short term loads, such as vehicles moving over ice, were separated from long-terms loads, such as stationary loads. From this research activity, ice bearing capacity charts and graphs were the first manifestation of guidance documents that emerged later.

In 1971 the National Research Council of Canada's ice researcher (Gold 1971) published an influential paper that provided guidance on using the simplified version of the linear elastic bending plate equation:

$$P=Ah^2 \quad [1]$$

where P is the load in kg, h is the ice thickness in cm, and A (in kg/cm2) is a parameter accounting for the ice properties (primarily flexural strength) and load configuration (load radius). He conducted a survey of pulp and paper mill operators that built and used ice roads for their winter site operations for moving loads. This survey requested information on ice thickness, vehicle loads, and they noted whether their specific situations were successful in crossing the ice or had breakthroughs (ice failures) for about 100 cases. From this data set, he plotted this ice thickness vs load data on a log-log plot where equation 1 now plots as a straight line with the slope representing the A parameter.

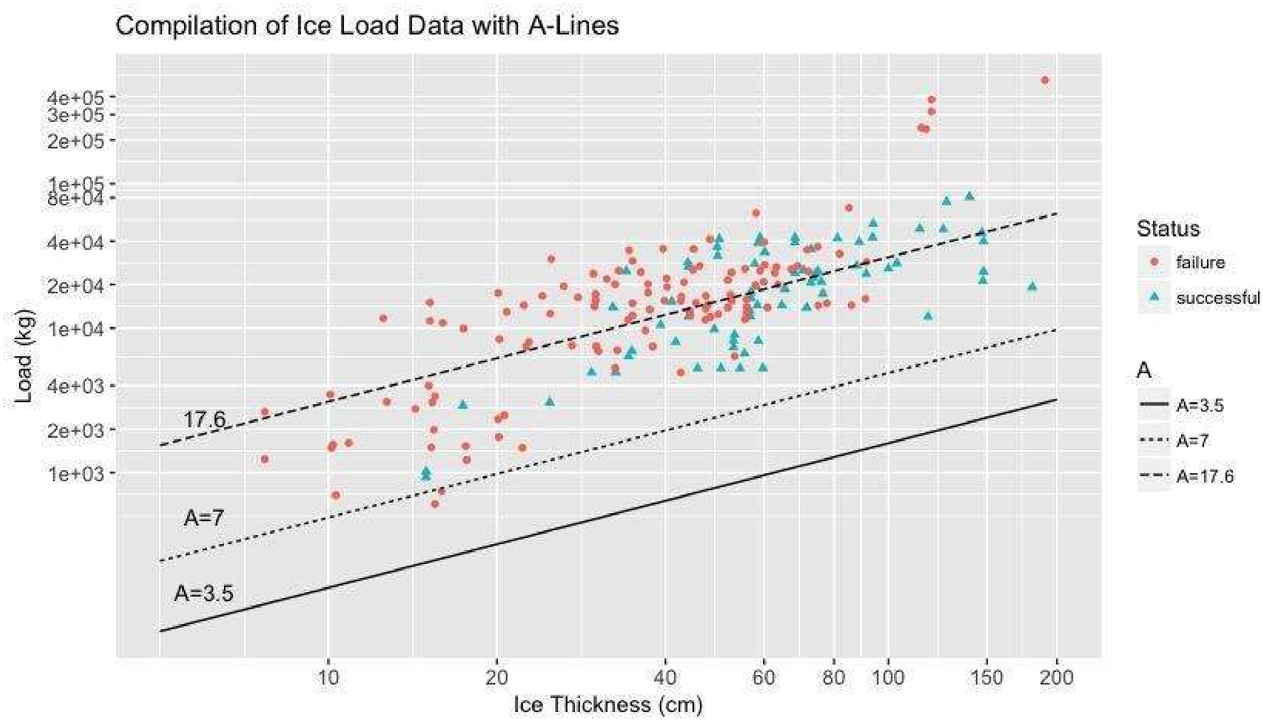

Figure 1 Compilation of load vs ice thickness results

The survey showed an appreciable overlap between the successful and failed ice observations because of other uncontrolled factors (e.g., vehicle configurations, axle loads, ice temperature, ice type) influencing the results. For example, some failures occurred when the vehicles left a prepared area and travelled over untested ice cover. Based on the survey data, Gold proposed three lines representing slopes of A=3.5, 7.0 and 17.6 for providing limits on ice bearing capacity for moving loads, depending on the user's risk tolerance as shown in Figure 1:

- A=3.5 is interpreted as low risk as it gives the lowest load for a given ice thickness and almost all the survey failures occurred at higher loads.
- A=7 is a recommended as an upper limit for safe operations.
- A=17.6 is very high risk but there are a few successful ice covers at loads above this.

