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# Risk study of ship navigation in ice areas

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# RISK STUDY OF SHIP NAVIGATION IN ICE AREA

By

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A research paper submitted to the World Maritime University in partial Fulfillment of the requirements for the award of the degree of

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**(MARITIME SAFETY AND ENVIRIONMENTAL MANAGEMENT)**

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**DECLARATION**

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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# ABSTRACT

Title of Research paper: **Risk Study of Ship Navigation in Ice Areas**

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The Arctic route has irreplaceable political and strategic status and is directly associated with the economic interests of countries worldwide. As the Arctic ice area has been melting, the sailing ship market in the Arctic sea ice area has continued to decrease. Yet there are few ships China has designed independently to sail in the ice area. To transit from a large shipbuilding nation to a strong shipbuilding nation, China must fully understand the navigation and design risks of ships in cold weather.

First and foremost, the ship cryogenic navigation data should be collected and studied, and the relevant risk research should be conducted. The paper primarily studied the ten major risks that ships may face while navigating at low temperatures, which include the stability loss risk, hull failure risk, failure risk of power system, failure risk of cargo system equipment, failure risk of deck equipment, failure risk of lifesaving equipment, and the failure risk fire fighting system, reduced comfort risk, failure risk of navigation equipment, and reduced risk of personnel safety.

Secondly, the 55 risk effects of the studied ships under the noted ten risks of cryogenic navigation should be complied. 55 risk effects were classified according to the severity of the failure and the frequency of occurrence criteria, the hazard identification work was completed, and the results were formed into a risk analysis matrix in accordance with the relevant standards for formal safety assessment (FSA). These risks fall into three types, i.e., unacceptable risks, reasonably practicable (ALARP) risks and negligible risks, in line with the risk analysis matrix The results reveal that unacceptable risks take up 32%; reasonable and feasible low risks take up 60%, and negligible risks take up 8% among the 55 risk effects.

Finally, the risk control measures were identified, and the antifreeze measures and deicing measures of the ship under low temperature were studied in line with the risks of the ship's cryogenic navigation. Besides, the antifreeze measures consist of antifreeze measures for ballast tanks, antifreeze measures for major and auxiliary propulsion equipment, antifreeze measures for the deck equipment, antifreeze measures for the lifesaving equipment, antifreeze measures for the navigation equipment, antifreeze measures for cabins and safe passages.

**Keywords:** Ice Navigation; Low Temperature Navigation; Formal safety assessment; Antifreeze.

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| ALARP | As low as reasonably practicable |
| DMU | Dalian Maritime University |
| FSA | Formal Safety Assessment |
| FI | Frequency Index |
| FSICR | Finnish-Swedish ice class rules |
| IACS | International Association of Classification Society |
| IMO | International Maritime Organization |
| MARPOL | The International Convention for the Prevention of Pollution From Ships |
| MEPC | Marine Environment Protection Committee |
| ODME | Oil Discharge Monitoring System |
| RI | Risk Index |
| SI | Severity Index |
| SOLAS | International Convention for Safety of Life at Sea |
| POD | Podded Propulsor |
| VLCC | Very Large Crude Carrier |
| WMU | World Maritime University |

# Chapter I

# Introduction

## 1.1 Background

As the ice melting continues to increase in the Arctic Ocean, the strategic position of the Arctic Ocean route has become progressively prominent, and the transportation volume will become lengthy. It is preliminarily estimated that by 2030, 1/4 of the trade between Asia and Europe will be transported via the Arctic ocean route, and the Arctic ocean route will be fully opened in the coming 50 years (e.g., Li, You & Wang, 2015; Zhang, Tu, & Gou,2009 ).

In October 2014, South Korea's Samsung Heavy Industries received orders from Russian shipowners for three 42,000-ton ice-breaking shuttle tankers. The total value of the contracts was nearly USD 441 million, and the price of each vessel was about USD 147 million (South Korea's Samsung Heavy Industry wins orders for 42,000 DWT-class icebreaker, 2014) . The average new shipbuilding price of the 300,000-ton very large crude carrier (abbreviated as VLCC) on the market is around USD100 million. The load capacity of the 42,000-ton ice-breaking shuttle tankers takes up merely 1 / 7 of the VLCC, yet the price of the tankers is 1.5 times that of VLCC. It is suggested that the ships in the ice area pertain to ships with high added value. In the meantime, all types of performance requirements will be very high on the ships in the ice area in comparison with those on the conventional cargo ships. Accordingly, the shipyard risk of winning such ship orders will also be very high.

For the Chinese shipbuilding industry these days, we must first understand the potential risks of sailing ships in the ice region. A truly practical ice sailing vessel can be better designed and built by studying and analyzing the above-noted risks. Damage caused by ships at low temperature may be attributed to the reasons as follows: (1) The Movement of Ice: ice block impact may cause hull damage when the ship is driving in icy waters; (2) The effect of low temperature：The effects of low temperature on the ship primarily comprise the influence on the allowable stress of the material; the influence on the viscosity of liquids, inclusive of the fuel oil and the lubricating oil, and the threat of low temperature to personnel operations.（3）Operation of other ships：Ships navigating in the ice area have the limited maneuvering ability and are easy to collide with other ships.

## 1.2 Significance of the Research

The international research on the risk of ship navigation at low temperature has been increasingly improved, and some risk response measures have progressively become the relevant norms and regulations. Some studies have been conducted on the design of ice area ships in the Chinese shipbuilding industry. Some of the shipyards have built the reinforced ships for ice zone. Yet there has been little research on the risk of ship navigation in the domestic system. Besides, most of the studies on ships in ice areas in China primarily fixate on the research and the development of hull ice-enhanced ships of conventional ships, such as oil tankers and bulk carriers. Besides, the risk studies are relatively rare.

### 1.2.1 Previous Research in China

China's research in the Arctic is disadvantaged and has a late start. The Arctic scientific research was initiated in the 1990s in China. Eight Chinese scientific expeditions have started on the exploration in the Arctic, which is supported by the support platform of "Snow Dragon". The hydrometeorological and geological conditions, the ocean, the ice and snow in the sea area associated with the Arctic channel have been observed comprehensively using the multi-disciplinary knowledge, and many valuable field data and samples have been acquired. In July 2004, China founded the China Arctic and Yellow River Station in the Spitsbergen Islands, Norway, to support China's long-term and in-depth research on multidisciplinary research and major scientific issues in the Arctic region (Arctic scientific investigation, 2018) .

The studies on the risk of ship's low-temperature navigation have been rare in China. Most of the research and design of low-temperature navigational vessels in China merely apply to the winter ice temperature and to the thin ice layer appearing on the sea surface in the Gulf of Bohai because China is not adjacent to the Arctic Circle. There is still much room for the systematic study on the risks of different systems and regions in ship navigation at low temperatures.

### 1.2.2 Current Status of International Research

Some countries and organizations have raised the ice grade requirements on the ships sailing in the ice area, and ships should have sufficient operational capacity in the ice area. Thus, there are now various ice grade requirements around the world on ships in ice area. For instance, the Finnish-Swedish ice class rules (abbreviated as FSICR), the International Association of Classification Societies'（abbreviated as IACS） polar ice scale specification, and the specification on various classification societies, etc. The FSICR, which appeared in 1830s, has now served as the standard for ships entering the North Baltic Sea in winter. In this specification, ice grades fall into IAS, IA, IB and IC, class II and class III. The specific ice grades of ship functions are listed in the following Table1.1.

**Table 1.1 Ice Class Category by FSICR**

| Ice Class | Description |
|---|---|
| IA Super | Ships can travel at a speed of not less than 5 nodes on the floes covered with floating ice.（The maximum thickness of floating ice is 1 meters, and the thickness of crushed ice is not less than 0.1 meters.） |
| IA | Ships can travel at a speed of not less than 5 nodes on the floes covered with floating ice.（The maximum thickness of ice floes is 1 meters, and there is no dense ice.） |
| IB | Ships can travel at a speed of not less than 5 nodes on the floes covered with floating ice.（The maximum thickness of ice floes is 0.8 meters, and there is no dense ice.） |
| IC | Ships can travel at a speed of not less than 5 nodes on the floes covered with floating ice.（The maximum thickness of ice floes is 0.6 meters, and there is no dense ice.） |
| II | It can travel on its own thruster in areas with little ice floe. |
| III | A ship that does not belong to the above ice level |

(Source：Finnish-Swedish ice class rules)

In December 2002, the International Maritime Organization (IMO) issued the "IMO Guidelines for Ship Operating in Arctic Ice Covered waters" in the way of the MSC/Circ.1056-MEPC/Circ.399 letter, which was approved on the 48th Session of the Marine Environment Protection Committee (MEPC 48) and the 76th Session of the Maritime Safety Committee (MSC 76)(Guidelines for Ships Operating in Arctic Ice-covered Waters, 2002, p.1) The aim of these guidelines is to guide the ships engaged in operations in Arctic Ocean waters to resist the risks of ice and cold environment, such as ship construction, equipment allocation, and operational requirements.

IMO started to formulate the mandatory rules for the operation of ships in polar waters from MSC 86 in 2009. In November 21, 2014, IMO passed the International Code for Ships Operating in Polar Waters at the ninety-fourth session of the Maritime Safety Committee (MSC94). (The International Code for Ships Operating in Polar Waters, 2014, p.1) The rule is virtually an independent document with no coercive effect. Yet IMO makes it the mandatory rules by adopting the way of amending the SOLAS and MAPPOL conventions, and making an explicit reference to the Polar Code. The Polar Code will take effect on the newly built polar navigation ships after January 1, 2017 and take effect on the existing polar ships that have changed their certificates after January 1, 2018.

