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MANAGING AND MITIGATING THE RISKS OF MATERIALS SELECTION FOR THE WINTERISATION OF EXPOSED DECK EQUIPMENT AND SYSTEMS

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ABSTRACT

More and more ships are operating in cold climates. At the time of design such ships require a focused review of their arrangements, systems and components. Coupled with the increased number of ships operating in cold regions, is an increase in specialised ships being designed and built for dedicated trade routes or specific locations, or modes of operations. This level of specialisation also requires a focused review to account for the peculiarities of the ship design and operating environment. This paper discusses the development of Lloyd's Register's winterisation rules which account for the specific nature of operating in low temperature environments, and in particular focuses on the need to undertake a systematic review of the ship and its systems, using in this instance a risk assessment approach for materials selection of deck equipment and systems as an illustrative example. This paper highlights some of the considerations in undertaking this approach and outlines how the results of risk assessments may be applied in the context of winterisation rules.

1. INTRODUCTION

Most ships are designed to operate safely in temperatures down to freezing conditions, typically associated with an average air temperature of -10^{o}C, providing that the crew carry out basic precautions to prevent freezing of critical items. When operating at temperatures below this, the design will require a more focussed review of the fittings and materials, as well as the crew's safety, and their ability to operate the ship and carry out their tasks effectively and efficiently. Preparation for the challenges and understanding the risks is a key factor for successful operation in this harsh environment.

The need to assure safety and effectiveness for the growing trade in cold regions has inspired a rise in technology and innovation for ships, and is illustrated by the introduction of Lloyd's Register's Winterisation Rules[1]. The Winterisation rules have been developed to provide a standard of protection against cold temperatures and the effects of icing on the operation of the ship[2]. The rules are based on the experience Lloyd's Register has of these ships, as well as contributions from external specialists and feedback from experienced operators and shipbuilders. The challenge has been to provide requirements for the key features and balance the need to prescribe rules, whilst avoiding over-prescriptive solutions which might not accommodate the wide variation in operations, conditions and ship arrangements.

The winterisation rules are intended to cover two aspects associated with cold climates:

- *Cold temperatures* may affect the material properties or reduce operation of equipment and systems. For example, freezing liquids within pipes.
- *Icing* will cover exposed equipment and areas of the ship in ice and this ice must be removed to allow access and operation of the equipment.

In both instances, heating is one of the most effective means of protection, however, this may lead to increased energy, crew issues and maintenance (e.g. trace heating of steel will increase the temperature of the material and the subsequent reaction with water may result in accelerated corrosion of the steel). Therefore, alternative mitigation measures and means of protection need to be considered. Many of these design features are of a practical nature, such as materials selection, providing covers or locating pipe-work in internal spaces, to protect the crew and improve the ship safety.

Significantly, the winterisation rules provide requirements for the suitability of exposed hull construction materials as well as the materials for equipment and components at low temperatures. However, the latter, ensuring the suitability of materials for equipment is a difficult task, with manufacturers applying different materials, standards and methods dependent on the design working stress, testing method, item criticality and frequency of operation. Likewise, ships, and particularly those in cold climates, are employing more complex arrangements and technological features. Examples, of these include integrated electronic systems or complex containment systems such as those found on LNG carriers, as well as specific winterisation solutions such as electrical trace heating systems and ice class ships designed with dedicated operational profiles in ice. Other examples of designs specifically for ice applications are improved propulsion arrangements for ice, such as podded or azimuth propulsion units, as well as new improved materials including thicker and higher strength steels.

Regulations have also seen a movement towards providing a clearer basis and a rational approach. The International Maritime Organisation (IMO) goal based approach being one such development with the intention of providing a defined level of safety. The work at the International Maritime Organisation (IMO) developing a Polar Code is encompassing a risk based approach, with submissions being presented which discuss this approach with data from operations in Antarctic and Arctic waters[3]. The Arctic Marine Shipping Assessment (AMSA) report[4] is another example of recommendations being developed based on the hazards these regions present coupled with casualty and incident data.

This paper outlines the risk assessment approach taken to develop the Lloyd's Register Winterisation rules as a means of balancing complex arrangements with operational experience and practices. It explores some of the key features of the approach and uses illustrative examples to highlight some of the considerations and findings.