Since the publication of that work, Gold's equation, as it is known in Canadian practice, has become the basis for most Canadian jurisdictional ice bearing capacity guides. Ice safety guides in the 1990s provided the ice bearing capacity A values, procedures on ice thickness measurements, and guidance on operational practices. The A values varied from A=4 (GNWT), to 7.03 (Manitoba and Alberta) with the US Army Corps of Engineer's CCREL recommending A=8.8. These variations can lead to significant differences in allowable loads (e.g., for 50 cm of ice, A=4 gives 10,000 kg while A=7 gives 17,500 kg). The discrepancy is explained by the different approaches to accounting for the ice strength when evaluating the ice thickness from ice measurements. Manitoba and Alberta required measuring the thickness of blue ice and white ice but dividing the white ice thickness by 2 before adding it to the blue ice to give the ice thickness for load calculation. CRREL's recommendation for A=8.8 only considered clear, sound ice (excluding white ice) in the ice thickness. These recommendations were based on the commonly accepted belief in a difference in ice strength between blue ice (clear with no air bubbles) and white ice (with extensive air bubbles). Blue ice is formed once the primary ice cover has formed and the freezing front moves downward through the still water underneath. White ice is associated with natural overflow ice that is formed when snow accumulates on the primary ice cover loading it down which is saturated by water seeping onto the ice surface on through cracks. Overflow ice is recognized having a highly variable ice strength due to natural variability in air content (Ashton 1986). Consequently, its lower strength is handled by discounting its contribution to the ice thickness. NWT's guide approach to ice strength variability was to adopt a lower A=4 (NWT, 2015).

Operational practices included those engineered and administrative controls meant to reduce the risk of vehicle breakthrough due to hazards other than weak or thin ice. Administrative controls were formed around rules of the road to direct vehicle operators and ice road operators. Among the hazards are over-stressing due to hydrodynamic waves associated with excessive vehicle speeds and excessive deflections under stationary loads. A load deflects the ice cover, creates a bowl underneath and this deflection bowl moves with the vehicle. However, as the vehicle speed increases, a critical speed is eventually reached where the stresses are magnified in the ice by 50% and a series of leading and trailing waves are initiated (Takizawa 1988). The critical speed depends mainly on the water depth and ice thickness, and based on typical river/lake water depths and ice thickness, the critical speed varies between 30 to 60 km/h. Consequently, the rules of the road recommend speed limits between 15 and 50 km/h to reduce vehicle related ice deflections below those causing ice cracking or damage.

Likewise, stationary loads on ice have been observed to deflect with time and can reach excessive deflections if they are loaded to the maximum for moving loads. These deflections were found to occur minutes or hours after initial deflections began (Frankenstein 1963). Parking on the ice is restricted to no more than 2 hours to prevent excessive deflection due to stationary loads.

The final recommendation is to monitor the ice for cracks forming after sudden drops in air temperatures. Under rapid cooling, the ice undergoes thermal contraction which can lead to cracking on the fixed ice cover surface. Depending on their depth and extent, these cracks can pose a hazard to vehicle traffic. Additional ice monitoring is required to check for cracks after sudden cold snaps.

Starting in the 1980s industrial ice roads became critical for economical access to remote sites for mining exploration and development (Hayley and Valeriote 1994, Hayley and Proskin 2008) in NWT. Industrial roads had special hauling demands for fuel, equipment and other materials that increased the size and number of vehicle loads from those of resupply of remote communities. For example, the Lupin Winter Road was re-supplying the Lupin Gold Mine from 1982 to 2005 via a 600 km winter road from Yellowknife, NT (Braden 2012) to Lupin on Contwoyto Lake. Construction and operation of the Lupin mine required about 700 vehicle loads of diesel fuel, construction materials, and equipment to be brought in by winter road each year as the feasible method for bulk transport. The winter road operating season was on average 60 days with about 15 loads per day with total haulage of 24,000 metric tons. During this period winter road construction camps were built at Dome Lake, Dry Bones Lake and Lac des Gras to facilitate construction and maintenance of the ice crossings and the overland portages.

