8-26-2018

Comprehensive research on safe measures for ice navigation in Yingkou ice-covered waters

Tianpeng Wang

WORLD MARITIME UNIVERSITY

Dalian, China

COMPREHENSIVE RESEARCH ON SAFE MEASURES FOR ICE NAVIGATION IN YINGKOU ICE-COVERED WATERS

By

Wang Tianpeng

The People's Republic of China

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

MASTER OF SCIENCE

(MARITIME SAFETY AND ENVIRONMENTAL MANAGEMENT)

2018

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.

(Signature):..............................

(Date): ....

Supervised by: Zhu Yuzhu

Professor

Dalian Maritime University

Assessor:____________________

Co-assessor:_________________

ACKNOWLEDGEMENTS

I am grateful to World Maritime University and Dalian Maritime University for having given me the opportunity to study in MSEM 2018. I also express my sincere appreciation to all professors of WMU and DMU, who have tutored and supported me a lot during my learning in Dalian. Although different teachers have different teaching styles, they are all models of teachers.

The research paper was completed under the guidance of my tutor professor Zhu Yuzhu, the completion of the research paper is inseparable from the professor's concern, guidance and supervision in the writing process of research paper. Professor Zhu's rigorous attitude towards studying and positive life enthusiasm left a deep impression on me, at the same time, professor Zhu encouraged me to apply what I have learned to work in the future, combining theory with practice, so as to maximize the knowledge benefit. Although I encountered many unexpected difficulties in the writing process of research paper, most of them were solved by my teachers and classmates. I also would like to express my heartfelt thanks to all the teachers and students who have helped and guided me!

This paper quotes some research literatures of several scholars, and it would have been very difficult for me to finish the research paper without the help and inspiration of scholars' research results. I would also like to thank my leaders and colleagues for their encouragement and support during my studying. Through MSEM courses, I have a deeper understanding of maritime affairs.

Finally, I would like to thank my families for their care and help during my study, they are always my spiritual inexhaustible power and strong back.

ABSTRACTS

Title of Research Paper: Comprehensive Research on Safe Measures for Ice Navigation in Yingkou Ice-Covered Waters

Degree: Msc

The yellow sea and Bohai sea in China experienced continuously sea ice disaster since the beginning of winter. As the northernmost sea ice waters in China, sea ice of Yingkou waters has seriously hazards on the safe navigation, port operations and fishery, and causes different losses because of different sea ice condition. Therefore, it is necessary for ships to have good safe navigation measures when navigating in such areas, and to fully understand the local sea ice characteristics.

The interaction between ships and sea ice is a very complex dynamic process. At present, the research on the safe navigation of ships in ice area at home and abroad is mainly divided into two aspects: The first is to simulate and set up related model to deduce the ship-to-ice interaction process and sea ice forecast system based on the obtained experimental data. The second is seafarers with experience in ice area navigation puts forward matters and relevant suggestions for safe navigation in ice area based on their own experience. Researches aims to provide accurate and early sea ice information for seafarers and MSA to reduce the accidents and losses.

The research paper selects Yingkou ice-covered water as the research object, first of all, by collecting and consulting the research materials of relevant scholars and organizations at home and abroad and analyzing the related research results, to summarize characteristics of ice navigation and the relationship between ice condition and accidents. By referring to the "Rules of Navigation on the Water Area of the Northern Sea Route", "Ice Navigation in Canadian Waters", "Polar Code" and

"Finnish–Swedish winter navigation system" and other ice navigation rules to analyze mature practices of IMO, Russia, Canada and other countries. We can conclude that sea ice monitoring and forecast, crew training, ship construction, sailing support services and emergency plans is the most important aspects for ice navigation. Then we combine characteristics of Yingkou ice-covered waters with mature rules and measures abroad, to put forward the safe measures and suggestions which are suitable for Yingkou ice-covered waters. Such as sea ice monitoring and forecasting system, sailing support services, qualitative analysis on safe distance and safe speed of ships under escort of icebreakers and emergency response. Finally the paper summarizes the whole body and puts forward the research direction of safe navigation in ice area in the future.

KEYWORDS: Sea Ice, Ice-covered waters, Hazards, Ice navigation, Ice class, Safe Measures, Monitoring, Forecast, Services, Emergency, Oil spill.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AIS	Automatic Identification System
ANSR	Northern Sea Route Administration
ASPPR	Arctic Shipping Pollution Prevention Regulations
CCGS	Canadian Coast Guard Ship
CCTV	Closed Circuit Television Inspection
CCS	China Classification Society
CIS	Canadian Ice Service
JIGs	Joint Industry - Government Guidelines
IACS	International Association of Classification Societies
IMO	International Maritime Organization
LR	Lloyd's Register of Shipping
MARPOL	The International Convention for the Prevention of Pollution From Ships
MSA	Maritime Safety Administration
MSC	Maritime Safety Committee
NNE	North-North-East
NSR	Northern Sea Route
PPI	Plan Position Indicator
SAR	Search and Rescue
SOLAS	International Convention for Safety of Life at Sea
SSW	South-South-West

STCW	International Convention on Standards of Training, Certification and Watchkeeping for Seafarers
UK	United Kingdom
USA	United States of America
VHF	Very High Frequency
VTS	Vessel Traffic Service
WMO	World Meteorological Organization

CHAPTER 1 INTRODUCTION

1.1 Research Background

Sea ice is a unique marine disaster in polar waters and high latitudes waters, which is known as the "white killer" for shipping safety. When the condition of sea ice is light, which could hinder ship sailing and delay ship schedules. When the condition of sea ice is severe, it may cause damage to the ship's hull, rudder and propeller(Sun Wenlin.,2016) (Figure 1.1).

Figure 1.1 Sea ice damage for ship's hull and propeller

(Source: Sun Wenlin, Wang Chao, Kang Rui & Wang Guoliang. (2015). Several considerations in the design of propulsion systems for ice-covered navigation of ships.)

The global distribution of ice-covered waters are located in the polar waters (Antarctica and Arctic), the northern hemisphere subpolar regions, mid and high latitudes waters, such as the Baltic sea, the Okhotsk sea, the Bering sea, the Hudson sea, the Cook inlet, the gulf of Finland, the Yellow sea and the Bohai sea(Lan Yang., 2015,pp.80-83). The Baltic sea is shallow and low salinity, the sea water is easy to freeze(Figure 1.2). Every year the northern and eastern waters of Baltic sea, there are usually some ice periods that is unfavorable for ship sailing. Due to the milder climate than polar regions, the annual maximum ice extent of Baltic sea is highly variable, up to 35% of the sea ice mass can be composed from metamorphic snow, rather than frozen seawater, and in places snow and superimposed ice can make up to 50% of the total ice thickness(Granskog, M., Kaartokallio, H., Kuosa, H., Thomas, D. N., & Vainio, J.,2006,pp.145-160). In severe winter, almost the whole Baltic sea was covered with sea ice, the average thickness of sea ice thickness is 65cm(Figure 1.3). According to the historical data, the gulf of Bothnia was frozen for 210 days, the gulf of Finland and the vicinity of Stockholm for 185 days. Such sailing conditions make it difficult to transport by shipping, in March 2010, a large area of sea ice appeared in the Swedish waters, about 50 ships were stranded by sea ice, bringing the disaster to thousands of tourists (Zhang Baoxin.,2018).

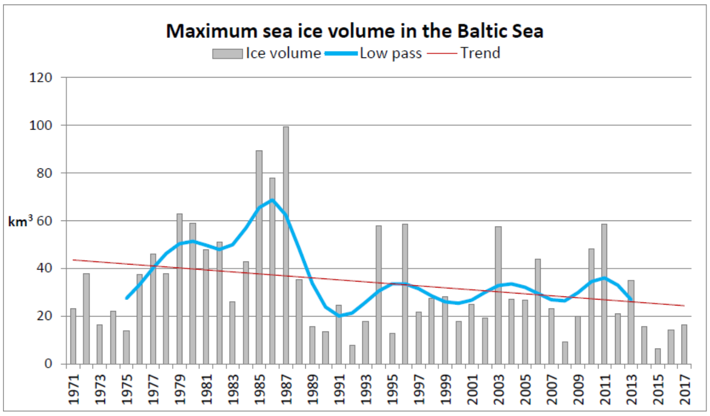

Figure 1.2 Yearly maximum sea ice volume of the Baltic Sea for the period 1971 – 2017

(Source: Dr. Sandra Schwegmann & Dr. Jürgen Holfort. (2017). The ice winter of 2016/17 on the German North and Baltic Sea coasts with a brief description of ice conditions in the entire Baltic Sea region)

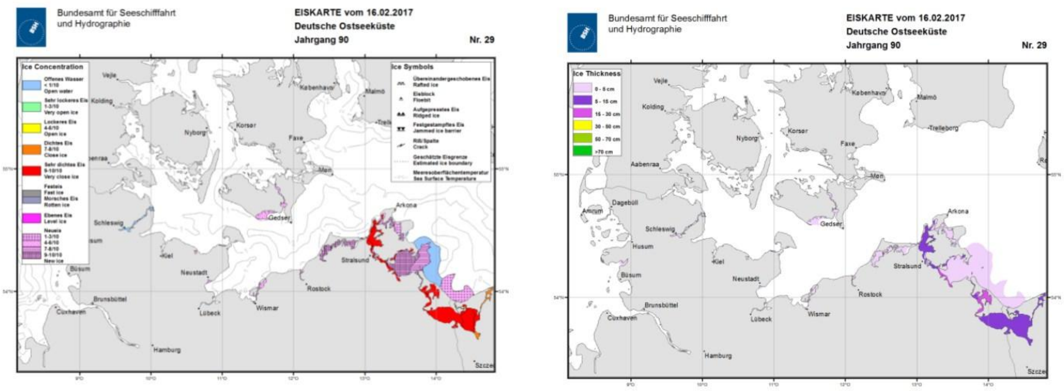

Figure 1.3 Sea ice extent and thickness in Baltic sea coasts in the ice winter 2016/17

(Source: Granskog, M., Kaartokallio, H., Kuosa, H., Thomas, D. N., & Vainio, J. (2006). Sea ice in the Baltic Sea – a review.)

The main area of ice-covered waters in China are the Bohai sea and north of the Yellow sea, which is also the lowest latitude ice-covered waters in the world, every winter different degrees of sea ice are formed. Especially for Bohai sea, connecting the Liaodong peninsula and Jiaodong peninsula, which has superior geographical position, which has always been one of the busiest maritime traffic areas in China. Historically, due to sea ice disaster, there have precedents of large losses caused by sea ice in Bohai sea. In recent years, especially in the winter of 2009~2010, the sea ice disaster in the Bohai sea once again caused severe impacts on the safe navigation of ships, according to sea ice disaster loss statistics of China's Marine Disaster Bulletin 2009-2010, the annual sea ice disaster caused a total of 7157 ships damaged, 296 ports and piers were frozen, the direct economic losses amounted to 6.318 billion yuan.

Yingkou waters is located in the Liaodong bay of the Bohai sea, which is the highest latitude waters in China. And the Yingkou port is the nearest sea port in northeast China and eastern Inner Mongolia, even in severe ice periods, every day there are nearly 200 ships calling the port, including international passenger liner and key resources transportation, which plays an important role in the regional economic development and even national economic development. Yingkou waters is one of the most severely affected areas by sea ice, sea ice begins in the middle of December every year, January and February are more serious. According to the relevant information, the thickness of sea ice could reach the 40cm meanwhile there are large area fast ice and floating ice. Especially from the end of 2009 to the beginning of 2010, the sea area had experienced the worst sea ice disaster which caused the severe sailing conditions in 30 years(Figure 1.4). Every winter Yingkou waters lasts 2-3 months ice periods.

Figure 1.4 The severe sailing condition in 2009-2010 in Yingkou waters in winter

(Source: From the Yingkou MSA)

According to statistics of MSA, from the December 31 2017 to the March 31 2018, only in the Yingkou waters, the sea ice caused the main engine failed 62 times, dragged anchors 235 times and difficulty sailing events with 82 times. It is necessary to fully understand hazards of sea ice to the safe navigation of ships, taking effective measures to prevent and respond to the ice navigation to ensure the safe navigation of ships.

1.2 Research Significance

Sea ice in Yingkou waters poses a long-term risk to the safe navigation of ships in winter. If the ship is unfamiliar with condition of ice-covered waters, and insufficient knowledge of navigational hazards in ice-covered waters, then the ship is easily affected by sea ice, wind, current, etc., causing collision, grounding, dragging anchor and other serious accidents(Zhang Zengguang.,2010). When the air temperature is very low, the icing can impact the ship's stability and ship's buoyancy very seriously, in particular, ships with low freeboard and long sailing time may even capsizing. In order to reduce the occurrence of ship accidents caused by sea ice, it is especially important to correctly judge the risk of ships caused by the sea ice and sea ice condition. How to ensure the safe navigation of ships in Yingkou ice-covered waters, to reduce or avoid the maritime accidents caused by the sea ice and to improve the navigational efficiency of ships in Yingkou ice-covered waters have great practical significance. Through analysis and research the impact of sea ice for ships, we can provide some effective measures and suggestions to ensure the safe navigation of ships in Yingkou ice-covered waters.

In recent years, due to the greenhouse effect, global warming is melting the ice of polar areas, the Arctic covered by sea ice has reached its smallest area since satellite observations began in 1978, about 12 million square kilometers(Figure 1.5). And polar waters have many available natural resources, abundant fishery resources and mineral resources under the sea, especially for oil and gas, which already become the main target of the national competition. In the recent three years, the navigable time of the Arctic routes has been extended from two or three months to five months in summer each year (early July to early December). Chinese ships pass through the Arctic routes can greatly shorten the voyage, save fuel and costs, which can improve economic efficiency and international shipping competitiveness. Such as a ship from Shanghai port to New York or Rotterdam, passing through the Arctic routes (Figure 1.6) can save more than 40% voyage distance and more than 40% fuel compared with traditional routes passing through the strait of Malacca strait and the Suez Canal, its economic value is enormous. Research on the safe navigation of ships in Yingkou ice-covered waters in winter, not only conducive to ensure the safe navigation of ships in related waters, based on the research of this paper, it is expected to provide some references for future research on the safe navigation of ships in polar waters, and play a positive role in reducing the risk of navigation of Chinese ships in polar region.

