Design and Operation of Ice Roads

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DESIGN AND OPERATION OF ICE ROADS

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Design and Operation of Ice Roads

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16. Abstract

This manual provides for the safe and efficient design, construction, maintenance, and operation of ice roads over freshwater. As such, it provides the parties responsible for the ice road guidelines for ensuring the safe operation of the ice road including route selection, minimum ice thicknesses, repair strategies, maximum vehicle weights and speed, and proper signage. The information provided in the manual represents best practices compiled from existing literature and from those who have experience working on ice roads. While every scenario cannot be foreseen, the information contained in this manual should provide sufficient knowledge to extrapolate safe solutions which are not explicitly covered here.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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EXECUTIVE SUMMARY

The primary purpose of this manual is to provide for the safe and efficient design, construction, maintenance, and operation of an ice road. This manual has ten chapters and three appendixes.

Chapter 1. Introduction. This chapter describes the purpose, background, and the organization of the manual. This manual does not present an in-depth development of the principles of ice mechanics. Safety is stressed throughout the manual.

Chapter 2, Ice Road Framework. This chapter presents a framework for the design, construction, and operation of ice roads. The framework is a series of phases (or steps) to be followed for establishing an ice road or crossing. The phases are Pre-Season, Pre-Construction, Ice Road Operation, and End of Season. A very brief description is provided of the main activities that occur in each Phase, and the chapter of the manual that provides information on each activity is referenced.

Chapter 3, Ice Road Background. This chapter starts with an overview of bearing capacity. In addition to ice thickness and quality, two factors that can impact the bearing capacity, vehicle motion and creep of the ice cover are described. Gold's formula for estimating the bearing capacity provides a way of estimating the risk associated with a minimum ice thickness requirement for a specified load. Finally, the distinct types of ice that can be encountered and how those types of ice impact the load bearing are described.

Chapter 4, Ice Road Hazards. This chapter reviews the hazards that can affect the integrity of the ice road and the safe operation of vehicles on the ice cover. A primary hazard to the ice cover integrity is the formation of cracks. There are two basic types of cracks, dry cracks, and wet cracks. The causes of cracks are described. Other hazards, including blowing snow, warming, and end of the season are discussed.

Chapter 5, Ice Road Design. The design of ice roads starts with route selection. Steps for route selection are then described for ice roads located on rivers, located on lakes, and for river crossings. The minimum road widths are presented. The required ice thickness is described in terms of Ice Road Risk Management. Ice Road Risk Management allows the ice road operators to balance the needs and requirements of the ice road users and the resources available to the operators at an acceptable risk level. The risk level is set by the selection of the *A* value for Gold's Formula. Loads are divided into three classes: Lighter loads, Traffic Loads, and Extreme Loads.

Chapter 6, Ice Road Construction. Ice thickness surveying is a fundamental part of Ice Road Construction and is discussed first in this chapter. Ice road construction starts with the pre-construction phase. During the pre-construction phase the layout of the road across lakes and along rivers is finalized, and the ice thickness along the route is systemically surveyed and recorded. When the ice thickness is sufficient to support construction vehicles, then the actual construction can begin. During the construction phase the travel lanes are prepared, the ice cover is strengthened by removing the snow cover from the ice and flooding the ice surface if necessary, and access points are developed. The required equipment is described, along with safety features, safe operations, worker safety, and record keeping.

Chapter 7, Ice Road Signage. Winter ice road traffic signs are an important part of ice road safety. It is required that ice road signage follows standard Manual on Uniform Traffic Control Devices (MUTCD) standards and guidance (FHWA 2009), where applicable. Ice roads are considered Low Volume Roads as defined by the MUTCD. Ice road signage shall be designed in accordance with the provisions contained

in Part 5 of the MUTCD, “Traffic Control Devices for Low-Volume Roads”, and where required, in other applicable parts of the MUTCD. Generally, all required signage must be in place before an ice road or crossing is open to the public. There are three categories of signage: Construction, Entry signs, and regulatory and advisory signs.

Chapter 8, Ice Road Vehicle Control. This chapter describes the maximum speed limits, minimum distances between vehicles, control of stationary loads, and load management for ice roads.

Chapter 9, Ice Road Monitoring and Maintenance. Monitoring the ice cover is done through visual inspection and ice thickness surveying. The required frequency of monitoring activities is described. Maintenance involves repairing dry and wet cracks, controlling loads, directing traffic during repairs, modifying, replacing, or adding to signage, and other tasks required to keep the ice road in good order and allow traffic to move. The required frequency of maintenance activities and the process of repairing cracks are described.

Chapter 10. This chapter covers the issues that are associated with the End-Of-Season closure of the ice road. These are ice cover melting, end-of-season monitoring, closure procedures, and emergency procedures.

Chapter 11. Use of Uncrewed Aircraft Systems (UAS). This chapter gives an overview of how UAS may be used to select routes and monitor the condition of the ice road.

Appendix A, Uncrewed Aircraft Systems (UAS). Small uncrewed aircraft systems (UAS) or drones can be used in support of ice road monitoring by collecting still images and dynamic videos over target areas of rivers, lakes, and their surrounding landscapes throughout the year. Types of UAS, their payloads, data products, flight requirements, operation considerations, and recommendations are described.

Appendix B, Examples of MUTCD Signage. This chapter provides illustrations of MUTCD signage that is applicable to ice road use.

Appendix C, References.

Design and Operation of Ice Roads

CHAPTER 1. INTRODUCTION

1.1 Purpose

The primary purpose of this manual is to provide for the safe and efficient design, construction, maintenance, and operation of an ice road over freshwater. As such, it provides the parties responsible for the ice road guidelines for ensuring the safe operation of the ice road including route selection, minimum ice thicknesses, repair strategies, maximum vehicle weights and speed, and proper signage. The information provided in the manual represents best practices compiled from existing literature and from those who have experience working on ice roads. While every scenario cannot be foreseen, the information contained in this manual should provide sufficient knowledge to extrapolate safe solutions which are not explicitly covered here.

Some of the information presented in this manual is new. As such the experience base may be limited. Such information will be clearly identified as new with limited testing.

1.2 Background

Frozen rivers and lakes have been used for travel for millennia because of the relative ease of movement whether walking, sledding behind a team of dogs, riding on a snowmobile- or riding in a vehicle. As man moved from walking, to sledding, and finally to motorized vehicles, the need to engineer the ice road became increasingly important. Recent increases in traffic are causing an increased interest in developing standards of practice in the routing, construction, maintenance, and operations of ice roads.

While the science of ice mechanics and floating ice sheets are well established, the complexity of the formation of ice on rivers and lakes requires the use of judgment by those who are responsible for the ice roads. Varying ice thickness, ice strength, varying temperatures, and other parameters simply do not lend themselves to a purely mathematical solution. Consequently, it is necessary to blend science with experience and judgement. Rather than require ice road operators to understand the ice science, hydrology, and the subtleties of floating ice sheets, this manual provides tables and graphics based on that science which can be used to determine minimum ice thicknesses for the anticipated traffic stream, to establish appropriate speeds, and other operational characteristics.

The formation of ice is highly variable due to the dependence on temperature, river stage, changing slope of the river bottom, and precipitation. Unfortunately, those responsible for the ice road have no influence over any of these factors. As a result, operators must wait for nature to run its course. Ice thickness and strength may be estimated or measured which in turn can provide the information required to allow travel over the frozen surface.

As with most engineered structures, there are inherent risks of failure. Understanding and managing those risks must be a conscience decision. This manual uses a risk-based approach pioneered in the Canadian Provinces. Using this approach requires an understanding of the risks involved and keeping those risks within acceptable limits. That said, the operators must remain vigilant to ensure changing conditions are closely monitored and appropriate action taken.

Finally, users and operators must ensure the operational parameters, especially weight and speed, are strictly adhered to. Failure to stay within these parameters could result in the vehicle falling through the ice, or worse result in the loss of life.

1.3 Organization of the Manual

The organization of the manual is intended to enhance the user's ability to find information easily. While it is not necessary to read the manual in the order it is written, the information is presented in the order in which the novice reader might need the information, that is each chapter builds on the previous chapters. Consequently, it is important that the user be familiar with the entire contents of the manual.

Rather than describing each chapter, it is suggested that the reader review the Table of Contents to get a global understanding of the depth and breadth of the information contained here.

1.4 Limitations

An in-depth development of the principles of ice mechanics is not presented here. For those who wish to gain a more in-depth knowledge of the fundamental relationships used in developing this manual, please refer to the references. However, an overview of the principles required to operate an ice road is provided so that the practitioner has a basic understanding of the performance of an ice sheet under traffic loadings.

1.5 Safety Considerations

While safety is stressed throughout the manual, it is impossible to consider every safety scenario. It is the responsibility of everyone, including those responsible for the operation of the ice road as well as the user to know and adhere to the safety requirements. It is important that all safety requirements be readily available to anyone who ventures out on the ice and that the ice conditions and user behavior be continuously monitored. The frequency of monitoring depends on the condition of the ice, traffic loadings and level of risk selection. In general, worse conditions along with higher risk require more frequent monitoring.

Follow the old rule: If it looks unsafe, it probably is.

CHAPTER 2. ICE ROADS FRAMEWORK

2.1 Introduction

This chapter presents a framework for the design, construction, and operation of ice roads. The framework is a series of phases (or steps) to be followed for establishing an ice road or crossing. The phases follow each other in time: The order of the phases is as follows:

Pre-Season. The Pre-Season phase covers the open water period before the rivers and/or lakes to be used for the ice road freeze up. The main activity of the Pre-Season is planning for the ice road construction and operation.

Pre-Construction: In the Pre-Construction phase, the route is selected, and the ice thickness is surveyed along the route. Surveying the ice thickness during Pre-Construction can be the most dangerous period of the winter season due to the relatively thin and unknown ice conditions.

Construction: The Construction phase begins when the ice is thick enough to allow safe transit of the construction vehicles. Ice road construction involves setting the ice road widths, increasing the ice cover thickness, if necessary, through snow clearing and flooding of the ice cover, and installing signage.

Ice Road Operations: During the Ice Road Operations phase the Ice Roads and crossings are opened for public use. The three main activities during this phase are Monitoring, Maintenance, and Administration.

End of Season. During the end of season phase the public use of Ice Roads and crossings is ended, signage is removed or modified, and barricades set up as needed.

2.2 Ice Road Phases

The Ice Road Framework is shown in Table 2.1 with the Phases shown in Column 1. Next the Ice Road Phases are briefly described along with references to the chapters in the manual where the phases are described.

Table 2.1 Ice Road Framework

Phase	Main Activities	Tasks
Pre-Season	Planning	Route Planning
		Select Operations Level
		Determine Signage Requirements
		Determine Equipment Requirements
Pre-Construction	Surveying	Manual Surveying
		GPR Surveying
	Route Selection	Route Selection
		Access Points
Construction	Ice Road Establishment	Preparing Travel Lanes
		Snow Clearing
		Ice Strengthening
		Surveying
	Signage	Construction Signs
		Entry Signs
		Regulatory and Advisory Signs
Ice Road Operation	Monitoring	Visual Inspection
		Surveying
	Maintenance	Repairing Cracks
		Traffic Control
		Updating Signage
	Administration	Controlling Loads and Speeds
		Safety
		Training
End of Season	Shutdown	Close Ice Road to Public Use

2.3 Pre-Season

The primary activity of the Pre-Season is planning for the upcoming winter construction and operation of the ice roads. The major tasks of the Pre-Season are route planning, selection of the operations level, determination of the signage requirements, and determination of the equipment requirements. It would be appropriate during the pre-season to review Chapter 3, Ice Road Background, and to be familiar with the physical concepts that impact ice road design, construction, and operations.

2.3.1 Route Planning

Pre-season route planning lays on the basic routes and access points that will serve the needs of the public with a recognition of certain site features that will directly influence the safety and practicality of the proposed route. Pre-season route planning provides information on the ice road lengths, level of effort, required material and equipment, and other important factors for the upcoming winter season. Route planning is covered in Chapter 5 Design of Ice Roads

2.3.2 Ice Road Risk Management

Ice Road Risk Management sets the level of risk associated with use of the ice road. The level of risk is determined by the required ice thickness for a given load level. The levels of risk are described as Low Risk, Tolerable Risk, Moderate Risk, and Substantial Risk. The level of risk is described in Chapter 5 Design of Ice Roads. "Low Risk" is expected to be the most common level of risk used in ice road construction and operations. At this point in the Pre-Season, the hazard controls that will be needed and the overall resources for operating the ice road can be assessed.

2.3.3 Signage Requirements

Signs are considered an important part of safety. It is important in the pre-season to determine the signage requirements for the ice road so that the necessary signage can be ordered and/or constructed. Signage requirements are described in Chapter 7, Ice Road Signage.

2.3.4 Equipment Requirements

The equipment needed for ice road construction and maintenance is described in Chapter 6, Ice Road Construction.

2.4 Pre-Construction

During the pre-construction phase the layout of the ice road across lakes and along rivers is determined, access points are located, and the ice thickness along the route is systematically surveyed and recorded. When the ice thickness is sufficient to support construction vehicles, then the actual construction can begin.

2.4.1 Route Planning

The final route selection is made during the Pre-Construction phase. This includes setting the ice road alignment and lane widths, the development of access points, and other factors. Route planning is covered in Chapter 5 Design of Ice Roads.

2.4.2 Surveying

Surveying the ice thickness during pre-construction can be the most dangerous period of the winter season due to the relatively thin and unknown ice conditions. Surveying can either be done manually or using GPR. Surveying is described in Chapter 6, Ice Road Construction.

2.5 Construction

During the Construction phase the Ice Road is established and Signage is installed. The Ice Road was established by preparing travel lanes, increasing the natural ice cover strength by thickening the ice cover through snow removal and flooding the ice surface if necessary, and developing access points. The final step of the construction phase is the installation of signage to communicate with users. After Construction is completed, the Operations phase begins.

2.5.1 Preparing Travel Lanes

Constructing travel lanes includes developing access points, setting the lane alignment and the lane widths. Preparing Travel Lanes is described in Chapter 5 Design of Ice Roads.

2.5.2 Increasing the Ice Strength

There are two approaches for increasing the ice cover thickness to increase the bearing capacity of the ice cover: clearing the snow cover from the ice road and flooding the ice cover. Increasing the ice cover thickness is often referred to as "strengthening the ice cover." Strengthening the ice cover is discussed in Chapter 6, Ice Road Construction.

2.5.3 Surveying

Monitoring the ice thickness during Construction is done to meet the ice thickness required for construction equipment and to ensure that the final thickness required for the Ice Road is achieved. Surveying is described in Chapter 6, Ice Road Construction.

2.5.4 Signage

All required signage must be in place before an ice road or crossing is open to the public. There are three categories of signage: Construction, Entry signs, and regulatory and advisory signs. Signage requirements are described in Chapter 7, Ice Road Signage.

2.6 Ice Road Operation

The primary activities during Ice Road Operation phase are Vehicle Control, Monitoring, and Maintenance. It would be appropriate to review Chapter 4, Ice Road Hazards, to be familiar with the hazards that require vehicle controls, and the need for monitoring and maintenance.

2.6.1 Vehicle Control

Vehicle control involves setting maximum speed limits, setting minimum distances between vehicles, prohibiting stationary loads, and load management. This can be done by posting maximum loads, maximum speeds and minimum vehicle spacing on signage when low risk levels are adopted. (See Chapter 5 Design of Ice Roads for a discussion of risk levels.) At higher risk levels there may need to be active enforcement of speed limits and requirements for scale tickets for all applicable vehicles. Vehicle controls are described in Chapter 8, Ice Road Vehicle Control.

2.6.2 Monitoring.

The frequency and intensity of monitoring is determined by the Ice Road Risk Management level that is adopted. Monitoring the ice cover is done through visual inspection and ice thickness surveying. Visual inspection requires personnel to travel the entire route of the ice road looking for dry cracks, wet cracks, water on the ice cover, snow drifts, and other problems that may compromise the integrity of the ice cover and interfere with the movement of vehicles. Visual inspections are conducted at fixed intervals determined by the risk level assumed. Records of the visual inspections should be made and archived. Any problems encountered should be reported. Monitoring programs are described in Chapter 9, Ice Road Monitoring and Maintenance. Ice thickness surveying can be done manually or using GPR. Manual surveying is acceptable at low risk levels. All survey data should be recorded and archived. Thin sections of the ice cover should be reported. Surveying is described in Chapter 6, Ice Road Construction.

2.6.3 Maintenance.

The frequency and intensity of maintenance is determined by the Ice Road Risk Management level that is adopted. Maintenance involves repairing dry and wet cracks, controlling loads, snow removal, and directing traffic during repairs, modifying, replacing, or adding to signage, and other tasks required to keep the ice road in good order and allow traffic to move. Maintenance can be conducted on a ‘as needed’ basis at low risk level. The interval of maintenance should be shortened if higher risk levels are adopted, with daily maintenance occurring at higher, less conservative values. Maintenance programs are described in Chapter 9, Ice Road Monitoring and Maintenance.

2.7 End of Season

End of season describes the shutdown of the ice road when the season ends. Details of the process are given in Chapter 10, End of Season Closure. Hazards associated with End of Season are described in Chapter 4, Ice Road Hazards. Appropriate signage is described in Chapter 7, Ice Road Signage.

CHAPTER 3. ICE ROADS BACKGROUND

3.1 Introduction

Loads allowed on an ice road must be supported by the ice cover within an acceptable level of risk. Bearing capacity is the ability of the ice cover to support a load and is of fundamental importance to the use of ice roads for transportation. This chapter starts with an overview of bearing capacity. Two factors that can impact the bearing capacity, vehicle motion and creep of the ice cover are described. Gold's formula for estimating the bearing capacity provides a way of estimating the risk associated with a minimum ice thickness requirement for a specified load. Finally, the distinct types of ice that can be encountered and how those types of ice impact the load bearing are described.

3.2 Bearing Capacity

When a load is placed on an ice cover, the ice cover deflects in response to the load. The amount of deflection is proportional to the magnitude of the load and the thickness and strength of the ice. The ability of the ice cover to support a load is the *bearing capacity* of the ice cover. The cover deflects until the water pressure on the bottom of the ice cover has increased sufficiently to balance the load, as shown in Figure 3.1. It is the water pressure on the bottom of the ice cover that is the source of bearing capacity. The load is supported by the water, not directly by the ice cover. The ice cover merely governs the area over which the load is distributed. It deflects to distribute the weight of the applied load over an area larger than the footprint of the load. The sum of the increased water pressure over the area of the deflected shape equals the weight of the applied load. The deflection profile shown in Figure 3.1 shows the cross section of a "*deflection bowl*" caused by a point load on the ice. The vertical scale in the figure is exaggerated for clarity. In typical ice road operation, the deflection caused by a load does not exceed the *freeboard* of the ice cover.

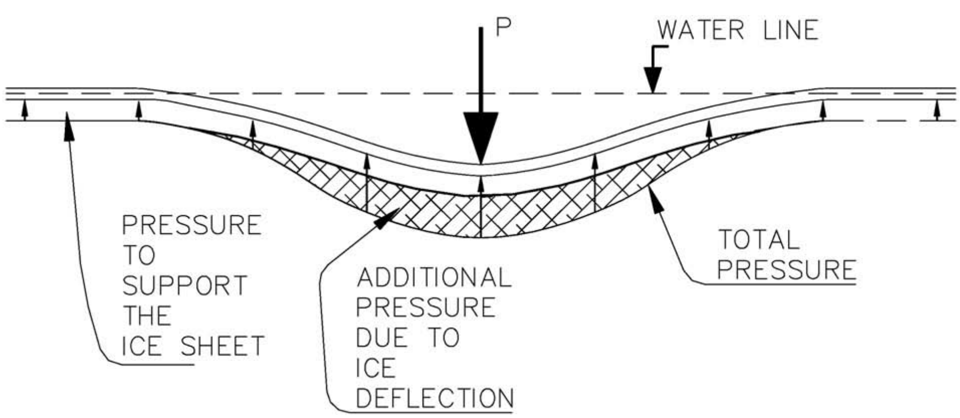

Figure 3.1 Cross section of the deflection bowl created by a point load on the ice (not to scale).

3.3 Flexural Rigidity

The actual shape and size of the deflection bowl is determined by the ice cover resistance to bending. The resistance of an ice cover to bending is known as its *flexural rigidity* or *stiffness*. The greater the flexural rigidity of an ice cover the less it deflects and the larger the area over which the ice cover deflects. The two basic parameters that determine flexural rigidity are the ice cover thickness and its elastic modulus. The elastic modulus (also known as Young's modulus) quantifies the relationship between stress (σ) and strain (ε) for the ice cover (see Eq. 1). It takes a lot of stress to strain (compress or extend) competent freshwater ice. A typical value of the elastic modulus (E) of ice for relatively small strain levels is around 1.2 million psi (Ashton 1986). Because it is difficult to measure the elastic modulus of ice in the field, it is rarely done. The value of the elastic modulus for freshwater ice can be assumed with fair accuracy if the ice cover is competent and of decent quality. (This will be discussed further in Chapter 3,) This leaves ice thickness as the primary determiner of the flexural rigidity of the ice cover. As a result, the only field measurements used in practice to estimate the bearing capacity of competent, decent quality, freshwater ice is the ice thickness.

$$E = \frac{\sigma}{\varepsilon} = 1{,}000{,}000\ psi \qquad \text{(Eq. 1)}$$

3.4 Flexural Strength

Deflection of the ice cover creates both compressive and bending stresses in the ice cover. The flexural strength of the ice cover is defined as the bending stress (tensile stress) at which the first crack forms. This occurs at the bottom surface of the ice cover, where tensile strain is maximum and ice temperature is at 0°C. For a given load, the greater the flexural rigidity of the ice cover, the lower the deflection, the lower the bending stress, and the less likely a crack is formed.

Ice is 7-8 times as strong in compression as it is in tension. Note from Figure 3.1 that during deflection from a load, the top of the ice cover is in compression and the bottom of the cover is in tension. The compressive strength of the ice is often referred to as the crushing strength. The compressive strength of ice is between 725 and 3600 psi while the tensile strength of is between 100 and 450 psi (Ashton 1986). Consequently, the ice roads rarely fail due to crushing.