In 1991 diamondiferous kimberlite pipes were found near Lac des Gras. This find started a rush in NWT with over 70 million acres staked in 1992. The impact of this rush on winter road demands was dramatic. The number of loads increased from 750 to 932 and then 1700 loads from 1992 to 1994. Likewise, the average number of loads per day increased from 15 to over 100 by 2002 and the average number of operating days increased from 50 to 70 days (Braden, 2012). By 2002 the Tibbitt to Contwoyto Winter Road (TCWR), the new name for the Lupin Winter Road, was handling 124 loads per day with a total number of 8061 loads that had hauled 254,900 metric tons. With these increased demands, relying on natural ice growth was either insufficient or unreliable to accommodate the number of vehicle loads and or their heavier weights. Consequently, ice road builders began to supplement natural ice growth with water flooding on the floating ice speed up ice road growth. This was either required to open the road for heavier loads or to open it earlier for lakes with slower ice growth.

Under these increased demands for the industrial roads like the TCWR , the current ice guides were inflexible in three ways. First, the bearing capacity A values sometimes required ice thicknesses that could either delay deployment of vehicles until that ice was reached in the field or were unachievable with very heavy loads. For example, there was considerable operational experience demonstrating that A=6 was safe to use despite it exceeding the weights given by the more conservative A=4 in the NWT guide. Second, ice road contractors did not interpret surface flood ice as white ice in their thickness calculations. From their field experience they found good quality (completely frozen, no significant air voids) flood ice was comparable to natural blue ice. Third, winter road operators implemented operational and administrative controls for equipment and vehicle operators, that could be monitored and enforced on users during construction, maintenance and operations. The TCWR developed a rules-of-the-road (Tibbitt to Contwoyto Winter Road Joint Venture, 2022) which established rules for vehicles for both winter road construction and operations that were meant to reduce the risk of vehicle breakthrough.

3 EVOLUTION OF ICE COVER PRACTICES

In the early 2000s the Tibbitt to Contwoyto Winter Road Joint Venture (JV) had taken over the permit for the winter road operations since it was critical to the construction and re-supply of Ekati and Diavik mine sites and other partners. The JV brought in EBA Engineering Consultants Ltd. (EBA) to update the winter road technology as a basis for their revised operating procedures (EBA Engineering Consultants Ltd. 2003) for winter road operations. EBA combined engineering analysis with the road's industrial experience to update operational rules regarding bearing capacity analysis and recommended specific uses for A values for bearing capacity analysis:

- A=4 for initial opening of ice road and operations on ice less than 50 cm
- A=5 for snow removal equipment with continuous ice profiling data during construction
- A=6 for standard highway legal configurations during normal road operations

EBA recommended conducting bearing capacity analyses with available closed form solutions for non-standard highway axle configurations and for vehicles heavier than 62,500 kg. Engineering analysis can account for ice properties, load configuration and other operational variables that are not considered explicitly in empirical equations. The most widely adopted engineering analysis models floating ice as a bending plate and calculating an ice thickness that limits the maximum flexural stress to an allowable value (Wyman 1950, U.S. Army Corps of Engineers 2006).

EBA also recommended augmenting natural ice growth with surface flooding in thinner ice cover areas. At this time the ice road contractor was using surface flooding more selectively for: (a) construction thickening at areas known to have thinner ice; (b) construction thickening ice at shoreline approaches; (c) maintenance repair of damaged ice areas after opening to traffic; (d) maintenance repair areas that were thinning after opening. The contractor's experience suggested the surface flood ice was comparable to natural blue ice in terms of bearing capacity. By 2009 well made surface flood ice was recognized for its role in providing satisfactory bearing capacity (Masterson 2009).