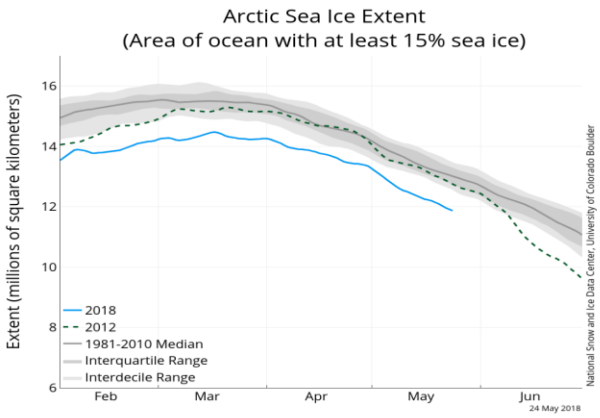

Figure 1.5 Sea ice extent of Arctic Ocean

(Source: http://nsidc.org/arcticseaicenews/)

Figure 1.6 The passage route through the Arctic Ocean

(Source: Zhang Xingjie. (2015). Risk assessment of safe navigation of merchant ships in polar regions.)

1.3 Research at Home and Abroad

1.3.1 Domestic Research Situation

Domestic research on safe navigation of ships in ice waters is mainly about ship operation in ice waters, interaction of ship-to-ice during collision, ship-to-ice collision simulation and the way to prevent ice trapped, etc. Several captains with practical experience in ice navigation had made analyses of ice conditions at different ports to put forward suggestions about ship maneuvering in ice waters.

Sun Fengyu (1995), Gao Xulong (1998), Wu Tianchun(2006), Wang Shiyan (2008), Li jian (2010) and experienced persons, they summarized the danger sources and some emergencies that ships often encounter when sailing in the ice waters according to the actual experience of ice navigation in ice.

Zou Zhongsheng(2010) of Dalian Maritime University, in his master's thesis, after taking into account the wind, current and sea ice factors affecting the safe navigation of ships, he calculated the external force on a ship while anchoring in ice waters, effects of sea ice on buoyancy and stability of ships and the distribution of ship icing.

In 2011, Sun Yuhao of Dalian Maritime University, in his master's thesis he established simulation scenarios of sea ice breaking and sea ice floating with wave, to realize the rapid collision detection between sea ice and ship during ice navigation.

In 2012, Liu Qiang, Sun Jian and Wang Fengwu of Dalian Maritime University, they studied and analyzed the characteristics of sea ice of the Yellow sea and Bohai sea recent years. And from the perspective of affecting the safe navigation to analyze the influence of sea ice for seafarers, the impact for the ship and port operations.

In 2013, Song Yanpin and Zhang Aifeng of Dalian Maritime University used finite element numerical simulation method to simulate the collision process of ship's broadside with sea ice, and summarized the collision law. They obtained the stress change of ship's broadside during collision process, the damage deformation of ship's hull and the method for calculating the safe speed of ships in ice waters. Chen Hailong of Dalian Maritime University, in his master's thesis, he introduced the forces on the bare hull when the ship was sailing in the ice waters, and he analyzed the impact of sea ice on the main engine and propeller. It was found that when the sea ice was in contact with the propeller, the thrust coefficient of the propeller decreased by 2% to 4%, and the torque coefficient increased by 14% to 17%. The effect of sea ice on rudder was relatively small.

Professor Zhu Yuzhu of Dalian Maritime University cooperated with Yingkou Maritime Safety Administration wrote the first handbook about safe navigation in ice waters - ship safe navigation in ice waters in the Liaodong bay and the north of Yellow Sea. The handbook studies and summarizes the characteristics of sea ice in the Liaodong bay and the north of yellow sea in winter.

To sum up, domestic research on safe navigation of ships in ice waters is still in its infancy. Most studies are based on a summary of sailing experience, although relevant scholars have begun to study the interaction of ship to sea ice, and they have made some progress. However, due to the imperfect domestic experimental facilities, the data based on ship-to-ice collision model and full-scale ship observation are relatively few, so there is no systematic study on the safe navigation of ships in ice waters.

1.3.2 Overseas Research Situation

The study on safe navigation safety of ships in ice waters abroad flourished after the 1960s, ship-to-ice model, indoor ice pool and simulation study are all applied to this subject. After obtaining a large number of experimental data through plenty of experiments, using advanced analytical and mathematical tools, scholars have inferred the relevant theory and formula of ship-to-ice interaction, and also put forward the suggestions of ship design of ships in the ice waters and matters needing attention when ships are sailing in the ice waters.

Johansson and Makinen(1973) conducted a simulation experiment that included 9 bulk carriers colliding with sea ice to test sea ice resistance, they found that when the collision angle of ship-to-ice reduced from 82 °to 75 °, ice resistance could be reduced about 60%. If ship's length increased by 38% then ice resistance increased by about 30%, on the contrary ice resistance decreased by about 10%. If ship's breadth increased 33%, the ice resistance increased by about 40%. However the ship's draft had little effect on the change of ice resistance.

Carter (1983) proposed a formula to calculate the maximum resistance of sea ice to ships when sailing in the ice waters. In the formula, he ignored the influence of the inertia force and buoyancy of the broken ice, He believed that the energy loss of sea ice was absorbed in the process of sea ice bending, twisting and breaking, when sea ice collided with ships. He then tested his theory with data from six icebreakers who broke the ice.

From 1997 to 1999, the UK, Norway, Germany, Finland and Russia and 12 research institutions jointly conducted the research "Ice Routes the application of advance technologies to the routing of ships through sea ice", studying the possibility of improving safe navigation and reducing shipping costs in ice areas such as the Baltic sea, Greenland Sea, the Kara Sea and Barents Sea.

In 2006, Liu Jiancheng, Michael Lau and Mary Williams of Memorial University of Newfoundland, proposed and introduced a new ship-to-ice interaction model to simulate various ship operations in flat ice. In this model, they calculated effectively the longitudinal force, rolling force and yawing moment of ships caused by sea ice.

In 2008, Kyungsik Choi and Seong Yeob Jiong from Canada compared the experimental data and full scale testing data of 6 different icebreakers, deriving the semi-empirical formula based on the speed, power of main engine and ship's draught for estimating the sea ice load of icebreaker.

In 2011, the British Lloyd's Register (LR) proposed a new software "Ship Right FDA

ICE" for structural fatigue assessment of ships in ice waters. The contents of the software included the load produced by the interaction of ship with sea ice, impacting frequency of sea ice load, the distribution of sea ice load and fatigue characteristics of hull structures at low temperatures.

In 2012, Ingvill Bryn Thorsen of Norwegian University of Science and Technology, in his master thesis he studied the interaction between sea ice and ship's hull, and discussed the angle from which ships collide with sea ice to minimize damage to the ship's hull.

Overall, overseas research and practice of sea ice disaster has gone through a long period of time, the study of sea ice and the practice of safe navigation has been mature, as the maritime safety administration of China, we should adopt good practice in order to improve the quality of ship safety supervision.

1.4 Research Contents and Methodology

In this research paper, the writer consulted the research material and data of relevant organizations and scholars at home and abroad, according to existing information and relevant research results, to pick the safe navigation of ships in the Yingkou ice-covered waters as research object, In the writing process of the research paper, the writer used Inductive Method, Deductive Method, Literature Research Method, Case Study Method and other research paper methods to conduct corresponding research.

In this research paper, the whole page discuss and analysis the safety problems in ice navigation of ships, and also point out that it is of great significance to study and analyze the safe navigation of ships in ice waters. The main research content of this research paper as follows:

I. The research paper introduce the research background and significance. The research on the safe navigation of ships during the ice period not only increases the safety of ships sailing in ice waters in China, but also accumulates experience for the ships navigation in polar regions.

II. The research paper starts with the concept of basic characteristics of sea ice to introduce the basic properties and observation methods of sea ice. At the same time, Combined with the different characteristics of sea ice, the research paper introduce the possible hazards of sea ice on safe navigation of ships, and discuss the effects and losses caused by sea ice disasters.

III. The research paper studied the safety sailing measures and safe navigation rules in ice waters abroad, and the paper analyzes and summarizes the mature navigation regulations, ice conditions detection, early warning and the safe navigation measures of ice waters in foreign countries.

IV. The research paper introduce the navigation condition of Yingkou ice-covered waters during sea ice period in detail. It analyze the navigable environment of Yingkou ice-covered waters, ice navigation services and sea ice forecast situation.

V. According to the advanced practices at home and abroad and the characteristics of the sea ice in Yingkou ice-covered waters, the research paper propose reasonable safety measures for ice navigation in Yingkou ice-covered waters to ensure the safe navigation of ships in the ice area.

VI. Finally, the paper summarizes the whole paper and provides a direction for the reform and development of safe navigation of ships in the Yingkou ice-covered waters during the sea ice period.

CHAPTER 2 CHARACTERISTICS AND HAZARDS OF SEA ICE

2.1 Formation of Sea Ice

Sea ice is a mixture of freshwater ice crystals, brine and salty bubbles, including fresh water ice (ice from glaciers and rivers) from the mainland and salt water ice that is frozen by sea water. The type of sea ice are abundant. The formation factors of sea ice are related to sea surface conditions and atmospheric conditions, and are also closely related to the density, depth, salinity, turbulence and condensation nucleus of sea water.

i) Water depth has a significant influence on the formation of sea ice: low heat capacity in shallow water, however deep water has a high heat capacity, so the frozen of sea ice is from shallow water to deep water.

ii) The effects of salinity on sea ice formation are complex: first of all, there is a functional relationship between freezing point and salinity, the higher the salinity, the smaller the freezing point, so sea waters with low salinity freezes first, those with high salinity freeze later. Second, as a result of the increase in salinity, the reduction rate of the highest density temperature($\theta_{\rho max}$)was steeper than that of the freezing point temperature(θ_f) of the sea water, and they cross each other, the Figure 2.1 shows the relationship among the freezing point temperature of sea water(θ_f), The highest density temperature（$\theta_{\rho max}$）and salinity. If the salinity of sea water is lower than 24.6, the water temperature is higher than the freezing point temperature, when the water is cooling, the density of surface waters decreases, there is no vertical circulation, the result is that the thin layers of the surface water are cooled merely, the sea water will soon be frozen. But when the salinity is higher than 24.6, the vertical circulation caused by convection current mixes cold water of sea surface with deeper water before cooling from the sea surface. As a result, sea waters with salinity above 24.6

are harder to freeze than those with a lower salinity.

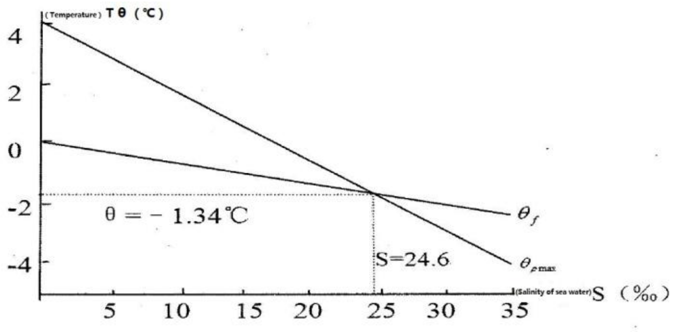

Figure 2.1 The relationship among θf、θρmax and salinity

(Source: Zou Zhongsheng. (2010). Safety analysis of ship icing and anchorage in ice-covered areas.)

iii) condensation nucleus plays a significant role in the formation of sea ice: When sea water contains many condensation nucleus, the water that reaches freezing point will be frozen quickly.

iv) The turbulence in the ocean tends to bring sea water temperatures into the same level, delaying the formation of sea ice.

Sea ice is initially formed as acicular or thin ice crystals, then it forms like paste or sponge, after further frozen, it becomes ice crust or ice cake floating on the sea. When the sea is covered with ice crust or ice cake, it extends in the direction of thickness, forming grey ice and white ice covering the sea.

2.2 Classification of Sea Ice

According to the movement state and development process of sea ice, it can be divided into floating ice and fast ice, among which, floating ice is divided into new ice, ice rind, nilas, pancake ice, gray ice, gray white ice and white ice(Figure 2.2). Fast ice is divided into coastal ice, ice foot and stranded ice. According to the thickness of sea ice which can be divided into: fresh ice(the thickness of 10 cm ~ 30 cm), first-year ice (the thickness of 30 cm ~ 2 m), second-year ice(the thickness reaches 2.5m) and multi-year ice(the thickness over 3m)(Lv Xiaodong.,2015,pp.77-79). The specific classification is shown in Table 2.1 and Table 2.2.

Figure 2.2 The types of sea ice

(Source: Lv Xiaodong. (2015). Basic knowledge of sea ice and matters needing attention in sailing ice-covered waters.)