3.5 Stationary loads vs. Moving loads

The deflection bowl created by a vehicle moves with the vehicle (see Figure 3.1). As it moves, the deflection bowl pushes the underlying water aside in a manner comparable to a shallow draft boat. The interaction with the underlying water and the properties of the ice cover both combine to modify the maximum deflection and the shape of the deflection bowl compared to a stationary load. The influence of the water and ice properties changes as the vehicle speed increases. A key point is the existence of *critical speed*, so called because at this speed "a phenomenon similar to resonance occurs and ice sheet deflection and stresses are amplified" (Ashton 1986). Field measurements show that at low speeds, the deflection bowl maintains its symmetric shape around the vehicle and there is minor impact from the fluid motion created by the deflection. As the vehicle speed increases the deflection bowl becomes deeper and narrower, and the rim around the bowl rises. At critical speed, the maximum ice cover deflection is roughly two times the deflection that occurs when the vehicle is stationary. At high speeds, 140% of the critical speed or more, the ice cover deflection for a moving vehicle is less than the deflection for a stationary vehicle and the vehicle assumes a position approximately half-way up the forward slope of the deflection bowl. In effect, the vehicle is climbing up onto the wave being formed beneath the ice sheet much like a boat getting on step. Unfortunately, the stresses that occur as the vehicle reaches critical speed will likely result in failure of the ice.

It is difficult to estimate critical speed because it depends on the water depth, and the thickness and material properties of the ice cover as shown in Figure 3.2.The critical speed is controlled by the water depth in shallow water, roughly twenty feet deep or less, and by the thickness and material properties of the ice cover in deep water. In deep water there is usually little or no additional risk for vehicles that match or exceed the critical speed. The chief risks happen when a vehicle enters shallow water at excessive speed. Critical speed drops rapidly as the water depth decreases and vehicles can inadvertently exceed critical speed even if their speed is unchanging. This is an especially important consideration at access points to and from the ice cover where the water depth is always shallow.

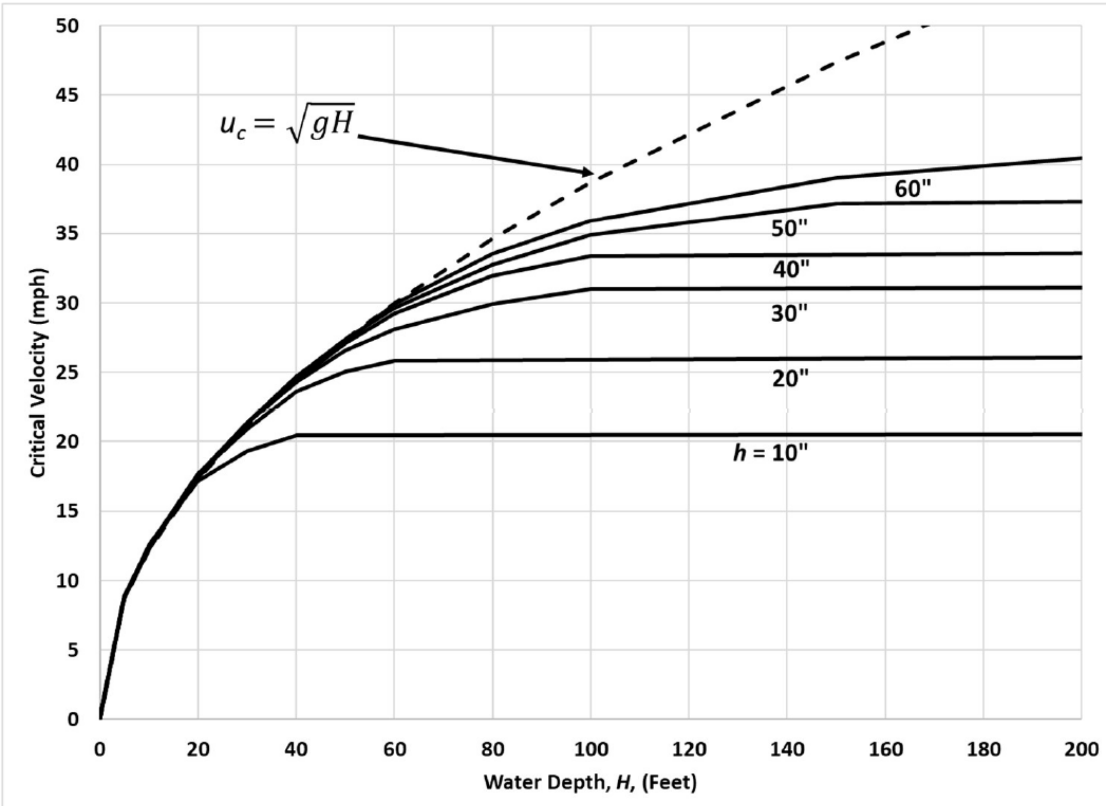

Figure 3.2 Critical velocity as a function of water depth and ice thickness (Nevel 1970). In this figure, u_c = the critical velocity; g = gravity; H = water depth; and h = the ice thickness.

The discussion above clearly shows speed has a dramatic impact on the safety of ice travel. Speed limits will be discussed further in Chapter 8, Ice Road Vehicle Control.

3.6 Creep

As described above, when a load is placed on an ice cover, the ice cover deflects immediately in response to the load, and the deflection is proportional to the magnitude of the load. This deflection and support of the load defines the bearing capacity of the ice cover. However, it is observed that the immediate deflection is often followed by a gradual increase in the magnitude of the deflection over time. The additional deflection is known as *creep*. Creep begins almost immediately when a load is placed, for example “by vehicles parked for more than a few minutes” (Saskatchewan Ministry of Highways and Infrastructure, 2009). In effect, creep reduces the bearing capacity of the ice cover with time. If the load is close to or at the maximum bearing capacity of the ice cover, creep can lead to an eventual failure and breakthrough of the ice cover. The occurrence of creep requires that stationary (or long-term) loads placed on the ice must be treated differently than moving loads.

3.7 Progressive ice cover failure

The process of ice cover failure under loading occurs through the formation of cracks as the ice cover deflection increases with time. In most cases, the increase in deflection is caused by creep. The pattern of crack formation with time is shown in Figure 3.3. The location of the load is shown in Figure 3.3 by the black circle. The plan view of the cracks is shown and the deflection bowl due to the load is not indicated. The progression starts on the left with the formation of one or two *radial cracks*. The radial cracks occur when the bending stress of the ice cover immediately at the load exceeds the flexural strength of the ice cover. The number of radial cracks increases as the deflection increases. Radial cracks can propagate outward from the load for a considerable distance. Eventually the radial cracks form ice wedges surrounding the load. While the presence of radial cracks reduces the bearing capacity of the ice cover, the wedges can still support some load. As the deflection continues to increase, successive *circumferential cracks* form. Each new circumferential crack forms at a smaller radius than the previous cracks. Breakthrough occurs along the innermost circumferential crack, typically located several ice thicknesses away from the load. Breakthrough leaves a failure hole in the ice cover. In many cases, water seeps through the cracks and partially floods the deflection bowl prior to the breakthrough.

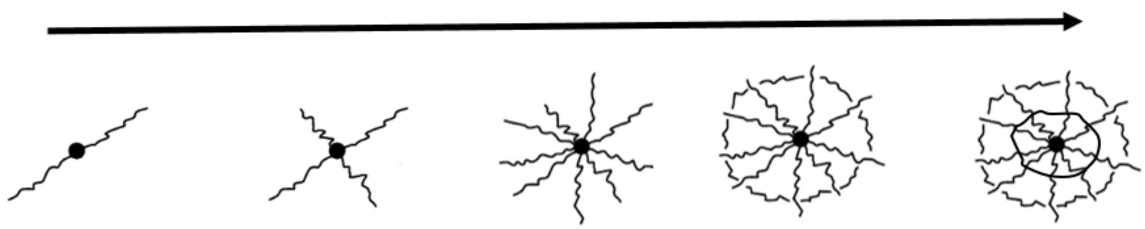

Figure 3.3 Steps leading to ice cover collapse (Ashton (1986) with changes)

As shown in Figure 3.3, there are a series of steps before final breakthrough, with the ice cover becoming more unsafe with each step. A valid question is at what step does ice cover failure occur? The *first crack criterion* was developed to address this question. Rather than select one step of this process and declare that the ice cover has failed at that step, the first crack criterion prevents the very first crack from occurring. Limiting the load on the cover limits the tensile stress and prevents the first radial cracks from forming.

3.8 Gold's Formula

Gold (1971) developed an approach for estimating allowable loads has found wide acceptance and application. This approach, known as "Gold's Formula," is specifically for short-term moving loads on the ice where creep is not an issue, and the vehicle speed does not influence the bearing capacity. Gold's Formula is an estimation of the allowable load for a given ice thickness and maximum allowable flexible strength:

$$P = Ah^2 \qquad \text{(Eq. 2)}$$

where *P* = the magnitude of the load, *A* = a coefficient that is proportional to the allowed flexural strength, and *h* = the ice thickness. Note that in Equation 2 the units of the load, *P*, is pounds force (lbf); the units of the ice thickness, *h*, is inches (in); and the resulting units of *A* are lbf in^{-2}. Rather than estimate *A* based on a formula, Gold selected an empirical value for *A* based on field observations. He collected dozens of observations of loads supported by ice covers and noted whether the ice cover had failed. This provided a range of A values and a range likelihoods of ice failure.

The selection of an *A* value sets an allowable load for a given ice thickness, and it sets a level of risk in using the ice road for transportation. In fact, *A* is sometimes described as "a risk factor that determines the likelihood of failure" (IHSA 2014). The level of risk increases with increasing *A* values. The limits of A suggested by Gold (1971) can be placed in a "commonly used risk paradigm," as shown in Figure 3.4. In this figure, risk of failure is shown as extending from the category of "Very Unlikely" through the category "Very Likely." The limits of "Normal Operation" extend from *A* = 50 to *A* = 100 based on the observations of Gold and ice road usage in Canada. Note that the risk of failure over the range of Normal Operation is labeled "Possible." Operation of an ice road with an *A* value above 50 must balance the "level or risk with operational controls."

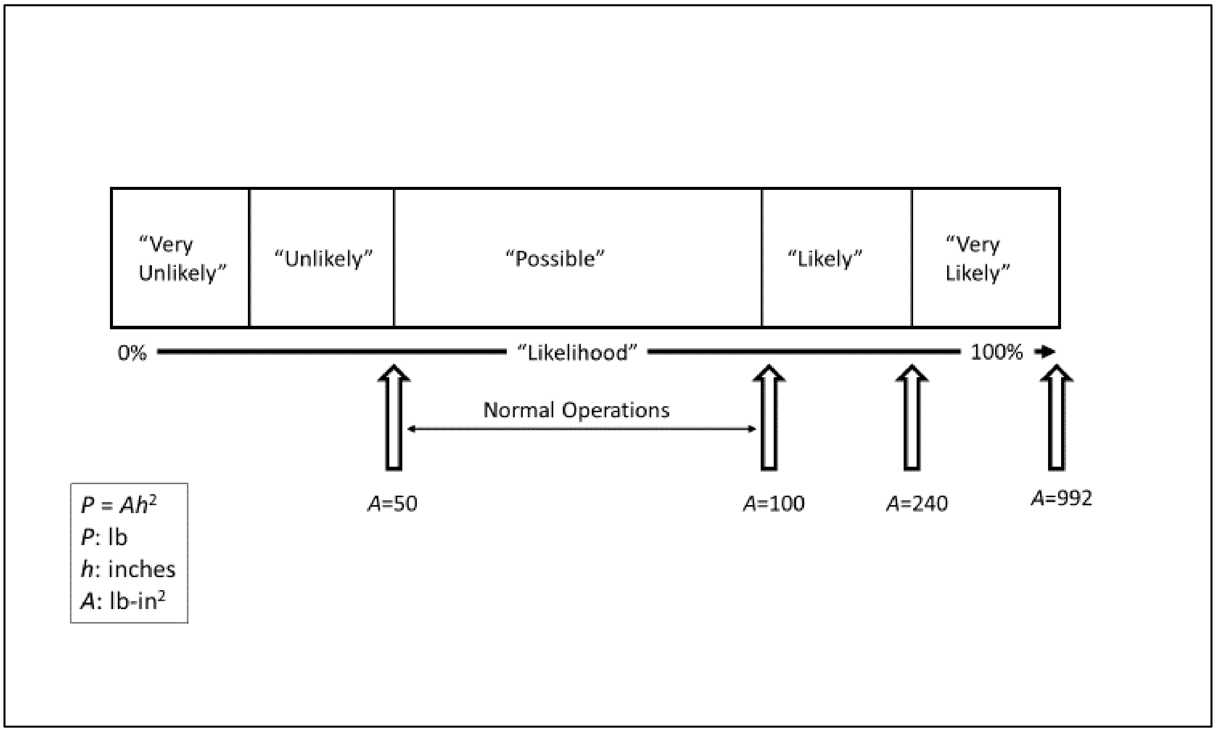

Figure 3.4 Characterizing Failure Risk (Adapted from Hayley and Proskin 2008)

3.9 Ice Types

Every ice cover is composed of myriads of individual ice crystals that are frozen into a continuous mass of solid ice or are deposited under the cover as a mixture of ice crystals and liquid water. It is only the completely solid ice portion of the ice cover that can provide bearing capacity necessary to allow the ice cover to be used for transportation. The ice type is a product of the formation process that created the ice cover. The ice type is identified by the size, shape, and orientation of ice crystals within the solid ice. The three ice types that have the most application to ice roads are fine grained ice, columnar ice, and snow ice.

3.9.1 Fine grained ice

Fine grained ice is derived from frazil ice. It is formed when the water between the frazil crystals freezes to form solid ice. It is called "fine-grained" in reference to the small size of the individual crystals, generally in the range of 0.04 - 0.20 inches (1-5 mm). The crystals are randomly oriented. In general, fine-grained ice forms strong, competent ice covers. It tends to be resistant to decay caused by the absorption of sunlight within the cover. It is quite common to find ice covers composed of fine-grained ice in flowing rivers. Typically, fine-grained ice is not found in lakes unless turbulence was induced in the surface layer of the lake by winds at the time of freeze up. The fine-grained ice will be a relatively thin layer at or near the surface of the ice cover in a lake.

3.9.2 Columnar Ice

Columnar ice (also known as congelation ice), forms due to heat transfer from the bottom of the ice cover to the atmosphere above. (Figure 3.5) It is also called blue or black ice. The ice crystals comprising columnar ice tend to be much longer than wide – hence the name columnar, and the long axis of the crystals tends to form vertically in parallel with the heat flow direction. The diameter of columnar ice increases as the ice cover grows downward – and can reach one inch or more. In general, columnar ice forms strong, competent ice covers. Columnar ice may include air bubbles. The air bubbles form during periods of rapid thermal growth and are incorporated into the ice cover. Often the air bubbles will be in layers corresponding to the thickness of the ice when the ice growth was rapid.

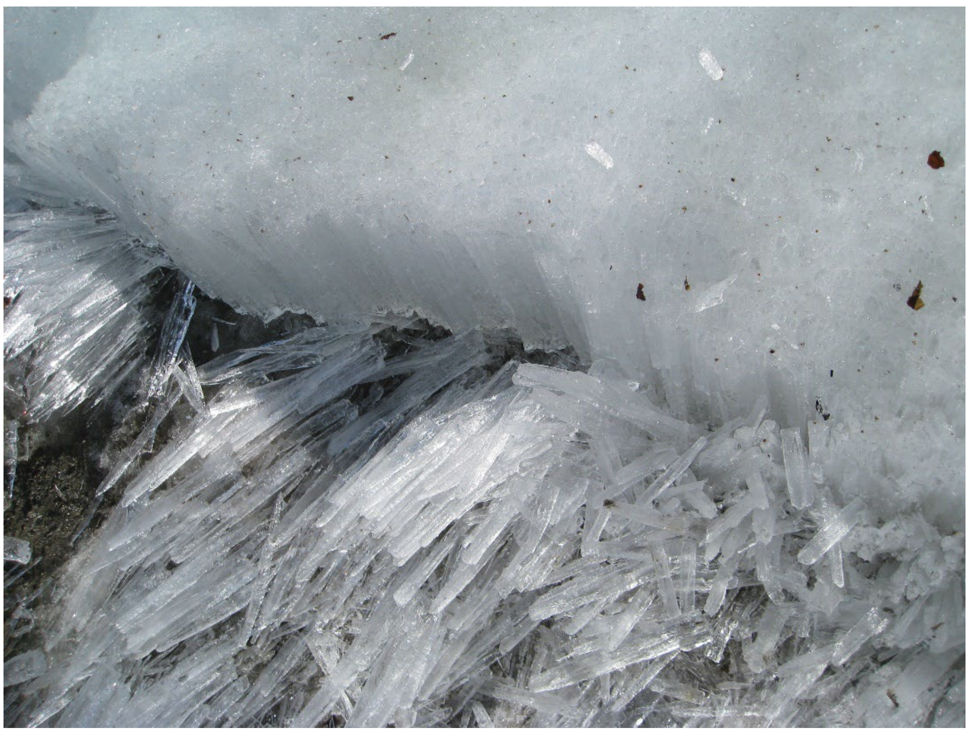

Figure 3.5 Candle ice formed from columnar ice crystals

3.9.3 Snow Ice

Snow ice is formed when an ice cover covered with snow floods and the saturated snow/water layer at the ice cover surfaces freezes. It is also called white ice. The size of snow ice crystals ranges from less than 1 mm to 5 mm, the shape is round to angular, and the grains are equiaxed with a random crystal orientation. When snow ice forms air is usually trapped in the ice as small bubbles. This gives snow ice its whitish appearance. The density of snow ice is less than that of fine-grained ice or columnar ice and can vary from 90%-98% of the density of pure ice. Snow ice strength is assumed to be half the strength of clear ice. Consequently, the equivalent thickness of snow ice is assumed to be one half the thickness of clear ice, i.e., one inch of snow ice equals one-half inch of clear ice.

3.9.4 Aufeis

Aufeis (also called overflow or icing) forms when the water is forced to the top of the ice sheet through cracks due to hydraulic pressure forming successive layers of ice. The ice can be several feet thick and may create aufeis which cover the entire width of the river valley. This form of ice tends to be quite strong. However, aufeis may create other dangers including thin sheets of water on the ice which create slippery conditions or pressure domes due to the hydraulic pressures. The use of aufeis for ice roads is not discussed in this manual.

3.9.5 Multiple ice types in the ice column

The literature debates the impact of ice columns which contain multiple types of ice. While the formation of the types of ice above provides insight into the flexural strength of the ice there are but two types of ice of interest, clear ice and white or snow ice. Clear ice is fine grained ice, or columnar ice which is generally quite strong. Snow ice is formed when the snow on the top of the ice is flooded and freezes. Because snow ice contains a high air content it tends to have less strength than clear ice

Referring to Figure 3.1, the bottom portion of the ice beneath the load is in tension while the upper portion of the ice is in compression. Since snow ice is generally at the top of the slab, it is in compression while the clear ice is in tension. As stated earlier, the tensile strength of ice is much smaller than the compressive strength. Consequently, it is unlikely that the compressive strength of the snow ice will be exceeded.

CHAPTER 4. ICE ROAD HAZARDS

4.1 Introduction

This chapter reviews the hazards that can affect the integrity of the ice road and the safe operation of vehicles on the ice cover. A primary hazard to the ice cover integrity is the formation of cracks. There are two basic types of cracks, dry cracks, and wet cracks. The causes of cracks are described. Vehicles traveling on the ice cover can cause cracks to form, and the many ways that vehicles can induce crack formation are presented. Cracks can also form due to the layout of the road itself with thickened ice in the road and the placement of snowbanks to either side. Finally, cracks can form due to conditions of the ice road environment, such as rapid changes in air temperature, winds, and changes in water level. Various vehicle controls for reducing or preventing crack formation, such as speed limits, vehicle spacing, prohibiting stationary loads, and load control are reviewed. Finally, other hazards, including blowing snow, warming, and end of the season are discussed.

4.2 Crack Types

Cracks form in the ice cover when stress fractures the ice cover. There are basically two types of cracks that are of interest: dry cracks and wet cracks. Generally, dry cracks that do not penetrate deeply into the ice cover are not considered an immediate problem while dry cracks that extend through more than 50% of the ice cover thickness may need immediate attention. Remediation of the cracks is discussed in Chapter 9. The water in wet cracks indicates that the cracks extend to the bottom of the ice cover. Wet cracks that extend in plan for more than several feet reduce the bearing capacity of the ice cover. Calculations show that the bearing capacity of the ice cover is reduced by 50% (Ashton 1986) by the presence of wet cracks. Areas with wet cracks in the roads are a definite hazard and should be dealt with immediately,

4.3 Causes of Crack Formation

Causes of crack formation fall into three broad categories. These are cracks that are vehicle induced, cracks that result from the ice road layout, and cracks that are caused by the environment.

4.3.1 Vehicle induced

4.3.1.1 Excessive loads

A load that exceeds the first crack criterion is excessive. Overloading the ice cover leads to three stages of cracking, as shown in Figure 3.3. The first stage is the formation of radial cracks. Radial cracks are a warning that the ice cover is overloaded, and the load should be removed immediately. The second stage is the formation of circumferential cracks. Circumferential cracks are a warning that the load is about to break through the ice and personnel should be evacuated from the loaded area. The final stage is the formation of pie-shaped wedges that indicate that the ice cover has failed.

At this point the load can break through at any moment. The time from first loading to complete breakthrough can vary depending on the load, the bearing capacity of the ice sheet, and the time the load remains at one location on the ice. If the load is only slightly larger than the bearing capacity, the first crack will happen, but it may take a relatively long time for breakthrough to occur. If the load is much greater than the bearing capacity, breakthrough may occur immediately, leaving personnel little time to evacuate.