In the early 2000s the TCWR ice road contractor Nuna Logistics started using Ground Penetrating Radar (GPR) ice profiling equipment to assess ice thickness (EBA Engineering Consultants Ltd. 2003). GPR wave velocity depends on the dielectric constant of the media. When a transmitted wave encounters a change in dielectric constant, such as that between ice and water, the wave is reflected back (Proskin et al. 2011). Knowing the speed of electromagnetic waves in ice and the transit time of the wave, the distance the wave travelled, the ice thickness, can be calculated. The accuracy of the method is checked when the GPR signal is calibrated to an ice thickness measurement in the field. This had the advantage of calibrating the equipment to locations with flood ice over blue ice and the opportunity to re-calibrate as new ice conditions were encountered. GPR ice profiling made no distinction between white ice and blue ice thicknesses. Ice profiling permitted the contractor to efficiently confirm the minimum ice thickness for each of the 50 lakes at various stages throughout construction and operations. After construction ice profiling was completed, periodic ice profiling was performed during road operations to check for thinning ice areas and to aid in maintenance and repairs.

The JV formalized construction and operational controls in their Rules of the Road. It captured the various lessons learned from previous seasons experience with ice construction, ice monitoring, and hauling vehicle operations. The Rules of the Road also prescribed ice conditions and constraints for construction vehicles prior to opening for vehicle hauling. Vehicle operational rules regarding vehicle spacing, speed limits, dispatching rules are also stipulated. as to capture the various construction and operational controls that evolved during the previous decades.

More recently risk management approaches have been developed to account for the quality assurance and operational controls used with ice road design. Proskin and Fitzgerald (2014) discuss the risk management framework developed for the Tibbitt to Contwoyto Winter Road over 7 years. The risk management framework combines developments in GPR ice profiling and vehicle dispatch tracking to better understand and manage the risks associated with ice roads. It also provides more flexibility in handling heavier haul vehicles and higher traffic volumes associated with larger projects or abbreviated hauling seasons.

4 ALBERTA GUIDE FOR BUILDING AND WORKING SAFELY ON ICE

4.1 Development

The 2009 edition of the Alberta Guide was initiated through a creative sentencing requirement assigned to ATCO as the result of a worker fatality on their project involving an ice crossing over the Peace River in January 2005. The intent was to replace the existing Alberta ice guide with one that aligned with Part 2 of the Alberta Occupational Health and Safety regulation regarding the hazard assessment and controls during the building and work operations on ice. ATCO created a multi-stakeholder advisory committee composed of people with experience in safety, engineering, construction and maintenance for work on ice covers. The TCWR experience and knowledge were acknowledged as a major influence on the implementation of ice road risk management practices included in the Alberta Guide.

The Alberta Guide has four sections covering ice cover hazards, ice cover hazard controls via design, monitoring and maintenance (engineering controls), ice cover safety plan (administrative controls), and PPE. Section 2 explains the ice cover hazards such as ice type (e.g., natural flood ice), ice crack types (e.g., radial cracks), load types (e.g., stationary vs moving), ice road routes (e.g., rivers vs lakes), and operational factors, such as schedule that could affect safety. Section 3 classifies the engineering, administrative and PPE controls to be applied for on-ice work. Section 4 describes how ice road design, monitoring (e.g., ice thickness profiling) and maintenance are engineering controls that can reduce ice road hazards. Section 5 provides guidance on preparing an ice safety plan that describes the administrative controls, such as speed limits, vehicle separation and vehicle weight confirmation, to reduce operational hazards. Section 5 on PPE emphasizes the use for flotation suits for workers involved in pre-construction and construction phases on ice covers.

The Alberta Guide had some editorial updates in 2013.

The 2024 Alberta Guide edition had a more substantive review of technical developments since the 2013 edition. The following section discusses the four significant technical changes.