Table 2.1 The type of floating ice

(Source: Made by the author)

Type of Floating Ice	Symbol	Characteristic of Sea Ice
New Ice	*N*	The general term for the initial stage of sea ice, which is formed by direct frozen of sea water or snow falling to the cold sea surface without melting, it is usually in the form of acicular, patches, grease or spongy. The new ice is loose, it has a certain shape only when it is concentrated and floating on the sea, attached to rocks and other objects. When there is

		new ice, the sea surface reflects faintly, without luster.
Ice Rind	***R***	The ice crust layer formed by frozen new ice or frozen directly over calm sea surface. The surface of ice rind is smooth, moist and glossy, the thickness of ice rind is about 5cm, which can rise and fall with the wind, easily broken by the wind and waves.
Nilas	***Ni***	The thickness is less than 10 cm of elastic thin ice crust layer, matt surface, under the external force and wave it is easy to bend and break, and produce "finger" overlapping phenomenon.
Pancake Ice	***P***	Circular ice with a diameter of 30cm~300cm and thickness of 10cm, It has a humped edge due to collision with each other, and can be frozen from new ice, can also be broken from ice rinds or nilas.
Gray Ice	***G***	The thickness of ice cover layer is 10cm~15cm, it is formed by nilas, its surface is smooth and moist, most of them is grey. It is easy to break by waves and overlap when pressed.
Gray White Ice	***Gw***	The thickness of ice layer is 15cm~30cm, which is formed by gray ice. Its surface is matt, most of them is offwhite. When they are pressed they can form the ridged ice.
White Ice	***W***	The thickness of ice layer is greater than 30cm, which is formed by gray white ice. Its surface is matt, most of them is white.

The floating ice floats to everywhere with the winds direction and currents direction on the sea surface. In waters with weak currents, sea ice is affected by wind, and its drift speed is 1/50 of the wind speed, its movement direction is affected by the earth's deflection force, which is not same with the wind direction, in the northern hemisphere, the direction of floating ice is 30° to 40° to the right of the wind direction, while in the southern hemisphere, it moves to the left. In strong currents waters, the movement of floating ice is more complex and it is affected by both wind and current.

Table 2.2 The type of fast ice

(Source: Made by the author)

Type of Fast	**Symbol**	**Characteristic of Sea Ice**

Ice		
Coastal Ice	Ci	Coastal ice that frozen with coasts or shoals, extending from the coast to the sea. Coastal ice can move vertically with movement of sea waters.
Ice Foot	If	The narrow ice belt fixed on the coast, which is the ice belt formed by the aggregation and frozen of the remaining parts of the coastal ice or the gelatinous floating ice and spray droplets attached to the coast during high tide.
Stranded Ice	Si	Sea ice left in inter-tidal zones or stranded in shallow water at low tide

2.3 Monitoring Methods of Sea Ice

Sea ice monitoring methods mainly include visual measurement, remote sensing measurement and radar detection method. Visual measurement is the earliest method, and then there appeared shore-station radar measurement, aerial remote sensing measurement, underwater sonar measurement to detect conditions of sea ice, they are in their own field plays an indispensable role.

2.3.1 Visual Measurement

Sea ice is directly observed by the sight(Figure 2.3), the drawback is that the error is large, however, this method is simple and easy to operate. With the summary and accumulation of people's experience, visual error can be gradually reduced to an acceptable range, usually the result is less than the actual thickness of sea ice. This method can be used to assist the measurement of sea ice thickness, simple estimation and as a reference source for continuous observation of sea ice information.

Figure 2.3 Visual measurement

(Source: From the Yingkou MSA)

2.3.2 Remote Sensing Measurement

At present, more and more satellite data are available, The spatial resolution ranges from a few meters to a thousand meters, the time period ranges from a few hours to dozens of days, and the space scale can range from several tens of kilometers to several thousand kilometers. Microwave remote sensing belongs to active remote sensing(Figure 2.4). Through statistical analysis of satellite remote sensing data, the movement process and thickness of sea ice can be determined. Microwave remote sensing has become a new, convenient and scientific method for sea ice observation.

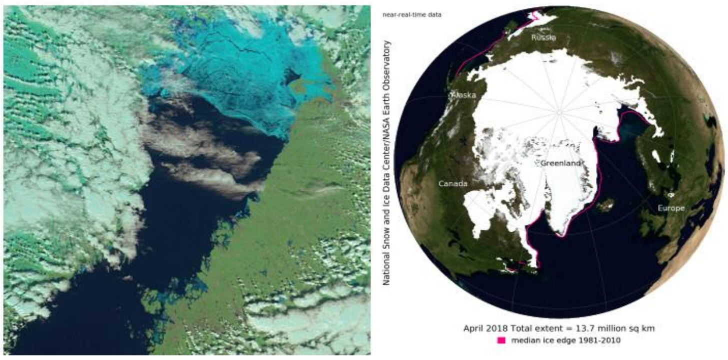

Figure 2.4 Remote sensing measurement

(Source: http://nsidc.org/data/search/#keywords=sea+ice)

2.3.3 Radar Measurement

Using radar to detect and identify the sea ice is another effective method(Figure 2.5). Because of the different nature of water and sea ice, the echoes displayed on the radar are different. In the case of proper radar using, heavy ice and pack ice show a strong white echo on the radar, continuous thin ice and new ice show a dim weak echo on the radar, scattered floating ice show weaker pitting echoes on radar, open water has no echo on radar.

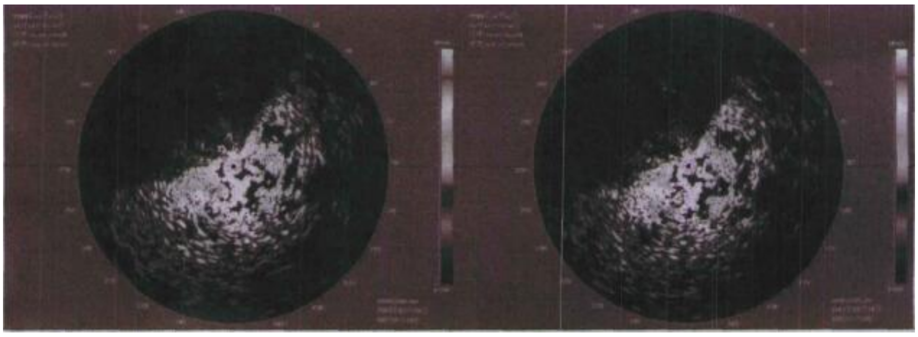

Figure 2.5 Radar ice PPI images

(Source: Zhao Baogang. (2008). Research on monitoring and forecasting technology of sea ice in Liaodong bay.)

2.4 Hazards for Ice Navigation

Harsh winter conditions result in sea environments with complex and dynamic sea ice. Together with winter darkness reigning over these northern areas, these conditions present specific operational risks for ships navigating in these conditions. Sea ice condition may result different maritime accident, Figure 2.6 shows the relationship between sea ice conditions and accidents. The participant groups of ice navigation were composed by icebreaker captains and officers, pilots, and VTS operators who have long experience in the performance of their duties(Valdez Banda, O. A., Jalonen, R., Goerlandt, F., Montewka, J., & Kujala, P.,2014,pp.416-423).

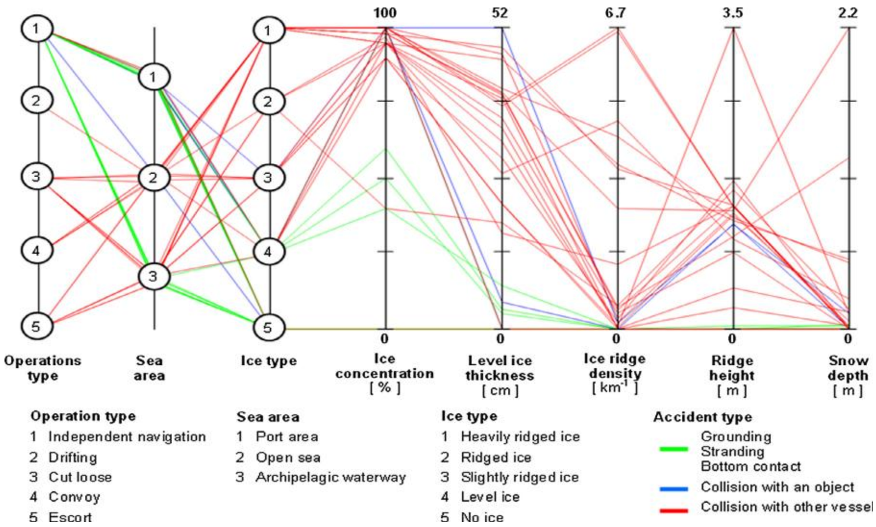

Figure 2.6 Ice navigation accidents in relation to sea ice conditions

(Source: Goerlandt, F., Goite, H., Banda, O. A. V., H?glund, A., Ahonen-Rainio, P., & Lensu, M. (2017). An analysis of wintertime navigational accidents in the northern Baltic Sea.)

2.4.1 Hazards for Seafarers

The hazards of sea ice on seafarers are mainly reflected in the following aspects: first of all, when the ship drop anchor in a anchorage of ice-covered waters, or the offshore facilities and platforms are frozen by sea ice, which is difficult to supply fuel, food and fresh water affecting normal life of seafarers who work on ships and offshore facilities. Secondly, the sea ice caused by the cold weather, icing on the ship deck may increase the difficulty and burden of the seafarers' deck work, which will affect the physical and mental health of the seafarers. Thirdly, the reflection of sea ice will have some influence on the visual perception of ship officers. Finally, if the seafarers in distress at sea, the distressed seafarers will have less life support time in sea ice than in normal water, and SAR is more difficult, increasing the risk of people in distress.

2.4.2 Hazards for Ships

Sea ice affects ships in many aspects. Direct impacts on safe navigation of ships as follows:

I. The influence for ship's structure and equipment:

i. Main engine: When the sea is covered by sea ice, which will increase the navigation resistance of ships leading to the load increase of main engine. The main engine may be damaged in severe situation.

ii. Piping system: The ships' piping system may be frozen or blocked by sea ice causing the piping system to rupture. The broken sea ice may block the water inlet of the main engine circulating cooling water, making the main engine unable to operate normally.

iii. Ship's stability: Superstructure icing is a complicated process which depends upon meteorological conditions, condition of loading, and behavior of the vessel in stormy weather, as well as on the size and location of the superstructure and rigging. The more common cause of ice formation is the deposit of water droplets on the vessel's structure. When the icing appears on ship, which is easy to reduce the stability of the ship. There are three possible causes of icing, including fog, precipitation and water spraying. Superstructure icing is possible whenever air temperatures are -2.2 ℃ or less and winds are 17 knots or more(Figure 2.7). It is very likely to take place when these conditions occur at the same time.

iv. Rudder and propeller：The rudder and propeller are easily damaged by collision with sea ice(Figure 2.8).

v. Ship's hull: When the ship collide with sea ice, which can cause hull damage or deformation.

vi. Navigation equipment: Sea ice may affect the normal transmission of radar echoes, radio waves and other signals. And because of the ice on the navigation equipment antenna, which may cause radio equipment and radar to fail.

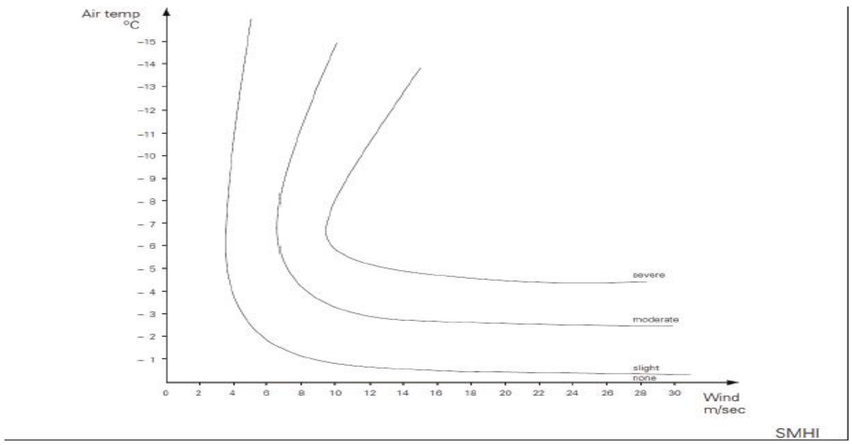

Figure 2.7 The relationship between the degree of ice formation, wind force and air temperature

(Source: Dr. Sandra Schwegmann,Dr. Jürgen Holfort. (2017). The ice winter of 2016/17 on the German North and Baltic Sea coasts with a brief description of ice conditions in the entire Baltic Sea region.)

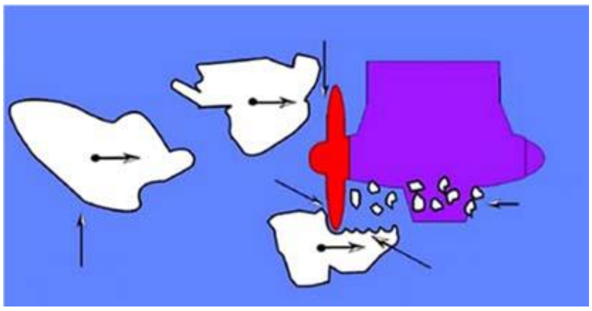

Figure 2.8 The interaction between sea ice and propeller

(Source: Sun Wenlin, Wang Chao, Kang Rui & Wang Guolian. (2015). Several considerations in the design of propulsion systems for ships sailing in ice-covered.)

II. The influence for ship's maneuvering:

i. Fix the ship's position: Sea ice has a particularly strong impact on buoys. At the beginning of the ice period, the sea ice and buoys are frozen together, with the movement of sea ice most of the buoys will be pushed by the sea ice to break the chain and run away, which will lost navigational function of buoys. It may even make ships aground.

ii. Course stability: When a ship is sailing in a large ice waters, in order to proceeding forward, ship need to break the sea ice by pushing and colliding with sea ice. Because of the ice on both sides of the ship, the course stability is well, but it is hard for a ship to turn the curse especially in the way point, changing the course may cause the ship aground.

iii. Ship speed: The frictional resistance of ship sailing in ice waters is much higher than that of ship sailing in normal waters, so the speed of ship sailing in ice waters will be greatly reduced. If the ship is sailing in ice waters with strong wind and current, the ship may not be able to move forward because of resistance from wind ,current and sea ice.

iv. Anchoring safety: Sea ice can make the ship drag anchor and break the anchor chain seriously. If the anchorage is covered by sea ice, the anchorage cannot be used.

v. Berthing safety: in port operations, the ship use the rudder and propeller frequently, therefore in the basin are crushed ice. When the ship is going to berthing operation, the crushed ice will gradually accumulate between ship and pier, which will impair the ship berthing or even berthing failure.