## 1.3 The Main Work of the Paper

This research focuses on the risk of shipbuilding structure and equipment caused by low temperature during the navigation of ships in the ice area. Relevant studies on hazard identification were conducted to find some risk countermeasures. This research will contribute to the understanding of the risk of ship navigation in ice area for domestic ship designers.

# ChapterII

# Study on the Ship's Cryogenic Navigation Risk

Ships sailing in a low-temperature environment are primarily exposed to the risk of multiple forms of ice. The effect of ice is formed by the condensation of rain, snow, and moisture on the hull, as well as the effect of ice on the sea surface. It is suggested by collecting and studying the relevant data that ships under low temperature may be subject to the possible risks in low temperature environment, which are primarily manifested in the following ten aspects.

## 2.1 Effect on Stability

Low temperatures can cause condensation of water vapour to ice, and icing can lead to additional weight on the hull, which will cause the loss of freeboard and buoyancy. Ice on masts, decks and cargo equipment, and superstructure may raise the center of gravity of the ship. Ships may even experience an asymmetric ice load, which will increase the roll moment and make the vessel excessively roll. It poses a risk to the personnel working on board and even to the ship itself. Besides, the deicing of ships is complex, time consuming and dangerous work.

Freshwater ice originates from fog, rain or snow, while the seawater ice is formed generally when the air temperature is below minus 2 °C and there are strong winds. When the deck is frozen, people should be careful when moving and working on the ship. It is noteworthy that the ice may be formed on the outer surface of the ship, or in some of the internal space of the ship. Sea wave droplets on deck can usually be reduced by decreasing the speed and changing the course of the ship. Also, the excessive accumulation of ice should be prevented, and the relevant risks should be avoided.

## 2.2 Effects on the Hull

### 2.2.1 Material Selection

In ships sailing in the environments at low temperature, the hull structure usually requires the selection of hull steel in accordance with the design service temperature. The risk of breaking the structure under small loads will increase if the material is designed to be brittle at the service temperature, and even if there are minor defects, such as welding defects. This danger manifests itself as: The toughness of carbon steel decreases with the decrease of the temperature, resulting in brittle fracture without deformation. To avoid the occurrence of the above brittle fracture, it is necessary to perform the toughness test of the corresponding hull material. The detailed requirements for such tests are usually found in the codes of each classification society (Kurniawan, 2015).

### 2.2.2 The Structure and Layout of the Bow

In the ice area, the ship's bow is the first point to contact the ice, so the ice design should be considered more. For instance, the transition between the stem post and the shell plate should be as smooth as possible, and the non-destructive testing is performed on the joint to further increase the anti-icing capability. Merchant ships may need to balance the performance of ships in open water navigation and ice voyages. For instance, the bulb bow is installed to reduce the wave resistance. Yet the maneuverability is poor and easy to damage when operating in the ice area.

In the FSICR, the stem post reinforcement is required to extend from the flat plate keel to 0.75m above the loading waterline. This is because the entire stem post area will also encounter ice load when the ship sails on the ice ridge, and even if there is icebreaker assistance. When the ribs in the stem post area are not perpendicular to the shell plate, some tripping brackets are also required to withstand higher impact forces. The structure of the stem area should be properly strengthened in line with the operating requirements of the sailing ice area. It is advisable to have a bollard fitted to the towline on the deck so that the icebreaker can tow in the course of rescue.

### 2.2.3 Ballast Tanks

At moderately low temperatures, the problem the ballast tanks may be subject to is not the formation of ice on the surface of the ballast water, but the formation of ice in the ballast tank air pipe; During the operation of the ballast water, the risk of damage to the internal structure and accessories caused by the falling of ice suspended in the tank are noteworthy.

A heating system is to be provided in the ballast tanks above the water line to prevent the formation of ice from the ballast water and cause damage to the deck and the side shell when the ship is sailing at low temperatures for a long time. For large oil tankers or ships with large ballast tanks, the risk of freezing ballast water will be reduced. Yet heating systems may be provided on the waterline in small tanks or other ballast tanks that are likely to be frozen. The height of ballast water loaded in ballast tanks must be considered. The volume of water produced was changed when the ballast water in the tank is fully frozen in order to avoid damage to the hull structure caused by the increase in volume when water forms ice.

Given that the seawater does not fall to the same temperature as air does, the ballast temperature below the waterline will not fall below -5°C. Accordingly, ballast tanks below the water line do not provide a heating system and can also satisfy the winter operations, and generally do not form ice inside the piping system.

### 2.2.4 Stern Structure and Rudder

When cruising in an ice zone, the tail also bears the ice load (Xu, 2002). The rudder is especially susceptible to ice strikes at the tail. Under the large ice load, the rudder rake is required to be reinforced with additional structures. The rudder is both a machine and a hull structure as it needs to meet both of these design requirements.

The trim serves as an effective means to reduce such dangers in ships, so that the susceptible hull area is not exposed on the ice. Yet this may cause the rudder stock and the steering gear to yield the additional torque due to the ice impact force. The scale on the rudder angle indicator is noteworthy when the ship is sailing towards the stern. If the angle is offset, the ship should be stopped promptly and then reversed after moving to the bow.

Two major operational modes should be determined for ships sailing in ice area, i.e. intact ice and crushing ice. Because the smaller ice is easier to move, the force of the intact ice on the rudder is usually greater than that of the crushed ice. When the ship is sailing on the edge of the channel and ice ridge, it will yield significant ice load and can serve as intact ice. The ice loads must also be considered in full load and ballast conditions. The rudder horn may also face the impact of ice when turning.

### 2.2.5 Exterior Coating of the Hull

Ice will have a large frictional effect on the shell plate of the ship sailing in the ice area. Thus, a wear-resistant epoxy coating suitable for navigation in the ice area should be employed in the shell plate area of the ship. Yet the abrasion-resistant epoxy paints are difficult to adhere well to the shell plate, and minute cracks will be produced in the coating if the shell plate is a large non-stiffened plate frame. The entire coating system will fail after a period of time, so the greater the stiffness of the plate frame for the coating, the better it will be.

### 2.2.6 Hull Attachments

Most ships will generally have bilge keels. Yet the bilge keel of a sailing ship in the ice area may be damaged by ice, and the structure connected to the major hull may be damaged under the damage of the bilge keel. To limit the damage caused by the partial loss of the bilge keel, it is optimal to design the bilge keel into several separate box configurations. Also, it is better not to install the keel in the front 1/3 of the ship's length. Likewise, the fin stabilizer will be particularly susceptible to ice damage. When the ships are sailing in ice areas, they are generally limited by ice. As most ships are sailing at low speeds, the use of fin stabilizers is not very obvious.

## 2.3 The Effect of Low Temperature on Engine Room

To maintain the safety of the ship and the effective operation of the propulsion and auxiliary systems when the ship enters a cold climate area, the main engine, transmission device, shaft and propeller of ships should also be considered in line with the possible service conditions in the cold areas they serve.

### 2.3.1 Main Propulsion System

The ability to sail in the ice region depends to a large extent on the ice-breaking capacity of the ship. This is primarily dependent on the power of the main engine. Thus, there are specific requirements on the main engine power in the classification requirements of the classification society (Zhang, 2012) . For instance, the Finnish-Swedish ice class rules have a minimum power requirement on ships sailing in the Baltic Sea. The ice-breaker has a large power and displacement ratio, which is to overcome the frictional resistance of ice to meet the ship's need to break ice and move in the ice. Normally, the joint determination of ice area navigation and open water speeds are the primary driving force of non-icebreakers.

### 2.3.2 Impact on Cooling Water System

When a ship sails in an ice zone, the blockage of the seawater cooling inlet is easy to cause, which will cause an accident in the absence of cooling water in the ship's main engine or generator. These accidents may lead to the failure of the entire ship's power, or lead to the stranding accidents. Accordingly, some deicing measures must be provided for the sea chest. For instance, a filter can be installed at the suction port, and the filter screen can serve as a filter to prevent ice blockage. A proper heating system can also be arranged at the suction port of the cooling system. The heating system of the sea chest should be inspected from time to time to confirm that it is in good working condition, and it is necessary to ensure that the heating system can run continuously when the ship is sailing in the ice-prone water.

Ships sailing at low temperatures will cause damage to the main engine, when the hull is severely over-cooled. The number of chillers in the operation of the main engine should be increased, the cooling temperature should be raised, the load of the air cooler should be adjusted, and the exhaust gas temperature should be monitored to ensure that it is always within the limits. The correct cooling water temperature should be used and all valves and pumps should be checked to ensure that the cooling system is in ice service before the ship enters the ice area when a recirculating cooling system is installed on the ship.

### 2.3.3 Propeller

The general advantage of a fixed pitch propeller is that the propeller is simple and strong, whereas it is difficult to make a paddle that meets the requirements of the ice zone. The use of controllable pitch propeller helps maintain a constant engine load; yet the disadvantage is that the pitch will decrease at low speeds, which increases the time for the ship to resume sailing in the ice ridge. The use of all-direction propeller and podded propulsor（POD） can increase the maneuverability and reduce the weight and size. It is now applied in plenty of Finnish icebreakers, yet it is expensive.

It has been proved practically that the propeller with independent blades is more suitable for the ships in the ice area in comparison with the propeller with integral casting. This is because there may be cases in some damage accidents where only a single blade is damaged while the other blades are still operational. Another benefit of this type of propeller design is that a single damaged blade can be replaced by the trim of the vessel without the ship entering the dock for repairs.

In all ballast conditions during the ship sailing, the propeller should be able to be fully immersed under ice. The immersion of the propeller at this time suggests that when there is a minimum tailing and sufficient draft, the distance from the top of the propeller blade to the waterline is greater than the thickness of the ice layer. Yet this may limit the size of the propeller diameter, which results in the design of a double propeller arrangement.