4.2 Technical Changes

The most significant updates made in the 2024 edition were:

1. Section 2: Definitions of constructed flood ice and natural flood ice
2. Section 4: Expanded limitations on load capacity charts
3. Section 4: Other load capacity methods
4. Section 4: Guidance for GPR ice profiling (Mesher et al. 2008)

4.3 Constructed Flood Ice and Natural Flood Ice

Among the ice hazards described in 2009 edition of Section 2, a simple set of freshwater ice type definitions, based on industry practices, are provided to assist builders and operators to build good quality ice covers. White ice is defined as ice that forms on top of the surface of the ice by natural or artificial flooding of snow. However, it does distinguish between good quality lake ice and poorer quality natural flood ice in terms of its bearing capacity. With good ice monitoring data and high level of operational controls, good quality lake ice can carry higher loads compared to less reliable natural flood ice.

The 2024 edition revised the ice type definitions to distinguish between constructed flood ice and natural flood ice (Figure 2). Natural flood ice forms under uncontrolled conditions and may have macroscopic air voids and be incompletely frozen before additional flooding takes place. In contrast, constructed flood ice is produced with surface water saturating any snow to eliminate macroscopic air voids and allowed to freeze completely before any new water is added. Constructed flood ice made under these conditions and validated with field observations can be considered to have strength similar to freshwater lake ice (Masterson, 2009).

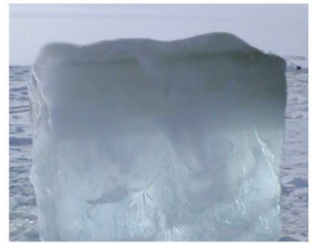

Figure 2 Updated definitions of constructed flood ice and natural flood ice (Alberta OHS, 2024)

4.4 Expanded Limitations on Gold's Equation

Gold's ice capacity equation continues to serve as the basis for estimating ice thickness required for most common vehicles and relying on selecting A values and their associated level of hazard controls. However, recent research has reinforced the limitations on the use of Gold's equation for certain types of vehicles. Fitzgerald and van Rensburg (2024) analyzed a case of two vehicle types, a Cat 336 excavator and a 5 axle tractor-trailer each weighing 39,100 kg. With Gold's equation and an A=5, the required minimum ice thickness is 89 cm for this load. However, when analyzing the stresses using bending plate theory, the 336 excavator, with its more closely spaced loads (Figure 3a) generated higher ice stresses (780 kPa) compared to the 5 axle highway legal vehicle (550 kPa) (Figure 3b). Although A=5 represents moderate risk in Table 3 of the Alberta Guide, the 336 excavator ice stresses exceed the commonly accepted flexural strength for the freshwater ice of 500 kPa.

Another analysis was performed for a 29,500 kg D7R crawler and the same load on a 5 axle tractor-trailer with similar findings of the crawler ice stresses (810 kPa) exceeding the ice strength. They recommended that Gold's equation should not be used for heavy equipment. Consequently, the Alberta Guides does not recommend Gold's equation for heavy construction excavators, loaders and crawler tractors, with gross vehicle weights greater than 10,000 kg. Furthermore, the upper limit on the application of the Gold's equation for highway legal vehicles was reduced from 63,500 kg to 46,500 kg (6 axle tractor-trailer).

4.5 Other ice bearing capacity methods

The Alberta Guide has an expanded section explaining the are other analysis methods available for estimating the bearing capacity of freshwater ice covers. There are also field methods available for assessing in situ strength and performance conditions of ice covers under load.

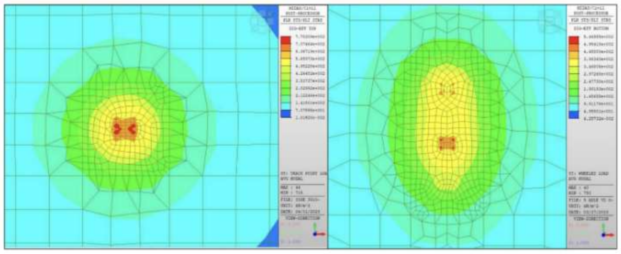

Figure 3 Ice stress contours due to (a) 336 Excavator and (b) 5 axle tractor trailer (Fitzgerald and van Regensburg, 2024)

Ice stress analysis methods using bending plate theory or numerical modeling are available that can estimate flexural stresses in the ice cover for various load configurations. Professional engineers use these methods for heavy construction equipment, special load configurations and stationary loads. Field investigations can also be performed that provide additional information on ice strength.