2.4.3 Hazards for Port Operations

The influence of sea ice on port operation is mainly reflected in the following aspects: first of all, when the sea ice is severe, the port will be blocked and closed according to the sea condition, which will affect the berthing operation and cargo operation of ships. Secondly, a large amount of sea ice accumulates in the fairway and anchorage, which affects the speed of ships entering and leaving the port to lead the delay of ships. Third, if ships are trapped by sea ice or drafted by sea ice, which is easy to cause collision between ships. In addition, the expansion pressure of sea ice will greatly damage the port facilities and ships, some navigation lights, lighthouses and other facilities will be seriously damaged, which affect normal shipping activities (Wu Tianchun.,2006,pp.17-19).

CHAPTER 3 SAFETY MEASURES FOR ICE NAVIGATION ABROAD

Whether the ship can pass through the high risk water covered by sea ice, it is necessary to fully identify and evaluate all related risks of its navigation environment. IMO and some countries who are plagued by sea ice a long time put forward mature safety regulations and safety measures for ice navigation through long-term research and practice, such as Russia, Canada whose research and safe navigation on ice-covered waters are more distinctive.

3.1 IMO

The SOLAS convention sets minimum standards for the construction, equipment and operation of ships to ensure the safe navigation of ships, the provisions of articles V/5, V/6, V/31 and V/32 of the SOLAS convention explicitly involve into the safe navigation of ships in ice waters, mainly including hydro-meteorological service, patrol in ice waters and reports of hazardous information and etc. The " International Code on Integrity Stability, 2008", which became mandatory on 1 July 2010 by amending the SOLAS convention, including mandatory part A and recommended part B, the relevant provisions of part B chapter 6, related to the influence of icing on the ships' stability and the factors to be considered. IMO also formulated the "Guide for Cold Water Survival" (MSC.1/Circ.1185), and provided guidance on how to prevent and reduce the harm caused by cold water, including some self-help skills, cold water survival and rescue checklist. In addition, IMO made the "Enhanced Contingency Planning Guidance for Passenger Ships Operating in Areas Remote from SAR Facilities"(MSC.1/ Circ.1184) and "Guideline on Voyage Planning for Passenger Ships Operating in Remote Areas" (A.999(25)), the two guidelines aim to enhance planning arrangements for ships operating in ice-covered areas and cooperate with relevant RCCs, the guidelines also give suggestions including ice information, ice navigators, operational limitations due to ice, safe distance to icebergs, carriage of special or enhanced equipment.

In 2010, the IMO Manila Conference adopted the resolution "Measures to Ensure the Competency of Captains and Officers Operating Ships in Polar Waters", Resolution mentioned that: " Due to the specific education, training, experience and related qualifications required for the master and officers sailing the polar waters, it is recommended that governments take practical measures to ensure that captains and officers sailing in polar waters to receive specialized training and experience, especially when the wind direction and visibility are unfavorable in the ice covered waters, the ship officers has the ability to enable the safe navigation of ships in the polar waters. In section B V/g of the Manila amendment of the STCW convention, detailed guidance on the training of captains and officers operating in polar waters(Wen Jin.,2015). It is suggested that the master, officers duty and should be trained the basic knowledge before taking up the polar ships, including the characteristics of sea ice, ice waters, icing, ship performance in cold climate, ship's voyage and passage plan, rules and recommendations for operating ships in ice waters, restriction of ship's equipment, safety precaution and emergency procedures.

On November 21, 2014, IMO MSC 94th Conference adopted the SOLAS convention's new chapter XIV amendment "Safety Measures for Operating in Polar Waters" and the "Polar Code". The "Polar Code" applies to all passenger ships operating in Polar waters and Polar ships over 500GT. The polar code are mainly composed of two parts, including mandatory parts and recommended parts, Part I-A is safety measures, including construction, equipment, communications, navigation, risk assessment, emergency, operation manual, personnel training, etc, I-B is recommendation, such as the reference to the IACS for polar class ship building standards. Similarly, part II-A is related to oil and sewage installation, ship's sewage discharge and other contents, including relevant mandatory requirements in the appendix of MARPOL convention, part II-B is recommendation also.

3.2 Russia

The northeast passage of arctic mainly passes through arctic coastal waters Russia, whose total distance is about 5620 n mile(Zhang Xingjie & Wang Chenlu.,2014,pp.21-24). The sea ice in Russia's northern sea route (NSR) is extensive, high density and high strength, and the condition will last a long term, which has important effects on ship structure, seafarers' skills, emergency response and environmental protection. In 2013, the Russia issued "Rules of Navigation on the Water Area of the Northern Sea Route" to explicitly defined the extent of NSR, which starts from the north of Bering Strait, passing through Chukchi Sea, De Long Strait, East Siberian Sea, Severnaya Zemlya, Kara Sea to reach the north of Novaya Zemlya(Figure 3.1). According to the website of Russia's northern sea route authority, the number of ships passing through NSR has increased year by year in recent years(Figure 3.2), ships passed through NSR in 2016 in Table 3.1.

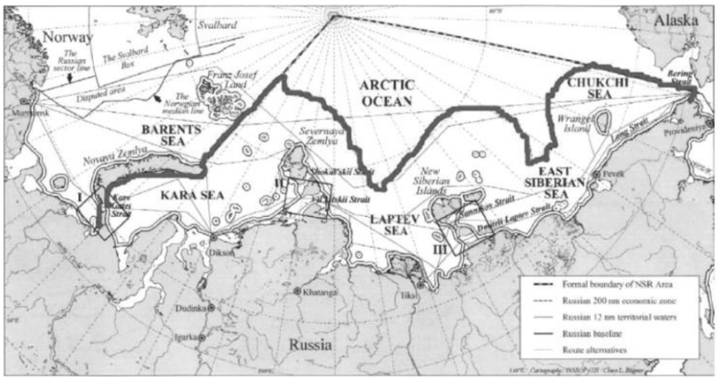

Figure 3.1 The extent of NSR

(Source: Zhang Xiao & Ding Yamin. (2014). Introduction of the navigation regulations of the northern sea route of Russia.)

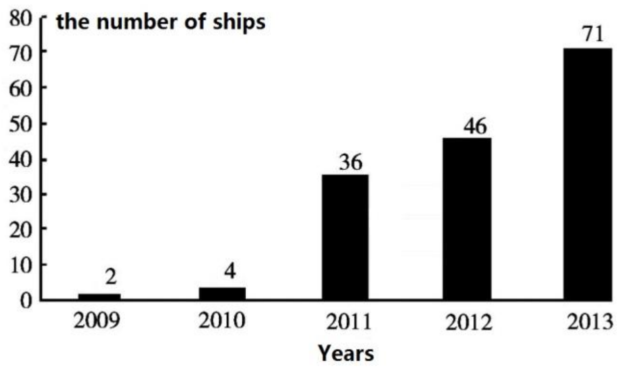

Figure 3.2 The number of ships passing through NSR

(Source: Zhang Xingjie & Wang Chenlu. (2014). The operation of merchant ships in the northern sea route (NSR) of Russia.)

Table 3.1 Ships passed through the NSR in 2016

(Source: Zhang Xiao & Ding Yamin. (2014). Introduction of the navigation regulations of the northern sea route of Russia.)

Ship Types	Quantity	Cargo Quantity	Ships' Displacement	Westing	Easting
Tanker	31	911 867		23	8
bulk carrier	4	276 939		3	1
LNG	1	66 868		1	0
General Cargo Ship	13	100 223		9	4
Light Ship	15		469 703	1	14
Others	7		38 027	4	3
Total	71	1 355 897		41	30

The "Rules of Navigation on the Water Area of the Northern Sea Route" is the most important for ships passing the NSR, The Rules include requirements on ships traffic organization, ice-breaker guidance, pilot in ice waters, recommended routes, hydro-meteorological services, maritime radio communication, pollution prevention from ships and etc.(Solski, J. J.,2013pp.362-366)

In accordance with the Rules, foreign ships sailing or transiting the NSR shall be subject to the licensing system, the license is issued by ANSR(Zhang Xiao & Ding Yamin.,2014,pp.14-17). The ship owner must ensure that the ship complies with the requirements of the ship design, equipment and seafarers of the Rules before entering the NSR.

The reporting area of NSR requires all ships passing through the northern Russian sea to report to the competent authority. The captain shall report to ANSR once a day on 1200 noon time (Local Time) during the ship enters the western or eastern boundary and before it leaves the NSR. The content of reporting includes: Ship's name and IMO number, ship's position, course, speed, wind direction, wind speed, visibility, wave, current, air temperature, sea temperature, fuel, fresh water, types, thickness and concentration of sea ice and etc.

In moderate and severe sea ice conditions, all ships sailing in NSR (except icebreakers) must be piloted by icebreakers. Communications between ships use VHF channels specified by the captain of the icebreaker in charge of piloting(Zou Leilei, Huang Shuolin & Fu Yu.,2014,pp.515-521). When ships follow the icebreaker, the master ensure that steering the ship in the position designated by the captain of icebreaker, keeping safe speed and safe distance designated by the captain of icebreaker, carrying out the captain's order of icebreaker, reporting to the icebreaker immediately if position, speed and distance cannot be maintained. hips passing through NSR shall be carried that personal cold protective equipment, personal survival kit, submerged pump, searchlight, red flashing light and facsimile equipment receiving the ice information. Over the years, the sea ice monitoring stations has provided abundant data on marine hydrology, meteorology and sea ice conditions in the Arctic area(Xie Guoqiang.,2014).

3.3 Canada

Canada is also one of the countries affected by sea ice. The northwest route of Arctic is mostly concentrated in the Canadian arctic islands waters, the total distance is about 800 n mile. The ice in east coast waters of Canada mainly belongs to sea water ice, which is usually made up of first year ice. The thickness of sea ice ranges from 30cm to 120cm, the area of sea ice are different, smaller one may reach about ten square meters, the bigger one may reach dozens of square meters. The bay of St. Lawrence is affected by the Labrador and Greenland cold current, and the St. Lawrence river releases a lot of fresh water into the ocean. So St. Lawrence bay has a long ice period.

The sea ice in coast of Canada is thick, large and widely distributed, which is constantly moving due to the influence of rivers and currents. When ship is sailing for a long time, it will be hit and pushed by sea ice, which will impact navigation of ships. So it is very difficult to avoid collision and keep steady on the course. Therefore, Canada has conducted analysis and research on the sea ice and impacts on ships, and issued the "Ice Navigation in Canadian Waters" to ensure safe navigation of ships in ice-covered waters.

Ice Navigation in Canadian Waters is published by the Canadian Coast Guard in collaboration with Transport Canada Marine Safety, the Canadian Ice Service of Environment Canada and the Canadian Hydrographic Service of Fisheries and Oceans Canada(Canada, F. O.,2012). The publication is intended to assist ships operating in ice in all Canadian waters, including the Arctic. This document will provide masters and watchkeeping seafarers of ships transiting Canadian ice-covered waters with the necessary understanding of the regulations, shipping support services, hazards and navigation techniques in ice (Xu Haijun, Liu yong & Li qiang.,2018,pp.58-60).

Ice Navigation in Canadian Waters is divided into 5 chapters and 3 appendixes, it gives the management guides of ships sailing in the ice waters of the Canadian from the aspects of icebreaking and shipping support services, regulations and guidelines, ice climatology and environmental conditions, navigation in ice covered waters and ship design and construction for ice operations.

Chapter 1 mainly introduces the icebreaking and shipping support services in ice waters, mainly related to operational considerations, communications and reporting requirements of navigating in ice waters, sea ice warning and shipping support services and etc. A variety of ice-breaking and support services can be used to ships passing through the ice-covered waters of Canada, such as ice information services for Canadian navigable waters are provided by Environment Canada’s Canadian Ice Service(CIS), the CIS has fully qualified ice service specialists, ice reconnaissance aircraft and icebreaker(Figure 3.3), the aircraft are equipped with radar remote sensing systems that are able to penetrate cloud cover to obtain a view of the surface below. The government of Canada provides up-to-date information on ice conditions, and advises ships to pass or bypass sea ice, and coordinates with icebreakers to assist sailing((Zou Leilei, Huang Shuolin & Fu Yu.,2014,pp.515-521). Meanwhile the government provides a limited number of icebreakers to support sailing.The document also encourages the captain to follow the recommended route(Figure3.4).

Figure 3.3 Dash-7 ice reconnaissance aircraft and Heavy icebreaker CCGS Terry Fox

(Source: Canada, F. O. (2012). Ice navigation in Canadian waters.)

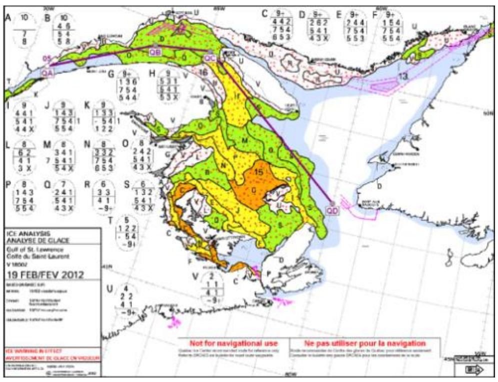

Figure 3.4 Example of a recommended ice route in the Gulf of St. Lawrence

(Source: Xu Haijun, Liu yong & Li qiang. (2018). Precautions for navigation in Port-Cartier and ice-covered areas of Canada)

Chapter 2 provides a summary of the rules and regulations for shipping through the Canadian ice area. The Canada Shipping Act applies to all Canadian territorial waters and fishing zones. These acts and regulations were created to enhance safety and to protect life, health, property and the marine environment. It is the responsibility of ship owners and operators to ensure that they comply with all applicable acts and regulations. For example, when a ship is sailing in an active ice control area, the guidelines apply to ships that have at least one "ice advisor" who meets the requirements of JIGs. Meanwhile, according to the related Acts, Arctic waters are divided into 16 safety control areas by ASPPR, the ice conditions are the most severe in area 1 and the lightest in area 16(Figure 3.5).