4.3.1.2 Moving Loads

As discussed in Chapter 3, Ice Road Background, a load on the ice cover creates a deflection bowl that moves with load and creates waves in the ice cover and water beneath the ice cover. The speed of the waves is dependent on the depth of the water, the thickness of the ice cover, and the strength of the ice. The greatest deflection and the most severe stresses occur when the vehicle moves at the critical speed. At this speed “a phenomenon similar to resonance occurs and ice sheet deflection and stresses are amplified” (Ashton 1986). In deep water, greater than about 20 feet, the critical speed will be much greater than the vehicle speed and the vehicle moves without inducing excessive stresses in the ice sheet. However, when the water depth beneath the ice cover is shallow, for example, if the ice road passes over sandbars or shoals, or when the vehicle is near an access point, the critical speed will be much less, and it is more likely that the vehicle will match the critical speed. The formation of cracks is much more likely when the vehicle travels at the critical speed on an ice cover in shallow water. In addition, the waves created by moving loads can reflect from the shoreline. Reflected waves are greatest when a vehicle approaches a shoreline at a right angle. This reflected pattern can be critical when the vehicle weight is close to the load-bearing limit of the ice. Ultimately, this could lead to what is called a ‘blowout,’ induced by the pressure exerted by the water onto the ice cover.

Maximum speed limits are presented in Chapter 8, Ice Road Vehicle Control.

4.3.1.3 Multiple Loads

When two or more vehicles approach each other, the overall deflection bowl created by all vehicles is the sum, at every point of the ice cover, of the deflection bowl created by each vehicle. In the same manner, the stress in the ice cover created by all the vehicles is the sum, at every point of the ice cover, of the stresses created by each vehicle. Minimum distances between vehicles and equipment are required to prevent large stresses in the ice cover. If two vehicles are moving in the same direction, they should maintain a minimum distance and the rear vehicle should not attempt to pass the forward vehicle. If two vehicles are approaching each other they should minimize their speed when passing.

Minimum vehicle spacings are presented in Chapter 8, Ice Road Vehicle Control.

4.3.1.4 Frequent Loads

Frequently repeated loadings will cause damage such as rutting, potholes, and cracking. Gold (1971) reported that the “quality of the ice cover can … deteriorate because of fatigue.” There are no quantitative observations relating frequency of loading to ice cover deterioration.

4.3.1.5 Long-Term Loads

The ice cover under any stationary load will creep. Creep begins almost immediately when a load is placed, for example “by vehicles parked for more than a few minutes” (Saskatchewan Ministry of Highways and Infrastructure 2009). The time required for a stationary load to be considered a long-term load varies from a few minutes to 6 hours. If the deflection under the load exceeds the freeboard of the ice cover, the ice surface will flood, and the bearing capacity of the ice cover will be compromised. If the load is close to or at the bearing capacity of the ice cover, creep can lead to the formation of radial and circumferential cracks with time, and breakthrough can result.

Prohibitions against stationary loads on ice roads are presented in Chapter 8, Ice Road Vehicle Control.

4.3.2 Ice Road Layout

Stresses caused by the layout of the ice road, with thickened ice in the road itself and bounded by snowbanks on either side, can lead to the formation of “longitudinal” cracks in the ice cover. They are referred to as longitudinal cracks because they run parallel to the long dimension of the road. The thicker ice in the cleared lane rises above the ice that is depressed beneath the heavy snowbanks. This causes an upward bending of the ice cover that reaches a maximum in the middle of the cleared lane. When the bending becomes severe enough, cracks form on the surface of the ice to relieve the stresses. In most cases, the cracks do not extend deep enough to create a breakthrough hazard. Longitudinal cracks can occur under snowbanks built along the edge of the road during snow clearing. The snowbanks act as a heavy long-term load causing the ice cover to creep beneath them. The snow also insulates the ice from the frigid air above so that the ice under the snowbank tends to be thinner than the ice in the ice road. These cracks extend upward from the bottom of the ice cover. Some of the cracks may extend completely through the ice cover creating wet cracks.

4.3.3 Environment Induced Cracks

Three significant environmental causes of cracks in the ice cover are changes in the air temperature (thermally induced cracks), the stress of wind blowing across the ice (pressure ridges), and water level changes.

4.3.3.1 Thermally Induced Cracks

Abrupt decreases in air temperature can cause cracks to form. The decrease in air temperature causes the temperature of the top surface of the ice cover to drop. The bottom surface of the ice cover, in contact with water, remains at a constant temperature of 32°F. The top portion of the ice contracts in response to the change in temperature. This causes the ice cover to bend upwards, in concave fashion. Cracks form where the bending stress exceeds the flexure strength of the ice. Often the cracks are very regularly spaced. Most often these cracks are dry cracks. The bottom of the cracks is sealed because the cracking does not result in separation of the pieces. If the temperature drop is large enough or there is movement of the ice cover due to wind or water flow the crack can open and become a wet crack.

4.3.3.2 Pressure Ridges

Pressure ridges typically form in larger lakes where the thermal expansion effect and the wind stress can accumulate over several miles. Pressure ridges form when a portion of the ice cover is driven into a stationary portion due to thermal expansion or wind stress. Typically, pressure ridges form at weak locations in the ice cover, weakened by the presence of thin ice or the formation of thermally induced cracks. As in-plane compressive pressure builds, the ice cover fails, either in flexure or by buckling, creating rubble blocks that accumulate to form the ridge structure. Pressure ridges can reach heights of 10 feet or more and extend for hundreds or thousands of feet across the lake. Pressure ridges are significant hazards because they can be areas of reduced bearing capacity, loss of freeboard, or be difficult to cross.

4.3.3.3 Water Level Changes

Changes in water levels can cause cracks. These usually occur in rivers, but they can occur in any body of water that is subject to water level changes. Changes in water levels can result from tides or from the wintertime decline in the river discharge. These cracks are almost always wet, tend to follow the shoreline, and occur around grounded ice features. Changes in water levels may produce cracks near and generally parallel to the shoreline where the floating ice drops or rises while the ground fast ice remains fixed. This can create hanging ice where the ice cover can separate completely and form a significant drop.

4.4 Blowing Snow

High winds can cause blowing snow with reduced visibility which can make it difficult to see the limits of the safe travel way on the ice road. Extreme winds can stress the ice cover, especially in large lakes, and lead to the formation of wet cracks and pressure ridges. In some cases, drifted snow along with snow placed in windrows along the ice road can cause thawing beneath the snow because of the insulation provided by the snow on the ice. Regions above tree line are especially prone to blowing snow, snow drifting across ice roads (Figure 4.1), and poor visibility due to whiteouts. Enhanced marking of the road edges can improve visibility. Ice road operators should make regular checks of the weather to identify potential storms and whiteout conditions in advance. Road closures during these periods may be necessary. Finally, individual drivers should be equipped with appropriate survival equipment if they are stranded for an extended period of time in whiteout conditions.

Figure 4.1 Heavy snow drifts on ice roads (Image courtesy of Stan Zuray)

4.5 Warming Periods

If the air temperature remains less than 32°F, the ice temperature should remain below freezing. Heat resulting from penetration of solar radiation into the ice cover can be relatively efficiently transferred to the frigid air above to keep the ice cover cold and strong. However, once the air temperatures rise above 32°F heat transfer from the cover is suppressed by the stability of the atmosphere. At this point, the interior of the ice cover warms to 32°F, and penetration of solar radiation into the ice cover causes internal deterioration. This results in a loss of structural integrity and a general weakening of the cover. The result is a substantial reduction in the cover bearing capacity.

Warming becomes an issue when the air temperature remains above 32°F for 24-48 hours or more. When this happens the allowable load for the minimum ice thickness currently present is reduced by 50%. The ice conditions need to be monitored for signs of decay, cracking, and water. The reduction of the allowable load can be re-evaluated if the average air temperature falls below 32°F and remains below for 24 hours or more, and inspection of the ice cover does not reveal any problems or cracking.

4.6 End of Season

Proper quality control and monitoring measures will extend the safe operating life of most ice roads. In general, ice roads are forced to close at the end of the winter season due to deteriorating road surface conditions before the integrity of the ice cover has been compromised. Surface degradation can include the accumulation of excessive water on the surface from surface melt and softening of the upper portion of the ice cover to a degree that prohibits travel. In late winter, the energy of the sun provides enough energy to melt the ice surface, even when the air temperatures remain below freezing. Dark material on the ice cover such as sand, gravel, and dust from vehicles will reduce the surface albedo and increase the absorption of sunlight. Maintenance at the end of the season can extend the length of the season by scraping dark material off the ice road surface at regular intervals.

CHAPTER 5. ICE ROAD DESIGN

5.1 Introduction

The design of ice roads starts with route selection. Steps for route selection are then described for ice roads located on rivers, located on lakes, and for river crossings. The minimum road widths are presented. The required ice thickness is described in terms of the Ice Road Risk Management. Ice Road Risk Management allows the ice road operators to balance the needs and requirements of the ice road users and the resources available to the operators at an acceptable risk level. The risk level is set by the selection of the *A* value for Gold's Formula. Loads are divided into three classes: Lighter loads, Traffic Loads, and Extreme Loads.

5.2 Route Selection

Development of ice roads requires route planning and recognition of features that will influence the safety and practicality of the proposed route. There are three different applications of ice roads discussed in this section: ice roads over lakes, ice roads following rivers, and ice roads that cross rivers (referred to as *crossings*).

5.2.1 Previous Experience

The chief benefit of constructing ice roads in the same location every year is being able to build on previous experience by thoroughly evaluating the previous use. However, caution is advised when considering field experience because water levels, channel locations, weather and ice conditions vary from year to year and methods and equipment need to adapt to changing conditions.

5.2.2 Local Climate

The thickness of the ice cover and the resulting ice cover bearing capacity are determined by the climatic conditions along the proposed routes. The primary parameters controlling ice thickness are the daily average air temperature and the snow cover depth. Local climatic variations and year to year variability may need to be considered if data from local weather stations are used in route selection. Throughout the Arctic and near Arctic, warming trends associated with climate change are affecting the function and design of infrastructure that relies on frozen conditions. In Alaska, these trends include fall and winter air temperatures warmer than average, fewer very cold days, river break-up happening earlier, annual precipitation increase, increase in the occurrence of freezing rain, and a shrinking snow season, among other impacts.

5.3 Ice Road Widths and Channel Bank Offsets.

Ice road widths determine the distance perpendicular to the direction of vehicle travel where snow is cleared (Figure 5.1). The *cleared width* includes the *driving lanes*. The *driving lanes* allow vehicle traffic to simultaneously travel safely in opposite directions. The snowbanks created by snow plowing are formed outside of the cleared width. *Channel bank offset* is the minimum distance from the cleared width to the channel bank that forms the limit of the channel width at each point along the ice road. The effective channel bank can be the two shorelines of the river, the shore of an island, or even a sandbar. The river channel should be wide enough to accommodate the cleared width of the ice road and a bank offset on either side (Table 5.1).

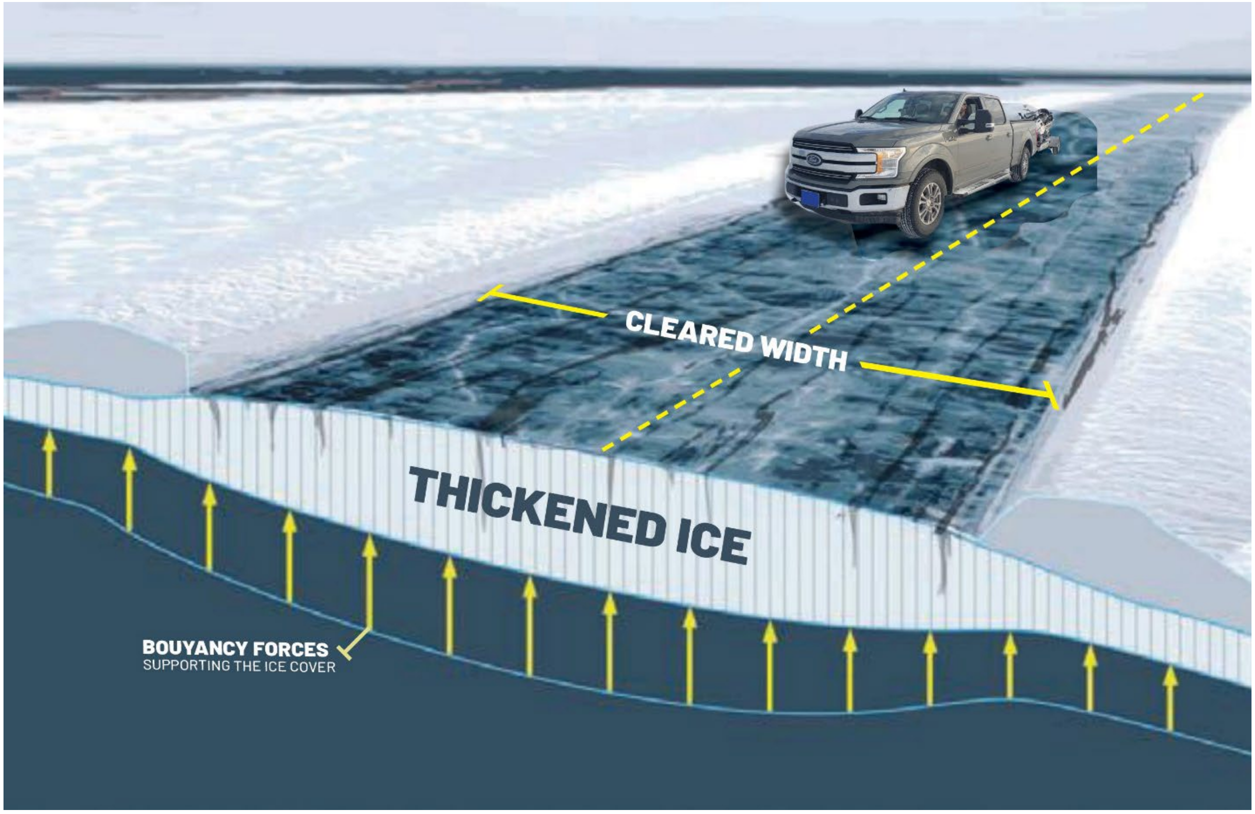

Figure 5.1 Cross section of ice road (Adapted from Alberta Government 2013)

Table 5.1 Minimum Road Widths

Operating Vehicles	Cleared width - Between snowbanks	Driving lanes - Total width	Channel Bank Offsets on each side
Light vehicle traffic (11,000 lbs)	65 ft	32 ft	32 ft
Construction (50,000 lbs)	82 ft	50 ft	50 ft
Super B Train (140,000 lbs)	100 ft	65 ft	65 ft

The ice road widths and bank offsets can be adjusted at locations where the channel width is not sufficient to accommodate the cleared width of the ice road and a bank offset on either side. However, adjustments in widths and/or offsets may lead to reductions in the maximum loads that can be supported by the ice road.

The ice road widths can be reduced if the travel lanes are separated, for example if each travel lane is routed on the opposite sides of an island.

5.4 Route Selection for Ice Roads following Rivers

Route selection for ice roads following rivers is challenging for three main reasons.

Variable Channel Geometry. The overall shape and layout of the river or stream can vary widely from location to location along the length of the channel. Rivers with a single channel that is wide, deep, and straight present the fewest problems in route selection. However, few rivers are consistently straight, consistently deep, or even consistently wide. More often rivers meander and each bend can have a different curvature. Associated with bends is varying channel geometry that can include shallows, sand bars, sudden changes in depth, changes in the velocity of the water and other variations. Rivers can also have islands, and multiple channels, and their form and layout can change from year to year. Reaches may have several small channels, often referred to as braided rivers, which present many difficulties for route selection that may be difficult if not impossible to overcome.

Complex Ice Formation Process. Ice cover formation in rivers is a complex process that can result in varying ice thickness along the channel and across the channel. A stable ice cover progresses from downstream to upstream as it forms. The ice cover initially forms from the slush ice, ice pans, and ice floes transported downstream with the flow. Variations in the channel flow velocity caused by changes in the channel slope, width, direction, and depth influence the ice cover formation. In high velocity reaches a stable ice cover may not be able to form at all and the reach can remain open throughout the winter. Once an ice cover forms, its thickness increases as the ice grows downward due to heat transfer from the bottom of the ice cover it to the frigid air above it.

Wintertime Decline in River Discharge. The wintertime flow consists only of groundwater drainage after the surface runoff, channel drainage, and interflow are depleted. As a result, the channel discharge declines throughout the winter as the groundwater levels are reduced. The water surface elevation drops as the discharge declines. This can cause the floating ice to contact the bed or nearly contact the bed in areas near the riverbanks and in shallow areas. Ice close to or in contact with the bed can melt due to the seepage of groundwater. Ice frozen to the banks can be suspended by the banks as the water level decreases. Ice in contact with the bed or banks can reduce the expected bearing capacity of ice cover. This can happen even if the ice in contact with the bed or banks is remote from the traveled lanes of the ice road.

5.4.1 Year-round River Observation.

River observations during the open water season can provide valuable information to use in ice road route selection, including river channel locations, estimate of water depths, and areas of bank erosion and buildup. Take time to note the velocity of the water, any waves, falls and location of riffles.

5.4.2 Access Points.

The locations of access points onto and off the river ice cover are key factors in deciding on the ice road route. The shoreline at the access point should be stable from hydrological, geotechnical, and environmental perspectives. The vehicle speed becomes critical when vehicles are approaching the shoreline at an access point. The interaction of the waves created by the moving vehicle and their reflection from the shorelines are greatest when a vehicle approaches a shoreline at a right angle. If possible, access points should allow vehicles to meet the shoreline at a 45° angle or less. It is critical that drivers obey the posted speed limit when a road meets the shoreline at an access point.

5.4.3 Optimum River Channels for Ice Routes.

If possible, ice roads following rivers should use channels that allow proper ice road widths and channel bank offsets, have the required depth, and can provide the proper conditions throughout the winter season as the discharge declines. **In general, select routes with uniform depths and water velocities.**

5.4.4 Required Depth.

The ice road route must provide for sufficient depth beneath the ice cover (the depth is measured from the bottom of the ice cover to the bed directly below). There is no minimum water depth requirement, however, the ice cover must not contact the channel bed within the *cleared width* at any time over the course of the operating season. The ice cover may contact the channel bed and banks only at the outer edges of the channel bank offset, if necessary. It is preferable that there is no contact in the cleared width of the ice road and the channel bank offsets on either side at any time. The actual depth under the ice will decrease as the season progresses due to the combined effect of an increase in the ice cover thickness and a decrease in the water surface elevation. If the depth beneath the ice cover is shallow, less than 20 feet, then the vehicle speed will need to be reduced to prevent problems related to the critical speed.

5.5 Route Selection for Ice Roads Crossing Lakes

The two key factors to be considered during the planning phase when the proposed route crosses lake ice are the access points onto and off the lake ice cover and the water depth along the route. Access points near river and stream outlets or inlets should be avoided as the lake ice near these locations is usually unreliable. The shoreline at the access point should be stable from hydrological, geotechnical, and environmental perspectives.

The water depth along the route is an important consideration because the hydraulic conditions created by moving loads can interact with sandbars and other shallows, leading to ice cracking and blowout. The route should follow the deepest water in the lake even if this is not the shortest route. The critical velocity increases with water depth. Consequently, over very deep water, the vehicle is usually traveling at lower velocity than the critical velocity. The vehicle speed becomes critical near the shoreline. The interaction of the waves created by the moving vehicle and their reflection from the shorelines are greatest when a vehicle approaches a shoreline at a right angle. If possible, roads and vehicles should meet the shoreline at a 45° angle. It is important that drivers obey the posted speed limit when a road meets the shoreline at a 90° angle and when a vehicle's weight is close to the maximum load limit for the ice.

5.6 Route Selection for River Crossings

Site selection. The best crossings have the deepest water and most uniform bottom conditions. This is often the widest crossing site. Nearby islands, sandbars, and other features created by active erosion or deposition can indicate channel shifting and unpredictable currents.

Variable ice thickness. The greater variability of river ice results from drifting snow, under ice currents, frazil ice deposition, and other factors. This places stress on monitoring ice thickness and its variability. It is recommended that river ice thickness be monitored and verified with technical aids such as Ground Penetrating Radar (GPR) profiling along with manual measurements, and/or corings.

River bottom conditions. Sand bars and other features that determine bottom topography (bathymetry) can affect ice cover thickness and extent. It is recommended that river bathymetry be mapped with either manual water depth measurements or with geophysical methods (sonar or GPR).

Riverbank stability. Like lake ice access points, river access points should be stable from hydrological, geotechnical, and environmental perspectives.

Changing water levels. As described in Chapter 3, Ice Road Background, river water levels should slowly decline during the winter season following the freeze up period. However, dams located upstream or downstream can impact water levels at any time. Rivers connected to the ocean or to estuaries can be impacted by tides.

5.7 Required Ice Thickness

In this section the required ice thickness is described in terms of the Ice Road Risk Management. Ice Road Risk Management allows the ice road operators to balance the needs and requirements of the ice road users and the resources available to the operators at an acceptable risk level. The risk level is set by the selection of the *A* value for Gold's Formula. The selection of the *A* value determines the maximum load that is acceptable for the ice cover thickness. The risk levels are characterized as Low Risk, Tolerable Risk, Moderate Risk and Substantial Risk. The frequency and intensity of ice road monitoring and maintenance must increase with increasing *A* values to offset the level of risk. Ice road monitoring and maintenance are described in Chapter 9.

There are three ranges of loads to be considered: Lighter Loads, loads less than 11,000 lbs, in which a minimum effective ice thickness is required; Traffic Loads, greater than 11,000 lbs and less than 140,000 lbs, which cover most of the loads transported on the ice road; and Extreme Loads which are greater than 140,000 lbs and require special analysis by a Professional Engineer with expertise in ice bearing capacity.

5.7.1 Lighter Loads.

These are loads of less than 11,000 lbf. In these cases, there is a minimum effective ice thickness required. The ice thickness requirements for lighter loads are listed in Table 5.2.

Table 5.2 Effective ice thickness requirements for lighter loads

Load/Situation (Slow-moving Loads)	Estimated Weight (lbf)	Minimum Effective Ice Thickness (Inches)
Person walking	260	4
Snowmobiles (machine + rider)	< 1100	7
3/4-ton 4x4 vehicles	GVW* < 11,000	15

*GVW = Gross Vehicle Weight

5.7.2 Traffic loads.

Traffic loads are moving loads on the ice. Creep is not an issue with traffic loads as explained earlier, and the vehicle speed does not influence the bearing capacity (because it is below the critical speed). The Traffic Loads should apply to most of the loads that the ice roads are designed to support. Traffic Loads range from 11,000 to 142,000 lbs. The allowable loads in pounds for a given effective ice thickness and *A* value is listed in and shown in Table 5.3. The required effective ice thickness for a given load and *A* value is listed in Table 5.4.