### 2.3.4 Bow Thruster

If equipped with bow thrusters, ships sailing at low temperature should avoid using under severe ice conditions because ice may cover the thruster's louvers. Otherwise the water will be prevented from entering the bow thruster system. Additionally, the all-direction propeller unit can be configured to replace the bow thruster as it can be retracted in the main hull while sailing in the ice zone and the shell plate can remain smooth after retraction.

### 2.3.5 Generator

Ships sailing at low temperatures should ensure that generators and emergency generators and their auxiliary equipment can work normally under the extreme cold conditions. Given the aim of normal operation, an additional heating unit can be provided to protect the coils at extreme cold temperatures from freezing. The emergency generator cylinder liner should be equipped with an electric heater with a temperature regulation function, and it should be ensured that the generator can transmit the load promptly. Also, the additional space heating must be provided in the emergency generator room to ensure that cool air from the ventilation system reaches a certain temperature when entering the generator room.

Additionally, the electric heating methods are used in many anti-icing measures for ice navigation. This part of electricity should be considered when the capacity of the generator is calculated, so as to avoid the shortage of generator capacity.

### 2.3.6 Cable

Cables outside the living area and engine room should ensure that the cable material is not damaged by cold temperatures when they are exposed to cold air. For this purpose, the cable may require the use of a special material housing or covered insulation. For cables on open decks, it may be necessary to install them in galvanized or glass-steel sealed terminal boxes with a drain function. Besides, the distributing box and distribution board located outside of the engine room and living area may require a space heater.

### 2.3.7 Compressed Air System

If the ice is formed in a common air system, ships sailing at low temperatures may have problems. Air supply equipment onboard can be problematic. It is advisable that all air systems be equipped with dryers.

### 2.3.8 Engine Room Ventilation System

Vessels sailing at low temperatures may consider stopping all ventilation equipment except the main engine room ventilators to maintain a reasonable design temperature of the cabin. To maintain the normal operation of the boilers, main engines and auxiliary engines, ventilation should be provided to maintain air flow when these devices cannot be provided with independent ventilation ducts.

Yet it should be ensured that the vents of the main unit ventilation system are not directly blown onto the fuel lines and the heavy fuel delivery systems. Also, the pneumatic and manual vent covers should be inspected frequently to ensure they are operating properly to prevent freezing or jamming ( Tang, 2014) .

### 2.3.9 Emergency Batteries and Battery Compartments

The emergency battery of communication equipment should be properly protected to ensure that it is not affected by the extremely low temperatures. Batteries generally do not freeze at low temperatures, but they can be covered with a plastic film to prevent getting frozen.

### 2.3.10 Fresh Water Tanks and Distilled Water Tanks

In ships sailing at low temperatures, the water in the gauge glass of these tanks should be drained as far as possible when there is no water in the fresh water tanks and the distilled water tanks. All lines in the storage tank should be completely drained if you do not use evaporation equipment. The temperature of the water in the storage compartment should be monitored, and the water entering the storage compartment should be maintained at a suitable temperature. The supply line from the fresh water tank to the booster pump is generally easy to freeze, and precautions should be taken according to its location.

### 2.3.11 Lubricating Oil

Ships sailing at low temperatures should be determined to use only oil and grease meeting the expected temperature. Diesel can be mixed with kerosene to decrease the melting point, as listed in Table 2.1.

**Table 2.1: The melting point of diesel and kerosene**

| Diesel and kerosene ratio | Melting point reduced temperature (°C) |
|---|---|
| 3：7 | 23 |
| 4：6 | 18 |
| 5：5 | 14 |

(Source：Diesel fuel melting point characteristics)

It is noteworthy that the increase of kerosene ratio will lead to the decrease of the lubricity of the mixture, and the machine may need more frequent inspection and maintenance. Besides, the flash point of the final mixture should meet the requirements of the IMO rules (Imai, & Okamoto, 2010).

## 2.4 Impact of Low Temperature on Cargo System

Before entering the cold area, the valve ports of all cargo systems and other auxiliary systems must be inspected to determine that there is no water in the driving gear box and that there is an excellent lubrication. If there is a small amount of water in the gear box and bonnet, it will be frozen with the fall of the temperature, which will adversely impact the valve body, and in extreme cases it will make the valve freeze or even fail to open.

### 2.4.1 Deck Piping

Deck piping can be affected by low temperatures, and such problems on oil tankers can be especially serious. The low temperature will cause a certain temperature difference between the air and the cargo because there are a considerable number of deck lines on the tanker, which will cause thermal expansion of the loading line. This deformation will be generally smaller in the longitudinal direction than the deformation caused by the sagging and hogging in the ship. Thus, the longitudinal pipeline generally is not required to consider any special design. Yet the design of the fixed support of the transverse deck pipeline should consider the effect of the expansion of the pipeline caused by the temperature difference.

### 2.4.2 PV Valves

The entire PV valve should be comprehensively inspected before the ship enters the cold area. To avoid the accumulation and growth of ice, Canopy protection or steam heating measures can be used on the line valve. At extremely low temperatures, the canvas cover is more effective than the steam heating protection, yet the use of a canvas cover should ensure that it does not interfere with the effective operation of the PV valve. Quick acting valve base surface enables antifreeze paint to not get frozen in the closed position, which can effectively prevent the formation of ice film.

### 2.4.3 Vacuum Circuit Breakers

The vacuum circuit breaker of the PV valve should be filled with antifreeze liquid according to the instructions of the manufacturer before the ship enters the freezing temperature. Also, the concentration control of the glycol in the circuit breaker is crucial. When the concentration is too high, it may fail. To ensure that the circuit breaker remains in proper working condition, the concentration of antifreeze should be regularly checked. Once out of the cold navigation zone, the liquid density in the vacuum circuit breaker should be readjusted to the concentration required for operation at normal air temperature conditions.

### 2.4.4 Inert Gas Discharge Columns

The inert gas discharge column and inert gas line should drain all liquid before the vessel arrives in port. To ensure there is no ice on the fire protection network, fire network should be inspected before loading and unloading cargo. Grease and canvas cover are applied for protection if there are automatic and manual valves on the injection line of inert gas and oil tank. The pipe diameter of the general inert gas discharge column should not be less than 50mm.

### 2.4.5 Cargo Pump

To avoid the ice removal before unloading and prevent the delay in loading and unloading, the engine and bearing shall be protected by canvas cover if a deep well pump is installed on the deck； Submerged hydraulic pump system, hydraulic oil should be able to work below -25 ℃； When the vacuum system is employed to strip the system, the pump and the water supply tank should be protected to prevent the freezing. Anti-freeze ingredients can be added to the water to ensure the safety of operation according to the manufacturer's recommendation. The freeze-thaw ingredients can be added to the water to ensure safe operation according to the manufacturer's recommendation.

### 2.4.6 Cleaning System

The water in the seawater washing line should be drained and separated from the drive system. Check the branch pipes of the cleaning system to minimize the amount of residual water in the piping if the cargo compartment needs to be cleaned in a cold area.

### 2.4.7 Heating Coils in Cargo Holds

Ships sailing at low temperatures should be drained and air dried inside the pipeline if they are not using heating coils. The steam line should be closed to avoid the occurrence of blockages, and it is best to be isolated from the main line.

### 2.4.8 Pump Room

Ships sailing at low temperatures should minimize the influence of temperature on the pump room. The port of the pump room should be kept as closed as possible to ensure that the temperature in the pump room is minimized by the ambient temperature. Steam lines in pump rooms should be drained, which include those connected to heaters. If a pump room heater is fitted, it should remain on constantly. If there are heaters on different levels of the platform, use at least one on each platform, which help maintain a suitable temperature in the pump room.

### 2.4.9 Oil Discharge Monitoring System (ODME)

ODME's freshwater supply system and pumps should be drained together in ships sailing at low temperatures. Because the system is susceptible to failure or damage in cold climates, special care should be taken when disconnecting and draining the ODME.

## 2.5 Effect on Deck Equipment

All deck equipment should be considered to maintain operational capacity under extreme cold weather conditions and provide appropriate deicing measures and corresponding protection.

### 2.5.1 Hydraulic Equipment

The operating temperature range of the hydraulic oil should be highlighted by ships sailing at low temperatures, hydraulic equipment on deck, such as winches and lifting equipment. The control box is protected by a canvas cover. The ship should be operated and tested before it enters the sub-zero temperature. And all equipment with heating devices should be carefully checked, such as heating equipment in the crane cab. For a hydraulic drive system, when the ambient temperature is below 0 °C, the system should be continuously cycled to ensure that the hydraulic fluid remains at operating temperature.

### 2.5.2 Mooring Line

Ice may be formed in unprotected mooring lines and may damage the fibers of the cable at low temperatures. Accordingly, the mooring line is protected by a canvas cover to prevent ice from forming inside the mooring line before use.

### 2.5.3 Mooring Arrangement

When the ship is sailing at low temperatures, the mooring winches and windlass on the ship in the bow area are particularly easy to freeze. Windlasses and winches can cause severe ice accumulation as they are exposed. Before reaching the port, windlass and winch should be ensured to be operable, which may require additional time to clear the accumulated ice.

### 2.5.4 Deck Scupper

Ships sailing at low temperature shall employ the anti-freezing measures for the deck scupper to prevent it from being covered by ice and ensure cooperation with the hole plug.

### 2.5.5 Other Equipment on the Deck

The motor employed to lift the gangway should provide adequate protection against ice accumulation. Also, some small deck fittings may have ice and snow accumulated, and antifreeze and deicing measures should be provided.

## 2.6 Effect of Low Temperature on Lifesaving Equipment

### 2.6.1 Life Raft

All life rafts provided by ships at low temperatures should be ensured to operate safely under anticipated environmental conditions. Snow and ice accumulated on life rafts and landing equipment should be removed frequently to keep them available.