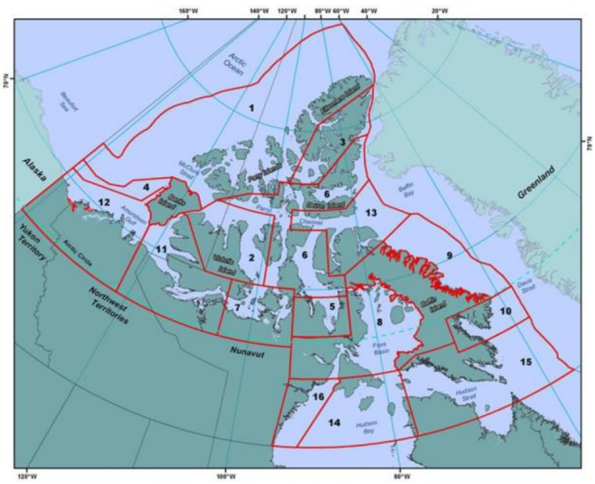

Figure 3.5 Shipping safety control zones

(Source: Canada, F. O. (2012). Ice navigation in Canadian waters.)

Chapter 3 focuses on the foreseeable environmental conditions in some areas of Canada, including the marine environment, important summary of the characteristics of meteorology and oceanography, basic description of the sea ice and the forecast of sea ice in different parts of Canada.

Chapter 4 is essentially instructional measures. It aims to provide the assistance and services for ships' officers without ice navigation experience, including the voyage plan, ice navigation program, ship maneuvering in ice water, SAR, oil spill and other necessary operating procedures in ice water. Ice is an obstacle to any ship, even an icebreaker, and the inexperienced Navigation Officer is advised to develop a healthy respect for the latent power and strength of ice in all its forms. However, it is quite possible, and continues to be proven so, for well-found ships in capable hands to navigate successfully through ice-covered waters(Canada, F. O.,2012).

The first principle of successful ice navigation is to maintain freedom of maneuver. Once a ship becomes trapped, the vessel goes wherever the ice goes. Ice navigation requires great patience and can be a tiring business with or without icebreaker escort. The open water long way round a difficult ice area whose limits are known is often the fastest and safest way to port, or to the open sea when leaving a port. Excessive speed is the major cause of damage to ships by sea ice, in the ice water all ships need to keep safe speed(Canada, F. O.,2012). Experience has proven that in ice of higher concentrations, four basic ship handling rules apply:

i. Keep moving - even very slowly, but try to keep moving;

ii. Try to work with the ice movement and weaknesses but not against them;

3. Excessive speed almost always results in ice damage; and

iii. Know your ship’s maneuvering characteristics.

This chapter also provides communications between ships and icebreakers. Reporting requirements before the start of the icebreaker escort and the safe distance between the icebreaker and the protected ships. Table 3.2 lists the letter, sound, visual, or radio-telephony signals that are for use between icebreakers and assisted ships. These signals are accepted internationally and they are restricted to the significance indicated in the table(Canada, F. O.,2012).

Table 3.2 Operational signals to be used to supplement radiotelephone communication between icebreaker and assisted ships

(Source: Canada, F. O. (2012). Ice navigation in Canadian waters.)

Code Letters	Icebreaker Instruction	Assisted Vessel(s) Response
WM	Icebreaker support is now commencing. Use special icebreaker support signals and keep continuous watch for sound, visual, or radiotelephony signals	
A	Go ahead (proceed along the ice channel)	I am going ahead. (I am proceeding along the ice channel)
G	I am going ahead, follow me	I am going ahead. I am following you
J	Do not follow me. (proceed along the ice channel)	I will not follow you (I will proceed along the ice channel)
P	Slow down	I am slowing down
N	Stop your engines	I am stopping my engines
H	Reverse your engines	I am reversing my engines
L	You should stop your vessel instantly	I am stopping my vessel
4	Stop. I am icebound	I am stopping my vessel
Q	Shorten the distance between vessels	I am shortening the distance
B	Increase the distance between vessels	I am increasing the distance
Y	Be ready to take (or cast off) the tow line	I am ready to take (or cast off) the tow line
FE	Stop your headway (given only to a ship in an ice channel ahead of an icebreaker)	I am stopping headway
WO	Icebreaker support is finished. Proceed to your destination	
5	Attention	Attention
Signals which may be used during icebreaking operations		
E	I am altering my course to starboard	I am altering my course to starboard
I	I am altering my course to port	I am altering my course to port
S	My engines are going astern	My engines are going astern
M	My vessel is stopped and making no way through the water	My vessel is stopped and making no progress through the water

Chapter 5 provides for seafarers with basic information on the ship design, ship construction, hull requirements and auxiliary systems for the operation of ships ice water. Such as the type of bulbous bow, hull shape, stern shape, ship structure arrangement, construction materials, main engine, propeller, auxiliary system(Figure 3.6) and other equipment related to safe navigation(Sun Wenlin, Wang Chao, Kang Rui & Wang Guolian.,2015,pp.31-36).

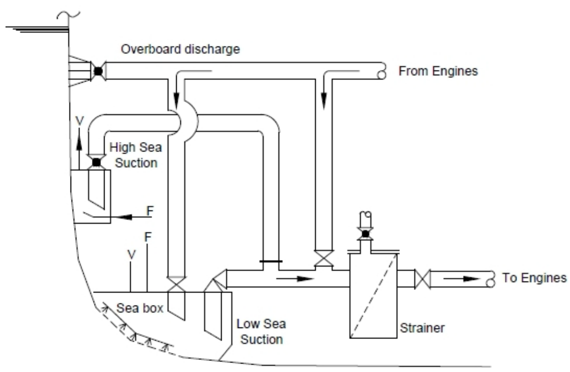

Figure 3.6 De-icing returns on sea boxand at strainer – section view

(Source: Canada, F. O. (2012). Ice navigation in Canadian waters.)

3.4 Summary

IMO regulations related to ice area are covered design, construction, equipment, operation, training, SAR and environmental protection of ice-area navigation ships. IMO focuses more on the regulations formulated to provide uniform regulations and safe suggestions for ice navigation, avoiding the disorder of navigation caused by different rules。

The navigation rules of the Russian ice-covered waters have made a detailed discussion on the application for convoy, navigation management, pilotage requirements and ship seaworthiness, etc. It has certain reference significance for ships passing through the NSR. The " Ice Navigation in Canadian Waters" aims to help ships sailing in the ice-covered waters of Canada, including the arctic areas. This manual helps the captain and officers on duty to know the laws and regulations to be observed when sailing in the ice-covered waters of Canada, available shipping support services in ice-covered waters, sea ice forecast, the risks in ice-covered waters and maneuvering skills, etc. Russia and Canada have the comprehensive navigational rules for ice navigation, but according to different navigational environment there are some different points between two countries.

Other countries and organizations also provide effective suggestions for ice navigation, such as IACS gives the specified ice class for ship construction, Canada also supports use of the Polar Class set out in the IACS(Table 3.3). EGG CODE (Figure 3.7) also is used for safe navigation in ice-covered waters provided by WMO. In Finnish waters, the safety of the wintertime maritime transportation system is managed through the Finnish–Swedish winter navigation system. This system results in different operational modes of ship navigation, with vessels either navigating independently or under icebreaker assistance. For Yingkou ice-covered waters, we need combine the local condition and mature measures abroad to put forward safe measures of ice navigation for itself.

Table 3.3 The Polar Classes set out in the IACS

(Source: Lin Dehui. (2016). Describition of Polar Code and related IMO and IACS documents.)

Polar Class	General Description
PC 1	Year-round operation in all Polar waters
PC 2	Year-round operation in moderate multi-year ice conditions
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

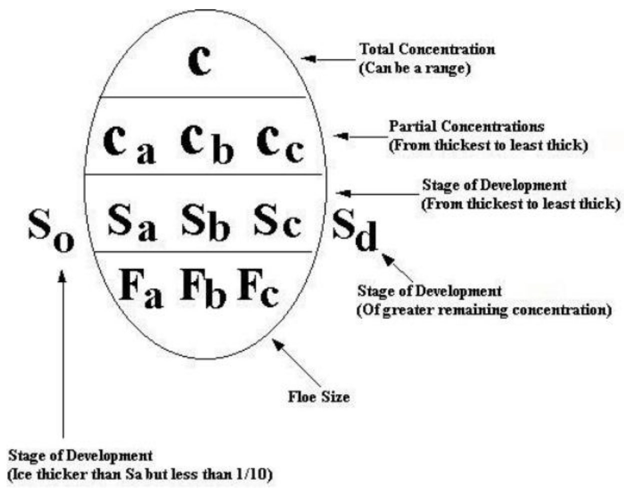

Figure 3.7 EGG CODE

(Source:https://www.bimco.org/ships-ports-and-voyage-planning/ice-information/general-information/wmo_egg_code)

CHAPTER 4 ANALYSIS ON THE CURRENT SITUATION OF ICE NAVIGATION IN YINGKOU ICE-COVERED WATERS

4.1 Natural Environment

4.1.1 Meteorological Environment

According to statistics, the temperature of Yingkou waters is fluctuation in winter, extreme minimum temperature is -30.8 ℃ occurring in February. In the 63 winters of 1951-2011(Figure 4.1), average temperature of the warmest winter is -5.5 ℃(1996), average temperature of the coldest winter is -7.6 ℃(1956).

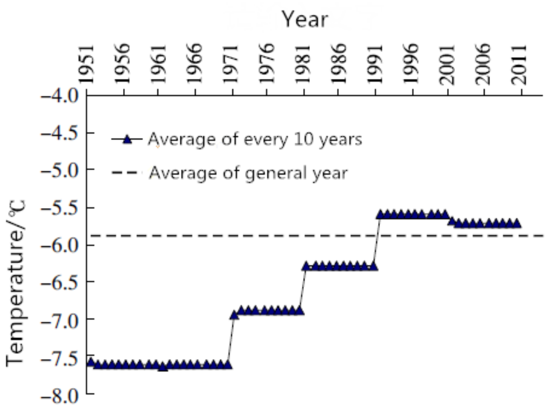

Figure 4.1 Winter temperature statistics of Yingkou waters from 1951 to 2011

(Source: Li Chunhua, Bai Shan, Liu Qinzheng & Song Jiaxi. (2008). The relationship between the ice area and the temperature of Yingkou.)

Fog is the main reason for the low visibility of the sea during the ice period in Yingkou waters. In the cold season, the Yingkou port water is steam fog. When the cold air passes through the open waters, if there is a large temperature difference between air and water, a large amount of water vapor evaporates from sea surface and condensation forms fog.

The perennial dominant wind direction is SSW, followed by NNE, with frequencies of 12.5% and 10.1% respectively. Autumn and winter are dominated by NNE. The combination of strong winds and sea ice can make the ship deviation, grounding and dragging anchor, and impact the maneuvering performance. In addition, the daylight is also the important factor in ice navigation, in the Yingkou waters, extended daylight conditions occur through the summer, whereas the converse is true during the winter months. Figure 4.2 illustrates the seasonal variability of daylight for different latitudes.

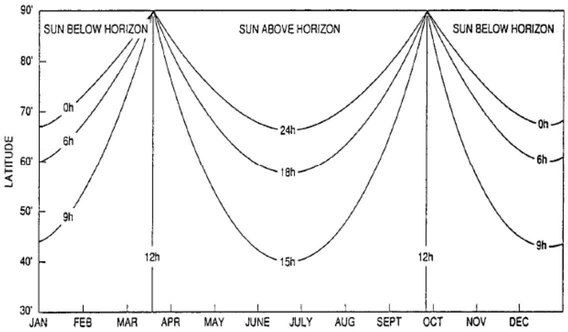

Figure 4.2 Seasonal Variability of Daylight by Latitude and Month

(Source: Xie Guoqiang. (2014). Study on navigation environment and safe navigation of the Arctic northeast route.)

4.1.2 Hydrological Environment

The current and tide accelerate relative speed of water flow on the side and bottom of ship, the counter-current ship side and the relative velocity of flow of bottom, which make the ship prone to collision, grounding and other accidents. Therefore, in general, the higher current velocity in the water, the more difficult it will be for ships to navigate.

The tides are irregular half-day mixed tides in Yingkou waters, rising and falling twice a day. The tidal current has obvious reversion, the direction of high tide is NNE and the direction of low tide is SSW during ice periods. Generally, the velocity of large tidal current is greater than that of small tidal current, and the velocity of high tide is greater than that of low tide. The period of high tide lasts 5h44min and the low tide lasts 6h42min. The average high water is 1.28m, the average low water level is -1.29m.

4.2 Sea Ice Information

Yingkou ice-covered waters lies between 40° 17′ N ~ 40 ° 14′ N(Figure 4.3), belongs to the typical semi-enclosed shallow inland waters, which is shallowest water in China. Due to the severe low temperature caused by frequent cold air invasion, there are different degrees of ice condition in winter. In addition to subject to weather conditions, the formation of sea ice also subjects to sunlight, salinity and other factors affecting the development of sea ice. In the the winter of 2011-2012 in Yingkou waters had the longest ice period, which is 96 days, and the annual degree of ice condition is 3. The winter of 2014-2015 had the shortest ice period, which was 74 days, and the annual degree was 1.0 (Table 4.1).