2. RISK ASSESSMENT APPROACHES FOR WINTERISATION

A risk assessment is a rational and systematic process for assessing the risks relating to safety and the protection of the marine environment. A risk assessment is also used to evaluate the options for reducing these risks, i.e. a tool to facilitate a transparent decision-making process. Where the risk is defined by the combination of the frequency (the number of occurrences per unit time) and the severity of the consequence (outcome of an incident), as outlined by the IMO Formal Safety Assessment (FSA)[5] and International Association of Classification Societies (IACS) Guide to Risk Assessments for Ship Operations[6]. One of the particular attributes that endears this approach to winterisation is that it provides a means of enabling potential hazards to be considered before a serious incident occurs. Such an approach is prevalent to operating in Polar regions where preparedness is a fundamental underpinning philosophy used in exploratory and research programmes in these remote locations.

Risk assessments also lend themselves to situations whenever there are uncertainties, e.g. in respect of data or expert judgment; whereby the significance of these uncertainties can be assessed. For example, operations in Polar regions are fewer compared to those in warmer regions of typical merchant activity and as such, less service experience is available to call upon. Classification Societies are also typically not always notified of failures or incidents of exposed equipment as often these are operational delays not affecting the Classification of the ship.

In the Polar regions there is higher preparedness of the crew and higher reliability and redundancy of systems on the ships and of the crew procedures. This increased level of reliability is set by the owners, operators and engineers who define level of risk by considering higher consequences of incidents such as the sensitivity of the Polar environments, coupled also with the demanding conditions, such as sea ice, posing an increasing threats and hazards. Risk assessment approaches provide a means of capturing this level of risk.

2.1 Problem definition

A key component of a risk assessment is the identification of hazards that may lead up to an event. This typically is the event which leads to the first of a sequence of events resulting in a hazardous situation, or system failure. Since winterisation covers a combination of systems and operational aspects, both independent and dependent events may occur, typically with both elements contributing to the final incident. A well-defined scope of risk assessment can help at this stage.

During this process typical defining questions include:

- What can freeze?
- What impact can freezing have on the systems function?
- What is exposed to icing?
- What items will be inaccessible due to ice accretion?
- Can the low temperatures freeze the liquid medium or ice cause a blockage?
- Will crew enter the (cold) space (during daily operations or an emergency)?

A winterisation checklist containing a list of generic items is often a useful tool in this process such that the applicable review can be made on the core items, such as safety systems, life saving appliances, fire fighting installations, deck equipment, navigation and habitability. The functions and systems can then be split in to an appropriate level of detail. However, any interactions of the systems should be borne in mind, i.e. compound effects.

2.2 Risk categories

The frequency and consequence may be determined from established practices. Typically three (or more) levels of risk are defined: Intolerable, Tolerable and Negligible. However, Classification focus is concentrated on the safety of the ship, the crew and environment and the resulting levels are associated with these. Winterisation also encompasses operational aspects, for example increased operational time due to restricted access to equipment covered in ice and time taken for removal, and thus categories may need to be included to address these aspects.

A risk matrix may be constructed to record the frequency and consequences of the occurrences, by adding or multiplying the frequency and consequence indices, often on a logarithmic scale to highlight the higher risk elements; although a clear understanding of these aspects is yet to be fully understood in the application to winterisation. As noted previously, these magnification aspects may include increased environmental sensitivity or account for the compound effects. From this table the relative risks may be established.

2.3 Mitigation and control measures

Risk control measures may prevent an event from occurring, reduce the frequency at which an event may occur or alter the consequences, to control the outcome of the event. Typical mitigation measures for winterisation include covers, drainage, circulation, flushing, heating, and suitable oils, lubricants and greases.

Preventive control measures are often preferred for Arctic and Antarctic operations, due to the remoteness of operation, higher consequences of failure in the operating environment and rapidly changing environmental conditions. The control measures may also be engineering or procedural based. For example, crew operations such as suitable training may be required, or changing rotations to reduce exposure times to low temperatures whilst engineering measures include protection of equipment and providing shelters for crew. The latter engineering systems may also be of a passive or active measure, for example, trace heating may be categorised as active when initiated by crew when operating in cold regions, or passive if automatically activated with a temperature sensor.

3. CASE STUDY

The following provides an illustrative case of using a risk assessment to develop winterisation requirements for materials selection ensuring appropriate material grades (toughness) and certification is applied.