### 2.6.2 Lifeboats and Rescue Boats

#### *2.6.2.1 Hull and Release Device*

Ships sailing at low temperatures shall employ the deicing measures for lifeboats, rescue boats and their launching devices. Deicing hammers near the life/rescue boat should be easy to be available. The permanent damage to the equipment should be avoided particularly when a deicing hammer is used. The colloidal shell of lifeboats should be checked comprehensively before the ship enters the ice area, especially to ensure the connection between the inner and outer fibers of the gliding shell is intact. If the lifeboat is equipped with a heater, it should always be on during the navigation to ensure that it is not frozen in the closed position.

#### *2.6.2.2 Engine*

The lifeboat engine on board the ship should be ensured to be ready for use at all times, and it can be started within 2 min in the expected low temperature environment. The lifeboat engine start-up procedure may differ from the normal start-up procedures in extreme cold conditions. All personnel who may be involved in starting the engine under low temperature conditions should learn the start-up procedure to ensure that they generally understand the operation. The engine should employ the suitable diesel or kerosene to prevent wax from the fuel system. When the fuel is replaced, the fuel tank and fuel line should be thoroughly cleaned. The engine should be tested and ready for use when the new fuel is replaced.

#### *2.6.2.3 Cooling Water System*

For ships sailing at low temperatures, antifreeze fluid is applied for protection if the lifeboat cooling system is an independent self-circulation system. If the system is not independent, it should be checked regularly to ensure the system is normal.

#### *2.6.2.4 Drinking Water*

Harmless antifreeze measures should be taken for drinking water stored in lifeboats before the ship enters the ice area.

#### *2.6.2.5 Free Fall Lifeboat*

It is unsafe to drop the free fall ship in the ice area. It is necessary to use the ship's engine or other methods to perform icebreaking before proceeding.

### 2.6.3 Immersion Suits and Insulation Equipment

For ships sailing at low temperatures, the operating temperature for the design of the suit usually ranges from -1.9 ℃ to 35℃. Immersion suits should increase the low temperature insulation performance as much as possible. Insulators should also be applied at low temperatures.

### 2.6.4 Lifebuoy

It should be ensured that the equipped lifebuoy in ships sailing at low temperatures will not be frozen in the storage position and be free to move and use.

### 2.6.5 Respirator and Oxygen Treatment Equipment

When the oxygen breathing or resuscitation apparatus is employed at low temperature, the possible danger of the freezing of the gas supply valve and the expiratory valve due to the water vapor from the user is noteworthy. Additionally, the low temperature (below -4℃) may cause lung tissue frostbite in ventilator users.

### 2.6.6 Helmet

The safe use temperature range of the safety helmet provided by the ship must be marked by the manufacturer in the cap under the cold environment. The crew should select a safety helmet that matches the ambient temperature.

## 2.7 Effects of Low Temperature on Fire Fighting Systems and Equipment

Due to the accumulation of ice or snow or low temperatures, the design or layout of fire fighting systems must be easy to operate in ships sailing at low temperatures.

### 2.7.1 Detection system

The exhaust port and vacuum pressure valve of the detection system should be properly protected to prevent the formation of ice and ensure the effective operation of the fire fighting system.

### 2.7.2 Portable Fire Extinguishers and Foam Equipment

In extremely cold environments, portable fire extinguishers located in exposed areas are susceptible to freezing. The low temperature can easily make the foam fire extinguisher to fail though it is generally considered that $CO_2$ fire extinguishers can perform safe and effective operations at temperatures above -20 °C. This is because the foam mixture may not be used due to the low temperature when the foam fire extinguisher is thawed. At these extreme temperatures, the contact with any part of the fire extinguisher or exhaust gas during operation should be avoided to prevent low temperature burns on the human body.

Unprotected foam and water fire extinguishers, safe and effective operating temperatures are generally above 1°C. Yet the effective operating temperature of water and foam fire extinguishers can drop to -20°C if specific additives are used. The operator should refer to the data provided by the manufacturer of the fire extinguisher to check if the use of the fire extinguisher is limited under actual conditions.

### 2.7.3 Hoses and Nozzles

The safe operating temperature of hoses for general marine fire-fighting systems is above -20°C, and the nozzle is above -25°C. Dedicated hoses can be applied at -40 °C and marked by special signs. The vessel selects hoses and nozzles in accordance with the lowest temperatures that may be encountered during the voyage.

### 2.7.4 Pipeline

When ships sail at low temperatures, to ensure fire-fighting water and foam piping on deck are ready for use, they should be well drained and maintained. Fire hydrants and all other moving parts should be well lubricated and protected with a canvas cover to prevent them from being used immediately due to ice and snow accumulation. Storage tanks for fixed foam extinguishing systems probably need to be heated, or temporary space heaters can be considered to maintain sufficient temperature.

### 2.7.5 Fire Hose Box

Fire hose box clips, locks and chains should be kept free of ice; water mist nozzles and connections should be well lubricated and dried. All hoses should be completely drained before the storage to avoid damage caused by low temperatures and ensure that they can be used promptly.

## 2.8 The Effect of Low Temperatures on the Living Compartment and Channel

The function of the crew cabin must be complete and suitable for living in the low temperature environment. The crew work and the escape passage must also meet the requirements that can be applied in the low temperature environment.

### 2.8.1 Insulation

To meet the living requirements under low temperature conditions, heating systems should be provided in the cabin, which include the air conditioning systems and the auxiliary heating systems. To reach the design temperature of the cabins in the ice area, outside walls and ceilings of cabins shall be provided with special insulation measures, such as adding insulation layers.

### 2.8.2 Channel

The safe access to the bow can be protected by a box structure or under deck. Emergency escape routes should also take certain anti-freeze measures to ensure the safety of personnel when passing through.

### 2.8.3 Ventilation System

The ventilator of the cabin is exposed to the outdoor environment when the temperature of the outdoor environment is very low. The inner surface temperature of the ventilator may be very low through heat conduction. When the inner surface temperature is lower than the dew point temperature of the inner air, a considerable amount of condensate steam will be produced on the inner surface of the ventilator, and the ice will be formed when the water temperature is below zero.

## 2.9 The Influence of Low Temperature on Navigation Equipment

### 2.9.1 Navigation Light

The navigation light is an essential navigation device, and the side lights and mast lamp must be visible at all times during the navigation of the ship. In the ice area, the navigation light of the ship can cause ice formation due to the spray of the waves, which will pose hidden dangers to the safety during the navigation. Thus, it is also necessary to provide some methods for deicing and snow melting.

### 2.9.2 Radar and Antenna

Radar and antennas are also important equipment for navigation. Under severe weather conditions, there is also the possibility of icing, which will threaten the safety of sailing ships.

Therefore, for radar, satellite communications, and antennas, it is also necessary to use a certain amount of protection.

#### 2.9.3 The Window of the Bridge

The formation of frost and ice on the bridge window can affect the driver's eyes. In the ice area, it is particularly necessary to pay attention to the antifreeze and deicing treatment of the bridge window.

### 2.10 The Impact of Low Temperatures on Personnel

#### 2.10.1 Damage to Exposed Persons

Prior to entering the ice area, the ship should customize and provide a sufficient number of winter clothes, including polar clothing and hats, snow goggles and underwater warm equipment. In order to prevent people from being sunburned, the windows of the bridge should be equipped with a sun filter and should be equipped with a sufficient amount of sunscreen lotion, anti-cracking lipstick and protective cream before entering the ice zone.

#### 2.10.2 Train

The captain and chief engineer should participate in the training of ice sailing courses and have ice sailing experience. If conditions are met, relevant course training may be extended to ordinary seafarers.

#### 2.10.3 Crew Activities

Ships sailing at low temperatures are likely to freeze on the passageway, and personnel should be especially careful when walking on board and should keep one hand free as much as possible. There should be anti-freezing measures or anti-skid treatment on the passages, which can be treated by heating, salting or sanding.

### 2.10.4 Deck Watcher

The deck watchers in cold weather should shorten the shift time and provide appropriate shelter. In the meantime, the deck watchers should try to rest as much as possible in the living area and ensure that hot food and drinks can be supplied directly to avoid the occurrence of hypothermia symptoms.

### 2.10.5 Crew Fatigue

When the ship is sailing in the ice area and operating at the terminal, duty schedules should be properly established to ensure that all crew members have enough rest periods.

### 2.10.6 Voyage Planning

Ships traveling at a low temperature should develop a navigation plan based on ice information from reliable sources. The reliable and effective ice area information may include navigational warnings, ice distribution maps, Baltic Sea weekly ice status reports, navigation manuals, marine meteorology, etc.

## 2.11 Chapter Summary

When the ship is sailing in cold weather, there may be some requirements beyond the general open water operation, due to the need to take into account the low-temperature related navigation risks. These risks are primarily: stability loss, hull failure risk, failure risk of power system, failure risk of the cargo system, failure risk of deck equipment, failure risk of life-saving equipment, failure risk of fire-fighting system, risk reduction of comfort, and failure risk of navigation equipment, personnel safety reduces risk, etc.

# Chapter III

# Hazard Identification of Ship's Low Temperature Navigation

Chapter II of this thesis has conducted a comparatively comprehensive study of the risks of sailing ships in ice areas. According to the relevant principles in the formal safety assessment (FSA) proposed by the International Maritime Organization, a risk analysis has been carried out on the risk points already mentioned. The failure status risk matrix is listed according to failure severity and occurrence probability criteria (Guidelines for formal safety assessment (FSA) for use in the IMO rule making process, 2002).