Two field methods have been used to measure in situ behaviour of ice covers. The ice deflection test involves monitoring the deflection of an ice cover as it is gradually loaded and performing a back analysis to estimate the required ice properties for estimating the bearing capacity. The borehole jack test (Figure 4) can be run in the field by drilling a shallow hole in the ice cover, inserting the jack and then loading the ice up to failure. Test measurements of the displacement and load provide the stress-deformation properties of the ice. Because these methods rely on field measurements of the ice properties, they can be used to assess as built properties of the ice cover for engineering analysis.

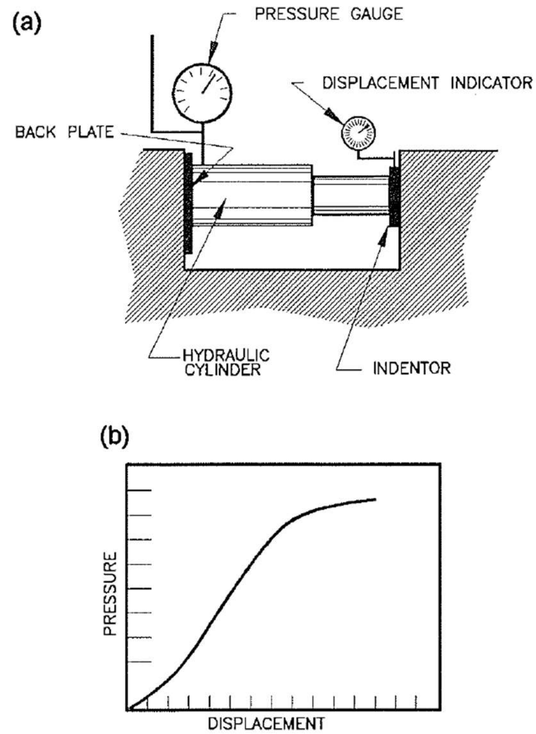

Figure 4 Borehole jack device: (a) installed in ice test hole and (b) pressure-displacement plot (Masterson and Graham, 1996)

4.6 Guidance for GPR Ice Profiling

The technology for ice profiling has evolved from a geophysics specialty in the early 2000s to off-the-shelf equipment that only requires a vendor training course to operate. The interpretation of the ice thickness, after a local calibration, is left to the software which is often integrated with GPS to provide geo-referenced ice thickness data.

Although manual measurements are still described in the Alberta Guide, they are only practical for small on-ice projects where manual measurements can be made at the required spacing and frequency to meet the Alberta Guide's requirements. For large ice surfaces that require ice thickness measurements, GPR ice profiling can digitally collect thousands of measurements that can be readily mapped and quickly analyzed. In some cases, the data can be interpreted to identify other features below the ice, such as grounded ice (Figure 5).