3.1. Materials selection

Operation in cold climates requires hull construction and equipment materials being selected that are suitable for the operating environment. For ferritic steels there is a tendency for the toughness to reduce as temperature decreases, i.e. to become brittle. Grades of mild steels are graded in terms of a defined temperature to achieved at a specified Charpy energy, i.e. grades A, B, D and E are tested at +20°C, 0°C, -20°C and -40^{o}C respectively. IACS Unified Requirement (UR) S6[7] consequently stipulates suitable steel grades to be used in a ship structure based on the location of the item, thickness of the member under consideration and the air temperature. However, there is no simple relationship between the test temperature and the minimum operating temperature because the risk of brittle fracture depends on additional parameters. For example, although brittle failure itself is not a time dependent phenomenon, the operating time at low temperature is important. As the length of period of service at low temperature increases, the risk of the steel reducing to the air temperature increases, the risk of encountering heavy weather increases and the risk of a fatigue crack growing to a critical size before discovery increases.

Materials selection for hull structures, using IACS UR S6 is well developed and verified through service experience and adopts a process of classifying the structural members into three classes dependent on the criticality, stress levels, construction techniques, etc. However, there are no readily available international standards for the selection of materials for equipment and systems.

The winterisation rules were introduced in 2006 with the shipyard taking responsibility for materials selection for deck equipment and systems exposed to low temperatures. At that time shipyards had to demonstrate suitable protection at low temperatures from any of the following or other appropriate methods:
(a) Based on international or national standards.
(b) Technical investigations based on engineering principles.
(c) Service experience at the operating temperature.
(d) Mechanical tests (e.g. Charpy impact tests).

Guidance for materials selection was subsequently developed to assist shipbuilders with requirements being developed after further technical investigations and risk assessments. The following provides a summary of some of the key elements undertaken to develop the winterisation requirements for materials and typical certification requirements for machinery and deck components e.g. valves and piping, for low temperature operation.

3.2 Verification with in-service data

To define a quantitative risk level, an analysis of the Lloyd's Register (LR) damage statistics database was conducted. The purpose of this was to provide incident statistics for deck equipment, and to see whether a trend exists between the damages experienced on ice class ships and those without an ice class. The following items were chosen as illustrative examples:
- Windlass
- Anchor chain cable
- Anchor

The data was accumulated from LR survey reports over 20 years (1987 – 2007). The data is for all ships (greater than 500gt) and for all ships with ice class (ice class notations 1C, 1B, 1A and 1AS).

The results of the data analysis for the windlass are shown in Table 1, whilst a further breakdown of locations is shown in Table 2 and Figure 1. The comparison totals for the anchor chain cable and anchor is shown in Appendix A.

Table 1. Windlass totals

	All ships	Ice class ships
Total number of machines at risk and monitored	13307	1292
Defects per machine	0.23	0.14
Vessels affected per machine	0.13	0.09

Table 2. Breakdown of level two locations for windlass

Level two locations	Percentage of total defects		Incidence per 10 yrs service	
	All ships	Ice class ships	All ships	Ice class ships
Windlass system	0.37	1.07	0.0009	0.0018
Hydraulic system	12.35	19.79	0.0309	0.0331
Prime mover	12.65	6.95	0.0317	0.0116
Windlass	74.64	72.19	0.187	0.1207
Total	100	100	0.2506	0.1671

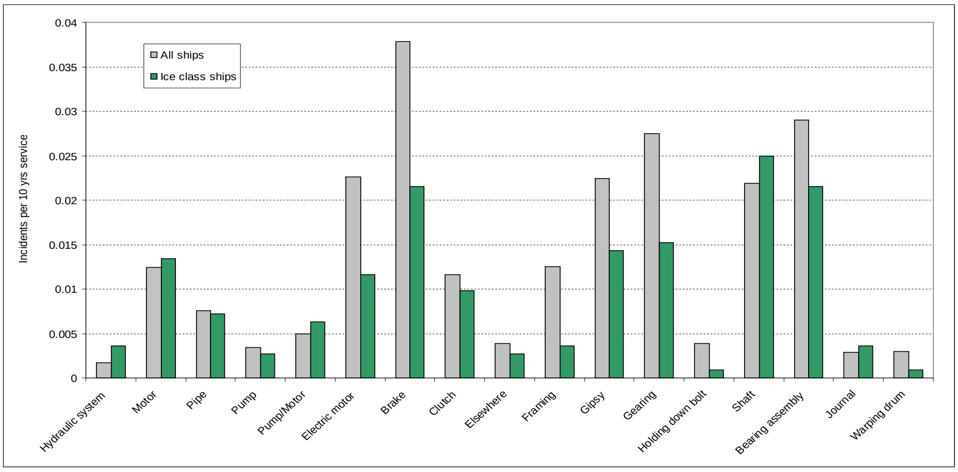

Figure 1. Location breakdown for windlass. Selected items shown only for incidents when recorded on ice class ships.