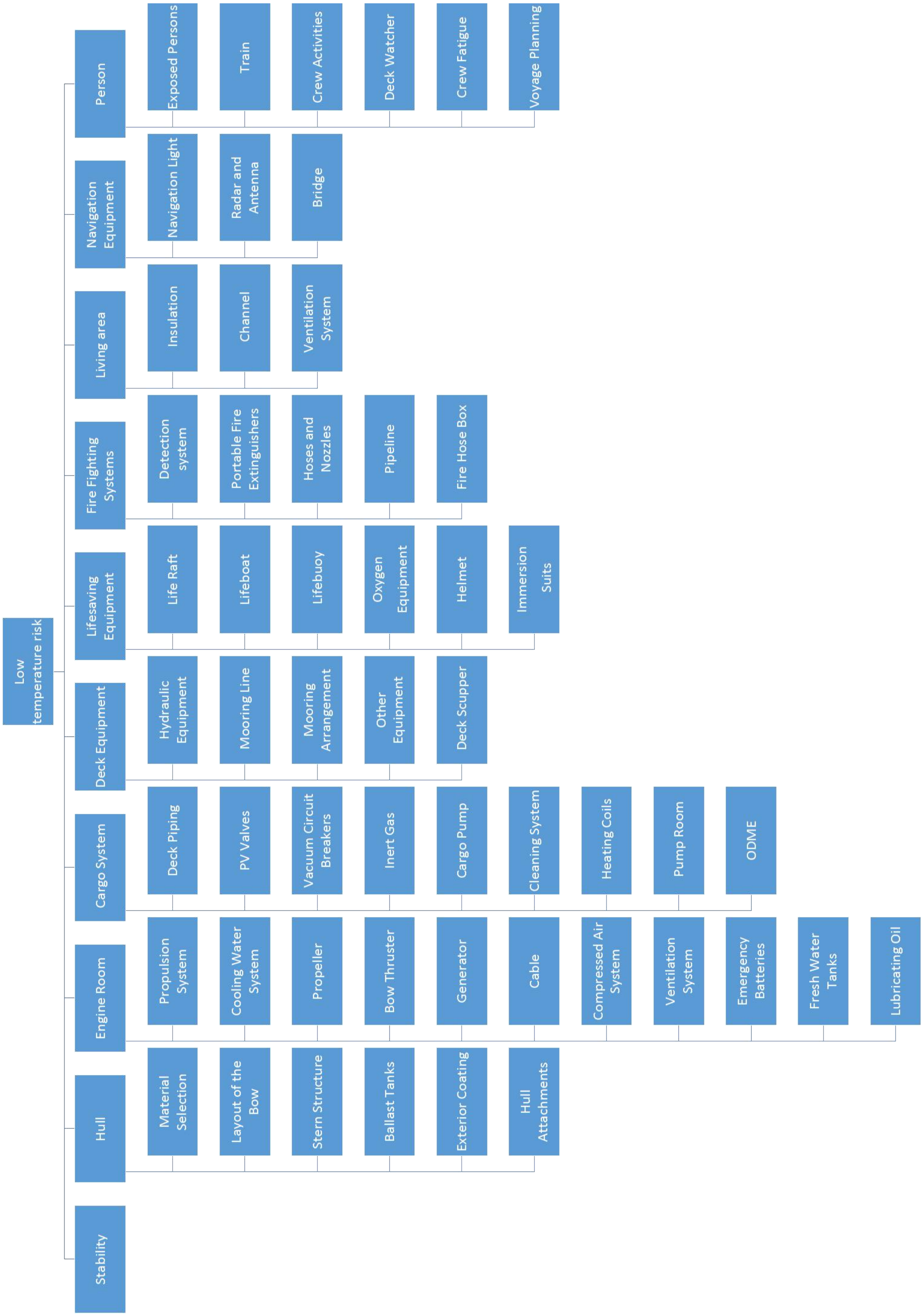
FSA is a structured and systematic analysis method. The FSA has been widely used in ship engineering design, shipping safety management, and development specifications. Through risk assessment and cost benefit assessment, all aspects of specification, design, operation, and inspection have been effectively and efficiently improved to improve safety at sea (Including human life protection, health, marine environment, etc.).

## 3.1 Scope Definition

This thesis mainly focuses on the potential risks that may threaten ships, equipment and people under low temperature conditions; risks under normal temperature conditions (e.g., stranding, collisions, mechanical accidents, and fires) are not considered.

## 3.2 Analysis

In the second chapter of this thesis, after collecting and researching relevant data, the possible risks faced by ships in low-temperature environments primarily fall into the following ten types, as shown in the following figure 3.1.


Low temperature risk
Person
Exposed Persons
Train
Crew Activities
Deck Watcher
Crew Fatigue
Voyage Planning
Navigation Equipment
Navigation Light
Radar and Antenna
Bridge
Living area
Insulation
Channel
Ventilation System
Fire Fighting Systems
Detection system
Portable Fire Extinguishers
Hoses and Nozzles
Pipeline
Fire Hose Box
Lifesaving Equipment
Life Raft
Lifeboat
Lifebuoy
Oxygen Equipment
Helmet
Immersion Suits
Deck Equipment
Hydraulic Equipment
Mooring Line
Mooring Arrangement
Other Equipment
Deck Scupper
Cargo System
Deck Piping
PV Valves
Vacuum Circuit Breakers
Inert Gas
Cargo Pump
Cleaning System
Heating Coils
Pump Room
ODME
Engine Room
Propulsion System
Cooling Water System
Propeller
Bow Thruster
Generator
Cable
Compressed Air System
Ventilation System
Emergency Batteries
Fresh Water Tanks
Lubricating Oil
Hull
Material Selection
Layout of the Bow
Stern Structure
Ballast Tanks
Exterior Coating
Hull Attachments
Stability

(Source：Drawn by the Author)

**Figure 3.1: Fault Tree**

The fault tree analyzes the potential risks of ships at low temperatures and lists 55 risk factors. The hazards are sorted in Table 3.6. IMO recommends the risk matrix method and the expert ranking method. In this thesis, the risk matrix method will be used to sort (Guidelines for formal safety assessment (FSA) for use in the IMO rule making process, 2002). Risk matrix method: Logarithmic form is used to define the frequency and severity of the accident (consequences).

$$\text{Risk} = \text{Frequency} \times \text{Consequences}$$

$$\text{Risk Index (RI)} = \text{Frequency Index (FI)} + \text{Severity Index (SI)}$$

**Table 3.2: Frequency Index**

| FREQUENCY | FI | DEFINITION | F (per ship year) |
|---|---|---|---|
| Frequent | 7 | Likely to occur once per month on one ship | 10 |
| Reasonably probable | 5 | Likely to occur once per year in a fleet of 10 ships, i.e. likely to occur a few times during the ship's life | 0.1 |
| Remote | 3 | Likely to occur once per year in a fleet of 1,000 ships, i.e. likely to occur in the total life of several similar ships | 0.001 |
| Extremely remote | 1 | Likely to occur once in the lifetime (20 years) of a world fleet of 5,000 ships. | 0.00001 |

(Source：MSC-MsEPC.2/Circ.12)

**Table 3.3: Severity Index**

| SEVERITY | SI | EFFECTS ON HUMAN SAFETY | EFFECTS ON SHIP | S (Equivalent fatalities) |
|---|---|---|---|---|
| Minor | 1 | Single or minor injuries | Local equipment | 0.01 |

| | | | | |
|---|---|---|---|---|
| | | | damage | |
| Significant | 2 | Multiple or severe injuries | Non-severe ship damage | 0.1 |
| Severe | 3 | Single fatality or multiple severe injuries | Severe damage | 1 |
| Catastrophic | 4 | Multiple fatalities | Total loss | 10 |

(Source：MSC-MEPC.2/Circ.12)

**Table: 3.4 Hazard identification worksheet**

| Risk | Stability | Material Selection | Compressed Air System | Emergency Batteries | Vacuum Circuit Breakers |
|---|---|---|---|---|---|
| Stage | All | All | Design | Design and Navigation | Navigation |
| Influence | Ship Stability | Material is broken | Air System Invalid | Lose emergency power | Vacuum Circuit Breakers can't be used |
| Reason | The additional weight caused by ice leads to buoyancy loss and the center of gravity rises. | When the temperature decreases, the toughness of the carbon steel will decrease and the steel will be brittle. | Water vapor is frozen in the compressed air system | Low temperature leads to damage to the Emergency batteries | The liquid in the vacuum circuit breakers is frozen at low temperature |
| Discovery | Drawing Approval,Crew Inspection | Drawing Approval, Surveyor's Regular Inspection | Drawing Approval, Site shipowner | Crew Inspection | Crew Inspection |
| Severity | Severe | Significant | Significant | Significant | Severe |
| Frequency | Reasonably Probable | Remote | Remote | Remote | Reasonably Probable |
| Applicable rules | Classification society requirement, | Classification society requirement | Classification society requirement | Classification society requirement | None |

| | | | | | |
|---|---|---|---|---|---|
| | IMO Res.A.1024(26) | | | | |

**Table: 3.4 Hazard identification worksheet (continued)**

| Risk | Bow Structure | Ballast Tanks | Propeller |
|---|---|---|---|
| Stage | All | All | Design and Navigation |
| Influence | Structural damage | Structural damage, Ballast piping damage | Propeller damage |
| Reason | The bow is the first to contact the ice | Air ducts and cabin icing cause structural damage | Easy to hit by ice, Material brittle |
| Discovery | Drawing Approval, Surveyor's Regular Inspection | Crew Routine Inspection, Surveyor's Regular Inspection | Drawing Approval, Surveyor's Inspection, Check after the dock |
| Severity | Severe | Significant | Severe |
| Frequency | Reasonably probable | Reasonably Probable | Reasonably probable |
| Applicable rules | Classification society requirement | Classification society requirement | None |