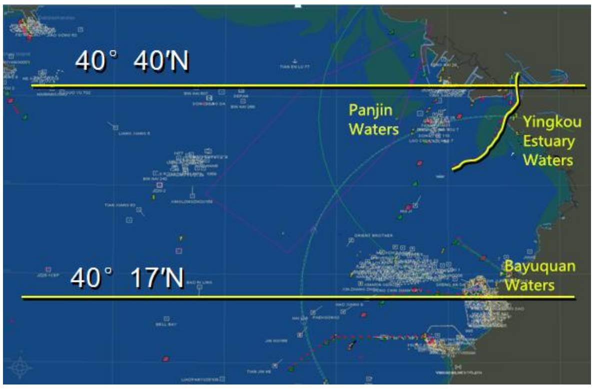

Figure 4.3 The extent of Yingkou Waters

(Source: From Yingkou MSA)

Year	Days of ice period	The difference from the average ice days	The degree of ice condition
2010–2011	82	−30	3.0
2011–2012	96	−16	3.0
2012–2013	87	−25	3.5
2013–2014	76	−36	1.5
2014–2015	74	−38	1.0

Table 4.1 Statistic of ice days in Yingkou waters in recent years

(Source: Yuan Shuai, Liu Yongqin, Liu Xueqin, Song Lina, Xu Ning & Shi Wenqi. (2017). Basic characteristics of ice conditions in Yingkou waters based on shore-based radar data.)

The distribution characteristics of sea ice in Yingkou waters can be divided into coastal frozen area, mudflat accumulation area and floating ice area from shore to sea:

i. Coastal Frozen Area: The coastal frozen area is located on a large area of mudflat, long time sea ice accumulating and low temperature controlling, which forms the large area ice field, the thickness of sea ice can reach above 90cm. Once coastal frozen area is formed, it moves vertically with the tide, the period of coastal frozen area lasts usually 60 to 70 days, and the regional range is stable.

ii. Mudflat Accumulation Area: There are many ice hills in mudflat accumulation area, the distribution is irregular(Figure 4.4). The ice hill has a complete internal structure, and its surface has been exposed to air, temperature of ice hills is very low controlled by air temperature, so the strength of the ice hills is very strong.

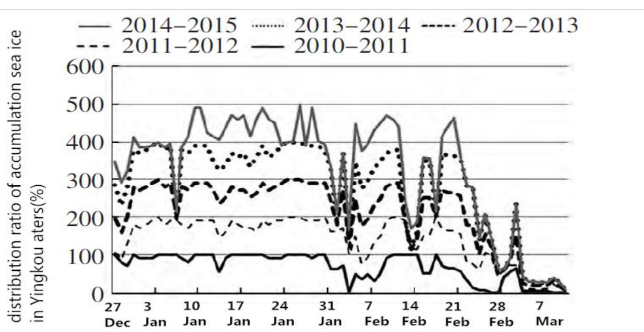

Figure 4.4 Line chart of accumulation sea ice in Yingkou waters

(Source: Wen Jin. (2015). Comprehensive assessment of safe navigation in ice-covered areas.)

iii. Floating Ice Area: Floating ice mainly comes from flat ice, ice ridge formed by extrusion between large sea ice, ice hill dropping from the coastal accumulation area. During the period of sea ice melting, there are often coastal gales leading to the accumulation of offshore ice, covering a large waters.

Gray ice, white ice and pack ice are mainly concentrated in coastal frozen area and mudflat accumulation area, which have great influence on coastal protection and port facilities. The floating ice is mostly distributed within 10 meters isobath, the grade of sea ice is 3/10~4/10, most of them are fresh ice and first-year ice with a diameter about 30 cm, especially under the strong wind and current. In recent years, during the ice period in Yingkou water, the beginning period was mainly ice rind, and the average distribution ratio of the beginning period was generally over 56%, followed by new ice, with an average distribution ratio of about 20%. For peak period, when the degree of ice condition was above 3.0, the ice type was mainly grey ice, the average distribution ratio was above 40%, the degree was below 3.0, the ice type was mainly nilas, the average distribution ratio was above 40%. The main ice types in the final period were mainly nilas, with an average distribution ratio of about 50%. Only in 2012-2013, when the degree of ice condition was 3.5, the final period was still dominated by gray ice, with an average distribution ratio of about 50%(Table 4.2).

Table 4.2 Statistical of ice types and average distribution proportion in different years in Yingkou ice-covered waters.

(Source:Yuan Shuai, Liu Yongqin, Liu Xueqin, Song Lina, Xu Ning & Shi Wenqi. (2017). Basic characteristics of ice conditions in Yingkou waters based on shore-based radar data.)

Year	Begining Period		Peak Period		Final Period		Degree of Ice Condition
2010–2011	Ni	R	G	Ni	R	Ni	3.0
	63	30	49	28	50	22	
2011–2012	R	N	G	Ni	Ni	G	3.0
	64	29	41	30	51	34	
2012–2013	R	N	G	Gw	G	Ni	3.5
	57	22	43	33	51	24	
2013–2014	R	N	Ni	R	Ni	R	1.5
	67	23	59	25	51	31	
2014–2015	R	Ni	Ni	G	Ni	R	1.0
	56	26	42	40	53	35	

4.3 AIDS to Navigation in Ice-Covered Waters

When the sea ice condition is serious, the light buoy often suffers from the body damage, shifting, abnormal lights, etc in Yingkou ice-covered waters, which reduce the efficiency of navigational AIDS or failure of light buoys. During ice periods most of the conventional buoys are lifted and are replaced in critical areas by unlit winter spar buoys(Figure 4.5). It should be noted that there is a possibility that these winter spar buoys may be:

a) under the ice,

b) off position,

c) of a dull or misleading color, or

d) missing from the charted position; thus, caution should be exercised accordingly when navigating in areas where they are used.

Similarly, the charted or listed characteristics of these lights should not be relied upon. The current edition of Notices to Mariners should be consulted for details(Yang Li.,2001).

Figure 4.5 Examples of winter buoys in Yingkou ice-covered water

(Source: An Hailun. (2016). Thinking on the light buoys operation in spring and winter in north sea area in China.)

4.4 Sea Ice Information Monitoring and Forecast

At present, sea ice prediction in China mainly relies on the establishment of accurate calculation formula of sea ice, and the application of mathematical statistical methods for ice trend prediction and numerical prediction. Yingkou Marine Environment Forecasts Institute holds daily sea ice status signal forecast service meetings, according to sea ice and meteorological conditions, combined with radar monitoring and remote sensing monitoring information(Figure 4.6), ship observations and the numerical prediction method, forecasting the sea ice development trend in the future. Sea ice warning is issued irregularly, it is a temporary emergency measures, the content including sea ice conditions, trend prediction and safety recommendations to attract the attention of the relevant aspects, reducing sea ice disaster.

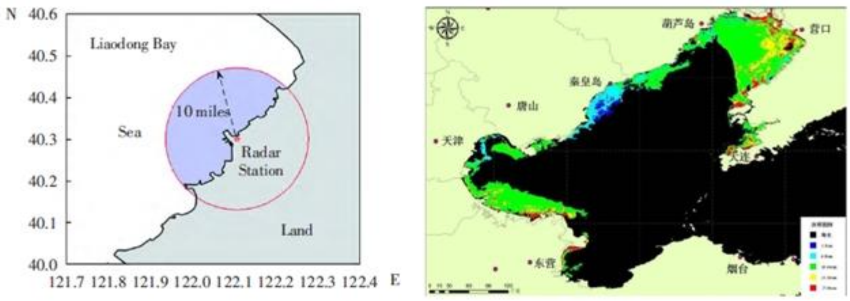

Figure 4.6 Radar Monitoring and Remote Sensing Monitoring of Sea Ice

(Source: From the Yingkou MSA)

4.5 Ice-Breaker Services

Ice strengthening refers to the strengthening measures that ships need to take on ship structures, main engine, shafts, propellers and cooling water systems related to sea ice when navigating the ice area. The extent of the strengthening is expressed by ice class. In 2006 CCS regulated the additional notations of ice strengthening, which means that the ship has the ability to break the ice under the corresponding ice conditions (Table 4.3). If a ship has not the related ice class, the port authority may decide whether to take the corresponding escort and ice-breaking services according to the ice condition when ship is entering the port.

Table 4.3 Ice class and navigational standards in China

(Source: Made by the Author)

Additional Notation	Description	
Ice Class B1*	The worst ice conditions	Navigating under severe ice conditions without the assistance of icebreakers.
Ice Class B1	Hard ice condition	Navigating under severe ice conditions, but icebreakers are needed when necessary.
Ice Class B2	Moderate ice condition	Normal navigation capability under moderate ice conditions. However, it should be assisted by icebreakers when needed.

Ice Class B3	Light ice condition	Normal navigation capability under light ice conditions. However, it should be assisted by icebreakers when needed.
Ice Class B	Light floating ice	Normal navigation capability under floating ice conditions.
Icebreaking	Icebreaking capacity	Non-ice-breaking vessels with independent ice-breaking capacity can navigate the frozen waters in the current year

The port authority provides a certain amount of ice-breaking tugboats to escort ships in and out of the port from the anchorage to piers(Figure 4.7 and Table 4.4). For small ships that cannot drop anchor in anchorage, the ice-breaking tugboats will sail to the area where the small ships are anchored to escort them to enter the port safely. Ice breaking in Yingkou port is free for customers throughout the journey.

Figure 4.7 Ice-breaking tugboats standby points in Yingkou ice-covered waters

(Source: From the Yingkou MSA)

Table 4.4 Ice-breaking tugboats in Yingkou waters

(Source: Made by Author)

Ship's Name	Types	Ship's Length	Gross Tonnage	Main Power(Hp)	Speed	Icebreaking Capacity
BeiFang 1	Tugboat	38	433	4800	12.5	B3
BeiFang 2	Tugboat	38	424	4800	12	B3

BeiFang 5	Tugboat	38	427	4800	12	B3
BeiFang 6	Tugboat	38	427	4800	12	B3
BeiFang 7	Tugboat	38	451	4800	12	B3
BeiFang 11	Tugboat	38	490	4800	12	B3
Xin BeiFang 1	Tugboat	35	490	6500	12	B3
Xin BeiFang 2	Tugboat	35.5	490	6500	12	B3
Xin BeiFang 3	Tugboat	35.5	494	6500	12	B3
Xin BeiFang 6	Tugboat	37.7	495	6500	12	B3
Xin BeiFang 7	Tugboat	35.99	575	6500	12	B3
Xin BeiFang 11	Tugboat	40.95	615	7800	12	B3
Xin BeiFang 12	Tugboat	40.95	615	7800	12	B3
Ying Gang 10	Tugboat	32.8	282	3200	13	B3
Ying Gang 11	Tugboat	29.5	177	980	10	B3
Ying Gang 12	Tugboat	54.68	857	3000	10	B3
Panjin Gang 1	Tugboat	34.5	370	3400	10	B3
Panjin Gang 2	Tugboat	34.5	370	3400	10	B3
BeiFang 10	Tugboat	38.5	490	4800	10	B3
BeiFang 12	Tugboat	38.5	490	4800	10	B3

CHAPTER 5 OPTIMIZATION OF SAFETY MEASURES FOR ICE NAVIGATION IN YINGKOU ICE-COVERED WATERS

As the maritime safety administration, it is necessary to continuously improve the regulations and measures on the safe navigation of ships in Yingkou ice-covered water from the aspects of supervisions and services. In order to cope with the current risks of sea ice, wind and other special navigational environment in Yingkou ice-covered waters, based on the research of ice navigation rules and safe measures of ice navigation abroad to improve the navigation efficiency of ice area.

5.1 Improve Sea Ice Monitoring and Forecast System

When sailing in the ice-covered water, the seafarers is not only concerned about the extent of sea ice, but also about dynamics and thickness of sea ice around the ship. Sea ice monitoring and forecast system play important role in preventing and reducing sea ice disasters, whether it is the large-scale sea ice movement form or small sea ice area characteristics, which have very important meaning and value. Therefore, it is very important to improve the ability of real-time monitoring and numerical forecasting of sea ice.

In sea ice monitoring system, sea ice satellite remote sensing monitoring technology has the characteristics of wide monitoring range and strong real-time performance, and with the development of technology, the precision of monitoring will be improved. Current sea ice satellite remote sensing mainly uses visible light and infrared remote sensing, which has advantages of wide monitoring area and visual image for sea ice monitoring, but its data easily affected by light, fog and other weather conditions, and it is difficult to obtain effective information of sea ice, affecting the continuity of the sea ice monitoring. Therefore, in the world, microwave remote sensing system is the main method, supplemented by visible light and infrared remote sensing to monitor sea ice, and SAR marine environment satellite is vigorously developed. The radar use microwave active detection method, which can penetrate clouds, rain, snow, smog and sand storms without being affected by weather factors. Because of the penetrating power of microwave, the SAR can obtain the microscopic physical structure information of sea ice, meanwhile the echo received by the radar is closely related to the surface shape of the detection area, it also reflect directly the surface roughness and texture information of sea ice. Foreign researchers can identify the physical characteristics of sea ice at different formation stages through SAR monitoring of sea ice in polar regions and the Baltic sea.

In sea ice numerical simulation, the sea ice data obtained by satellite remote sensing is only the precondition and data basis for sea ice numerical simulation and prediction. After obtaining the satellite remote sensing images of sea ice, through certain technical means, in combination with meteorological conditions, the evolution law of sea ice is studied in depth, numerical models were used to simulate sea ice evolution to establish the sea ice prediction model. The related parameters of sea ice forecast should have: trend of sea ice development, sea ice thickness and strength, concentration of sea ice, difficulty of navigation, etc. The most advanced and widely used model of sea ice in the world is the CICE 5.0 that is developed by Los Alamos national laboratory of USA, the model has a complex parameterization process and integrates the latest development of the sea ice numerical model(Liu Dayong.,2016,pp.5-6).

In China, we also lack advanced sea ice monitoring system and forecasting models, the monitoring of sea ice in China is generally based on large-scale satellite remote sensing monitoring, there are few mathematical models involved in studying sea ice monitoring on a small scale, it is difficult to grasp changes of sea ice in small scales. So advanced monitoring and forecast system is very important for us.