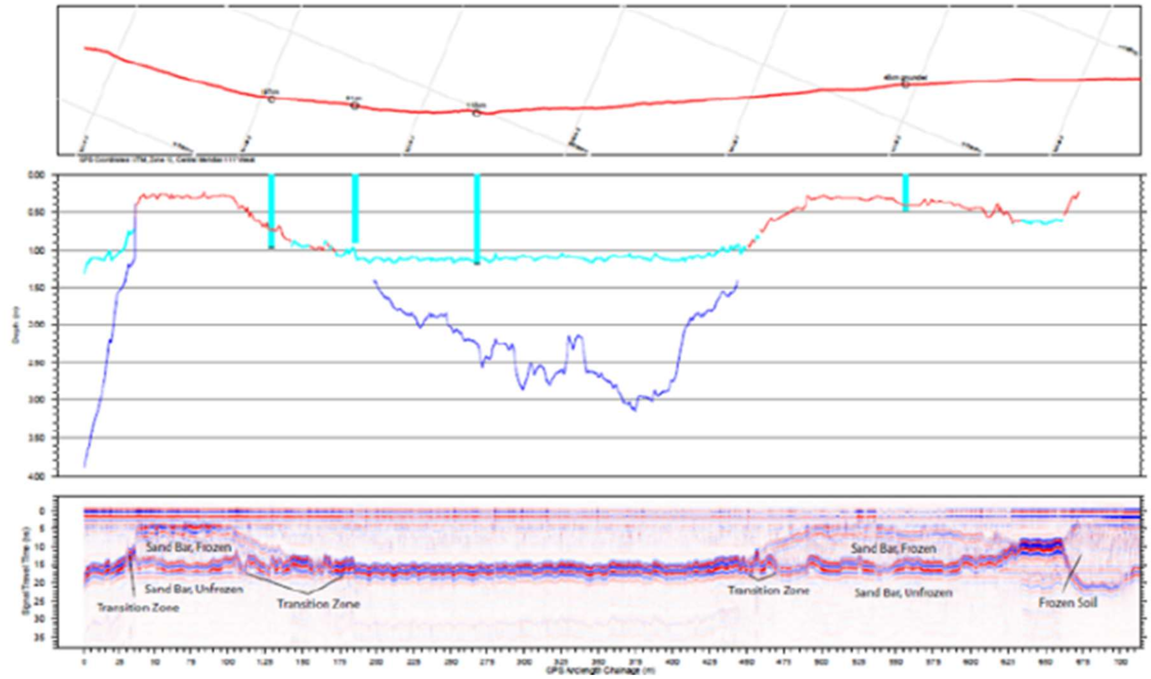

Figure 5 GPR ice profile: top box shows the plan view; middle box is the interpreted ice thickness and bottom depth; and bottom box is the GPR data (Proskin et al. 2011)

The Alberta Guide recognizes the value of continuous GPR ice profiling, when conducted in accordance with Alberta Guide guidance, in assuring the engineer that the ice cover quality and thickness has been adequately measured. It recognizes two scenarios for it:

Scenario 1: GPR ice profiling for construction purposes where it is used to confirm and monitor ice thickness during construction and operations of ice roads. This is associated with ice bearing capacity levels corresponding to A Values of 3.5 through 6 with experienced crews and appropriate control measures as outlined in Table 3 of the Alberta Guide.

Scenario 2: GPR ice profiling for engineer purposes where professional engineers use it to verify the ice conditions when specialized engineering analysis is required. This is usually when operators contemplate use of ice construction equipment heavier than 10,000 kg or wheeled vehicles heavier than 46,500 kg.

Appendix B of the Alberta Guide provides more details on the requirements for GPR ice profiling.

4.7 Other updates

One significant new hazard is Section 2.8.5 Depressions and Dugout. Depressions and dugouts can fill with water that later forms an ice cover during freezing temperatures. Should the ice cover become covered in snow, then it may be difficult for a worker or operator to delineate the area and depth of the ice covered water hazard. Such features, if they can fill with water more than 1 m deep and form an ice cover in freezing temperatures, should be identified as potential hazards if workers or equipment need to work near them.

Figure 6 Excavator breakthrough on an ice cover over a dugout (Alberta OHS, 2023)

5 CONCLUSION

Jurisdictional guidelines for ice cover safety continue to serve their various communities by providing guidance for projects considering using ice covers as temporary structures. Like other normative documents, they need regular updates to consider changes in regulatory, safety or engineering practices.

The Alberta Guide underwent a significant technical and editorial update in 2024 to reflect changes in the engineering practices. From an ice engineering perspective, the most significant changes in technology and industry practices are related to understanding the efficient use of good quality flood ice, the limitations of using Gold's equation for vehicles whose load distributions are more concentrated than highway legal axle configurations, the value of advanced engineering analyses and field methods to better predict ice bearing capacity, and the application of GPR ice profiling in enhanced monitoring of ice thickness and instilling more confidence in those measurements.

We also examined ice breakthrough fatalities that took place since the last update to see if additional measures could be included to reduce the likelihood of similar incidents. Depressions/dugouts are included as a potential ice covered water hazard that may be difficult to identify in the field.

It is our hope that Alberta Guide can continue helping those considering work activities on ice covers to plan their field programs and support them and their crews in safely building and working on ice covers.

6 ACKNOWLEDGEMENTS

We appreciate the support of the Government of Alberta for this technical update to the Alberta Guide. SP also acknowledges the mentoring and contributions of colleagues at Tetra Tech and NOR-EX Ice Engineering throughout his career.