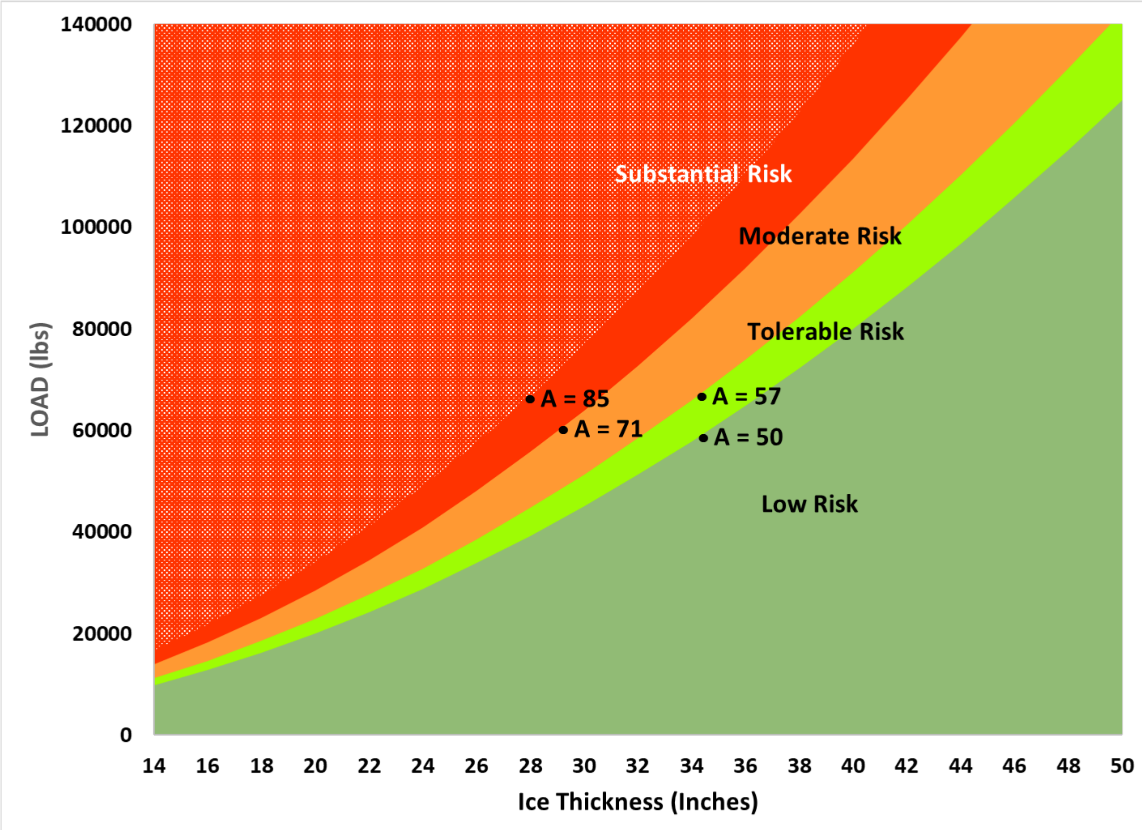

Figure 5.2 Allowable Loads in Pounds for Effective Ice Thickness and *A* Values

Table 5.3 Allowable Loads in Pounds for Effective Ice Thickness and *A* Values

	Low Risk ← Allowable Load (P=lbs) → Substantial Risk			
H = Effective Ice Thickness (in)	A = 50 Low Risk	A = 57 Tolerable Risk	A = 71 Moderate Risk	A = 85 Substantial Risk
4	*	*	*	*
6	*	*	*	*
8	*	*	*	*
10	*	*	*	*
12	*	*	*	*
14	*	11200	13900	16700
16	12800	14600	18200	21800
18	16200	18500	23000	27500
20	20000	22800	28400	34000
22	24200	27600	34400	41100
24	28800	32800	40900	49000
26	33800	38500	48000	57500
28	39200	44700	55700	66600
30	45000	51300	63900	76500
32	51200	58400	72700	87000
34	57800	65900	82100	98300
36	64800	73900	92000	110200
38	72200	82300	102500	122700
40	80000	91200	113600	136000
42	88200	100500	125200	**
44	96800	110400	137500	**
46	105800	120600	**	**
48	115200	131300	**	**
50	125000	**	**	**

** Professional engineer required for design
* Minimum ice thickness Required (See Table 5.2)

Table 5.4 Required ice thickness for a given load and corresponding risk values

	Low Risk ← Req. Ice thickness (h = in) → Substantial Risk			
P = Load (lbs)	A = 50	A = 57	A = 71	A = 85
	Low Risk	Tolerable Risk	Moderate Risk	Substantial Risk
200	*	*	*	*
400	*	*	*	*
600	*	*	*	*
800	*	*	*	*
1000	*	*	*	*
5000	*	*	*	*
10000	*	*	*	*
15000	17	16	15	13
20000	20	19	17	15
30000	24	23	21	19
40000	28	26	24	22
50000	32	30	27	24
60000	35	32	29	27
70000	37	35	31	29
80000	40	37	34	31
90000	42	40	36	33
100000	45	42	38	34
110000	47	44	39	36
120000	49	46	41	38
130000	51	48	43	39
140000	53	50	44	41
150000	**	**	**	**

** Professional engineer required for design

* Minimum ice thickness Required (See Table 5.2)

5.7.3 Extreme Loads.

Extreme loads are those over 140,000 lbs. A professional engineer should provide recommendations for required ice thickness and procedures for these loads.

5.7.4 Examples of estimating required Ice thickness

There are three ranges of loads to be considered: Lighter Loads, under 11,000 GVW, in which a minimum effective ice thickness is required; Traffic Loads which cover most of the loads transported on the ice road; and Extreme Loads which are greater than 140,000 lbs and require special analysis by a Professional Engineer with expertise in ice bearing capacity.

A person walking on ice. This is considered a Lighter Load. The required ice thickness is taken directly from *Table 5.2 Effective ice thickness requirements for lighter loads*. The required ice thickness is 4 inches.

Pickup truck with a total load of 8000 lbs. This is considered a Lighter Load as the weight of the vehicle is less than 11,000 GVW. The required ice thickness is taken directly from *Table 5.2 Effective ice thickness requirements for lighter loads*. The required ice thickness for vehicles under 11,000 lbs GVW (Gross Vehicle Weight) is 15 inches.

Truck with 40,000 lbs GVW. This is a Traffic Load as the weight of this vehicle is greater than 11,000 GVW. The required ice thickness can be taken from Table 5.4 or calculated directly.

Table 5.4: The required ice thickness can be estimated directly from "*Table 5.4 Required ice thickness for a given load and corresponding risk values*." It is necessary to first select the risk factor, *A*, which is applicable to the ice road. The results from the table are

- *A* value of 50, Low Risk: 28 inches of ice.
- *A* value of 57, Tolerable Risk: 26 inches of ice.
- *A* value of 71, Moderate Risk: 24 inches of ice.
- *A* value of 85, Substantial Risk, 22 inches of ice.

Calculated Directly: Gold's Formula (Eq.2, Section 3.2) can be rearranged to estimate ice thickness directly as

$$h = \sqrt{\frac{P}{A}} \qquad \text{(Eq. 3)}$$

where *P* = the magnitude of the load, *A* = the risk factor, and *h* = the ice thickness. Note that in Equation 3 the units of the load, *P*, is pounds force (lbf); the units of the ice thickness, *h*, is inches (in); and the resulting units of *A* are lbf in^{-2}. In this example, *P*= 40000. The calculations are rounded to the nearest whole inch. The results are

- *A* value of 50, Low Risk: 28.28 inches of ice, rounded to 28 inches.
- *A* value of 57, Tolerable Risk: 26.49 inches of ice, rounded to 26 inches.
- *A* value of 71, Moderate Risk: 23.74 inches of ice, rounded to 24 inches.
- *A* value of 85, Substantial Risk, 21.69 inches of ice, rounded to 22 inches.

5.8 Effective Ice Thickness

The effective ice thickness describes the decent quality, well-frozen, white, and blue ice that is measured in an ice cover. Poor quality or poorly frozen ice should not be included in the measurement of ice thickness. Table 5.6 lists examples of ice that should be excluded from measurements.

Table 5.5 Ice Types that should be excluded from thickness calculations

Ice layer with visible water lenses with a cumulative volume greater than 10% of the total volume.
Ice layer with visible incompletely frozen frazil (slush) ice.
Ice layer that is not completely frozen to the adjoining layer.
Ice layer that has been found to have a strength less than 50% of decent quality blue ice (a number of specialized methods are available for determining ice strength).
Ice that has wet cracks.

CHAPTER 6. ICE ROAD CONSTRUCTION

Ice thickness surveying is a fundamental part of Ice Road Construction and is discussed first in this chapter. Ice road construction starts with the pre-construction phase. During the pre-construction phase the layout of the road across lakes and along rivers is finalized, and the ice thickness along the route is systemically surveyed and recorded. When the ice thickness is sufficient to support construction vehicles, then the actual construction can begin. During the construction phase the travel lanes are prepared, the ice cover is strengthened by removing the snow cover from the ice and flooding the ice surface if necessary, and access points are developed. The required equipment is described, along with safety features, safe operations, worker safety, and record keeping.

6.1 Ice thickness surveying

Systematic ice thickness surveying along the route provides the information required to allow travel over the ice cover.

6.1.1 Manual ice thickness measurements

Manual ice measurements are made directly by personnel on the ice using augers to drill through the ice and then measure and record the ice thickness information (Figure 6.1). The safety of the personnel on the ice is a priority. There should be at least two surveyors on the ice at all times. The safety protocol will vary between pre-construction, construction, and operation phases of the ice road. The safety protocols are discussed in the respective sections of this Manual.

The simplest and most common method for measuring ice thickness is to auger holes in the ice, lower a tape or a stick in the hole, and take a reading of ice thickness. A measuring tape with a weight attached at the leading edge works well in holes 2-inches in diameter. A graduated rod with a right angle at the bottom works better for holes that are larger in diameter. Sometimes, in the presence of frazil ice under the ice cover, it can be challenging to determine the frazil and columnar ice interface. Poor quality or poorly frozen ice should be excluded from the measurement of effective ice thickness (see Section 5.9 for descriptions of poorly frozen ice).

Figure 6.1 Hand operated and gas-powered augers.

If detailed description of ice column is needed, ice coring can be helpful. Ice cores are extracted by drilling a rotating core barrel with sharp cutters at the end through the ice sheet. The ice core is then accurately removed from the barrel and used for analysis. Total ice thickness, effective ice thickness, and the measurement of the thickness of individual layers within the ice cover (fine grained, columnar, and snow ice) can be derived from ice core inspection. Thin sections can also be made from the cores, to examine the ice internal structure. It should be noted that, while ice coring provides considerable information, it is not as fast as auguring for simply determining the ice thickness.

If ice is covered by snow, a collocated measurement of snow depth is recommended. Snow depth is measured by vertically inserting graduated rod into the snow cover and reading associated depth measurement. The presence of liquid water in the snow or within the ice cover should be reported.

The position of each manual ice thickness measurement is commonly determined with a hand-held Global Positioning System (GPS). If a GPS device is not available, a marker can be placed in each hole and position can be marked on the map.

Systematic record of date, time, GPS coordinates, snow depth, total ice thickness, and effective ice thickness provides information to calculate allowable loads over the ice cover. Canadian guidance calls for measurements every 33 to 100 feet on rivers, and for lakes up to 820 feet apart, away from shore, with closer spacing near shore (Alberta Government, 2013; Northwest Territories, 2015; Saskatchewan Ministry of Highways and Infrastructure 2009). During early season (pre-construction and construction), it is important to take ice thickness measurements closely together for identifying and mapping sections of thin ice.

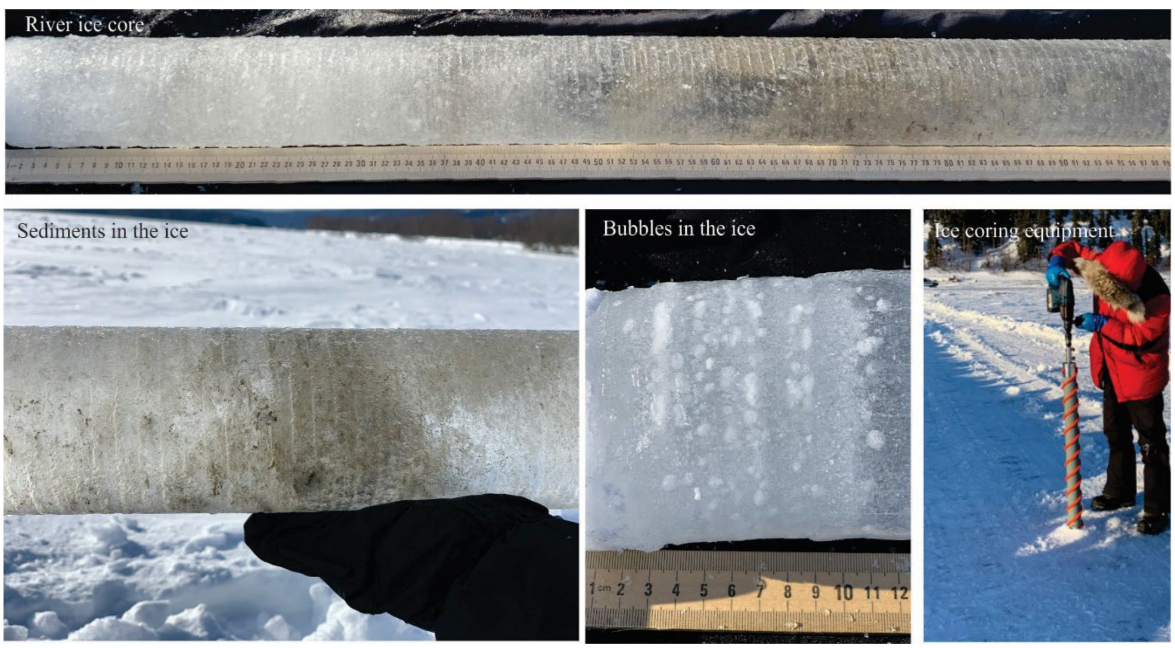

Figure 6.2 Photos showing river ice cores and coring equipment.

6.1.2 Ground Penetrating Radar profiling

Ground-Penetrating Radar (GPR) is a non-intrusive technique that uses radar pulses to image the subsurface of the ice cover and, after analysis and interpretation, produce a continuous estimate of the ice thickness. The GPR equipment consists of the radar itself, a compatible computer system, data cables connecting the computer to the radar, and a system of deploying the radar on the ice. In ice road applications, the GPR equipment is typically towed directly on the ice cover surface by snowmobile, pickup truck, or another vehicle (Figure 6.3).

Figure 6.3 Photo of GPR system pulled by snowmachine (Photo credit T. Sullivan).

The GPR transmits an electromagnetic (EM) pulse of extremely short duration, which is partially reflected from the interface between the bottom of the ice cover and the water below. The EM pulse can also be reflected from any discontinuities within and below the ice cover. An example of the continuous image produced by the GPR is shown in Figure 6.4. It requires a trained operator to identify spurious reflections and arrive at an accurate estimation of the ice thickness. Snow, snowdrifts, overflow, liquid water intrusions and air bubbles in the ice affect GPR estimate of ice thickness and should be reported (Richards et al 2022). Manual ice thickness measurements are required to obtain calibration data. The Saskatchewan Ministry of Highways and Infrastructure (2009) recommends calibrating GPR “at the start of each day, after four hours of use, and whenever erratic or questionable readings are obtained.”

During construction and operation of ice roads, GPR is often used to produce continuous estimates of ice thickness along the length of the ice road. Several commercially available GPR systems are available to estimate ice thickness. A typical ice profiling GPR system includes transmitting and receiving antennae and a digital data logger, GPS, and battery. The GPR system is connected by cable or wirelessly to a portable control unit with a monitor or laptop computer to display radargrams in the field. The antenna central frequency of 450 or 500 MHz is commonly used for ice thickness profiling.

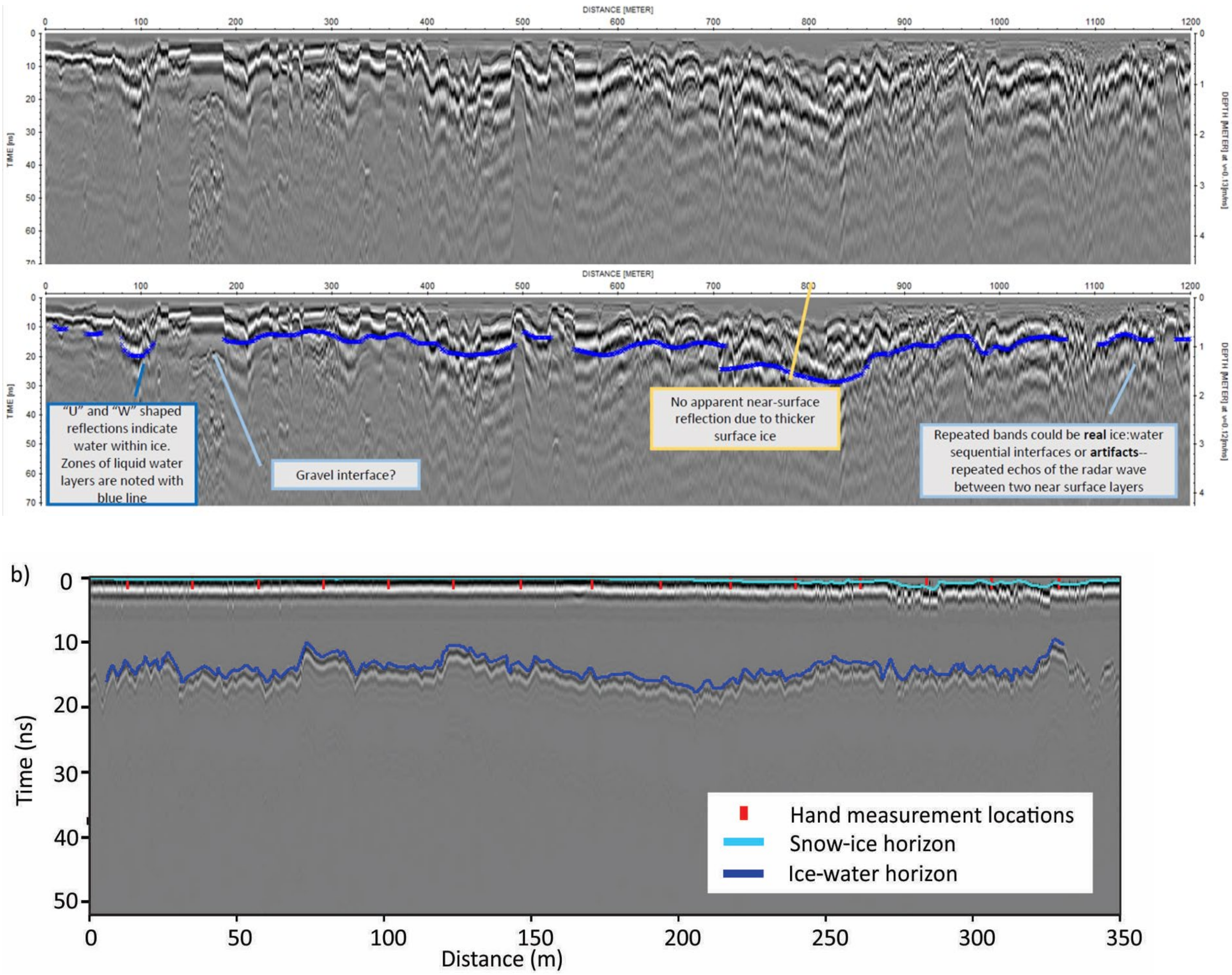

Figure 6.4 Examples of GPR surveying on the Delta River (a) and Yukon River (b) in Alaska. Top panel (a) shows the annotated "Image" (Radargram) of the subsurface. on the Delta River, Alaska. Bottom panel (b) shows GPR measurements on the ice road across the Yukon River near Tanana (Richards et al., 2022).

6.2 Pre-Construction

6.2.1 Surveying Ice Thickness during Pre-Construction

Surveying the ice thickness during pre-construction can be the most dangerous period of the winter season due to the thin and unknown ice conditions. An ice cover hazard assessment must be conducted and reviewed by field personnel prior to surveying. Suitable equipment and personal protective equipment (PPE), listed in Table 6.2, must be available. Initial testing should be conducted by at least two trained crew members travelling separately over the ice.

6.2.2 Minimum Ice Thickness during Pre-Construction

A conservative minimum ice thickness requirement is used during the pre-construction phase. An *A* value of 57 lbf-in^2 is required for heavy equipment. A minimum thickness is required for lighter loads, such as foot traffic, snowmobiles, or amphibious vehicles, as specified in Table 5.2

6.2.3 Spacing of Manual Measurements during Pre-Construction

The spacing of manual measurements during preconstruction should be such that significant variations in the ice thickness are measured. Canadian guidance calls for measurements every 33 to 100 feet on rivers, and for lakes up to 820 feet apart, away from shore, with closer spacing near shore (Alberta Government, 2013; Northwest Territories, 2015; Saskatchewan Ministry of Highways and Infrastructure 2009)   The ice thickness should be checked every two to three days to monitor the ice growth until minimum ice thickness is achieved to deploy heavier pieces of equipment. If GPR is used test holes are only required for calibration and mapping thin areas.

6.3 Construction

The construction phase involves creating ice roads with sufficient width and bearing capacity to support the expected vehicular loads. In addition, the ice surface trafficability must allow vehicles to move at the allowed speeds. Ice surface trafficability requires that the snow cover be removed from the ice road, and areas of rough ice are smoothed. Snow cover removal achieves two goals. It improves trafficability and increases bearing capacity. Bearing capacity is increased by removing the weight of the snow off of the road and exposing the ice surface to the air resulting in increased ice cover thickness.

6.3.1 Minimum Ice Thickness during Construction

A conservative minimum ice thickness requirement is used during the construction phase. An *A* value of 57 lbf-in^2 is required for all equipment.

6.3.2 Surveying Ice Thickness during Construction

The ice thickness should be checked every two to three days as the ice grows, to monitor its progress and approve the use of heavier vehicles. The most current ice profile data should be used to determine allowable load for construction equipment. If GPR is used test holes are only required for calibration and mapping thin areas.