5.2 Sailing Support Services for Ice Navigation

The ice-breaking service and SAR in ice-covered ports are mainly undertaken by powerful tugboats have ice class, which is difficult to meet the needs of anti-sea ice disasters in Yingkou ice-covered waters. At present, it is less likely to build specialized icebreakers for port operations. MSA and port authority should have specified powerful tugboats with ice class to meet needs of safe navigation of ships during ice periods, and strengthen ice-covered water patrol and SAR capabilities. Related departments accurately grasp the ice-breaking information and make full use of resources of all parties.

Pilotage is important for safe navigation of ships in ice-covered water, port authority should provide pilotage service for ships sailing in ice-covered water(Li Yingfa.,2010,pp.30-31). The port authority shall publish the pilotage information on website and handbook(Dai Xianshun.,2017,pp.48-49). When the ship need the service, the ship call the pilot station by VHF to receive pilotage service, and take action according to the notification of the pilot station.

VTS shall broadcast the navigation safety information of the ice-covered water, the maritime safety information should include: wind, wave, current, tide, weather conditions, fog, sea ice and other detailed information. And the forecast of maritime safety information should be as detailed as possible and ships should receive in real-time. At present, sea ice observation of Yingkou water is not perfect, sea ice information is not detailed. Therefore, more observation stations should be set up in Yingkou water, especially in severe ice-covered water. All ships in ice-covered waters shall keep watching continuously on the VTS working channel.

VTS shall also provide the traffic organization for ships entering and leaving the port, adopting the mode of "big ships with small boats, heavy ships with light ships, and increasing the safe distance of ships". In severe ice conditions, an ice-breaking tugboat is used to guide one ship in and out of port.

5.3 Safe Operation for Ice Navigation

5.3.1 Preparation Before Entering Ice-covered Water

Before entering ice-covered water, ships should conduct detailed analysis of the surrounding sea ice information, and analyze the ice conditions that may be received:

(I)Recommended routes: before entering the ice-covered water, it is necessary to choose the area with less ice and thinner ice water to navigate according to experience, and select recommended route issued by MSA so as to ensure the safe navigation of ship.

(II)Before ship enters ice-covered water, the seafarer shall make full use of bridge resources, and carefully integrate and analyze the received ice data to monitor the sea ice development. Extra lookouts must be posted and the bridge watch may be increased, depending on the visibility.

(III)In order to ensure the reliability of sailing, the seafarer should also check the main engine and the steering system, and ensure the normal operation of the equipment on the ship, especially for radar operation.

(IV)Accurately adjust the ship's draft and take into account the ship's draft difference. In order to ensure safety of the ship, generally increase the draft to keep the ship trimming to ensure the propeller in water, which is good for the increase of ice breaking capacity and the stability of the ship.

(V) The vessel should be at right angles to the edge of the pack ice at entry to avoid glancing blows and the point of entering the ice must be chosen carefully (Figure 5.1), preferably in an area of lower ice concentration.

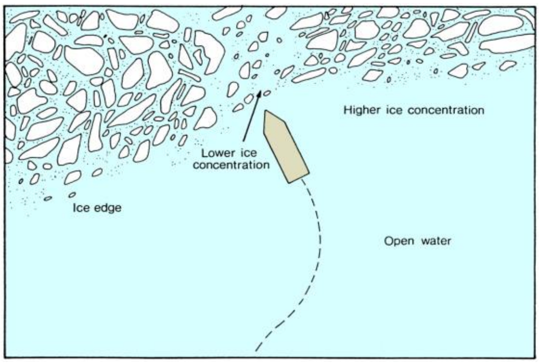

Figure 5.1 Correct approach to ice water: reduced speed and perpendicular to edge

(Source:Canada, F. O. (2012). Ice navigation in Canadian waters.)

5.3.2 Navigation Operation

Ice navigation operations are categorized in two general types: ship independent navigation and icebreaker assistance operations. Ship independent navigation is described as the navigational operation that begins when a merchant vessel enters areas covered with sea ice and navigates in them without in site assistance of any other type of vessel. Icebreaker assistance includes two main operation types: escort and convey (Rosenblad, 2007).

5.3.2.1 Ship Independent Navigation

(I) Maneuvering performance: When proceeding to ice-covered water, it is better to choose the leeward area to approach sea ice water slowly. When the bow has entered the ice area, properly reducing speed according to the situation(Li Huazhong & Zhao Daqi.,2013,pp.26-27). Special attention should be paid to the fact that under strong wind and lots of broken ice, ship need to move forward in leeward direction. Changes in course will be necessary when the vessel is in ice. If possible course changes should be carried out in an area of open water or in relatively light ice, as turning in ice requires substantially more power than turning in water, because the ship is trying to break ice with its length rather than with its bow, turns should be started early and make as wide angle as possible to achieve the new heading(Yin Lianghua.,2017,pp.20-21). Backing in ice is a dangerous maneuver as it exposes the most vulnerable parts of the ship, the rudder and propeller, to the ice. It should only be attempted when absolutely necessary and in any case the ship should never ram astern(Figure 5.2).

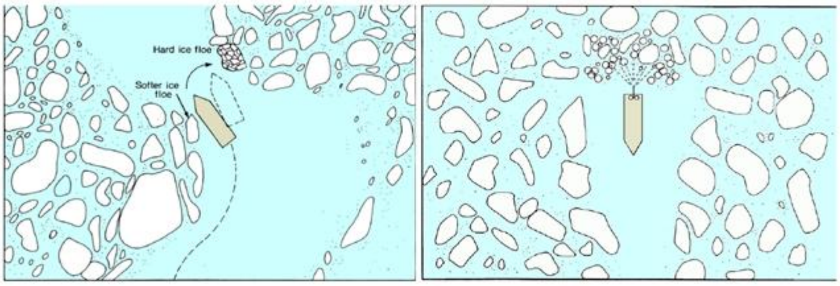

Figure 5.2 Turning and backing in ice-covered waters

(Source: Canada, F. O. (2012). Ice navigation in Canadian waters.)

(II)Ship positioning: Ships should strengthen their positioning when sailing in ice-covered waters with limited water depth. Before passing ice light buoys, officers should carefully check whether light buoys shifting and its reliability. As far as possible, isolated targets are chosen for radar positioning, seafarers make full use of the bridge resources, adopting a variety of methods positioning.

(III)Keep good lookout: When a ship is sailing in ice area, the bridge should strengthen the lookout so as to detect the other ship early, and take anti-collision measures as soon as possible. Hand steering should be used for anti-collision with other ships, because of influenced by sea ice resistance, it is note that the time for anti-collision should be earlier than usual, turning angle should be greater than usual and the safe distance should be longer than usual.

(IV)Ensure equipment is running normally and determine the safe speed: When sailing in the ice area, the officer shall timely check and maintain the bridge control system and the power system to ensure the ship can sail normally. In different ice area, there are different sea ice conditions, it is necessary to choose a suitable speed(Table 5.1) according to the structure and current situation of the ship.

Table 5.1 The safe speed in Yingkou ice-covered waters

(Source: From the documents of Yingkou MSA)

Sea ice condition	Under 4/10	5/10~6/10	7/10~8/10	Above 9/10
Speed	12	20	7	5

(V) Anchor in ice waters: Ships sailing in the ice-covered water should avoid anchoring as much as possible. The current generated by the high tide and low tide will cause the floating ice to drift. Ships anchored in the ice area are easy to be pressed by the floating ice. Where possible, the anchorage are far away from coast, suitable depth and sea bottom. When anchoring in ice area anchorage, if anchor chain is too long, it is easy to break the chain due to the movement of floating ice, so the short chain can be chosen. The length of the anchor chain should not be more than twice the water depth.

(VI)Berthing: When ship is berthing, there are sea ice intensively distributed between ship and berth, which is difficult for ship berthing. When approaching a berth in ice-covered waters it is desirable to have an officer stationed on the bow to call back the distance off the pier because a variation in ice thickness can result in a sudden increase or decrease in the closing speed of the bow and the wharf. It may be accomplished by landing the bow on the near end of the dock and sliding along the face, or by bringing the bow in to the desired location, passing a stout spring line, and going ahead slowly so that the wash flushes the ice out from between the dock and the ship .

5.3.2.2 Icebreaker Assistance Navigation

In areas with relatively high concentration of sea ice, the cooperation of icebreakers is needed for safe navigation of ships(Figure 5.3). The safe operation include safe distance, safe speed and good communication between icebreaker and ships assisted. The most important aspects are safe distance and safe speed. The officer of the ship needs to contact with the icebreaker timely to ensure the smooth communication.

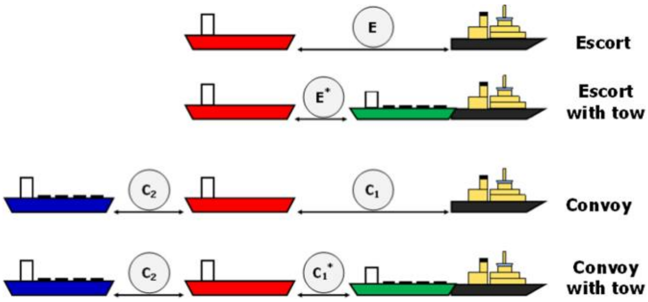

Figure 5.3 Distances in escort and convoy operations

(Source:Goerlandt, F., Montewka, J., Zhang, W., & Kujala, P. (2016). An analysis of ship escort and convoy operations in ice conditions.)

In escorting, an icebreaker breaks a channel and a vessel follows the icebreaker at a certain distance. In breaking loose operations, an icebreaker passes a ship beset in ice to break the ice beside and in front of the assisted ship, releasing the ice pressure. Convoy operations are similar to escorting but with several ships following the icebreaker. In double convoy operations, one icebreaker travels slightly ahead of the other icebreaker, to assist a vessel with a larger breadth than the icebreakers(Goerlandt, F., Montewka, J., Zhang, W., & Kujala, P.,2016). Simultaneously, a relatively proper speed is typically maintained in the convoy to ensure efficient transport flows. The empirical analysis results for the escort and convoy distances, escort and convoy speeds are presented in Figure 5.4 and Figure 5.5.

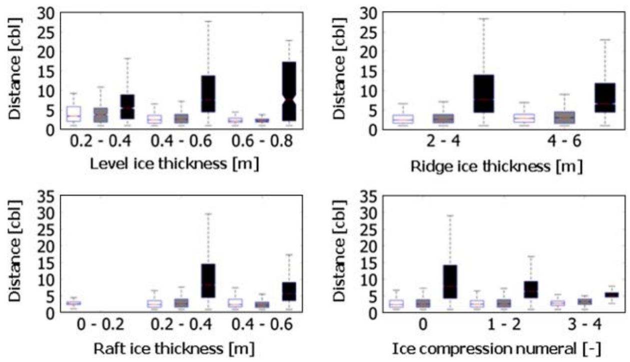

Figure 5.4 Distances in escort (white) and convoy (black) operations in different ice conditions (Source:Goerlandt, F., Montewka, J., Zhang, W., & Kujala, P. (2016). An analysis of ship escort and convoy operations in ice conditions.)

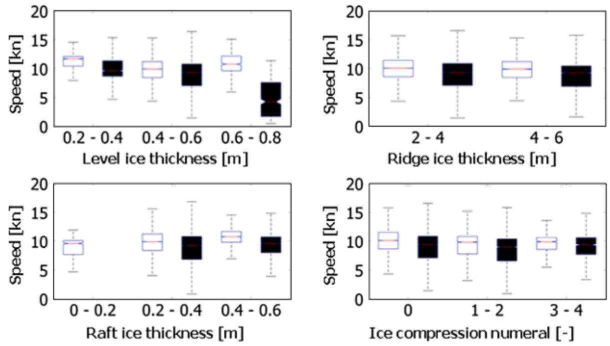

Figure 5.5 Speeds in escort (white) and convoy (black) operations in different ice conditions (Source: Goerlandt, F., Montewka, J., Zhang, W., & Kujala, P. (2016). An analysis of ship escort and convoy operations in ice conditions.)

5.4 Safeguard Measures of MSA

In addition to the ship needs to pay attention to the safety measures itself, the maritime authorities should provide many safeguards ahead of time, so that even in the event of severe sea ice condition, the ship will not be in danger during the voyage.

(I)Improve sea ice disaster emergency plan, detailed disposal plan should be included in the preplan including all emergencies facing during the ice period(Xiao Yang.,2014,pp.8-13). And maritime authorities regularly organize exercises to ensure appropriate emergency measures will be taken. The research work of sea ice disaster should be strengthened. All related departments improve emergency response capability and emergency rescue capability against the sea ice.

(II)Improve sea ice warning, timely broadcast navigational warning and notices to mariners. MSA broadcast accurate sea ice information to ships and relevant departments through radio communications, websites, television, mobile phone messages, etc. The MSA shall make full use of advanced means such as CCTV, AIS and VTS to strengthen information services for ships entering the sea ice area, and remind ships to pay attention to the sea ice condition.

(III)The navigational AIDS department shall make inspection of the AIDS operation, if any problem is found, the navigational warning shall immediately be broadcasted, and the department need timely maintain and replace the damaged navigational AIDS during the ice period. And navigational AIDS department carry out patrol inspection for navigational AIDS in key waters, and shorten the inspection period.

(IV)On-site inspection is very important to grasp the ice conditions at sea. MSA should step up patrol frequency and range of sea ice during the ice period, if the condition permits, using helicopters and patrol ship to monitor the sea ice condition, timely grasping the ice development.