**Table: 3.4 Hazard identification worksheet (continued)**

| Risk | Stern Structure | Exterior Coating | Hull Attachments |
|---|---|---|---|
| Stage | All | All | All |
| Influence | Structural damage,Rudder damage | Accelerated corrosion | Keel and fin stabilizer damage |
| Reason | Easy to hit by ice. | Difficulties in construction | Attachments was damaged by ice |
| Discovery | Check after the dock, Surveyor's Regular Inspection | Paint manufacturer, Supervisor | Check after the dock, Surveyor's Regular Inspection |
| Severity | Severe | Significant | Severe |
| Frequency | Reasonably Probable | Extremely remote | Reasonably probable |

| Applicable rules | Classification society requirement | None | None |
| --- | --- | --- | --- |

**Table: 3.4 Hazard identification worksheet (continued)**

| Risk | Fresh Water | Lubricating Oil | Deck Piping | PV Valves |
| --- | --- | --- | --- | --- |
| Stage | Navigation | Navigation | Design and Navigation | Navigation |
| Influence | Fresh water can't be used | Oil failure | The deck pipe is blocked and the joint can not be sealed | The cargo hold can't be breathable |
| Reason | Pipeline freezing | oil freeze | Liquid freezing in pipeline | Water vapor in PV valve is frozen at low temperature |
| Discovery | Crew Inspection | Crew Inspection | Drawing Approval, Site shipowner,Crew Inspection | Crew Inspection |
| Severity | Significant | Significant | Severe | Severe |
| Frequency | Remote | Remote | Reasonably Probable | Reasonably Probable |
| Applicable rules | None | None | Classification society requirement | None |

**Table: 3.4 Hazard identification worksheet (continued)**

| Risk | Inert Gas Discharge Columns | Cargo Pump | Cleaning System | Heating Coils |
| --- | --- | --- | --- | --- |
| Stage | Navigation | Navigation | Navigation | Navigation |
| Influence | Inert gas can't be discharged | Cargo Pump can't be work | Clogging of the cleaning system | Heating coils blocking |
| Reason | The existence of liquid is easy to freeze | The viscosity of oil is larger at low temperature | Ice in the pump and water tank | Water vapor in Heating coils is frozen at low temperature |
| Discovery | Crew Inspection | Crew Inspection | Crew Inspection | Crew Inspection |
| Severity | Significant | Severe | Significant | Significant |
| Frequency | Reasonably | Reasonably | Reasonably | Reasonably |

| | | | | |
|---|---|---|---|---|
| | Probable | Probable | Probable | Probable |
| Applicable rules | None | None | Classification society requirement | Classification society requirement |

**Table: 3.4 Hazard identification worksheet (continued)**

| Risk | Pump Room | ODME | Hydraulic Equipment | Mooring Line |
|---|---|---|---|---|
| Stage | Navigation | Navigation | Navigation | All |
| Influence | Pipeline blockage | ODME can't be used | Hydraulic Equipment can't be used | Strength reduction of mooring line |
| Reason | low temperature | System damage caused by water freezing | The viscosity of oil is larger at low temperature | Ice crystals destroy the mooring line structure |
| Discovery | Crew Inspection | Crew Inspection | Crew Inspection | Crew Inspection |
| Severity | Significant | Significant | Severe | Significant |
| Frequency | Remote | Reasonably Probable | Reasonably Probable | Reasonably Probable |
| Applicable rules | None | None | Classification society requirement | Classification society requirement |

**Table: 3.4Hazard identification worksheet (continued)**

| Risk | Mooring Arrangement | Deck Scupper | Life Raft | Lifeboats and Rescue Boats |
|---|---|---|---|---|
| Stage | Navigation | Navigation | Navigation | Navigation |
| Influence | Inability to enter port | Deck hydrone--phrosis | Bring safety hazards to the crew | Bring safety hazards to the crew |
| Reason | Mooring equipment is unwilling to operate because of ice and snow | Ice and snow cause scupper to be unused | Life raft is frozen on deck | Unused because of low temperature |
| Discovery | Crew Inspection | Crew Inspection | Crew Inspection | Crew Inspection |
| Severity | Significant | Significant | Severe | Severe |
| Frequency | Reasonably Probable | Reasonably Probable | Reasonably Probable | Reasonably Probable |

| | | | | |
|---|---|---|---|---|
| Applicable rules | Classification society requirement | Classification society requirement | Classification society requirement | Classification society requirement |

**Table: 3.4 Hazard identification worksheet (continued)**

| Risk | Immersion Suits | Lifebuoy | Oxygen Treatment Equipment | Helmet |
|---|---|---|---|---|
| Stage | Navigation | Navigation | Navigation | Design |
| Influence | Bring safety hazards to the crew | Bring safety hazards to the crew | Bring safety hazards to the crew | Bring safety hazards to the crew |
| Reason | Thermal insulation design does not meet the requirements of low temperature | Lifebuoy is frozen on deck | The valve is frozen at low temperature | Helmet design does not meet the requirements of low temperature |
| Discovery | Drawing Approval, Crew Inspection | Crew Inspection | Crew Inspection | Crew Inspection |
| Severity | Severe | Significant | Significant | Significant |
| Frequency | Reasonably Probable | Remote | Extremely remote | Reasonably Probable |
| Applicable rules | Classification society requirement | Classification society requirement | None | None |

**Table: 3.4 Hazard identification worksheet (continued)**

| Risk | Fire system Pipeline | Hoses and Nozzles | Detection system |
|---|---|---|---|
| Stage | Navigation | Design | Navigation |
| Influence | Bring safety hazards to the crew | Bring safety hazards to the crew | Bring safety hazards to the crew |
| Reason | Pipeline plugging in fire control system | Design temperature cannot meet the temperature of the voyage | The vents and the vacuum valves are frozen |
| Discovery | Crew Inspection | Crew Inspection | Crew Inspection |

| | | | |
|---|---|---|---|
| Severity | Significant | Significant | Severe |
| Frequency | Remote | Extremely remote | Extremely remote |
| Applicable rules | Classification society requirement | Classification society requirement | Classification society requirement |

**Table: 3.4 Hazard identification worksheet (continued)**

| Risk | Portable Fire Extinguisher | Fire Hose Box | Low cabin temperature | Channel icing | Ventilation System |
|---|---|---|---|---|---|
| Stage | Navigation | Design | Design and Navigation | Design and Navigation | Design and Navigation |
| Influence | Bring safety hazards to the crew | Bring safety hazards to the crew | Bring safety hazards to the crew | Bring safety hazards to the crew | Bring safety hazards to the crew |
| Reason | Portable fire extinguishers can not be used at low temperature | The box could not be opened because of ice and snow | Lack of thermal insulation design | No ice deicing design | No antifreeze design |
| Discovery | Crew Inspection | Crew Inspection | Drawing Approval, Crew Inspection | Drawing Approval, Crew Inspection | Drawing Approval, Crew Inspection |
| Severity | Significant | Significant | Severe | Severe | Severe |
| Frequency | Reasonably Probable | Extremely remote | Reasonably Probable | Frequent | Reasonably Probable |
| Applicable rules | Classification society requirement | None | Classification society requirement | Classification society requirement | Classification society requirement |

**Table: 3.4 Hazard identification worksheet (continued)**

| Risk | Navigation Light | Radar and Antenna | The Window of the Bridge | Personnel injury | No voyage forecast |
|---|---|---|---|---|---|
| Stage | Design and Navigation | Design and Navigation | Navigation | Navigation | Navigation |
| Influence | Influence the safety of navigation | Influence the safety of navigation | Bring safety hazards to the crew | Bring safety hazards to the crew | Bring safety hazards to the crew |
| Reason | The navigation lights are covered by ice and snow | Ice and snow cause the freezing of navigation equipment | Ice and snow piling in the window of the Bridge | The crew were injured due to fatigue and unfamiliar work in the ice area. | No information about route collection before voyage |
| Discovery | Drawing Approval, Crew Inspection | Crew Inspection | Drawing Approval, Crew Inspection | Crew Inspection | Crew Inspection |
| Severity | Significant | Significant | Severe | Severe | Severe |
| Frequency | Remote | Extremely remote | Reasonably Probable | Reasonably Probable | Remote |
| Applicable rules | Classification society requirement | None | Classification society requirement | None | Classification society requirement |

(Source：Drawn by the Author)

## 3.3 Risk matrix

The failure conditions should be qualitatively ranked using the matrix in Table 3.5 since the risks associated with various failure conditions are distinct from each other, which depends on the severity and frequency level of failure conditions. The higher the level value, the greater the risk will be.

**Table:3.5 Risk Index**

| Risk Index（RI） | | | | | |
|---|---|---|---|---|---|
| FI | Frequency Index | Severity Index（SI） | | | |
| | | 1 | 2 | 3 | 4 |
| | | Minor | Significant | Severe | Catastrophic |
| 7 | Frequent | 8 | 9 | 10 | 11 |
| 4 | Reasonably probable | 5 | 6 | 7 | 8 |
| 3 | Remote | 4 | 5 | 6 | 7 |
| 1 | Extremely remote | 2 | 3 | 4 | 5 |

(Source：MSC-MEPC.2/Circ.12)

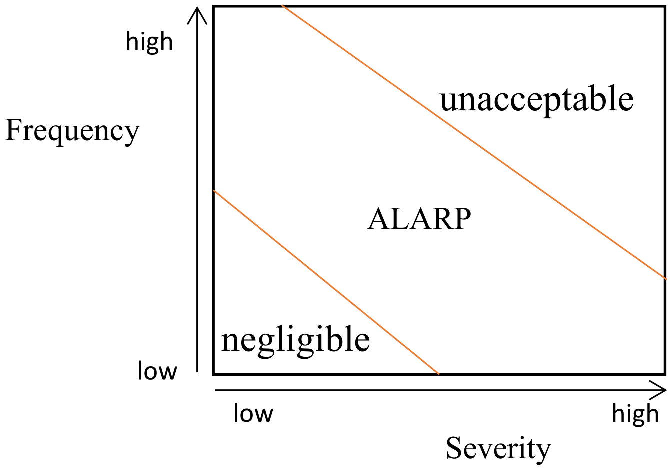
55 failures were identified in total by using the hazard identification worksheet. If their effects were judged to be "severe" or "catastrophic," they were marked as dangerous. Otherwise, they were typed as "significant" or "minor" failure condition. To easily rank these failure conditions, the severity of the failure effects and the frequency of occurrence should be evaluated. The hazard identification worksheet qualitatively evaluates each failure condition according to the definition in Table 3.2, and then the results of the hazard identification worksheet is transferred to the risk matrix in Table 3.6 below.