6.3.3 Rough Ice Surface

In some river locations the initial ice cover formation is formed from ice floes that have overturned. Overturning occurs at locations where the river flow velocity is fast enough to overcome the floe stability when it is carried against a stationary ice cover. A rough ice surface must be made smooth during ice road construction. Snowplows mounted on heavy equipment will be able to smooth rough ice and create a relatively smooth ice road.

Figure 6.5 Constructing an ice road in rough ice (Image courtesy of Mark Leary, Bethel, AK)

6.3.4 Increasing the Ice Cover Thickness

There are two approaches for increasing the ice cover thickness to increase the bearing capacity of the ice cover: clearing the snow cover off the ice road and flooding the ice cover. Each will be discussed in turn. Increasing the ice cover thickness is often referred to as “strengthening the ice cover.”

6.3.4.1 Snow Clearing

Snow clearing involves the use of snowplows and other equipment to move snow from the ice road to each side of the road (Figure 6.6). The snow is left in long *windrows* – snow piles with their long dimension parallel to the roadway. The windrows become a long-term load on the ice cover and can lead to crack formation directly under each windrow. It is important that sufficient room for snow storage is created on each side of the snow road so that the height of the windrows and their resultant load on the ice cover is minimized to the degree possible.

The snow clearing process recommended by Saskatchewan Ministry of Highways and Infrastructure (2009) is summarized in Table 6.1:

Table 6.1 Snow Clearing Procedure recommended.

The outside limits of the ice road should be marked in advance so that the operators know the portion of the ice cover where the ice thickness was surveyed and found to be of sufficient thickness.
Ensure that only as much road is opened as can be completed within one shift. Windrows should not be left on the ice road area for any appreciable length of time.
If the snow is heavy the clearing should start on the outside edges and continue towards the center.
If the snow is heavy additional ice thickness surveying may have to be done so that there is more area for snow storage.
If there is limited snow cover, clearing operations can start at the center and move to the outside clearing limits.
Ensure that windrows are flattened out so that excess weight is not put on the ice cover
Care must be taken not to leave large windrows in the area to be cleared. Water may appear on the ice cover if the weight of a windrow is sufficient to depress the ice cover below its freeboard. If this occurs, it is impossible to move the windrow safely.

Figure 6.6 Snow removal (Image courtesy of Mark Leary, Bethel, AK)

6.3.4.2 Flooding

Flooding is a technique for increasing the ice thickness by pumping water onto the surface of the ice cover. Most often the water is pumped directly on the ice cover surface, but it can also be sprayed into the air to increase the heat loss from the water and the production of ice. The cover thickness is increased when the layer of water on the ice cover surface freezes solid. This process can increase the ice thickness faster than the process of ice growth on the bottom of the ice cover that normally occurs. A water layer on the ice surface is exposed directly to the air above and the heat transfer rate is greater than by heat conduction through the entire thickness of the ice cover. Over one inch of ice a day can be grown by flooding depending on the air temperature (Masterson 2009). Ice created by flooding by qualified personnel with good practices can generate ice that is comparable to freshwater blue ice in strength and uniformity.

Flooding is usually accomplished with low head, high volume pumps which pump water from beneath the ice cover directly onto its surface. The pumps should be capable of operating in very cold temperatures, be submersible or Archimedes screw type which have no hoses to freeze and drain readily when shut down. An example of pumps used for flooding the ice surface are shown in Figure 6.7. The water is applied in layers of about one thick and allowed to freeze before another layer is applied. It is important to “plug” or bank snow around each hole after flooding is completed to prevent water from flowing back into the hole. It is best practice not to dike or confine the water but to allow it to flow freely and achieve a tapered cross section of the road or pad. This avoids sharp transitions and the formation of cracks at the edge of the flooded area. Snow dikes may be necessary in some cases to prevent water from escaping and to achieve the required ice accumulation. Flooding should only be done on bare ice or after any snow cover has been compacted. If uncompacted snow is flooded this will produce a layer of snow ice, which is weaker and less uniform. It is exceedingly difficult to pack slush that forms from flooded uncompacted snow and should only be attempted with extreme caution.

Figure 6.7 Example of pumps for flooding ice surface

6.4 Suggested equipment

Much of the equipment used for the construction of ice roads is the same as that used for snow removal from roadways. This includes motor graders, one and two-way plows, front-end loaders, and smaller support equipment such as pick-up trucks and compact track loaders (skid-steer loaders). Additionally, water trucks play a crucial role in ice road construction as they carry and distribute the water needed to grow and thicken the road (described in 4.6). It is imperative that the equipment be in good working order with lubricants and fluids appropriate for cold-weather operations. Tires must be appropriate for working on ice, and in some cases, chains may be needed. For ice management on traditional roadways, motor graders are sometimes equipped with serrated blades (also known as “scarifiers”) for the purpose of cutting small grooves along the ice. This creates better conditions for traction with rubber tires. Along an ice road, conditions may develop that warrant the use of this same technique in order to decrease ice slickness. Equipment utilizing metal or rubber tracks will require 'grousers' installed on alternating track links. Dangerous 'skate' conditions can occur when traversing side slopes with metal tracks not grouser equipped.

6.5 Safety features

In general, the safety features and practices observed for standard road construction may also be applicable to ice road construction, but a few points should be added and emphasized due to the unique nature of the construction process. Because ice road construction may often take place in dark winter seasons, each vehicle should have all work and safety lights functional, and, if necessary, equip additional lighting to ensure effective visibility both for the operator and others outside the vehicle. Each vehicle should have a working 2-way radio for communications for both operational activities and for safety considerations. Radios should be verified over long ranges and function in harsh conditions because of the unique and often remote locations. Marine safety equipment such as personal floatation devices (PFD) or similar should be included in the cab of each vehicle for use by the operator in the event of a breakthrough. In-cab heat should be fully functional for each vehicle, and an additional, stand-by heat source may be a consideration in some cases. Finally, operators should routinely ensure vehicles are equipped with basic safety equipment such as the following:

Table 6.2 Required Safety Equipment

• Reflectors or flares	• Shovel
• Hatchet, axe or saw	• Tow strap, rope, or chain
• Basic tool kit	• Jumper cables
• Flashlight	• First aid kit
• Personal survival kit (including thermal blankets)	• Food (rations)
• Matches • Personal Flotation Device	• Knife • Rescue Ropes • Ice cleats (or similar)

6.5.1 Safe operations

Construction equipment operation begins with a thorough daily inspection of the vehicle by the operator. Figure 6.6 shows an example of a checklist that can be used for such an inspection.

Heavy Equipment Daily Inspection Checklist
Prior To Use On Site

Inspection Date:______________________ Time: ______________________

Equipment Type: ______________________ Unit #: ______________________

Vendor: ______________________

What to Inspect and Look for:	Good/ Present	Needs Repair/ Not Present	N/A
Backup lights and alarm			
Blade/Boom/Ripper condition			
Brake condition (dynamic service, park, etc.)			
Brake fluid			
Cab, mirrors, seat belt and glass			
Cooling system fluid			
Coupling devices and connectors			
Engine oil			
Exhaust system			
Fall protection (lanyards/harnesses)			
Fire extinguisher condition			
Frame, ladder(s) and walkway			
Guardrails/ Outriggers/Brakes			
Ground engaging attachments			
Hand grabs and steps			
Horn and gauges			
Hose condition			
Hydraulic oil			
Lights			
Oil leak/lube			
OTHER			
Personal Protective Equipment			
Power cable and/or hoist cable (s)			
ROPS			
Safety Decals			
Seatbelts			
Steering (standard and emergency)			
Tires or tracks			
Transmission fluid			
Turn signals			
Wheels/ Tires			
Windshield wipers and fluid			

Figure 6.6 Example of pre-operation checklist.

As construction proceeds, operators should perform regular scans of the ice surface ahead, behind and on each side of the vehicle wherein they look for cracking or other hazards indicating poor ice quality. Operators should know the vehicle weight and the ice thickness in the area of operation. Construction vehicles should maintain safe speeds (Table 8.2) at all times. They should keep safe distances while working near other equipment in order to avoid overloading the ice cover.

Construction vehicles that may be equipped with metal tracks may damage the ice cover surface with zero-degree turns, and operators instead may consider multi-point turns if sufficient, safe area exists.

Construction and support vehicles should maintain the safe speed limit for their weight and ice thickness as discussed in section 4.3 and chapter 10.

6.5.2 Worker safety

As with any construction project, worker safety is the number one priority. Ice road construction is no different, and much of the same personal protective equipment (PPE) used on traditional jobsites is applicable here (Table 6.2). Equipment movement, environmental conditions, and other hazards are some of the primary considerations for worker safety. Any personnel walking or working near an operating piece of equipment should ensure clear communication with the equipment operator verifying that the operator is always aware of their proximal position. Given that any foot traffic on the ice cover is inherently slippery, appropriate footwear should be worn.

6.5.3 Record Keeping

Inspection reports, when properly kept, provide useful information such as weather conditions, operational and maintenance activities, unusual traffic, ice conditions, etc. This data can be reviewed at a later date to help make decisions about operational changes, develop correlations between observed data and performance, and identify conditions leading up to a failure. It is important that the information included in the inspection report provides only defendable data without opinion or interpretation. Figure 6.7 provides a suggested template for an inspection report.

Ice Road for The Village of		**Prepared by:**	
Date:			
Ice Road Inspected by			
Weather			
Ice Conditions			
Traffic			
Maintenance Activities			
Unresolved Issues			

Figure 6.7 Inspection Report Template

CHAPTER 7. ICE ROAD SIGNAGE

7.1 Purpose and Intent

Winter ice road traffic signs and route markers are an important part of ice road safety. It is required that ice road signage follows standard Manual on Uniform Traffic Control Devices (MUTCD) standards and guidance (FHWA 2009), where applicable. However, ice road conditions can change rapidly, and certain situations may require additional or different signage than permanent all-season roads.

The information presented in this chapter is intended solely for the purpose of signing and delineating ice roads. Where deviations from the MUTCD exist, the use of that signage may not be transferred or used in other conventional roadways applications.

Examples of MUTCD signage appropriate for ice roads are shown in Appendix B, Examples of MUTCD Signage.

7.2 Design

Ice roads are considered Low Volume Roads as defined by the MUTCD. Ice road signage shall be designed in accordance with the provisions contained in Part 5 of the MUTCD, "Traffic Control Devices for Low-Volume Roads", and where required, in other applicable parts of the MUTCD.

7.2.1 Signs and Plaques Sizes

The typical sizes for signs and plaques installed on low-volume roads shall be as shown in Table 7.1. The sizes in the minimum column shall be used given the ice road speed limits listed in Chapter XX. The sizes in the oversized column should be used where engineering judgment indicates a need based on high vehicle operating speeds, driver expectancy, traffic operations, or roadway conditions. Signs and plaques larger than those shown in Table 7.1 may be used (see MUTCD Section 2A.11).

7.2.2 Visibility

All signs shall be retroreflective or illuminated to show the same shape and similar color both day and night. The requirements for sign illumination shall not be satisfied by street, highway, or strobe lighting. All markings shall be visible at night and shall be retroreflective unless ambient illumination provides adequate visibility of the markings.

Conspicuity is defined as the quality of a sign or plaque to appear prominent in its surroundings. It is a measure of how a sign can attract or gain the driver's attention. Based upon engineering judgment, where the improvement of the conspicuity of a sign or plaques is desired, a number of methods may be used, as appropriate, to enhance the sign's conspicuity (see MUTCD Section 2A.15, Enhanced Conspicuity for Standard Signs).

Table 7.1 Sign and Plaque Sizes on Low Volume Road (Example. MUTCD (2009) pg. 532)

Sign or Plaque	MUTCD Manual		Sign Sizes		
	Sign Designation	Section	Typical (inches)	Minimum (inches)	Oversized (inches)
Stop	R1-1	5B.02	30x30	—	36x36
Yield	R1-2	5B.02	30x30x30	—	36x36x36
Speed Limit (English)	R2-1	5B.03	24x30	18x24	36x48
Do Not Pass	R4-1	5B.04	24x30	—	36x48
Pass With Care	R4-2	5B.04	24x30	18x24	36x48
Keep Right	R4-7	5B.04	24x30	18x24	36x48
Do Not Enter	R5-1	5B.04	30x30	—	36x36
No Trucks	R5-2	5B.04	24x24	—	30x30
One Way	R6-2	5B.04	18x24	—	24x30
No Parking (symbol)	R8-3	5B.05	24x24	18x18	30x30
No Parking	R8-3a	5B.05	18x24	—	24x30
No Parking (plaque)	R8-3cP,3dP	5B.05	24x18	18x12	30x24
Road Closed	R11-2	5B.04	48x30	—	—
Road Closed, Local Traffic Only	R11-3a	5B.04	60x30		—
Road Closed to Thru Traffic	R11-4	5B.04	60x30	—	—
Weight Limit	R12-1	5B.04	24x30	—	36x48

7.3 Application

Generally, all required signage must be in place before an ice road or crossing is open to the public. There are three categories of signage: Construction, Entry signs, and regulatory and advisory signs.

7.3.1 Construction Signs

While an ice road is under construction and not yet open to the public, barricades and signs are posted at the entrance to the ice road stating that it is closed. Best practices include regular checks and patrols to ensure barricades are always in place.

7.3.2 Entry Signs

Signs are posted at each major river crossing and at the entrance to all ice roads. The types of information that can be included in entry signs is listed in Table 7.2. Examples of entry signs are shown in Figure 7.1.

Table 7.2 Entry Sign Information

Whether the road or crossing is open or closed
Maximum allowable Gross Vehicle Weight
Maximum Speed limit
Minimum distance between vehicles
Phone number to call for road information
Services available on the road if any
Advisory on tire chains and survival gear
Distance to next community

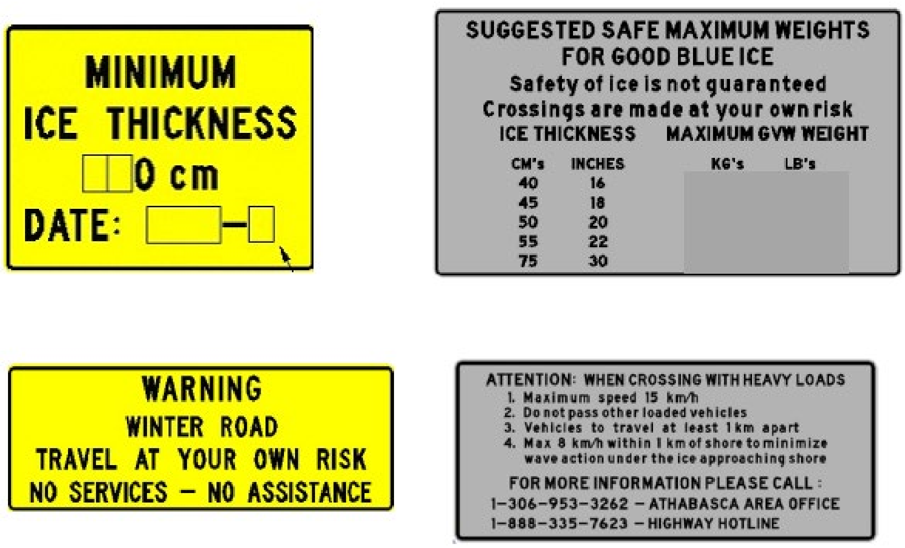

Figure 7.1 Example of Entry Signage (Saskatchewan Ministry of Highways and Infrastructure 2009)

7.3.3 Regulatory and Advisory Signs

Signs can be posted along the ice roads to provide information, reinforce regulations, delineate the travel lanes, advise travelers of road conditions. The types of information that can be included in entry signs are listed in Table 7.3.

Table 7.3 Regulatory and Advisory Sign Information

Type	Application	MUTCD Section
Speed Limit.	Speed limit signs should be posted as required.	5B.03
Weight Advisory.	Maximum allowable Gross Vehicle Weight	2B.49
Traffic Control.	Traffic control devices such as flags and barricades can be used to direct the flow of traffic.	Chapter 3H
Delineators	Delineators are particularly beneficial for marking the edges/limits of the maintained ice road which may not be apparent due to lack of contrast between ice and snow. Delineators provide additional guidance at night and during adverse weather. Delineators shall consist of retroreflective devices that are capable of clearly retroreflecting light under normal atmospheric conditions from a distance of 1,000 feet when illuminated by the high beams of standard automobile lights. Retroreflective elements for delineators shall have a minimum dimension of 3 inches.	Chapter 3F
Warning and Hazard Signs.	Signs/markers are used to identify and mark hazards on the ice road. When a hazard cannot be removed, road users should be alerted to the nature of the hazard.	Chapter 5C
Barricades.	Barricades may be installed in an emergency to attract attention to a sign message or to identify a particular hazard or obstruction.	6F.63
Information and Mile Markers.	Signs on ice roads inform users of the distance and route to the next community where fuel, accommodation and food are available. Mile markers are placed every 5 miles to indicate the distance from the start of the ice road.	2H.05
Acknowledgment Signs	To indicate the village/person who “adopted” or maintains the roadway	2H.08

CHAPTER 8. ICE ROAD VEHICLE CONTROL

8.1 Introduction

This chapter describes the maximum speed limits, minimum distances between vehicles, control of stationary loads, and load management for ice roads.

8.2 Maximum Speed Limits

The maximum speed limit allowed depends on vehicle loading, ice conditions, and the situation of the vehicle, such as approaching a shoreline, approaching an oncoming vehicle, etc. In addition, the interaction of the vehicle with the ice cover and the water beneath the ice cover can have a significant impact on the stresses on the ice. A stationary vehicle on the ice cover creates a symmetric deflection bowl. As the vehicle moves the deflection bowl it creates moves with it. The deflection bowl moves the underlying water aside in a manner like that of a shallow draft boat. At low speeds, the deflection bowl moves with the vehicle and maintains its symmetric shape around the vehicle. There is little impact from the fluid motion created by the deflection at these low speeds. As the vehicle speed increases the deflection bowl changes shape and rims of the bowl begin to rise. When the vehicle reaches the "critical speed" the ice sheet deflection and stresses are amplified. The critical speed is a well-defined speed at which the maximum ice deflection is approximately twice that of a stationary load. Critical speed is a function of both the water depth and ice thickness. It is shown in Figure 8.1. In shallow water the critical speed is determined by the water wave speed which is equal to the square root of the product of gravity, *g*, and the water depth, *H*. In deep water, the critical speed is determined by the ice thickness, *h*.

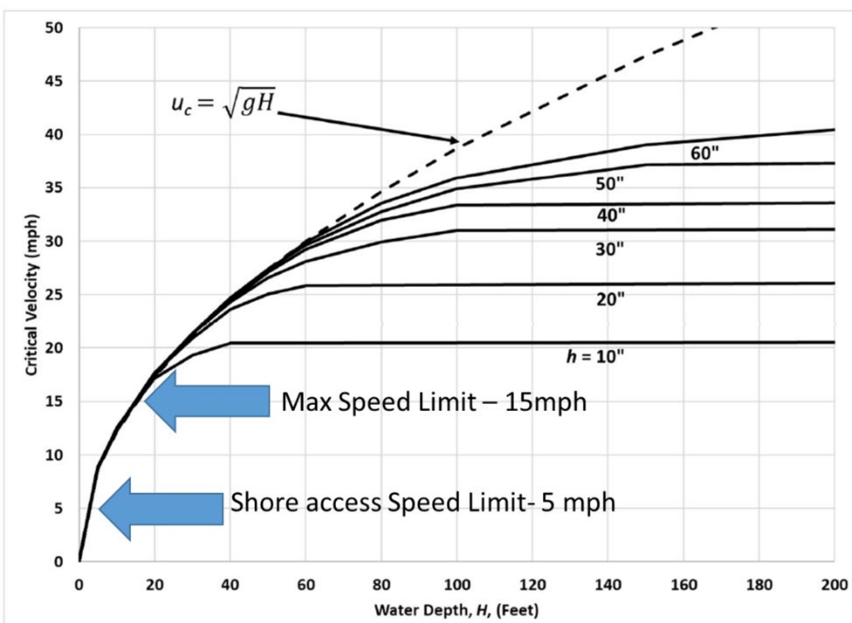

Figure 8.1 Critical Wave Speed as a function of water depth, *H*, and ice thickness, *h*.

The deflection of the ice cover goes through several stages as the vehicle approaches the critical speed and exceeds it. These stages are shown in Figure 8.2. The first stage occurs when the vehicle speed is less than 70% of the critical speed. This is the *quasi-static stage* where the actual deflection is about the same as for a stationary load. The next stage, between 70% to 85% of the critical velocity is a *symmetric transition stage* where the deflection bowl becomes deeper and narrower, and the rim around the bowl rises. The next stage, between 85% to 100% of the critical velocity is an a*symmetric transition stage*. In this stage the main ice deflection becomes deeper and narrower, and two asymmetric features start to develop: the forward rim of the ice depression begins to evolve into a wave-like pattern, and the center of the deflection bowl lags increasingly behind the vehicle. At speeds greater than the critical speed the vehicle enters a wave-generating mode with a well-defined wave train in the ice ahead of the vehicle. The vehicle assumes a position approximately half-way up the forward slope of the deflection bowl and retains this position at all higher vehicle speeds. The ice wave pattern changes progressively with increasing speed.