5.5 Emergency Measures of Oil Spill in Ice-Covered Waters

The reduction in the extent and thickness of sea ice, and the recent failings that led to the Deepwater Horizon oil spill, have prompted industry and its regulatory agencies, governments, local communities and NGOs to look at all aspects of oil spill countermeasures with fresh eyes in ice-covered waters. Oil spill combating tactics strongly depend on response time, prevailing ice and metocean conditions as well as the availability of suitable equipment for oil spill response. In addition, the properties of oil products, the amount of oil spilled into the sea and on the ice are important aspects for the choice of efficient oil spill response technology and contingency planning(Evers, K. U.,2009).

5.5.1 Characteristics of Oil Spill in Ice-covered Water

In winter, oil present in these open water regions, known as leads, is likely to be incorporated in any newly formed ice. If the lead closes, oil incorporated within the new ice will form the blocks of the pressure ridge, essentially making the oil inaccessible for clean-up operations(Figure 5.6). However, if the oil is released below the ice cover, from a sunken vessel, pipeline breach or well blowout, the oil will rise through the water column breaking down into small droplets as it rises at the transition point of the multiphase plume driven flow (Johansen et al., 2013,pp.327-355).

(I)When the oil spill occurs in ice water, the oil will be in the middle of floating ice, or under the sea ice.

(II)The diffusion rate of oil spill is relatively slow. Due to the influence of icing and low temperature, the diffusion and movement speed of oil spill is usually slow, and thick oil film zone is easy to be formed, which is conducive to recovery. The oil spill in the crushed ice, oil can only be spread among the floating ice, the diffusion speed is smaller than the open water.

(III)The weathering speed of the oil spill is relatively slow, in other words, the emulsifying speed and viscosity increase speed are relatively slow, which provides the opportunity for the emergency measure.

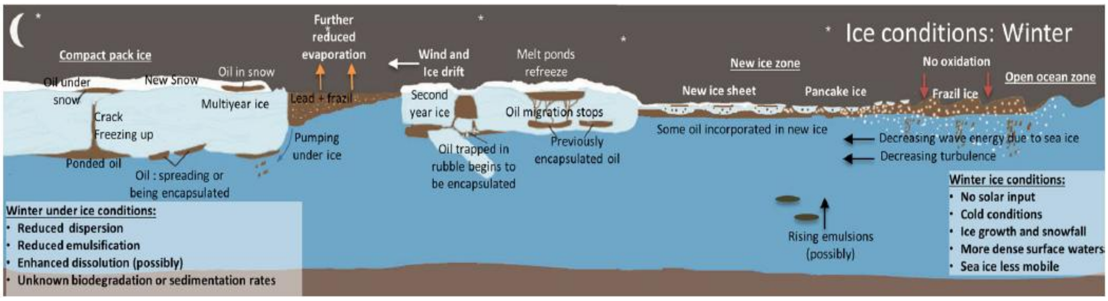

Figure 5.6 Oil spillage in ice-covered waters

(Source: Wilkinson, J., Beeglekrause, C. J., Evers, K. U., Hughes, N., Lewis, A., & Reed, M., et al. (2017). Oil spill response capabilities and technologies for ice-covered arctic marine waters: a review of recent developments and established practices.)

5.5.2 Emergency Measures for Oil Spill in Ice-covered Water

Many countries devote research on the equipment of oil spillage and measures for cleaning the oil. Such as Environment Canada has also been working to improve spill countermeasures in the Arctic. This has included the development and testing of new equipment including ice skimmers, conventional booms, water jet barriers, fire-resistant booms and slick igniters. Other countermeasures are also actively researched including the burning of oil and bitumens in ice, and the use of dispersants and other spill-treating agents(Hollebone, B., & Fingas, M. F.,2008).

(1)For water with large amounts of crushed ice, offshore inflatable containment booms and palisade containment booms should be considered first. Large quick protection containment boom, small containment boom and palisade containment booms are can be used in the early ice period and melting periods(Li Zhijun & Wang Peng.,2002,pp.1-6). For the oil spill containment below the sea surface, the oil can be recovered by means of the trawl of different sizes of nets. The proper application of the containment strategy should be paid attention when the implementation of oil spill containment in the ice area.

(2)Because of the special environment of oil spill in the ice area, emergency ships used in ice areas are generally required to be multifunctional, such as emergency ships can reach the accident site in any condition, can provide ice-breaking service, serve as oil spill emergency platform and oil pollution storage site, personnel evacuation and fire fighting in emergency situations, the ship need to meet the basic needs of the initial emergency response.

(3)Dispersants are a group of chemical agents, and the application of dispersants in emergency reactions can usually reduce the amount of oil spill on the water surface, thereby reducing the possible harm caused by oil spill. It is found that the application of dispersants is a feasible emergency method in ice-covered water because the interaction of floating ice can contribute to the dispersing process of dispersant.

Although the emergency and cleaning measures for oil spillage is developed, but the research of oil spill in ice-covered waters still not mature, the technology need to be improved. And there is currently very little in the scientific literature on the topic of worker safety and health in oil spill response in the Arctic, other ice-covered waters, and in very cold surface environments(Conway, G., Parker, W., & Burton, J.,2013,p.524). So we need focus on related aspect of oil spill in ice-covered waters in the future.

CHAPTER 6 CONCLUSION

If the ship does not have ice class certificate, it is not allowed to sail to the ice area in principle. Although Yingkou ice-covered waters cannot compare with polar waters and high latitude ice waters, but the sea ice in Yingkou waters still has great impacts for ship sailing and port operation. Sometimes due to operational requirements or emergencies, it is necessary to sail in the ice area under the escort of icebreakers. Only by mastering the distribution and movement laws of sea ice and understanding characteristics of sea ice, we can adopt the safe and effective measures in the ice area.

In this paper, based on the research of the sea ice characteristics and hazards, combined with foreign mature rules and measures, the paper put forward rationalized measures and suggestions from aspects of sea ice monitoring and early forecasting, ice navigation service, the maritime administration safeguard and oil pollution emergency in Yingkou ice-covered waters. China should be in strict accordance with the structure and strength requirements of IACS ice class to build the ice strengthening ships, promoting the use of ice class ships in the polar regions. Secondly in terms of crew training and certification, the relevant education and training institutions, should through the simulator training methods to increase ice navigation experience of the crew. Research on navigational facilities and sea ice monitoring technology should be strengthened to ensure the safe navigation of ships.

There are many deficiencies in this paper, such as how to use "big data" technology into sea ice monitoring, data fusion, analysis of multiple sea ice data so as to get more valuable information. The research on the escort mode of ships in ice area is also an important factor for the safe navigation of ice area, it is particularly important to study how to quantify the relationship between safe distance, safe speed and collision risk. It is hoped that the research of this paper will give certain reference role in the safe navigation safe of ice area in the future.

References:

An Hailun. (2016). Thinking on the light buoys operation in spring and winter in north sea area in China. *Tianjin Navigation*(2), pp.63-65.

Canada, F. O. (2012). Ice navigation in Canadian waters. *Manuals*.

Conway, G., Parker, W., & Burton, J. (2013). Occupational safety and health of arctic disaster and oil spill response workers. *International Journal of Circumpolar Health*, *72*, p.524.

Dai Xianshun. (2017). Precautions for pilotage in Yingkou ice-covered waters. *China Water Transport* (4), pp.48-49.

Dr. Sandra Schwegmann & Dr. Jürgen Holfort. (2017). The ice winter of 2016/17 on the German North and Baltic Sea coasts with a brief description of ice conditions in the entire Baltic Sea region.

Evers, K. U. (2009). Assessment of Oil Spill Response Systems and Methods for Ice-Covered Waters in Cold Environment. *Proceedings of the International Conference on Port and Ocean Engineering Under Arctic Conditions*.

Granskog, M., Kaartokallio, H., Kuosa, H., Thomas, D. N., & Vainio, J. (2006). Sea ice in the Baltic Sea – a review. *Estuarine Coastal & Shelf Science, 70*(1), pp.145-160.

Goerlandt, F., Goite, H., Banda, O. A. V., Hglund, A., Ahonen-Rainio, P., & Lensu, M. (2017). An analysis of wintertime navigational accidents in the northern Baltic Sea. *Safety Science*, *92*, pp.66-84.

Goerlandt, F., Montewka, J., Zhang, W., & Kujala, P. (2016). An analysis of ship escort and convoy operations in ice conditions. *Safety Science*.

Hollebone, B., & Fingas, M. F. (2008). *Oil Spills in the Arctic: A Review of Three Decades of Research at Environment Canada*. *Oil Spill Response: A Global Perspective*. Springer Netherlands.

Johansen, Ø., Brandvik, P. J., & Farooq, U. (2013). Droplet breakup in subsea oil releases--part 2: predictions of droplet size distributions with and without injection of chemical dispersants. *Marine Pollution Bulletin,73*(1), pp.327-335.

Lan Yang. (2015). Discussion on safe navigation in ice areas based on the Chinese merchant ships first voyage to the Arctic northeast route. *Joint Journal of TianJin*

Vocational College, 17(3), pp.80-83.

Li Chunhua, Bai Shan, Liu Qinzheng & Song Jiaxi. (2008). The relationship between the ice area and the temperature of Yingkou. *Marine Forecasts,25*(1), pp.1-4.

Li Huazhong & Zhao Daqi. (2013). Safe operation rules for entering and leaving Bayuquan ice-covered waters. *China Water Transport (Second Half)* (2), pp.26-27.

Li Yingfa. (2010). An overview of the safe pilotage of ships in Bayuquan ice-covered area in winter. *China Water Transport (Second Half),10*(10), pp.30-31.

Li Zhijun & Wang Peng. (2002). Prospect of oil spill cleaning technology in low temperature and ice-covered waters. *China Offshore Platform,17*(4), pp.1-6.

Lin Dehui. (2016). Describition of Polar Code and related IMO and IACS documents. *Ships, 27*(5), pp.101-109.

Liu Dayong. (2016). Analysis on safe navigation of ships in ice area. *Seamanship* (4), pp.5-6.

Lv Xiaodong. (2015). Basic knowledge of sea ice and matters needing attention in sailing ice-covered waters. *Pearl River Water Transport* (4), pp.77-79.

Sun Wenlin. (2016). *Research on propeller strength of ships sailing in ice area*. (Doctoral dissertation, Harbin Engineering University).

Sun Wenlin, Wang Chao, Kang Rui & Wang Guolian. (2015). Several considerations in the design of propulsion systems for ships sailing in ice-covered. *Ship Engineering* (9), pp.31-36.

Solski, J. J. (2013). New developments in russian regulation of navigation on the northern sea route. *Voen Med Zh, 685*, pp.362-366.

The Baltic International Maritime Conference web site gives further information on EGG CODE :
https://www.bimco.org/ships-ports-and-voyage-planning/ice-information/general-information/wmo_egg_code

The National Snow and Ice Data Center of USA web site gives further information on sea ice extent of Arctic:
http://nsidc.org/arcticseaicenews/

Valdez Banda, O. A., Jalonen, R., Goerlandt, F., Montewka, J., & Kujala, P. (2014). Hazard identification in winter navigation.*Journal of Applied Polymer Science,* *115*(115), pp.416-423.

Wen Jin. (2015). *Comprehensive assessment of safe navigation in ice-covered areas*. Unpublished master's thesis, Dalian Maritime University, China, Dalian.

Wilkinson, J., Beeglekrause, C. J., Evers, K. U., Hughes, N., Lewis, A., & Reed, M., et al. (2017). Oil spill response capabilities and technologies for ice-covered arctic marine waters: a review of recent developments and established practices. *Ambio, 46*(Suppl 3), pp.423-441.

Wu Tianchun. (2006). Safe navigation of navigable waters in ice-covered areas. *Seamanship* (6), pp.17-19.

Xiao Yang. (2014). Achievements, problems and prospects of cooperation in Arctic maritime and air search and rescue. *Journal of Ocean University of China (Social Science Edition)* (3), pp.8-13.

Xie Guoqiang. (2014). *Study on navigation environment and safe navigation of the Arctic northeast route*. Unpublished master's thesis, Dalian Maritime University, China, Dalian.

Xu Haijun, Liu yong & Li qiang. (2018). Precautions for navigation in Port-Cartier and ice-covered areas of Canada. *China MSA*(2), pp.58-60.

Yang Li. (2001). Analysis on the AIDS to navigation ability in Bayuquan waters in winter. *China Nautical Institute 2001 Coastal Light Buoys Academic Seminar*.

Yin Lianghua. (2017). Precautions of ships sailing and berthing in the frigid waters. *China Water Transport (Second Half),17*(4), pp.20-21.

Yuan Shuai, Liu Yongqin, Liu Xueqin, Song Lina, Xu Ning & Shi Wenqi. (2017). Basic characteristics of ice conditions in Yingkou waters based on shore-based radar data. Marine Science Bulletin, 36(5), pp.528-531.

Zhao Baogang. (2008). *Research on monitoring and forecasting technology of sea ice in Liaodong bay.* Unpublished master's thesis, Dalian Maritime University, China, Dalian.

Zhang Baoxin. (2018). Ice navigation and safety countermeasures. *Navigation* (2).

Zhang Xiao & Ding Yamin. (2014). Introduction of the navigation regulations of the northern sea route of Russia. *Seamanship* (6), pp.14-17.

Zhang Xingjie. (2015). *Risk assessment of safe navigation of merchant ships in polar* *regions*. Unpublished master's thesis, Jimei University, China, Xiamen.

Zhang Xingjie & Wang Chenlu. (2014). The operation of merchant ships in the northern sea route (NSR) of Russia. *China MSA*(9), pp.21-24.

Zhang Zengguang. (2010). Navigational risks and precautions in ice-covered areas. *National symposium on meteorological, marine environment and safe navigation of ships*.

Zou Leilei, Huang Shuolin & Fu Yu. (2014). A comparative study on the management of the northwest route in Canada and the northern sea route in Russia. *Polar Research* (4), pp.515-521.

Zou Zhongsheng. (2010). *Safety analysis of ship icing and anchorage in ice-covered areas*. Unpublished master's thesis, Dalian Maritime University, China, Dalian.