It may be noted from the statistics that in all instances; the total number of vessels affected and the number of defects per ship, are less for ice class ships than for all ships. On further examination with location, the general trend for ice class ships follows the same as for all ships. Minor differences exist, although this may be attributed to a lower number of ice class ships and the corresponding fewer instances of damages. Therefore, in the instances where there is a difference, between the ice class ships and all ships, the difference is small (and in most cases as a result of a single incident or failure). Consequently, a positive trend or difference between ice classed vessels and other vessels is difficult to ascertain from the statistics.

A further detailed search of the LR database was also undertaken for specific instances recorded as 'brittle fracture' for the windlass. Although, upon examination of the survey narratives, a number of the instances were dismissed, e.g. the ship was in warm waters or during the summer when the failure occurred. Indeed, the two instances attributed to cold weather were due to fatigue and then brittle fracture, and operation when ice accretion had frozen the windlass. There were no instances of brittle fracture recorded for anchors and chain cables.

It may be noted that the LR damage statistics presented here are inconclusive as to whether the material used for deck equipment on ice class ships is suitable for operation at low temperatures. The data shows that ice class ships experience similar damages to those without ice class. Therefore, there is no clear indication that materials currently used for deck equipment on an ice class ship are either sufficient or deficient.

3.3 Risk based framework

Due to the inconclusive nature of the statistical analysis of the in-service data, a qualitive risk assessment was undertaken with a number of specialists, notably, metallurgists, machinery and engineering systems experts, shipbuilders and seafarers with cold climate operation experience. The following describes some of the key aspects of the approach adopted.

During the process, the below risk categories were developed, and for all components, an assessment was made of the likelihood of failure and associated consequence as follows:

(a) **Likelihood of failure:**

This is the likelihood of failure during service and includes the frequency and size of loads (due to static/dynamic/fatigue loading and stress level), e.g. low stress and rarely used, low continuous cyclic stress or subject to high impact loads. Also included are consideration of manufacture and fabrication method (cast, forged, rolled, welded), exposure/corrosion, geometry, and the equipment location. The likelihood can additionally consider any relevant service experience, inspection and maintenance regimes, and engineering judgement as appropriate.

(b) **Consequence of failure:**

This considers the importance of the component, i.e. what effect will the failure of the components have on the operation of the ship or system? This is to include the impact on personnel safety, the environment or ship safety.

The likelihood of failure was graded between (1) and (3):

Likelihood of failure:

1. Low failure may occur during a ship's life.
2. Medium failure may occur during the mid life of a ship operation.
3. High failure may occur during any year of a ship's operation.

The consequence of failure was graded between (A) and (C)

Consequence of failure:

A. Low local failure with minor effect to operation with some impact on the item's intended function.

B. Medium possible loss of equipment/machinery/system, without any impact on personnel safety, the environment or ship safety.

C. High component fails and results in an impact on personnel safety, the environment or ship safety.

Appendix B shows an example extract from a winterisation risk assessment based on the above framework including some of the considerations during a risk assessment workshop.

A risk matrix was developed, which, as noted previously, is a tool for assessing risk based upon the likelihood of failure and the consequence of failure. By locating the component in the risk matrix, the class was determined based on three bands. See Tables 4 and 5.

Once the material class is determined, the thickness and lowest external design air temperature may be used to determine the corresponding material grade or testing temperature of the component to ensure suitable notch toughness. Tables 6, 7 and 8 shows examples of the criteria derived from IACS UR S6 used for determining the Charpy testing temperature for steel piping, valves and fittings used in machinery and systems components. Similar tables were developed for determining the Charpy testing temperature for steel forgings and castings used in exposed machinery and systems components.