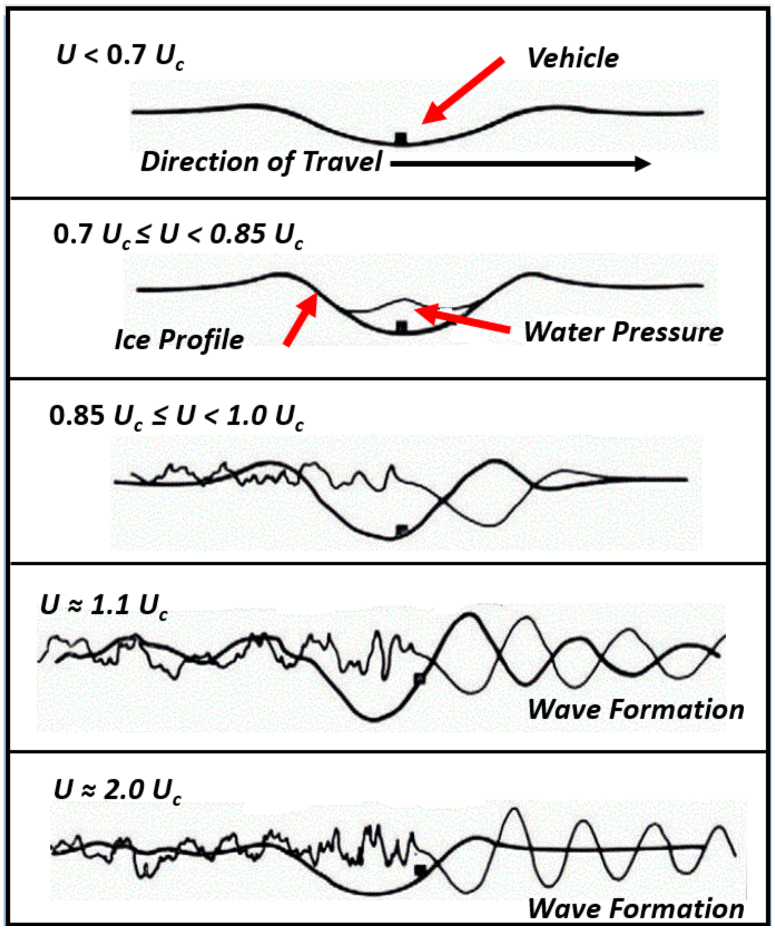

Figure 8.2 Stages of Ice Cover Deflection as a function of the Vehicle speed relative to the Critical Speed.

Moving loads traveling at and above the critical depth cause increased stress in the ice cover. The greatest risks occur when moving loads transit from deep water to shallow water over a short distance. This can happen at access points, sand bars, and other channel bottom changes and lead to ice cracking and blowouts. It is important to control vehicle speeds to reduce the chance of travelling at critical speed and cracking the ice cover during a depth transition.

The ice thickness recommendations listed in Chapter 4 are strictly for stationary loads. It is important that the set speed limits keep the vehicles in the *quasi-static stage* or less than 70% of the critical speed so that the weight limits remain applicable. The maximum speed limits for vehicles on ice are listed in Table 8.

Table 8.1 Maximum Speed Limits

Vehicle Situation	Maximum Speed Limit
Vehicle operating at the minimum ice thickness for its weight	15 mph (25km/h)
Vehicle operating at 2 x minimum ice thickness for its weight	25 mph (35km/h)
Approaching or leaving shore access points	5 mph (10km/h)
Meeting oncoming vehicles	5 mph (10km/h)
Passing work crews	5 mph (10km/h)
GPR Profiling	5 mph (10km/h)

8.3 Minimum distances between vehicles

Minimum distances between vehicles prevent the deflection bowl created by each vehicle from combining and causing excessive stress levels in the ice cover. Minimum distances also allow time for decay of any waves or hydraulic disturbances to the underlying water column that are generated by the moving load before the following load arrives. Recommended minimum distances between vehicles are listed in Table 8. (Northwest Territories 2015).

Table 8.2 Minimum Distances Between Vehicles

Vehicle Weight	Minimum Distances	Time Spacing at 25 mph
Vehicles < 11,000 lbs	660 ft (200m)	18 seconds
Vehicles > 11,000 lbs	1,640 ft (500m)	45 seconds

8.4 Stationary loads

Stopping or parking loaded trucks on the ice is always prohibited. Arrangements must be made to move disabled vehicles off the ice cover as soon as possible. Vehicles approaching a disabled vehicle should not stop but should slowly move past the disabled vehicle with as much spacing as possible.

8.5 Load Management

Traffic should be restricted to vehicles with a Gross Vehicle Weight that meets the requirements for bearing capacity of the current ice conditions. The ice cover bearing capacity is discussed in Chapter 4. It is important that the bearing capacity information be posted at every Access Point so that users can compare the Gross Vehicle Weight of their vehicles before accessing the ice road. However, it is not uncommon for the Gross Vehicle Weight including equipment, cargo, passengers, and fuel to be unknown within a large margin. If the Ice Road is operating under the Substantial Risk level, vehicles should be weighed using a portable vehicle scale "with all the components, fuel, tools, and gear included." This information should be affixed to the vehicle or equipment where the operator can read it to make sure it is safe to go on the ice.

CHAPTER 9. ICE ROAD MONITORING AND MAINTENANCE

9.1 Monitoring

Monitoring the ice cover is done through visual inspection and ice thickness surveying. The frequency of the monitoring program is described in Table 9.1. Visual inspection requires personnel to travel the entire route of the ice road looking for dry cracks, wet cracks, water on the ice cover, snow drifts, and other problems that may compromise the integrity of the ice cover and interfere with the movement of vehicles. Visual inspections can be conducted at fixed intervals of one week or more when conservative *A* values for Gold's Formula are adopted, for example *A* values in the range of fifty-seven or less. The interval of inspection should be shortened as the *A* value is increased, with daily inspections occurring at higher values. Records of the visual inspections should be made and archived. Any problems encountered should be reported.

Ice thickness surveying can be done manually or using GPR. Manual surveying is acceptable for conservative *A* values. However, as the *A* value is increased GPR surveying becomes mandatory. One critical point of surveying is to locate areas of the ice cover that are thin. GPR surveying of ice thickness provides a continuous record of ice thickness along the ice road. All survey data should be recorded and archived. Thin sections of the ice cover should be reported.

Table 9.1 Monitoring Program

A Value	Level of Risk	Visual Inspection	Surveying
50	Low	-At least once every three days -checking of ice quality	-Manual measurements every 10-14 days
57	Tolerable	-Regular Ice quality monitoring program	-Program of regular manual ice measurements
71	Moderate	-Daily Ice quality monitoring program	-Daily program of regular ice measurements or program for regular GPR ice profiling plus manual ice measurements
85	Substantial – Special Procedures	-Daily Ice quality monitoring program	-Daily program of regular ice measurements or program for regular GPR ice profiling plus manual ice measurements

9.1.1 Visual Inspection

Inspectors on frozen water bodies can deduce much simply by visual inspection of the ice cover surface. An example of cracks is shown in Figure 9.1. Some features that provide insight into ice quality are listed in Table 9.2.

Figure 9.1 Examples of ice cover cracks. A shallow dry crack and refrozen wet cracks are shown.

Table 9.2 Ice Cover Features of Interest

Cracks	Wet or Dry	Wet cracks extent completely through the ice thickness and liquid water is visible at surface. Dry cracks can be of any depth.
	Quantity	Density of cracks per unit surface area
	Length and Width	Cracking across the expanse of the water body could indicate a preferred failure point and should be marked.
Ice Color	Clear, blue generally indicators of favorable ice	
	White, milky generally indicators of snow ice or ice with more air bubbles which can be less favorable though still satisfactory	
	Brown, grey, or other off colors generally indicate frozen objects within ice such as sticks, rocks, or other organics which can decrease the load bearing capacity of an ice sheet.	
Ice Condition	Openings	If there are openings, inspectors should determine if the ice sheet has been undercut and, if so, to what extent. Undercut or overhanging sections of ice are generally unfavorable.
	Rough ice	If there are jagged or uneven sections of ice, it may indicate a rock or other larger frozen object below.
Standing Water	If possible, determine the source of the water	

The following table is a suggested checklist for visual inspections of ice sheets.

Table 9.3 Suggested Checklist for Visual Inspection of Ice Sheet

Date: ________	**Time:** ____________	**Location:**	
Cracking Extent and Geometry			
Dry Cracks	Number:	Max Penetration: _______%	
Wet Cracks	Number:	Max Width: ___________In.	
Comments:			
Ice and Surface Characterization			
Ice Color	Clear/Blue/Black	Thickness: ___________In.	
	White	Thickness: ___________In.	
	Other__________	Thickness: ___________In.	
Snow Cover	Depth: ___________In.		
Surface Roughness			
Water on Ice			

9.2 Maintenance

Maintenance involves repairing dry and wet cracks, controlling loads, directing traffic during repairs, modifying, replacing, or adding to signage, snow removal, and other tasks required to keep the ice road in good order and allow traffic to move. Maintenance can be conducted on a 'as needed' basis when conservative *A* values for Gold's Formula are adopted. The interval of maintenance should be shortened as higher *A* values are adopted, with daily maintenance occurring at higher, less conservative values.

9.2.1 Crack Repair

It is possible to repair dry cracks by flooding the ice surface, filling in the cracks, and allowing the water to freeze. Wet cracks can also be repaired by allowing them to freeze and then flooding them if required. The allowable vehicle load may need to be reduced while the cracks are being repaired, or the traffic may need to be detoured around the affected area, or in severe cases, the existing alignment may need to be abandoned. The procedure for crack remediation and load management is shown as a flow chart in Figure 9.2. Wet and dry cracks are handled separately. Three options are provided for wet cracks: close area to loads, close area and repair crack, and bridge crack with rig mat or an engineered mat. The ice road operators would need to select the option that best matched the actual field conditions and their level of operations. The options for dry cracks depend on the depth of the crack compared to the ice cover thickness. If the crack depth is less than 25% of the ice cover thickness the crack should be monitored and repaired as required. If the crack depth is between 25% and 50% of the ice cover depth, the area should be closed in sections and the cracks repaired. If the crack depth is over 50% of the ice cover thickness three options are provided: close area and divert loads, close area and repair crack before reopening, or reduce load by 50%.

Table 9.4 Maintenance Program

A Value	Level of Risk	Maintenance
50	Low	- Repairs and maintenance as needed
57	Tolerable	- Repairs and maintenance as needed
71	Moderate	- Regular program of repairs and maintenance
85	Substantial – Special Procedures	-Daily program of repairs and maintenance

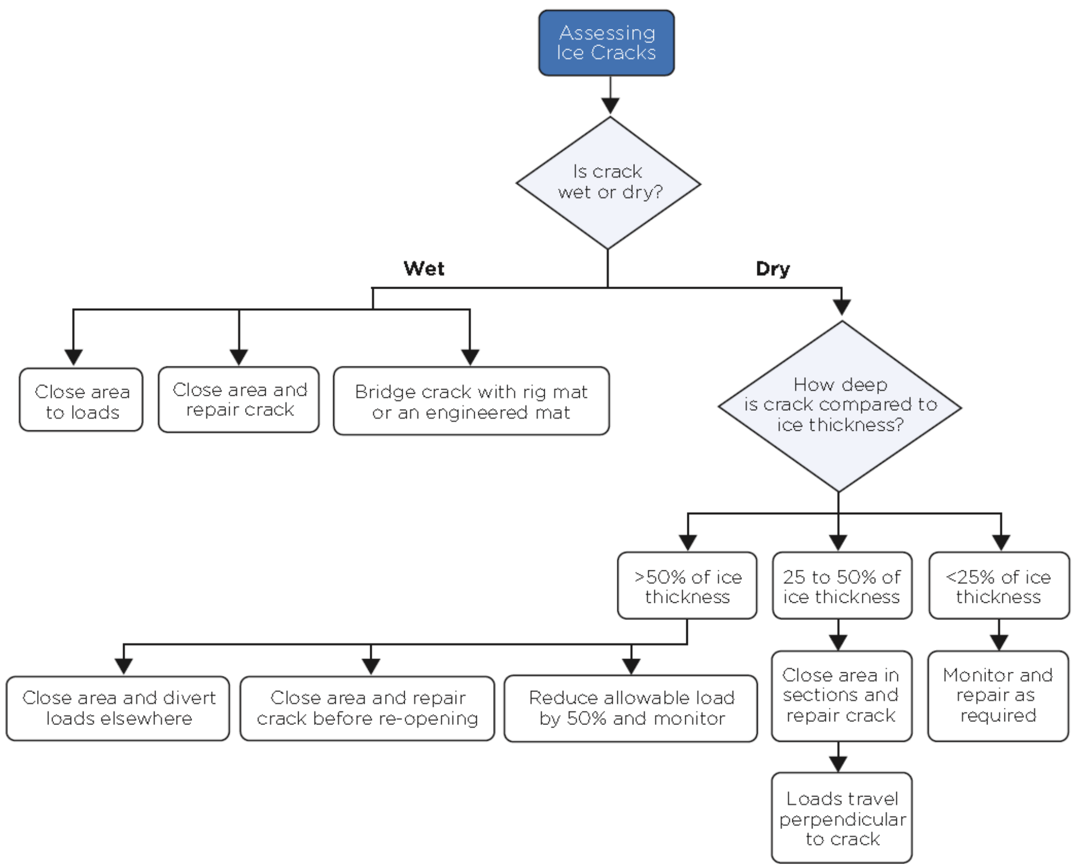

Figure 9.2 Assessing Ice Cracks for Maintenance (Alberta Government 2013)

9.2.2 Snow Removal

Keeping ice roads free from extensive buildup of snow covers is an important part of ice road maintenance. The buildup of snow covers can result from snowfall, snow drifting, or a combination of both. Generally, trucks, graders, and other available equipment are mounted with snowplows to remove the snow from the ice road. Large truck-mounted snowblowers can also be used. The best results are achieved when the snow is cast away from the ice road as far as possible.

The stress that snow removal places on equipment and personal depends on how rapidly snow builds up on the ice road through snowfall and drifting. If snow removal only occurs once when the snow road is constructed and then only intermittently during the period that the ice road is open, then the stress level will be relatively low. In this case, there will be enough time between snow removal periods that the equipment can be kept in good repair and the crews rested. If snow removal is required continuously and over an extended period of time, then the stress level will be high. Maintaining all the equipment in good working order will be difficult and the crew will be worked hard. There will be a premium on having new equipment as older equipment will tend to need to be repaired more often. There can be problems with the long-term loads that result from the windrows on each side of the road that can lead to the formation of wet cracks. If the height of the windrows exceeds the ability of the snowplows to cast the snow off the road, then the ice road may need to be abandoned and a new road constructed.

CHAPTER 10. END OF SEASON CLOSURE

10.1 Overview

The integrity of ice roads declines in late winter due to increases in air temperature and sunlight. This decline is the result of surface degradation, internal deterioration through penetration of sunlight, and thinning of the top and bottom of the cover. Eventually the ice road integrity declines to the point where public safety is compromised and the road must be closed for the season.

This chapter covers the issues that are associated with the End-Of-Season closure of the ice road. These are ice cover melting, end-of-season monitoring, closure procedures, and emergency procedures.

10.2 Ice Cover Melting

Ice cover melting includes several processes that occur when ice covers absorb heat. **Surface degradation** results from the accumulation of excessive water on the surface of roads or ice crossings due to surface melting and the softening of the upper portion of the ice sheet to a degree that inhibits travel for most vehicles. **Deterioration** generally refers to internal melting of the ice cover due to the absorption of sunlight within the cover. Internal melting increases the porosity of the ice cover and leads to significant losses in strength. Ice covers can deteriorate significantly with little or no change in thickness. The **thinning** of ice covers describes the reduction in the thickness of the ice cover through melting at the top and/or bottom surface of the ice cover.

In late winter, the energy of the sun is often strong enough to cause surface degradation, even when ambient temperatures remain below 32°F. Dark surfaces from sand, gravel, and other debris on the ice surface absorb energy from the sun due to their dark color. This results in melting in areas where there is a large concentration of dark sand/gravel. Maintenance crews can extend the length of the season by scraping these areas clean on a regular basis. Canadian sources (Northwest Territories 2015) report that most ice roads will be forced to close as a result of surface degradation, long before the integrity of the ice road is jeopardized.

Deterioration of ice covers is caused by sunlight penetrating the surface and melting the internal ice of the cover. Deterioration will happen most rapidly when the ice cover is bare and is exposed to long hours of sunshine. Deterioration is difficult to detect because it cannot be easily measured in the field. The integrity of the ice cover is directly degraded by deterioration.

Ice cover melting can occur at both the top and bottom surface of the ice cover. Generally, the water temperature is at or very near 32°F when an ice cover is in place so little or no melting occurs on the bottom of the ice cover. However, if open water leads form, then the flowing water is warmed by absorbing sunlight. This can cause rapid melting downstream of the leads.

10.3 End of Season Monitoring

The frequency of ice cover monitoring should increase near the end of the season. Ice thickness measurements should be a part of the monitoring program to determine if thinning has occurred. Ground Penetrating Radar cannot be used to measure the ice thickness when there is water on the ice surface. Cracks, excessive water, and areas of surface degradation should be located.

10.4 Closing Procedures

10.4.1 When is closing required?

As the ice cover melts eventually, the ice road will need to be closed. It is not possible to provide precise conditions when an ice road is unsafe to operate. However, the following guidelines are recommended to the ice road supervisors when exercising their judgement when an ice road should be closed. Ice roads can continue to be operated safely for as long as supervisors can maintain confidence in the **minimum ice thickness**, the **overall integrity of the ice**, the **trafficability of the ice surface**, and the **accuracy of the loading conditions**. When ice cover melting prevents the ability to maintain confidence in ice thickness, ice integrity, and the ice surface, the crossing should be closed.

10.4.2 Closing Access

When the ice road is closed all access points should be blocked with the use of signage, barricades, snow berms, or other practical means. Signage should be a Road Closed sign described in Table 7.1 and shown in Figures B.2 and B.4. (MUTCD designation R11-2.) Signs can be mounted on barricades located across the access roads as shown in Figure 10.1. The road closed signs and barricades should be monitored to ensure that they remain in place.

Figure 10.1 Ice Road closure sign mounted on barricade (Saskatchewan Ministry of Highways and Infrastructure 2009)

10.4.3 Announcing Closure

Signs located at access points are the primary means of announcing closure. In addition, public service announcements advising of the closure can be made on local radio stations, TV, newspaper, and social media.

10.4.4 Removing Signage

All signage should be removed from the ice road at the end of the season.

10.5 Emergency Procedures

Safe operation on ice and required safety equipment are discussed in Chapter 6. Ice incidents are always possible and especially near the time of Ice Road Closure. In the event of an ice incident the first priority is to secure the site to ensure that no one is in danger from further incidents. When visibility is poor and traffic is likely, it is important to ensure that those working on the incident site are not endangered by approaching vehicles.

Assess the scene. Determine if anyone is in immediate danger. A rescue effort may be required if a person is trapped in a vehicle and the vehicle is in an unstable position. Similarly, an injured person may need immediate medical attention. Deal with life threatening situations or injuries immediately. Deploy warning signs, flares or barriers to warm approaching traffic and protect those working on the incident.

Call for Help. Call for assistance at the first opportunity. Calls can be made by satellite phones, or 2-way radios as described in Chapter 6. Provide the following information

- Location
- Brief description of the accident
- Description of injuries
- Assistance required
    - Ambulance
    - Road closure
    - Additional personal or equipment
- Request that the police or other authorities be notified

Wait for Assistance. After calling for assistance, stabilize casualties and provide warmth and shelter. Maintain the security of the site and stability of casualties until assistance arrives.

Transport. Transport casualties to the nearest medical facility or a location where further transportation can be provided.

Long Term Response. Remove vehicles from vicinity of ice road and determine if ice road should be reestablished or closed for the season.

CHAPTER 11. USE OF UNCREWED AIRCRAFT SYSTEMS

11.1 Benefits and Limitations of UAS for Monitoring Ice Roads

Small uncrewed aircraft systems (UAS) or drones can be used in support of ice road monitoring by collecting still images and dynamic videos over target areas of rivers, lakes, and their surrounding landscapes throughout the year. Small UAS are defined as those that weigh more than 55 lbs. and less than 55 lbs., including all aircraft and payload components, during flight. UAS can provide a broad overview of an area by flying well above the water surface but can also zoom in to collect more detailed images using either the aircraft itself or sensors with zoom capacity. Using drones to identify and monitor ice roads reduces the uncertainty of land or ice-based visual observations and supports the identification of potential hazards to the road or crossing from a safe distance. The specific use cases of UAS to support monitoring of ice roads include but are not limited to, route selection, road establishment, regularly scheduled monitoring, post-storm inspections, and indicators of seasonal ice road deterioration.

11.2 Open Water

Before a seasonal ice road is established, understanding the baseline river, lake, and landscape conditions of a particular location where an ice road could be constructed is important. UAS can be used to collect high resolution baseline imagery of water bodies and the surrounding land from above allowing for rapid reconnaissance of potential routes. Prior knowledge of a given location can guide UAS operations towards likely ice road routes, where detailed examinations of channel locations, water depth, and erosional influences of that area can be performed well before freeze-up conditions. UAS can also be used during open water seasons to document the changing conditions of those water bodies and landscapes used to support ice roads from year-to-year that may influence the establishment or safe operation of an ice road. Commercially available UAS cannot be reliably used to penetrate the water’s surface, or “see through” the water, to systematically examine channel bed characteristics or other bathymetric features. In unique cases where the water is exceptionally clear, bathymetric features, as well as fish and other wildlife, can be seen in the UAS footage through the water, but the 3D interpretation of those images is currently limited to research and development applications.

11.3 Freeze-Up

Once the water begins to freeze, UAS can be flown over sections of lakes and rivers to identify open water, regular eddies that are not consistently freezing, and other features that will influence the water and ice formation throughout freeze-up and potentially throughout the winter season. These shoulder season flights can also provide information on the ice types developing in the water and rates of formation of pack ice that will eventually support construction. Commercially available UAS cannot be used as the only technology to reliably determine ice thickness. However, drones can be used to monitor ice development and be flown in tandem with manual surveys that are directly measuring ice thickness. Drone flights can also be used to establish freeze-up patterns of a given water way and the potential ice road routes once the ice is determined thick enough to support vehicle traffic. Drones can also be used to monitor the ice road construction progress, to identify efficiencies or in support of training ice road engineers.

11.4 Solid Ice

Once the ice road has been established, UAS can be flown in combination with on-ice visual inspections to identify dry cracks, wet cracks, water on the ice surface, snow drifts, and other problems that may compromise the ice road integrity and may not be visible from the inspector's location on the ice. Anomalous features identified during UAS flights over established ice roads can be further examined using zoom features on the sensor being carried by the drone, or by investigating on foot if the conditions are safe for foot traffic. UAS also can be flown after major storm events to ascertain the condition of the road to support what maintenance or repair steps need to be undertaken to return the ice road to safely passable conditions.

