Abstract. Freezing into ice is a complex phenomenon that presents challenges and risks in both individual and construction contexts. Work provides a concise overview of the key aspects surrounding freezing in ice. It highlights the dangers. For construction, the risks lie in compromised structural integrity, limited stability, and access difficulties. Calculating freezing in ice involves considering temperature, material properties, freezing time, ice formation, and expert consultation. Different types of freezing into ice are identified, and the freezing process is shown to be influenced by the type of ice, such as freshwater ice or sea ice. Dealing with freezing in ice requires strategic approaches, including following established procedures, utilizing proper equipment, seeking professional assistance, and adapting to changing conditions. Engineering construction aspects encompass planning, design, ground preparation, foundation design, construction techniques, material selection and monitoring. Understanding and managing freezing in ice is crucial for ensuring safety and successful construction projects in icy environments.

1 Introduction

Freezing into ice is a phenomenon that poses unique challenges and risks in various contexts, whether it involves individuals or construction projects. The freezing process and its implications depend on the type of ice, environmental conditions, and the specific circumstances at hand. Understanding the dynamics of freezing in ice, its effects, and how to effectively deal with it is crucial for ensuring safety, mitigating hazards, and achieving successful outcomes. Freezing in ice can have severe consequences when individuals become trapped in freezing water, leading to limited survival time. For construction, freezing into ice can compromise the structural integrity of the project, introduce instability risks, limit accessibility, and pose challenges to equipment and personnel. To address these concerns, various aspects come into play. Calculating freezing in ice involves considering factors such as temperature, material properties, freezing time, ice formation dynamics. Different types of freezing into ice exist (fig. 1), and the freezing process is influenced by the characteristics of the ice, whether it is freshwater ice or sea ice [1, 2, 3]. Dealing with freezing in ice requires a comprehensive and strategic approach. This includes following established procedures, using appropriate equipment, seeking professional assistance when necessary, and continuously monitoring and adapting to the evolving conditions. Learning from past experiences and implementing improvements are crucial to enhancing
preparedness and prevention. From an engineering construction perspective, effectively dealing with freezing in ice involves careful planning, design considerations, ground preparation, foundation design, the selection of suitable construction techniques and materials and on-going monitoring. Prioritizing safety, implementing preventive measures, and adapting construction operations to the freezing conditions are key to ensuring the successful completion of projects in icy environments [4, 5]. This work aims to explore the various aspects of freezing into ice, its dangers, the calculation methods, strategies for dealing with it, and the specific considerations from an engineering construction standpoint. By understanding the risks and implementing appropriate measures, we can navigate the challenges associated with freezing in ice and ensure the safety and success of individuals and construction projects alike.

![Example freezing in the ice](https://wiki.lesta.ru)

**Fig. 1.** Example freezing in the ice ([https://wiki.lesta.ru](https://wiki.lesta.ru))

### 2 Analysis

When some structure or vessel comes to freezing into ice, there are a few different types or scenarios that can occur. *Accidental freezing* happens when objects or materials come into contact with ice unintentionally. For example, if equipment, tools, or supplies are left on or near the ice surface and exposed to freezing temperatures, they can become trapped within the ice as it forms and expands. *Intentional embedment* refers to deliberately placing objects or materials into the ice for various purposes. This can include driving stakes, anchors, or supports into the ice to secure structures, markers, or equipment. The intention is for these objects to become frozen in place, providing stability or support. *Incorporation during Ice Formation:* During the formation of new ice, loose objects or materials on or near the ice surface can be incorporated into the ice structure. As the ice grows and freezes, these objects become trapped within the ice. This can occur if lightweight or porous materials are in contact with the ice during its initial formation. *Freezing of Waterways:* In some cases, waterways, such as rivers, can freeze over, resulting in objects becoming frozen within the
ice that forms on the surface of the water. This can happen if objects are present on the water or near its edges when freezing temperatures occur, causing them to become encased in the ice as it forms. *Ship or Vessel Freezing:* In icy conditions, ships or vessels can become frozen into the surrounding ice. This can happen if the ship is stationary or if it becomes immobilized due to ice formation and accumulation around or beneath it. Ships can be trapped in pack ice, fast ice (ice that is attached to the shoreline or seabed), or other ice formations.