**Table3.6: The frequency and severity of each risk**

| Frequency | Severity | | | |
|---|---|---|---|---|
| | Minor | Significant | Severe | Catastrop hic |
| Frequent | | | Free fall lifeboat, channel, person exposed. | |
| Reasonably probable | | Ballast tanks, bow thruster, inert gas discharge columns, cleaning systems, cargo heating coils, ODME, mooring lines, moorings, deck drains, liferaft, portable fire extinguishers and foam equipment, personnel activities on the icy deck, Deck view | Stability failure, bow structure and layout, stern structure and rudder, hull accessories, cooling water system, spiral slurry design, deck pipe system, PV valve, deck water seal, vacuum circuit breaker, cargo oil pump, hydraulic equipment, lifeboat, rescue boat, detection system, cabin insulation, cabin ventilation system, bridge windows. | |
| Remote | | Material Selection, Lifebuoys, Cables, Compressed Air Systems, Cabin Ventilation Systems, Emergency Batteries and Battery Compartments, Living Tanks and Distilled Water Tanks, Skid and Oil, Pump Rooms, Fire and Foam Systems, Fire Hose, Signal Lamps, Crew fatigue | Main propulsion system, generator, radar and antenna, personnel training and operation, lack of effective navigation plan. | |
| Extremely remote | | Hull exterior coating, respirator and oxygen treatment equipment, safety helmet, protective and foam system hoses and nozzles | Immersion suits and insulation | |

(Source：Drawn by the Author)

According to the equation: RI = FI+ SI, the higher the value, the higher the risk index will be. In accordance with the relevant principles in the formal safety assessment, the risk matrix can fall into three areas: unacceptable risks, as low as reasonably practicable (ALARP) risks and negligible risks, as shown in the following Figure3.5:




(Source：Drawn by the Author)

**Figure3.2:Risk distribution**

In accordance with the relevant principles in the formal safety assessment and figure 3.2, the 55 risk effects on ship's low-temperature navigation can fall into the 3 risk areas as follows.

（1）Unacceptable risk：. 18 of the 55 risk effects are unacceptable risks. These unacceptable risks are as follows: loss of stability, failure of the stern structure, failure of the stern structure, damage to the steering gear, damage to the hull attachment, failure of the cooling system, damage to the propeller, damage to the deck piping system, blockage of the PV valve, failure of cargo pumps, failure of deck hydraulic equipment, failure of lifeboats and rescue boats, fire detection systems, low cabin temperatures, slippery or icing of safety channels, freezing and clogging of ventilation systems, ice in cab windows, line of sight, personnel damage, and failure of vacuum circuit breaker.

（2） The ALARP risk: 33 of the 55 risk effects are ALARP. These risks consist of: material brittle fracture, sceptical loading structure failure and failure of ballast piping, design of the main propulsion system does not meet the requirements of cryogenic navigation, damage to the thrust, damage to the generator, damage to the cable, air system failure, ventilation system, loss of emergency power, unusable fresh water and steam feed water, freezing of oil and grease, blockage of the inert gas discharge column, failure of the cargo tank cleaning system, failure of the heating coil, invalid system failure, ODME failure, damage to mooring lines, failure of gangway, failure of elaborate equipment such as ladders and small cranes, and jamming of deck drain holes. Life raft cannot be used, lifebuoy will be frozen, water will be frozen for lifeboat rations, immersion suits cannot be used at low temperatures, portable fire extinguisher is unusable, fire protection and foam system piping are blocked, fire protection is soft, and the fire hose box cannot be opened in time.

（3）4 of the 55 risk effects are negligible risks. These negligible risks are respectively as follows: damage to the protective coating of the shell plate, the inability to use the respirator and oxygen treatment equipment, the inability of the helmet to meet the requirements for use at cryogenic temperatures, and the damage to the hose and nozzle at low temperatures.

## 3.3 Chapter Summary

In accordance with the relevant principles in the formal safety assessment, hazard identification is conducted according to the severity of the fault and the probability of occurrence. According to the acceptability of risk, the 55 risk effects can fall into 3 levels, of which the first two levels of risk are not negligible.

# Chapter IV

## Research on Measures to Solve the Low Temperature Risk of ships

This chapter presents targeted solutions for the navigational risks of ships at low temperatures, which primarily comprise the antifreeze and deicing measures.

## 4.1 Frost Protection Measures

### 4.1.1 Study on Antifreeze Measures for Ballast Tanks

The surface of the ballast water in ballast tanks may freeze at low temperatures. At present, the three major antifreezing methods in ballast tanks are as follows: heating, circulation and blowing air.

The most effective and commonly applied is the use of steam heating coils, which can be applied in cargo tanks, slop tanks and ballast tanks. The ballast system should have separate heating lines from the cargo system to prevent the possible contamination due to the damage to the heating lines. Additionally, when the water supply pipe and the condensate pipe are not applied, sufficient drainage valves should be provided on these pipes to prevent icing from occurring. The ballast water circulation method is also one of the effective antifreezeing measures and can effectively regulate the temperature of different media in the tank. The air bubbling equipment is similar to the ballast water circulation method, yet the pipe may be damaged due to the falling of ice. This may be attributed to the supercooling of the ballast water and the formation of ice crystals by cold air, which makes it hard to pump water out.

Given that the higher the salt content of the water, the lower the freezing temperature will be, the ballast water exchange method may also be considered to pressurize the salt content of the water-carrying water (Matousek,, Childers, Ahrens, & Routh,

2008) . Besides, ballast suction nozzles should be located close to the centerline of the hull and as close as possible to the stern, and the sea chest should also be provided with deicing measures. Ventilation arrangements for ballast tanks may be accompanied by the heating measures to prevent icing, yet the filters may be frozen and damaged and should be replaced in time in the discharge of ballast water.

### 4.1.2 Study on Antifreeze Measures for Main and Auxiliary Power Equipment

The engine room cannot maintain temperature, and appropriate measures should be taken to maintain a suitable operating temperature in extremely low temperature environments. An effective method to control the engine room temperature is to modify the chimney fire damper. It is recommended that the damper should be able to be closed step by step to ensure the temperature of the engine room.

A ship with a "Winterized" symbol is required to be restarted for 30 min in the state of a paralyzed ship when the ambient temperature is 20 degrees lower than the design temperature according to the requirements of the DNV specification. Thus, the ability of the emergency generator to start at a low temperature is also crucial for the start of the main engine. Two different independent start-up systems can be established, i.e., battery power start system and air power start system.

Under the extreme cold conditions, the main engine usually does not use intake air preheating design. Three methods can also be used, which are scavenging bypass, exhaust bypass, or a turbocharger that matches the low temperature. The scavenging by-pass is to blow some air back to the air inlet, which has the advantage of preheating the inlet air. The exhaust bypass is separated from the flue gas and passes through the turbocharger. Scrubbers matched to low temperatures are generally used only for ships having long sailed at low temperatures.

The effective supply of cooling water is one of the conditions to ensure the performance of the main engine. The main engine is overheated due to the lack of cooling water when the sea chest is blocked by ice, which will make the ship stop. One of the most effective solutions is to provide part of the cooling water back to the suction port to melt the ice that enters the sea chest. There are other methods that are not widely applied, such as air bubbling systems, steam systems, or circulating water using heating coils. Heavy ice crystals may also accumulate in the winter. Accordingly, the air pipe of the cooling system should be located in a protected area or be provided with anti-freezing measures, for example, the accompanying heating.

### 4.1.3 Study on Antifreeze Measures of Deck Equipment

Ships sailing in a low-temperature climate should minimize the number of outfitting items on the open deck. Given that the outfitting items are easy to freeze, they will be soon thickened once they are formed. It is preferable to install some rope and wire rope roller and other outfitting on the vertical structure instead of on the deck, which will simplify the deicing work of the deck and reduce the possibility that the flowing water will freeze on the deck due to the blocking. In the case of icing, the breakwater will accelerate the icing on the open deck, so when the ship is sailing in cold weather, the breakwater should be removed. All mooring equipment should be capable of operating at extreme cold temperatures. Some anti-freezing measures can be used, such as covering with waterproof canvas. Yet it is advisable to have a complete deckhouse or semi-closed structure for the windlass to prevent it effectively. The hydraulic system on the deck should be able to apply low temperature hydraulic oil, or install a heater for heating. Exposed pipes should have suitable insulation and effective drainage.

The control mechanisms for the cranes and booms on the deck should be provided with protective covers to prevent them from being frozen by ice and snow. The selection of steel construction materials for cranes and booms should also be selected in accordance with the design service temperature of the vessel's navigation.

Temperature changes on the ship will cause the shrinkage of deck pipeline, which may cause leakage of flange. Thus, the integrity of pipelines should be prudently checked before being used to ensure their tightness. All cargo oil pipeline, ballast pipeline, liquid tank cleaning line and crude oil washing pipeline on deck should be drained after its pressure test or use. The pipeline should be drained and the drain valve kept open until the ambient temperature rises until the liquid in the pipe no longer gets frozen when loading goods in cold weather. If possible, it is recommended that at least one injection chamber valve is normally open so that the pipeline can be drained to prevent overpressure of the pipeline because of the temperature variations.