The roughness of the ice road surface can be measured using commercially available drones to create 3D models of the ice surface using commercial data processing programs. Ice roughness can be an indicator of instability of ice depending on the time of year, recent weather, and the surrounding conditions of the ice and landscape, and is a component of the ice that can be measured confidently by using UAS as the only tool. A specific example of ice roughness that can be measured with drones are pressure ridges on lakes, which can be large or small, but indicate areas of unstable ice. Unlike surface roughness, commercially available sensors on small UAS cannot see through ice, thus cannot be the sole method used to determine ice thickness or continued ice growth throughout the season. However, investigations are still needed to determine if these commercial off the shelf UAS and sensor packages can determine if the ice has grounded to the bottom of the lake or river channel based upon the color or other components of the UAS-collected information.

11.5 Break-Up

Ice break-up, because of anomalous weather conditions or seasonality, is variable by the ice, the underlying water, and the weather conditions of the year. As described in Chapter 8, when the air temperature remains above 32°F for 48 hours or more, the ice road can decay significantly. Using UAS as a regular monitoring tool for ice roads can help ice road managers identify early indicators of ice changes that could lead to break-up conditions, thus reducing risk to operators on the ice roads. Upwelling, wet cracks, and open water can be observed with UAS when snow is not obscuring the surface and can be mapped relative to the shoreline to identify detours and other risk reduction strategies. Other ice features that may indicate break-up is imminent that can be observed with UAS include arched ice (indicating flow beneath), lifted ice (when ice breaks from the shoreline and is floating on the river, but not moving), and different ice.

One of the most powerful applications of UAS to increase safety prior to and during break-up is change detection analysis. To effectively monitor changes in ice roads using UAS, regular flights over a defined area need to be performed. The images and videos can be reviewed manually by ice road managers, but that process can be very time-consuming depending on how large the flight area is, and how much corresponding imagery or video has been collected. A more efficient method of reviewing larger flight areas is to use software designed to ingest UAS images to produce a single 2D map, or orthorectified map image, which can be displayed on a computer or printed in large format. If the same flight plan is used, and the same processing methods, subsequent 2D maps of the same area can be created and systematically compared to each other to identify changes from one flight to the next. This is the fundamental concept behind the structure from motion (SfM) processing, also known as photogrammetry, which is becoming more popular for landscape level change detection analyses. The repeated flights, maps, and analyses allow ice road managers to watch the dynamics of the ice over time to support management decisions, which are critical during break-up conditions. Artificial intelligence is ideally suited to support change detection analyses by identifying anomalous features from one ice road image to the another taken later in time, though a human reviewer should confirm any identified feature of the ice.

Larger river break-up trends can also be visualized safely using UAS. Once the ice sheets start to move, ice jams are a common occurrence in rivers which can cause flooding in communities upstream from the ice jam location when the flow of the river is blocked; this is also true of log jams during different seasons. Once these ice jams are released, either naturally or via intervention, communities can also experience flooding directly downstream from an ice jam, functionally transferring that flood risk downstream. UAS can be used to identify the ice jam itself, but also can be used to calculate volume of ice in the jam, changes in river height resulting from the jammed outlet, and aid ice road managers in the identification of jam release solutions, i.e., strategic ice dam release methods. Observations of these small to large-scale phenomena with UAS can also be submitted to the National Weather Service (NWS) River Watch Program (https://www.weather.gov/aprfc/riverWatchProgram). The Riverwatch program collects opportunistically acquired river condition observations made by pilots flying throughout Alaska. Observations are either relayed via radio from the pilot through the FAA, or provided to the NWS via electronic reports, or digital images that can be used to support community decision-making during break-up. This observational information is then synthesized by the NWS into maps for community planning, most often for emergency response because of ice jams, but also planning for non-emergency components of river break-up as well.

Multiple technologies, such as photogrammetry, live video, thermal imaging, and change detection analyses, can use UAS-collected data from over ice roads to support decision-making for ice road managers. The key to utilizing these valuable information streams is following through on all components of UAS information collection, processing, and dissemination of results to the ice road managers in a timely way so that important safety decisions can be made as close to when the UAS collected the data, and before the ice conditions change again.

APPENDIX A UNCREWED AIRCRAFT SYSTEMS (UAS)

A.1 Types of Small UAS to Support Ice Road Monitoring

Numerous manufacturers are building UAS for commercial use that could be used to support ice road monitoring. Those commercial-off-the-shelf UAS that are best suited for use in ice road inspection are those that can provide a real-time video feed to the operator and that records imagery collected during the UAS flight. There are three types of small UAS that are available for monitoring ice roads: multi-rotor, vertical-take-off and landing (VTOL), and fixed-wing UAS. **Multi-rotor** UAS are the most common UAS and operate by sets of paired propellers and are most similar in operation to crewed helicopters. These UAS are the easiest of the three types to operate, are typically easy to pack for transport in rigid plastic cases or backpacks, tend to be reasonably priced, and are well suited for operations when hovering over an area is a requirement. Like multi-rotor UAS, **VTOL** UAS have a small footprint for take-off and landing, are easy to transport, but these aircraft are not well-suited for hovering, as the vertical component of VTOL flights are exclusively take-off and landing during which the sensors are non-operational. VTOL UAS are good for surveying larger areas quickly, are typically more robust than multi-rotor UAS and can normally carry heavier payloads than multi-rotor aircraft but tend to be expensive in compared to multi-rotor UAS. Like other types of UAS, **fixed wing** UAS vary widely in complexity, but are fundamentally the most like airplanes of the three UAS body types. Fixed-wing UAS can be launched by hand or by dedicated mechanical launchers; those fixed-wing UAS requiring a launcher also require a larger dedicated area for take-offs. Fixed-wing aircraft can land by a number of means including belly landings, runway landings, or via the use of small clips on the end of the wings that fly into a taught, vertical rope, and slide down the rope to the ground (i.e., skyhook). Fixed wing UAS are well-suited for large area surveys, carrying heavier payloads, and when flights of long duration are needed, though all of these flight components vary by aircraft. Costs of purchasing fixed-wing UAS vary widely based on body composition, take-off and landing method, and power source, rendering these types of UAS either the most expensive or most cost effective of the small UAS depending on application. Table X highlights the differences among the three-common small UAS body types.

Table A.1 The three most common types of small UAS, primary characteristics, and sample aircraft of that type. NOTE: Images of UAS are not to scale.

Multi-Rotor UAS	Vertical Take-Off and Landing (VTOL) UAS	Fixed Wing UAS
		
Easy to operate, good for hovering operations and slower flights, easily transported, e.g., Skydio X2E	Easy to operate, good for surveying larger area and faster flights, easily transported, e.g., Wingtra Gen II	Easy to operate, good for surveying larger areas and faster flights, can carry heavier payloads, typically quiet operation, e.g., Sensefly eBee

Cost of the UAS, difficulty of operation, sensor payload, flight endurance, and operating range (temperature, wind, radio line-of-sight) are the key components to consider when selecting a UAS for ice road inspection applications. It should be noted that if UAS flights for inspections are being contracted from a UAS service provider, the choice of aircraft is irrelevant if the resulting information from the UAS service provider meets the informational needs of the ice road manager.

A.2 Sensor Payloads and UAS Data Products to Support Ice Road Monitoring

A.2.1 Sensor Payloads

UAS can carry a wide variety of sensors as payloads, some of which are quite easy and intuitive to use, and others that are very complex and require specialized training to use. The two types of sensors that are the most developed for commercial uses are electro-optical (EO) and infrared sensors. These two sensors can be used for a broad set of environmental monitoring missions to support ice road establishment and monitoring throughout the season.

The most common commercially available sensors in use are **EO sensors**, which capture still images and videos much like a digital camera. These sensors measure red-green-blue (RGB) light signals from the visible portion of the electromagnetic spectrum (Figure 9.2). EO image and video uses range from situational awareness about an area to detailed 2D and 3D mapping efforts. UAS outfitted with EO sensors are key tools for UAS support of ice roads.

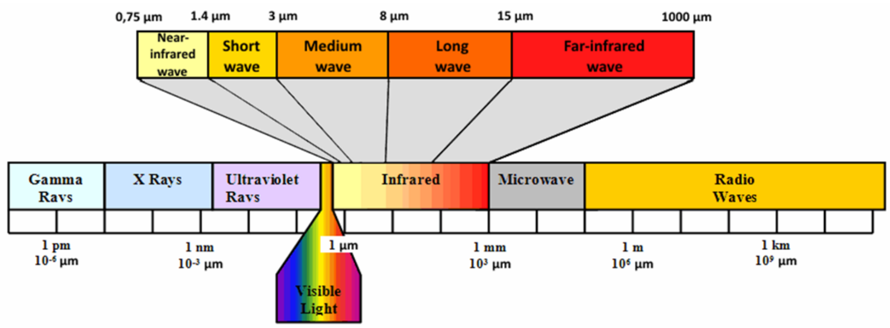

Figure A.1.The electromagnetic spectrum; opranic.com

Infrared sensors measure the portion of the electromagnetic spectrum between visible light and the microwave region (Figure 9.2). Longwave infrared sensors, also known as thermal infrared sensors, are the most common type of infrared sensors and are used in many environmental surveys as well as search and rescue efforts. Infrared sensors measure the energy emitted off an object as compared to the background environment. Infrared sensors are particularly good at identifying water or warm spots in an ice road as compared to cold background ice, or people lost or hiding in the environment. Besides EO sensors, infrared sensors have been the most extensively miniaturized in support of UAS operations.

There are other sensors that are commercially available that could be valuable for monitoring ice roads, but the data they can provide requires specialized training to collect and process. **Light detection and ranging (LIDAR)** mapping techniques are popular surveying tools for determining fine-scale differences in elevations on the ice roads that can be indicative of underlying ice or water changes or for measuring hydrodynamic processes. The complexity of data processing as well as the volume of data created by LIDAR target inspections conducted from a UAS reduce the accessibility of this sensor for operational decision-making on short time scales. LIDAR are energetically expensive and only recently effectively miniaturized for UAS and are not developed commercially for non-expert users.

Multispectral sensors provide imagery from multiple ranges of the electromagnetic spectrum as discrete bands that can be fused into an image composite or kept discrete to discern unique features about a target that would not visible otherwise. Multispectral sensors mounted on UAS have been used to examine water quality (i.e., ground water filled with silt, spring water from a creek, silty water from a glacier), and multispectral sensors on satellites have been used to successfully monitor river ice but adapting the technique to multispectral sensors mounted on a UAS is not yet common.

All of these sensors require light, or sunlight to be able to identify ice road features. An alternate sensor that can image an area at night or when it is precipitating is radar. **Synthetic aperture radar (SAR)** is a valuable tool for surveying an area at night or through a precipitation event and can be used to identify open water and wet ice. SAR sensors on UAS have not been commercialized due to the high energy requirements of the sensor, as well as the complexities and requirement for significant background knowledge to operate and to process into flight maps and reports.

A.2.2 UAS Data Products

The still images and videos collected by the UAS can be processed through specialized computer software into flight summary maps, or data products, which can be used by ice road managers for decision-making. These summary maps functionally stitch together the digital images collected by the UAS into a single map so that decision-makers do not need to examine each individual image or review minutes to hours of video collected by a UAS, but instead can get a holistic view of the entire area of interest in one map. Creating these types of summary maps is becoming easier as the image processing routines become more and more computer automated. Most of the software that is commercially available for creating summary maps for UAS-collected data only requires the UAS operator to input the UAS-collected imagery and select the type of map they want the software to create. UAS operators or analysts can then share the summary maps via electronic transfer (e.g., email, shared drives, alternative file transfer protocols) or by printing them, though printing will prevent any zoom capacity for areas of interest. The most common post-processing software to create summary maps with UAS-collected data are: DroneDeploy, Pix4D, DJI Terra, Global Mapper, and Drone2Map from ESRI.

The data collected with these light-dependent sensors (EO, infrared, LIDAR, and multispectral sensors) can be processed using specialized computer software to create maps and other useful information for ice road managers. **Digital surface models (DSM)** and orthorectified maps, or orthomosaics, are the two most popular products generated from UAS-collected data. DSMs are three dimensional maps of an area that include all natural and fabricated features and are used to calculate changes in height or topography. DSMs can be used to monitor ice road elevation at specific anomalous location or across the entire road and are used to support 3D mapping of landscape and riverbed features. The two primary sensors used for DSM generation are LIDAR and EO sensors. Using post-processing software, raw data collected from LIDAR or EO sensors is processed into a point-cloud to create a DSM. Once a DSM of an area of interest has been created, geospatial software packages can be used to create orthorectified (geometrically corrected) maps to identify or monitor environmental change of the area.

Structure from motion (SfM) is a popular processing and mapping technique used to make detailed orthorectified maps from georeferenced digital images collected with an EO sensor. The maps made from the SfM technique are most commonly used for change detection studies, or time-series information over a given area. SfM is an easier and cheaper data post-processing solution for DSM and subsequent orthorectified map creation than processes using LIDAR. SfM does not require ground control points for situating EO images in relative space, but instead relies on overlapping images of a target to develop orthorectified maps of an area. There are a number of commercially available software programs that can perform SfM processing that vary in price and complexity. One of the most powerful applications of SfM processing of UAS data over ice roads has to do with the different components of change detection. Consistent UAS flights over a given area and processed using the SfM technique may allow for ice thickness estimations across a season by looking at the elevation differences in the DSM created by the SfM software. These consistent flights and processed images of the ice roads may also provide early indicators of lateral ice movement in the spring or estimates of ice jam volumes to identify management strategies.

Artificial Intelligence, or **AI**, can be used to identify problem areas along an ice road. AI-based change detection algorithms can be trained to distinguish irregularities in an ice road image by detecting and flagging those irregularities for analysts and decision-makers to further examine. Using AI reduces the amount of time it takes to review UAS flight imagery by focusing the analyst's attention on what the AI has identified as potential problem areas. Currently, AI support of ice road feature identification is limited to post processing of the UAS-flight imagery after landing. Innovations are underway to integrate these semi-automated AI detection routines into UAS flight image processing during UAS flights, which would functionally be real-time detection of hazardous ice road components.

As with the type of commercially available UAS aircraft selection, the type of sensor and software that should be used to monitor a range of conditions or specific anomalies of ice roads depends on the type of information and information summary that will be most useful for ice road managers.

A.3 UAS Flight Requirements, Operational Considerations, and Recommendations

A.3.1 UAS Flight Requirements

There are several requirements that must be met for safe and legal UAS operation over ice roads, or potential ice road locations. These requirements are not limited to flights over ice roads, but instead are the general requirements that must be met when flying UAS for other than recreational use.

A.3.1.1 UAS Crew Qualifications and Responsibilities

UAS operations are under the authority of the Federal Aviation Administration (FAA). The UAS Team is typically composed of UAS Pilots and UAS Visual Observers, with the liability of the mission lying with the Remote Pilot in Command (PIC). The key responsibilities of the UAS Team are to provide situational awareness by collecting real-time imagery and to transmit real-time imagery or verbal assessment to ice road managers to support planning and decision-making. Costs will be dependent on the UAS service providers.

UAS Pilot UAS pilots collecting imagery of ice roads need to be able to safely operate UAS under one of two FAA regulations, 14 CFR Part 107 or 49 US Code 40102(a) and 40125 COA.

- 14 CFR Part 107 - Small Uncrewed Aircraft Systems; regulation addresses legal operation of aircraft less than 55 lbs. flown following Subpart B (Operating Rules) performing the role of Remote Pilot in Command as outlined in § 107.19; pilots flying using Part 107 certification as defined in Subpart C (Remote Pilot Certification) will be considered to have acceptable credentials for individuals representing Federal, State, Tribal or themselves as citizens; civil operator.

- Certificate of Waiver or Authorization (COA); regulation addresses legal operation of UAS performing governmental functions (Federal, State or Tribal) and statutory requirements of 49 US Code 40102(a) and 40125 for public aircraft; public operator.

UAS pilots are responsible for maintaining Flight Logs for each individual UAS flight (see Data Management guidelines below). Each log should at a minimum include date, crew, aircraft, sensors, and additional notes. UAS Pilots can operate a maximum of 8 consecutive hours and a maximum of 14 hours per day under specific direction and permission from the ice road manager (Augmented Operations as per 14 CFR Part 117). All responsibilities of the flight, including acquisition of waivers and reporting mishaps to the FAA are the responsibility of the Pilot in Command.

UAS Visual Observer (Observers) – Observers are responsible for scanning the airspace where the small UAS is operating and maintaining awareness of the position of the small UAS through direct observation. Observers must remain in communication with the pilot in command at all times and be able to coordinate collision avoidance maneuvers with the pilot in command, as necessary.

Other crew members can provide value by managing data, helping to secure a sterile cockpit (i.e., keeping the pilot safe from distractions), or by helping ice road managers interpret the information provided by the UAS. As with all field work, UAS operations should be undertaken in teams of at least two people: the PIC and the Observer.

A.3.1.2 Airspace

It is important that UAS operations over ice roads and adjacent areas are flown following the FAA requirements and guidelines for UAS. Do determine if your operational flights can be conducted without any prior approval from the FAA or if the UAS operation will require an Airspace Authorization because the area of interest is near a LAANC enabled airport, or if the operation will require a Flight Waiver to be conducted, visit B4UFLY, either at, https://b4ufly.aloft.ai/, or through the B4UFLY app on a smart phone. B4UFLY synthesizes all national airspace to provide a fast indication of regulations governing a given airspace of interest, and how to manage a UAS operation in that airspace.

A.3.1.3 Airspace Authorizations

Flights that need to take place near a LAANC enabled airport will require an Airspace Authorization request submitted through the LAANC system via one of the approved third-party LAANC portals. A detailed list of LAANC enabled airports is available from the FAA at, https://www.faa.gov/uas/programs_partnerships/data_exchange/laanc_facilities/#all. The Alaskan airports included in this list that are:

Table A.2 Airports Requiring Airspace Authorization

Anchorage (Ted Stevens International)	Deadhorse	Homer	McGrath	Talkeetna
Anchorage (Lake Hood)	Dillingham	Iliamna	Nome	Unalakleet
Anchorage (Merrill Field)	Fairbanks	Juneau	Northway	Yakutat
Barrow	Fort Yukon	Kenai	Sitka	
Bethel	Galena	Kodiak	St. Mary's	
Cordova	Gulkana	Kotzebue	Tanana	

To see the different UAS flight altitude restrictions for any of the LAANC enabled airports, visit the online UAS Facilities Maps, https://faa.maps.arcgis.com/apps/webappviewer/index.html. The UAS Facilities Maps can be used to identify unrestricted airspace nearby or to help build your LAANC Airspace Authorization request if operations within the restricted airspace around a LAANC enabled airport is required.

A.3.1.4 Part 107 Waiver Requests

For all UAS operations that fall outside of the permitted actions outlined under 14 CFR Part 107, or those that can be permitted through LAANC airspace authorizations, a Part 107 waiver will need to be requested from the FAA up to 90-days in advance of the UAS operation. The conditions under which a Part 107 Waiver would need to be requested are listed in Table A.3

Table A.3 Conditions that require a Part 107 Waiver

Fly a small UAS from a moving aircraft or a vehicle in populated areas	
Fly a small UAS at night without anti-collision lighting	
Fly a small UAS during periods of civil twilight without anti-collision lighting	
Fly a small UAS beyond your ability to clearly determine its orientation with unaided vision	
Use a visual observer without following all visual observer requirements	
Fly multiple small UAS with only one remote pilot	
Fly over a person with a small UAS which does not meet operational categories 1, 2, 3, or 4	
Fly a small UAS:	Over 100 miles per hour groundspeed
	Over 400 feet above ground level (AGL)
	With less than 3 statute miles of visibility
	Within 500 feet vertically or 2000 feet horizontally from clouds
Fly over moving vehicles with a small UAS which does not meet operational categories 1, 2, 3, or 4 or other conditions	

Part 107 Waiver applications and Airspace Authorization requests for non-LAANC airports can be submitted for review and approval by the FAA through **DroneZone**, https://faadronezone.faa.gov/#/. The DroneZone portal, operated by the FAA, requires the UAS pilot to be registered to access the waiver application system. To apply for a flight waiver through DroneZone, create an account, or log into an existing account. Select "Fly a sUAS under Part 107." Users of this service do not need to register a drone to request a waiver, but without a registered drone, a user must register with LAANC prior to each operation. In these cases, when prompted to input make/model information for the drone, users can move through the screen and keep selecting "next" to bypass the payment forms. Submit the application, including all supporting documents and attachments, through the FAA DroneZone account. Select the "Operational Waiver" option. Review and approval or disapproval of waiver requests will be completed within 90 days of submission. Processing times will vary based on the complexity of the request and the completeness of the initial application. Requesting a Part 107 Airspace Authorization and/or a Part 107 Waiver, is described in additional detail with additional links to FAA resources here, https://www.faa.gov/uas/commercial_operators/part_107_airspace_authorizations/

A.4 UAS Flight Operational Considerations

A.4.1 Land Ownership

Another legal consideration for UAS operations is the land ownership status of where the UAS is being piloted from and the land ownership status over which the UAS is flying if not immediately adjacent to the water. Rivers large enough to sustain ice roads are those that are deemed Navigable Waters under 33 CFR 329, meaning that permitted access is only to the lands and water below the ordinary high-water mark of the river. Land ownership status and maps are available from the State Departments of Natural Resources. It is important to receive permission from the landowner prior to commencing UAS operations from the property, or over the property if passing over on the way to perform ice road monitoring. These permissions can be easily obtained or not obtained at all, as such requesting permission to access the land should be made one to four weeks in advance if possible. Agreements can be obtained with landowners to cover seasonal access, and it is suggested to get the land access permissions in writing. These landownership principles also apply to ice roads and bridges over lakes.

It is important to note that UAS operations are currently illegal in U.S. National Parks, and often require special permitting when flying over other federal or state lands. Contact the representative office for those tribal, state, and federal offices well in advance of planned operations to allow for the processing of any permit applications that may be required for that area.

A.4.2 Weather

Small UAS are sensitive to weather. Each commercially available UAS has published tolerance ratings for wind, precipitation, and temperature, and most UAS are not rated for harsh winter conditions such as those encountered in Alaska and other northern tier states in the U.S. that could support ice roads. The primary risk of flying UAS outside of the environmental conditions that it is rated for is potential equipment failure that could lead to injury.