When construction materials freeze into sea ice, several effects can occur depending on the specific circumstances. If construction materials, such as equipment, tools, or structures, are left on or near the sea ice, they can become frozen and *integrated into the ice.* The freezing process may cause the materials to become trapped within the ice, making them difficult to retrieve or remove. This can be problematic if the materials are needed for future construction or if their presence hinders other activities on the ice.

Freezing temperatures can cause *damage to construction materials.* For example, if concrete or mortar is used in construction, the water within the mixture can freeze and expand, leading to cracks or even structural failure. Similarly, metals and other materials may become brittle and susceptible to breakage or damage due to the extreme cold.

If construction materials are used to create structures on or near sea ice, freezing conditions can *affect their stability.* The freezing and expansion of water within the ice can exert pressure on the structures, potentially causing shifting, tilting, or collapse. This is especially true if the construction materials are not designed or anchored to withstand the forces exerted by freezing and thawing processes.

If construction materials, such as stakes, anchors, or supports, are inserted into the ice during construction, they may become frozen and *embedded within the ice.* This can create challenges if the materials need to be removed later or if they interfere with future construction activities.

The presence of construction materials within the sea ice can *affect its physical properties.* For example, the materials can introduce variations in temperature, salinity, or structure, leading to localized changes in the ice's strength, thickness, or melt rate. These alterations can have implications for the stability and integrity of the surrounding ice and any ongoing construction or activities on the ice.

Construction materials can freeze into sea ice through a process called entrapment or incorporation. In general freezing can happen in several ways:

**Accidental Freezing.** Construction materials left on or near the sea ice can accidentally freeze into it. If the materials come into contact with the ice surface or are exposed to the freezing temperatures and moisture, they can become trapped as the ice forms and expands. This can occur if construction equipment, tools, or supplies are left unattended or if construction activities are halted abruptly due to weather or logistical reasons.

**Water Seepage.** If construction materials, such as concrete or mortar, are in contact with the ice surface or are exposed to water on the ice, they can absorb moisture. When the temperature drops below freezing, the absorbed water can freeze, leading to the entrapment of the materials within the ice. This can happen if construction work involves the use of water or if there are leaks or runoff that come into contact with the materials.

**Embedment during Construction.** During construction activities on or near sea ice, materials may be intentionally inserted into the ice for various purposes. For example, stakes, anchors, or supports may be driven into the ice to secure temporary structures, signage, or safety barriers. If the materials are not removed before freezing occurs, they can freeze in place and become embedded within the ice.

**Incorporation during Ice Formation.** When new sea ice forms, it can incorporate loose construction materials present on or near the ice surface. This can happen if the materials...
are in contact with the newly forming ice, and as the ice grows and freezes, the materials become trapped within its structure. This process is more likely to occur if the materials are lightweight or have a porous or granular nature.

Determining whether the freezing of a construction, such as a ship, has occurred and become trapped in ice can involve various observations and assessments. Here are some indicators that can help determine if freezing of a construction into ice has taken place: A visual inspection of the construction and its surroundings can provide initial clues. Look for signs of ice formation, such as ice buildup on the construction's exterior, ice formations around its base, or ice formations extending from the surrounding ice towards the construction. These visual cues can suggest that the construction has become frozen in place. If a construction, such as a ship, is expected to be mobile or has been stationary for a prolonged period, a lack of movement can indicate that it has become trapped in ice. If the construction was previously able to move freely but is now unable to do so due to ice obstruction, it suggests freezing into the ice. If there are signs of ice pressure or deformation around the construction, it can indicate that freezing into ice has occurred. Pressure ridges or cracks in the ice caused by the force of freezing can affect the construction and potentially impede its movement. The presence of ice formations, such as frozen-over water channels, brine formations, or layers of ice around the construction, can indicate freezing into the ice. These formations occur as a result of the freezing process and can be observed on and around the construction. Assessing the conditions of the surrounding ice can provide further insights. If the ice is thick and extensive in the area, with indications of freezing and consolidation, it increases the likelihood that the construction has frozen into the ice.