When a heating cable or steam heating pipe is set up, the heat transferred from the cable or pipe to the equipment or structure is not over concentrated, which should be noted. The spacing between cables or pipelines should be determined according to the heat loss on the equipment or structure. Do not blindly seek for more to avoid thermal stress.

The design of the outboard discharge port must have some antifreezing or heating measures. In line with the DNV specification, the area of the discharge opening can also increase by 30% without antifreeze or heating measures.

### 4.1.4 Research on Antifreeze Measures of Lifesaving Equipment

Low temperatures will significantly impact the emergency life-saving procedures and related life-saving equipment. As thick ice can support lifesaving equipment and thin ice areas cannot support people or lifeboats, careful confirmation must be made before evacuation in some special ice conditions. Icing on the equipment will prevent people from escaping and will also hinder the crew from carrying out rescue operations. Training of all emergency equipment at low temperatures should be involved in the crew's operations and training procedures. To ensure that the liferaft is available at extreme temperatures, it can be heated by an electric heating blanket or other portable heating device or stored in a deck room adjacent to the embarkation position. The liferaft hydrostatic release unit should be operated safely at the design temperature and provide protection against ice accumulation. In thin ice, the liferaft breaks open and floats in the water when entering water. Be careful not to damage it when it enters the water. Yet this type of operation is not suitable for expansive lifesaving because they are easily broken by ice. Adequate equipment and survival supplies should be prepared for all escape situations. It is noteworthy that the equipment should not be frozen on the surface of the ice.

Lifeboat engine cooling water system should be set to drain plug to ensure it can be completely drained. For closed cooling water, a circulation system should be provided to prevent freezing. In the lifeboat engine, a heater may be provided as required, and other heating methods may also be provided, which include the heating of the lifeboat engine and the cooling of water system before the start of lifeboat engine. Heaters should also be placed in the lifeboat to prevent the windows of the lifeboat from freezing. The devices such as wipers and demisters should be provided to maintain the visibility of the window on the lifeboat.

Lifeboats are stored on davits on the open deck, and waterproof covers can be provided as required. This method ensures that they will not be covered by ice and snow, which reduces the preparation time for rescue and escape. Davit materials should meet the requirements of extreme cold temperatures.

### 4.1.5 Research on Antifreezing Measures of Navigation Equipment

The navigation lights should be able to generate sufficient heat to keep them free of ice and maintain the required irradiation angle. Otherwise, the antifreezing measures should be provided. In the meantime, antifreezing measures shall be provided for the valves and piping of sound signal devices to prevent them from freezing. By installing the location as high as possible, radar and communication antenna protection can be achieved to reduce the impact of sea spray droplets. Radar motors and gears should provide heating equipment, and antennas can be used as deicing measures by heating and adding domes.

Extra space and power should be provided for ice-zone navigation and management equipment on the deck. This involves radar monitors, high-frequency mobile phones and searchlights, etc. installed on the wings of the bridge for contact with rescue icebreakers. Searchlights can also be located in the stem. These searchlights will help ensure that the ship follows the open channel developed by the icebreaker. It also helps provide more comprehensive illumination of some of the original unilluminated areas of the ship. In icebreakers and ships frequently cruising in ice areas, ice impact monitoring systems should be probably installed to monitor ice impact loads. The system is directly connected to the computer on the bridge, which displays the ice impact load and the percentage of the allowable load employed to determine the safe speed of the ship's navigation.

### 4.1.6 Research on Antifreeze Measures of Cabin Equipment

In low-temperature climate conditions, accommodation areas need to consider providing pilots with necessary items, such as changing rooms and storage facilities in addition to normal ship supplies. The open doors should be installed in the recesses of the cabin walls. When important doors are in very exposed locations, other openings should be provided.

Ship navigation may also be very bumpy in low temperature weather. Accordingly, vessels should be designed to provide corresponding facilities to ensure crew safety, which include deck skid resistance and handrails heating, etc. The additional insulation must be considered for the outer walls of accommodation at extreme temperatures. Yet it is not advisable to increase deck insulation in open areas as the internal humidity may cause insulation corrosion. Condensation occurs on the surface of the vessel at the junction of the heating zone and the freezing zone. Reducing the effect of the problem should be noted, and the methods of collecting and removing condensate should be considered.

In some outdoor areas that are occasionally used, the additional outlets for portable heaters should be provided. The ventilation system of the cabin should also be easy to freeze. When the volume of air is large, the use of heating equipment may become complex and expensive, so other simpler and more economical methods should be adopted. For instance, the suction port can be placed in an unreachable position of the sea foam; two air suction ports are provided on the port side and starboard side respectively, facing the opposite direction. For outdoor ventilated blinds and outdoor ventilated mushroom ventila, electric heat insulation and anti-freezing measures should be employed.

When ships are at low temperatures, important escape routes, assembly areas and lifesaving equipment boarding areas should be located at the least exposed places. The access rails of these premises should also provide anti freezing measures, inclusive of adding additional heating cables to the handrails. External escape passages usually require deicing and skid prevention measures, which include heating, spreading sand or salt on safety passages.

## 4.2 Research on Deicing Measures

When the ship is exposed to a temperature below the freezing point of sea water (about -2 ℃), the spray will quickly produce frost when the waves scour the ship, and the fog and snow may also accumulate on the deck. The deicing equipment on board depends on the route of the ship. For ships sailing at a low temperature for a long time, they may suddenly encounter severe ice areas. Thus, permanent deicing should be considered. The permanent deicing mode primarily includes heating cable, heating coil and steam pipeline, and the specific uses are clear in the previous chapters. When ships are occasionally sailing in low temperature areas, portable deicing equipment can be provided.

Artificial deicing is primarily applied for passageways, stairways and handrails, and deicing is achieved by steam blowing and hot water leaching. The common and fast method of deicing is to use brine. It is necessary to pay attention to the use of heating or unheated saltwater deicing while the excess brine must be free to enter the sewage well or out of the outboard before freezing. For large ice blocks, high pressure water jet can be used to cut and break, because if melting ice is used, it may take a long time. In difficult-to-reach locations, small hot water nozzles can be used for deicing. There are many steam pipes on the oil tanker, which can be connected with hoses like common air pipes, and can be readily applied for deicing in some areas of the deck. Yet its heating capacity is limited and it is possible to thaw some valves, but it is not possible to thaw the oil in the crude oil line that has solidified at a low temperature. Steam can only defrost locally, and hot water can be used instead of steam. Yet hot water can also cause ice in other deck areas at low temperatures. In these methods, steam is the most effective method for deicing relatively small or restricted areas, but if overused, it may cause loss of water supply, and the use of steam in the ice zone may cause water vapor to solidify and freeze in the body.

Among more effective and useful methods is to remove ice with simple manual tools, such as axes, mallets, shovels etc. These tools can be used to remove ice when inspecting sailors are on board. Storage devices should be installed for deicing devices, including shovels, canvas, mallets, etc. It is also necessary to note that when these storage devices are placed in open-air locations, there must be some anti-freezing measures to protect them.

## 4.3 Chapter Summary

This chapter addresses the countermeasures to deal with some risks of ships at low temperature. There are protective measures against frequent but less dangerous risks, such as anti-freezing measures for ballast tanks and deck equipment; there are protective measures against rare but serious risks, such as main and auxiliary propulsion equipment and safety passage anti freezing measures; there are protective measures against frequent and serious risks, such as lifesaving, firefighting equipment and anti-freezing measures in cabins. The ice removal measures of ships found at low temperatures can be summarized in the following six aspects:

(1) Selection of low temperature and anti-freezing materials, including navigation lights, lifesaving equipment, low pour point hydraulic oil, lubricating oil and grease.

(2) The cover method is primarily covered by steel and waterproof low temperature resistant materials to prevent the equipment from being affected by ice and snow accumulation and freezing.

(3) Shading protection arrangement, the equipment is arranged in enclosed spaces. For instance, design the windlass in the deckhouse to avoid freezing.

(4) Heating devices are added to provide heat to the equipment and piping on the ship through fixed and mobile heating equipment to prevent it from freezing.

(5) Personnel protection measures provide cold and warm clothes for the crew, and provide anti-freezing measures for food, water and other necessary daily necessities.

(6) Deicing measures, removal of accumulated ice and snow by tools and methods such as steam, hot water, portable tools, etc.

It is noteworthy that in the early stage of ship design, the relevant risks that may be encountered during the navigation of ships under low temperature should be specifically designed and the necessary protective measures should be taken according to the use of the ships to reduce the risk of ships sailing at low temperatures.

# ChapterV
# Conclusion

Under the impact of global warming, the sea ice coverage in the Arctic Ocean has seen a progressive year-on-year decrease, and the thickness of ice floes has been thinning year by year. The transport volume of the Arctic Ocean route will multiply, and the exploitation of Arctic resources will become possible. The development of the Arctic requires ships applying to navigation at low temperatures, whereas the relevant design experience is lacking in China. Many designers, ship owners, and crew also lack a systematic knowledge of the ships navigating at low temperatures. In this thesis, the risk and influence of ship's low temperature navigation are studied, and abiding by the relevant principles of comprehensive safety assessment, the risk classification and identification of ship's risk of low temperature navigation are studied, and the measures corresponding to some risks are sought.

There are some limitations in the study on the risk of low-temperature voyage, and not everything necessary is considered due to the limited knowledge level of the author. Hopefully, the experts and scholars can point out the mistakes made by the author. Hopefully, in the future study and work, further studies are needed to explore the risk of navigation at low temperature in a more comprehensive and in-depth way.

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