Wind can significantly impact UAS flights. Most multi-rotor UAS cannot operate in sustained winds greater than 15 miles per hour. Some UAS also have built in sensors that prevent the UAS from even taking off if the winds are too high. The most common impact of wind on drones is that flight times are greatly reduced because the UAS is using battery power to fight the wind to maintain stability, instead of flying over the target area collecting data. Some UAS can fly in winds up to 20 mph, but in those cases, most automated functions such as pre-planned flights, do not work, and data collection needs to be done with manual flights, i.e., not flying a pre-planned pattern that is uploaded to the aircraft. VTOL and fixed-wing UAS are more tolerant to wind during operation, but still have the challenges associated with launching on a windy day. It is recommended that UAS operators only fly within acceptable wind speeds as reported by the manufacturer. If winds are unexpectedly encountered during a UAS operation, it is recommended that the aircraft be landed as soon as possible so that it remains under the operator's control at all times.

Precipitation as rain or snow can damage exposed electronics on a UAS, causing malfunction or failure. Precipitation also can obscure the sensors as water droplets on the sensor lens. UAS flight operations should not be initiated during rain or snow events and should cease if rain or snow occurs. Part 107 regulations require flights to only be conducted when visibility of three miles from the ground control station can be maintained.

Extreme temperatures, both cold and hot, are known to impact UAS operations primarily through battery performance. Under the cold temperatures experienced during Alaskan winters, many UAS will not operate according to specifications, thus should not be flown due to the danger of losing control of the aircraft. Some UAS are outfitted with "smart batteries;" this is a regular feature on DJI batteries. Smart batteries prevent the UAS from taking off when temperatures are below the operating range specified by the vendor. The problem is using smart batteries in northern states during fall, winter, and spring as the operating temperature range is defined as 32-104 F/0-40 C, thus eliminating the value of the UAS to perform ice monitoring flights. Non-DJI multi-rotor aircraft (e.g., Skydio, Autel, etc.) do not use smart batteries thus have a larger operating temperature range. For example, the Skydio X2E has been demonstrated to fly well at temperatures as low as -10F/ -23 C, though they are only rated down to 23 F/ -5 C. As with wind, fixed-wing aircraft tend to be less sensitive to the impact of temperature, but not entirely. It is suggested that UAS operator know exactly what their UAS will do in different temperature conditions prior to flying at temperatures colder than the rated temperatures of the batteries and aircraft.

A.4.3 Wildlife

Flying over wildlife can be dangerous to both the animal and the UAS. Both the sound and sight of the UAS impacts wildlife, and not all wildlife responds the same to these disturbances. UAS operators should use due diligence identify the land management status over which they are flying and adhere to wildlife protection guidelines. Guidance on UAS operations from wildlife managers is not always clear, nor accessible when in remote locations, and needs to be undertaken early in the flight planning process. In cases where wildlife managers have jurisdiction over the lands or animals near or directly involved in a UAS operation, direct coordination with those resource managers needs to take place in advance of UAS operations. In many cases, specific permits are required to fly UAS over designated wildlife habitat or refuge areas and these permits require one to four weeks to process, and often have an associated processing fee. Any permits that have been acquired to support UAS flights over animals need to be included with other UAS operations documentation and be available for inspection on-site with the UAS team.

Special considerations and actions are needed if UAS are being operated over state or federal lands that are characterized as critical habitat for endangered species or migratory birds. The Endangered Species Act, the Marine Mammal Protection Act, the Bald and Golden Eagle Protection Act and the Migratory Bird Treaty Act are laws that are applicable to all operations that could impact the animals these laws have been put in place to protect. If the UAS operation is taking place in an area where any of these Acts apply, additional coordination with resource managers will need to take place in advance of UAS operations. The result of not complying with these laws is criminal prosecution.

To reduce wildlife disturbance in areas where no permitting or resource manager coordination is required, conduct UAS operations between 150 and 400 feet above the coastline/water so as not to directly impact wildlife. UAS operators need to avoid buzzing, hovering, landing, taking off, taxiing, excessive speed or sudden changes in speed or direction near wildlife on land or in the water. If animals appear to be alarmed or are responding by trying to get away from the UAS, the UAS pilot needs to increase altitude and vacate the area until the wildlife leaves the area, even if it means returning to the site a different day to perform the UAS flights. UAS operators also need to be aware that birds of prey (eagles, falcons, and hawks) as well as members of the Corvus family of birds (ravens, crows, magpies), commonly attack small UAS. If one of the types of birds becomes interested in the drone operating, it is advised to land the aircraft immediately and wait for those birds to move on. Not landing or moving the drone away from these types of birds may result in a direct attack on the drone, with the possibility for significant damage or destruction to the UAS.

A.4 Data Management

UAS are used to collect still images and video of target objects. Those images and videos, along with flight logs recorded on the aircraft, should be archived along with the visual inspection and/or ice thickness measurements each day according to data archiving and sharing protocols established by the ice road managers. Minimum archival should include preserving all summary flight reports (requirements below), manually recorded UAS Flight Logs (scanned as PDF or JPG), digitally recorded flight logs (T-logs and .DAT files), raw data files and any processed data products, such as maps. (See Table A.4)

Table A.3 Summary flight report information to support archiving of UAS flights

Information	
Date:	
Crew members (UAS pilot and UAS observer):	
Type of UAS platform (multi-rotor, fixed wing, VTOL):	
Type of sensor used:	
Location where the flights were conducted from (the ground control station; geographic location and land ownership status):	
Flight description (latitude/longitude of flight area, # of flights at location):	
Mission objectives (visual inspection support, post storm reconnaissance, etc.) :	
Type of survey or sampling method (e. g. line/strip transects, sunburst patterns, etc.):	
Altitude of flights:	
Total time flown:	
Total distances flown:	
Number of batteries used:	
Weather and other factors affecting visibility and detectability of targets (i.e.: fog/glare):	
Data file names:	
Data file archive location:	
Flight mishaps:	
Other notes:	

Quality data management is critical for being able to use UAS data of the ice roads over time. Combining quality data records with high quality data products allows for analyses of anomalous features, 3D maps of the ice surface, open water leads and specific damage from weather events. Ensuring high quality UAS data records are also important in the case of ice road accidents where review of imagery along a particular section of river can be critical to determine causes or impacts of accidents along these seasonal roadways.

A.5 Conclusion on UAS for Ice Road Support

UAS are useful tools for monitoring river and lake ice for road establishment and maintenance. UAS can be used to identify unique open water features that will influence ice during formation or stability of the ice near those features throughout the winter season. UAS can also be used to monitor ice dynamics and ice stability for ice road establishment, monitoring and maintenance before break-up. Though UAS can provide detailed images of ice roads and potential ice road routes, analyses of the observed ice road features and anomalies that can influence road safety still require trained interpretation by ice road managers.

As the impacts of climate change continue to influence weather including ice conditions, reducing uncertainty in ice road stability will continue to increase in importance. Combined with manual observations and measurements, the information that can be provided by a UAS can be used to reduce risk and uncertainty in ice road conditions across the seasons, which in turn could reduce costs and increase human safety. By combining regular ice observations that are collected from the road surface via GPR or direct thickness measurements, with UAS flights, a matrix of ice thickness as compared to UAS observations can be developed to maximize efficiency and safety for future ice roads. The primary benefit of using UAS to monitor ice roads is the reduction of risk and cost by providing the ability to safely observe the road and surrounding river without putting people on the ice or into a crewed aircraft.

APPENDIX B EXAMPLES OF MUTCD SIGNAGE

B.1 Reference Location Signs

Figure B.1 Reference Location Signs

B.2 Regulatory signs

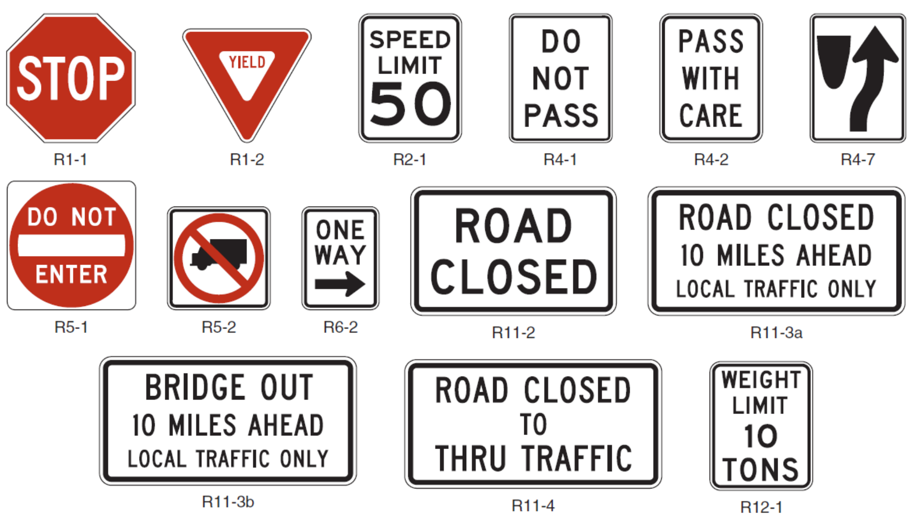

Figure B.2 Regulatory signs (Example. MUTCD (pg. 534))

B.3 Hazard Markers

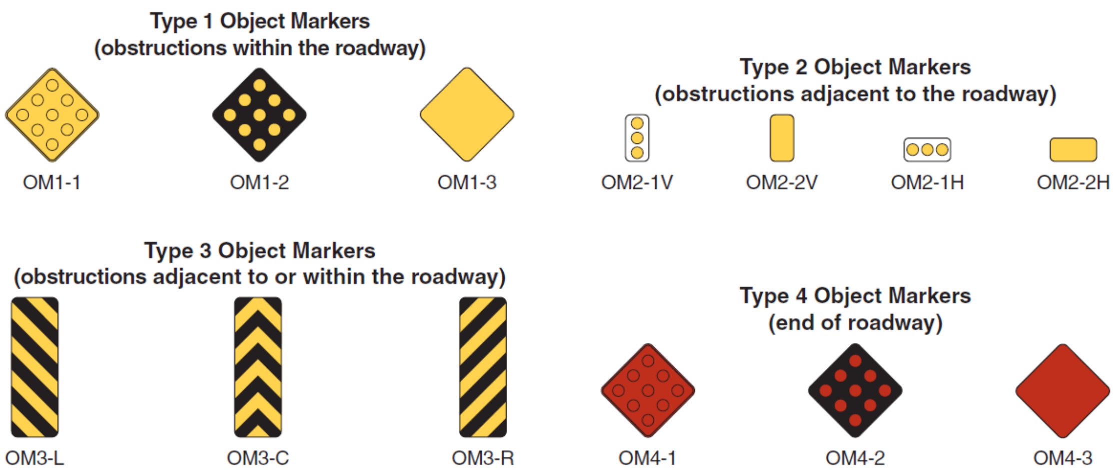

Figure B.3 Hazard Markers (Example. MUTCD pg. 536)

B.4 Closure Sign

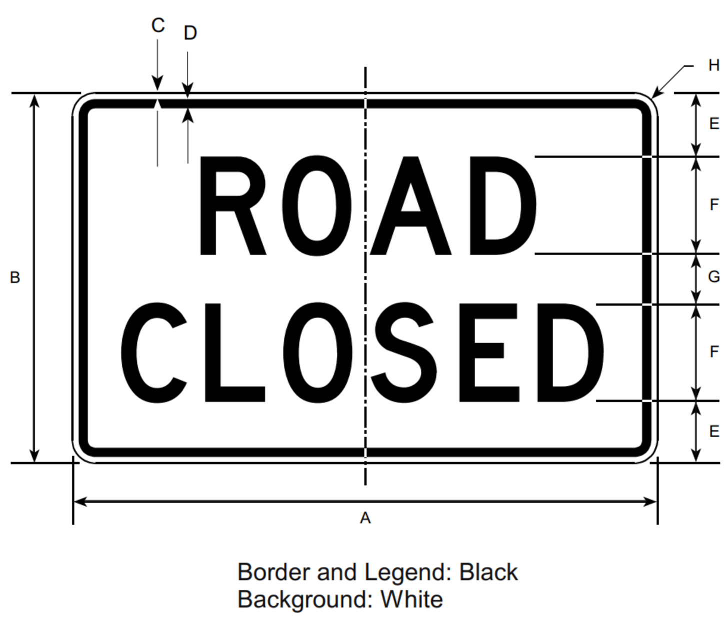

Figure B.4 Closure Sign (Example)

B.5 Supplemental Warning Plaques

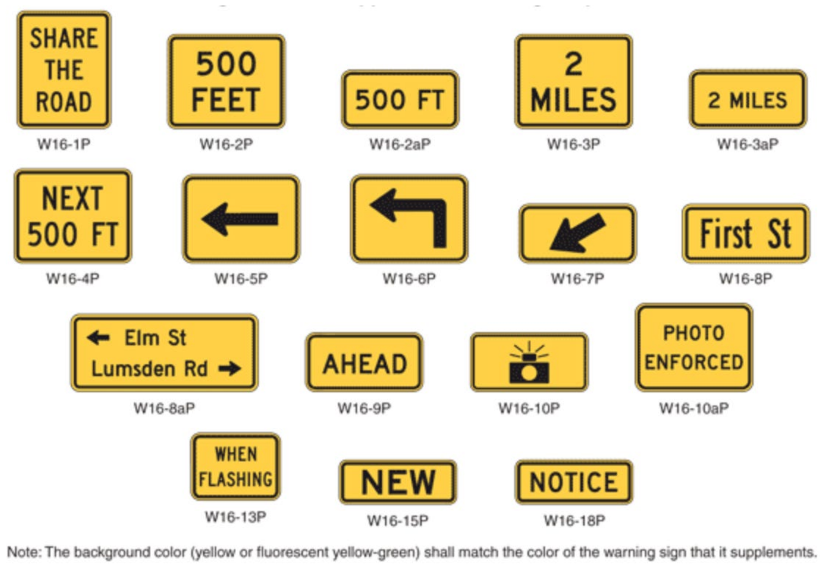

Figure B.5 Supplemental Warning Plaques

B.6 End of Roadway

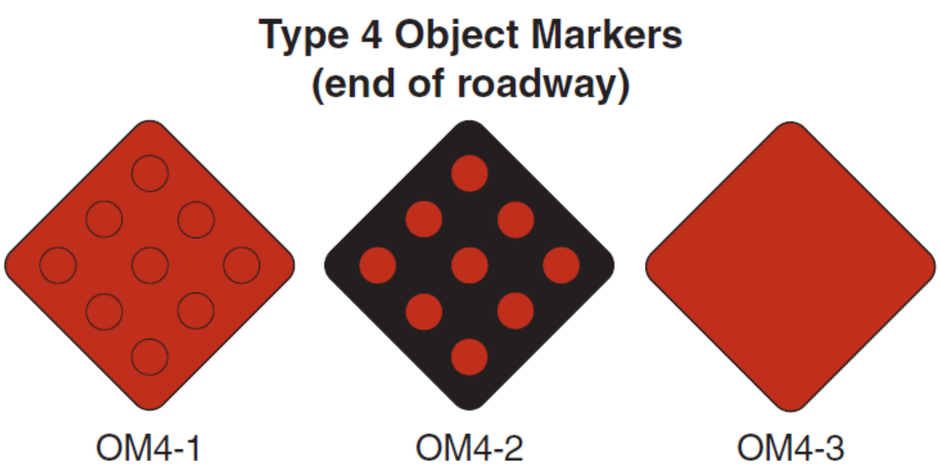

Figure B.6 End of Roadway (Example. MUTCD pg. 536)

B.6 Channelizing Devices

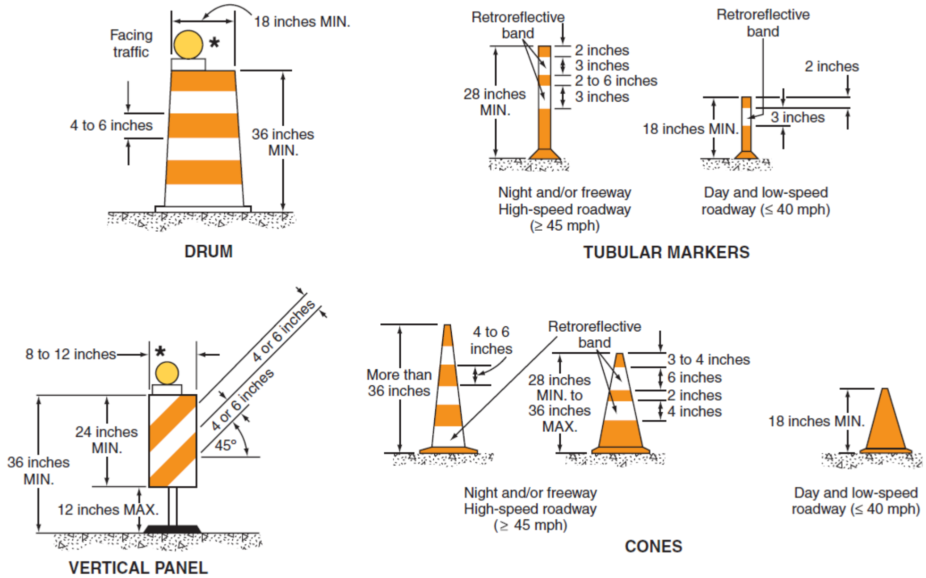

Figure B. 7 Channelizing Devices

B.7 Barricades

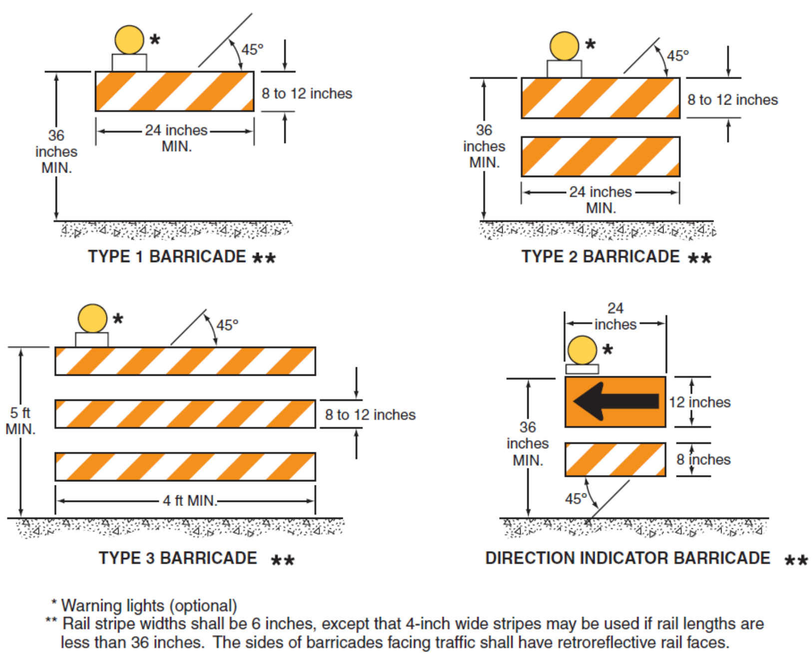

Figure B. 8 Barricades

B.8 Road Closure

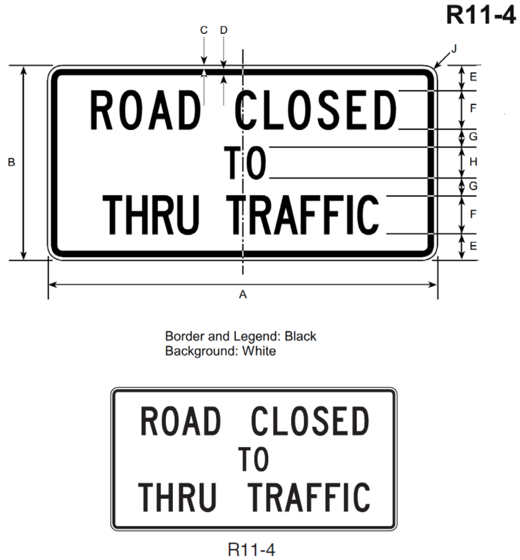

Figure B.9 Road Closure

B.9 Examples of Enhanced Conspicuity for Signs

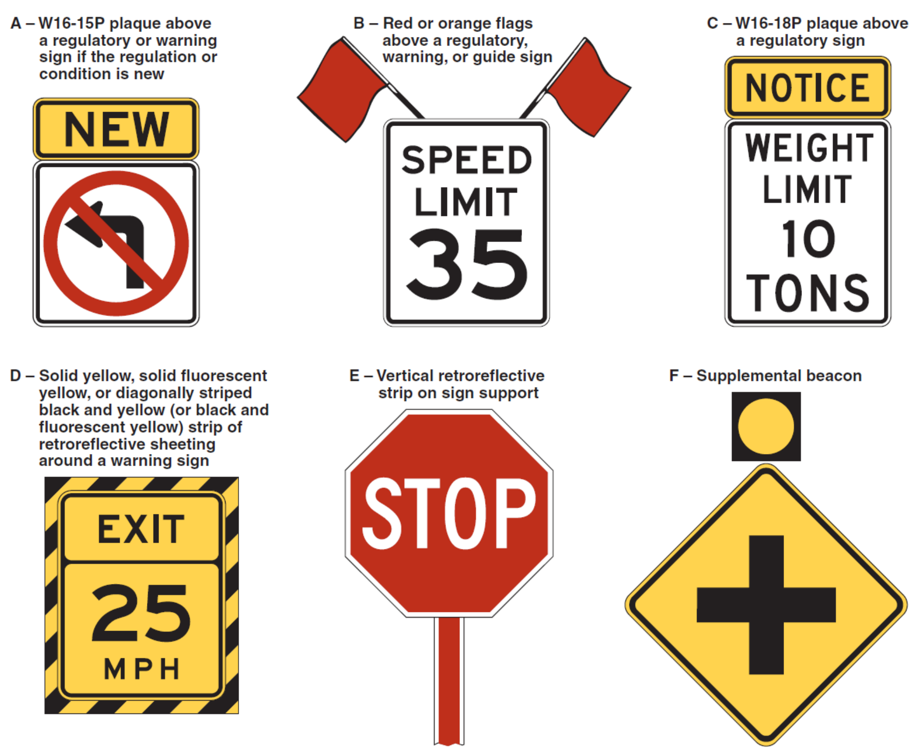

Figure B.10 Examples of Enhanced Conspicuity for Signs

APPENDIX C REFERENCES

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