7 REFERENCES

Braden, B. 2012. On good ice: the evolution of Canada's Arctic ice road : lifeline to gold, diamonds and the future. Tibbitt to Contwoyto Winter Road Joint Venture, Yellowknife, N.W.T.

EBA Engineering Consultants Ltd. 2003. Operating parameters for managing lake ice crossings. Consultant's report, Tibbitt to Contwoyto Winter Road Joint Venture, Edmonton.

EBA Engineering Consultants Ltd. 2010. Standard Operating Practice for Managing Ice Crossings Tibbitt to Contwoyto Winter Road. Issued for Review, Tibbitt to Contwoyto Winter Road Joint Venture, Edmonton, AB.

Fitzgerald, A., and Janse van Rensburg, W. 2024. Limitations of Gold's formula for predicting ice thickness requirements for heavy equipment. Canadian Geotechnical Journal, **61**(1): 183–188. NRC Research Press. doi:10.1139/cgj-2022-0464.

Frankenstein, G.E. 1963. Load test data for lake ice sheets. Technical Report, US Army Corps of Engineers, Hanover, NH.

Gold, L.W. 1971. Use Of Ice Covers For Transportation. Canadian Geotechnical Journal, **8**(2): 170–181. doi:10.1139/t71-018.

Government of Alberta. 2013. Best Practice for Building and Working Safely on Ice Covers in Alberta. *In* 2013th edition. Government of Alberta, Edmonton, Alberta.

Hayley, D., and Proskin, S. 2008. Managing the Safety of Ice Covers Used for Transportation in an Environment of Climate Warming. *In* Proceedings of the 4th Canadian Conference on Geohazards: From Causes to Management. *Edited by* J. Locat, D. Perret, D. Turmel, D. Demers, and S. Leroueil. Presses de l'université Laval, Quebec. p. 12.

Hayley, D.W., and Valeriote, M.A. 1994. Engineering a 300 km Winter Haul Road in Canada's Arctic. *In* 7th International Cold Regions Engineering Conference. *Edited by* D.W. Smith and D.C. Sego. Canadian Society for Civil Engineering, Edmonton, Alberta. pp. 413–425.

Kerr, A.D. 1976. The bearing capacity of floating ice plates subjected to static or quasi-static loads. Journal of Glaciology, **17**(76): 229–268.

Masterson, D. 2009. State of the art of ice bearing capacity and ice construction. Cold Regions Science and Technology, **58**(3): 99–112. doi:10.1016/j.coldregions.2009.04.002.

Masterson, D.M., and Graham, W. 1996. Development of the original ice borehole jack. Canadian Journal of Civil Engineering, **23**(1): 186–192. doi:10.1139/l96-019.

Mesher, D.E., Proskin, S.A., and Madsen, E. 2008. Ice Road Assessment, Modeling and Management. Transportation Association of Canada, Toronto, ON. p. 20.

NWT Department of Transportation. 2015. Guidelines for Safe Ice Construction. Government of NWT, Yellowknife, NT.

Proskin, S.A., Parry, N.S., and Finlay, P. 2011. Applying GPR in Assessing Ice Bridges, Ice Roads and Ice Platforms. *In* CGU HS Committee on River Ice Processes and the Environment. CRIPE, Winnipeg, Manitoba. p. 14p.

Proskin, S., and Fitzgerald, A. 2014. A Risk Management Framework for Ice Cover Operations. *In* GeoRegina 2014 Engineering for the Extremes. *Edited by* Organizing Committee. Canadian Geotechnical Society, Regina, Saskatchewan. p. 441.

Takizawa, T. 1988. Response of a floating sea ice sheet to a steadily moving load. J. Geophys. Res., **93**(C5): 5100–5112. doi:10.1029/jc093ic05p05100.

Tibbitt to Contwoyto Winter Road Joint Venture. 2022. 2022 Winter Road Rules. Tibbitt to Contwoyto Winter Road Joint Venture, Yellowknife, NT.

U.S. Army Corps of Engineers. 2006. Chapter 8 Bearing Capacity of Floating Ice Sheets. *In* Ice Engineering, Change 3. Department of the Army, Washington, D.C. p. 475.

Wyman, M. 1950. Deflections of an infinite plate. Canadian Journal of Research, **28**(3): 293–302.