The process and implications of freezing into ice can vary depending on the type of ice involved. Here are a few ways in which freezing into ice can depend on the type of ice:

Pack ice refers to a collection of floating ice pieces that are driven together by wind and currents. Freezing into pack ice can occur when objects or materials become trapped between ice floes or are embedded within the pack ice. The movement and dynamics of pack ice can affect the entrapment process, as well as the potential for freeing the objects.

Fast ice is ice that is attached to the shoreline or seabed, preventing its movement. Freezing into fast ice can happen when objects become frozen within the ice that is firmly connected to the land or seafloor. The attachment of the ice to the substrate can increase the likelihood of entrapment, making it more challenging to release the objects.

Brash ice consists of small fragments of ice that result from the breaking up of larger ice formations, such as pack ice. Freezing into brash ice can occur if objects or materials become embedded within the jumble of floating ice fragments. The loose and dynamic nature of brash ice can make it relatively easier to freeze into or dislodge objects compared to other types of ice.

Icebergs are large chunks of ice that have calved or broken off from glaciers or ice shelves and are floating freely in the water. Freezing into icebergs can happen if objects or materials become frozen within the iceberg itself or are caught in the crevasses and features on its surface. The stability and mobility of icebergs can influence the entrapment and release of objects.

Sea ice is formed from frozen seawater and can take on various forms, including thin sheets, floes, and pancake ice. Freezing into sea ice can occur if objects or materials become trapped within the ice layers or brine channels during the freezing process. The thickness, stability, and structural properties of the sea ice can affect the entrapment and potential for freeing the objects.

Calculating the freezing in ice involves considering the specific conditions and factors relevant to the situation:
Determine the **temperature** at which freezing occurs. The freezing point of freshwater is 0 degrees Celsius (32 degrees Fahrenheit), but seawater freezes at slightly lower temperatures due to its salt content. The exact freezing temperature will depend on the salinity and impurities in the water.

Understand the **properties of the material** or object that may freeze in the ice. Consider factors such as size, shape, thermal conductivity, and composition. These properties can affect how quickly the material freezes, how it interacts with the ice, and the potential for entrapment.

Estimate the **time** required for the material to freeze in the ice. This depends on various factors, including temperature, the thermal properties of the material, and the size or volume of the object. In general, larger or denser objects may take longer to freeze completely.

Consider the **ice formation** process and conditions. The rate of ice growth and the presence of brine channels or structural features within the ice can influence how materials freeze and become trapped. Understanding the local ice formation characteristics is important for estimating freezing.

Gather data and **observations** on ice thickness, ice structure, and the presence of existing objects frozen in the ice. This information can provide insights into the freezing process and help estimate the potential for further freezing.

**Numerical models** or simulations specific to the situation are available [9, 10]. These models can incorporate various parameters, such as temperature, material properties, and ice formation dynamics, to estimate the freezing process more accurately.

Freezing into sea ice can be dangerous for construction due to several reasons. First one is **structural integrity**. It is when sea ice is a dynamic and constantly changing environment. As the ice shifts, cracks, and expands, it can exert pressure on the construction, potentially causing structural damage or collapse. The freezing and thawing cycles of the ice can further weaken the construction's integrity over time. Another reason is **limited stability**, when sea ice is not uniformly strong or stable. Its thickness, density, and strength can vary significantly across different areas and even within a small area. If a construction becomes frozen into unstable or thin ice, it increases the risk of instability, tilting, or sinking, posing hazards to workers and equipment. Third reason is **ice movement** - sea ice can move due to wind, currents, or tidal forces. If a construction is frozen into the ice, it will move along with it. The movement of the ice can put stress on the construction, potentially leading to structural failure or detachment from its foundation. Forth reason: **access and egress challenges**: freezing into the sea ice can limit access and egress to the construction site. As the ice forms around the construction, it may obstruct pathways, entrances, or escape routes, making it difficult for workers to enter or exit the site quickly and safely in case of emergencies. Fifth reason is **isolation and rescue difficulties**: If a construction becomes frozen into sea ice in remote or harsh environments, it can result in isolation from support services and emergency response teams. Rescue and evacuation operations may become challenging or delayed due to the icy conditions, limited accessibility, and adverse weather conditions. Other reasons are **environmental hazards** and **equipment damage**: Working on or near sea ice involves exposure to extreme cold temperatures, wind chill, and other environmental hazards. Freezing into the ice increases the duration and severity of exposure, putting workers at higher risk of hypothermia, frostbite, and other cold-related injuries. Freezing into the ice can also damage construction equipment and machinery. Ice can accumulate on equipment, leading to mechanical issues, corrosion, or freezing of critical components. The movement and pressure of the ice can cause equipment to become immobilized or damaged.
When dealing with freezing in ice construction, the focus is on preventing freezing-related issues, ensuring structural integrity, and managing construction operations effectively. Following points should be taken into account:

Conduct a thorough assessment of the ice conditions and climate in the project area before initiating construction activities. Incorporate ice-related considerations into the project design phase, such as selecting appropriate construction techniques, materials, and equipment that can withstand freezing conditions. Determine the expected ice loads, ice thickness, and potential ice movement to ensure the construction design can accommodate these factors.

Prepare the construction site appropriately to mitigate freezing-related issues. This can include insulating the ground or installing thermally stable materials to minimize heat transfer between the construction and the ice.

Design the foundations of the construction to withstand ice forces and accommodate potential ice movement. Consider using pile foundations or other techniques suitable for icy conditions. Incorporate measures to prevent frost heave, which occurs when freezing temperatures cause the ground to expand and can adversely affect foundation stability. This may involve insulating the foundation or incorporating appropriate drainage systems.

Adapt construction techniques to suit the freezing conditions. For example, consider using heated enclosures or tents to protect construction areas from freezing temperatures. Implement measures to prevent equipment and materials from freezing, such as using heated storage or implementing insulation methods. Monitor ice conditions continuously during construction and adjust construction operations accordingly to ensure worker safety and structural integrity.

Select construction materials that can withstand freezing temperatures and resist damage from ice. Consider using materials with low thermal conductivity and good frost resistance. Evaluate the potential for corrosion due to contact with ice or seawater and select materials that are resistant to corrosion in these environments.

While construction freezing into ice is generally considered a challenge and potential hazard, there are a potential benefits that can arise from such a situation. One potential benefit is enhanced stability. It can be explained as if construction freezes into ice, it becomes partially or fully embedded within the ice, which can provide additional stability. The ice can act as a natural anchor, holding the construction in place and preventing movement or shifting due to external forces such as wind or waves. This enhanced stability can be advantageous in environments where the construction needs to withstand strong forces or remain in a fixed position. However, it's important to note that this benefit comes with certain caveats and considerations. The stability provided by freezing into ice depends on the strength and thickness of the ice, as well as its ability to withstand stresses and impacts. Additionally, freezing into ice can also introduce new risks and challenges, such as the potential for ice movement or the need for specialized procedures to release the construction from the ice once the freezing period is over.

3 Conclusion and discussion

Freezing into ice presents various challenges and risks, whether it involves individuals or construction in icy environments. The most dangerous aspect is when people become trapped in freezing water with limited survival time. For construction, freezing into ice can compromise structural integrity, stability, and access while posing risks to equipment and
personnel. However, there are measures to mitigate these dangers. Calculating freezing in ice requires considering temperature, material properties, freezing time, ice formation, observations, modelling. Different types of freezing into ice exist, and the freezing process depends on the type of ice, such as freshwater ice or sea ice. Dealing with freezing in ice necessitates prioritizing safety, following established procedures, using proper equipment, continuously monitoring and adapting to the situation. Learning from experiences and implementing improvements are crucial for future prevention and preparedness. From an engineering construction standpoint, planning, design, ground preparation, foundation design, appropriate construction techniques, material selection, monitoring are vital to manage freezing in ice effectively. While enhanced stability can be a potential benefit of construction freezing into ice, it must be weighed against the associated risks and challenges. Overall, understanding the dangers and implementing appropriate measures can help mitigate the risks associated with freezing into ice, ensuring the safety and success of individuals and construction projects in icy environments.

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