Table 4. Risk matrix

Risk matrix		Likelihood of failure		
		1 Low	2 Medium	3 High
Consequence of failure	A High	1/A	2/A	3/A
	B Medium	1/B	2/B	3/B
	C Low	1/C	2/C	3/C

The classes may be determined from the following bands:

Class I	1/C, 1/B or 2/C
Class II	1/A. 2/B or 3/C
Class III	2/A, 3/B or 3/A

Table 5. Illustrative list of selection of equipment and components and class

Main component	**Sub-component**	**Class**
Deck machinery and equipment		
Windlass	Cable lifter	II
	Gear wheel	II
	Shaft	II
	Casing	I
	Foundation bolt	II
	Brake system	II
	Stripper bar	II
Mooring winches	Gear wheel	II
	Shaft	II
	Casing	I
	Foundation bolt	II
Winch motors	Hydraulics piping	II
	Hoses	II
Winch controls	Hydraulics	II
Bollards / fair leads / bits		III
Anchor chain, *see* Note 3		II
Anchor	Crown/head, shackle & shank	II
	Crown/head pin & shackle/swivel pin	I
Anchor lashing		II
Chain stopper		II
Emergency towing system		I

Table 6. Extract of Charpy testing temperature (°C) for class I

Thickness, mm	Lowest external design air temperature		
	–30°C to –34°C	**–35°C to –39°C**	**–40°C to –45°C**
$t \le 10$	+20	+20	+20
$10 < t \le 15$	+20	+20	0
$15 < t \le 20$	0	0	0
$20 < t \le 25$	0	0	-20
$25 < t \le 30$	0	-20	-20
$30 < t \le 35$	-20	-20	-20
$35 < t \le 45$	-20	-20	-20
$45 < t \le 50$	-20	-20	-40

Table 7. Extract of Charpy testing temperature (°C) for class II

Thickness, mm	Lowest external design air temperature		
	–30°C to –34°C	**–35°C to –39°C**	**–40°C to –45°C**
$t \le 10$	+20	+20	0
$10 < t \le 20$	0	0	-20
$20 < t \le 30$	0	-20	-20
$30 < t \le 40$	-20	-20	-40
$40 < t \le 45$	-20	-20	-40
$45 < t \le 50$	-40	-40	-40

Table 8. Extract of Charpy testing temperature (°C) for class III

Thickness, mm	Lowest external design air temperature		
	–30°C to –34°C	**–35°C to –39°C**	**–40°C to –45°C**
$t \le 10$	0	0	-20
$10 < t \le 20$	0	-20	-20
$20 < t \le 25$	-20	-20	-40
$25 < t \le 30$	-20	-40	-40
$30 < t \le 35$	-40	-40	-40
$35 < t \le 40$	-40	-40	-40
$40 < t \le 50$	-40	-40	-60

In association with this approach, it may be noted that a lower risk class may be accepted whereby it can be demonstrated from available experience and proposed mitigation measures, where such are in place, that these measures provide a level of protection that mitigate the risk for a specific vessel type/arrangement. Conversely, a higher risk class may be required by the same reason.

4. CONCLUSIONS

Navigating in cold climates poses a number of challenges, not least the suitability of equipment and systems to operate in low temperature and with ice accretion. The review of these systems requires a focused and systematic approach. The unique aspects of such reviews lends itself to a risk based approach to account for the level of uncertainty, limited in-service data, and accounts for the specialised nature of the ships and operations.

Lloyd's Register has successfully applied a risk assessment approach to the development of the Winterisation Rules to provide a level of protection for ships that is commensurate with the envisaged operations and arrangements. The approach has considered a number of aspects of the Winterisation Rules including materials selection for equipment and systems, mitigation of risk (e.g. space heating) and for the reliability and redundancy of the provisions for the equipment and systems.

The study has provided a unique insight into the application of winterisation defining the criticality of deck equipment and systems and associated selection of appropriate materials for low temperature service. The Lloyd's Register Winterisation Rules have incorporated the findings of the study and requirements have been introduced into the latest publication. When the Winterisation Rules are complied with a notation, Winterisation M or MEn, may be assigned to recognise the equipment and systems suitability at low temperatures.

Further work is still required to further develop our understanding of both the equipment criticality, component temperatures and materials behaviour in low temperatures. Development of probability distributions and accurate data will be one such route to improvement in the future. As the number of ships operating in cold climates increases, and the technology and complexity also increases, the application of a risk assessment approach will provide a rational and systematic means of assessment to further improve the safety of the ships and provide a basis for future rule development.

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APPENDIX A Comparison for anchor chain cable and anchor

Anchor chain cable	ALL SHIPS	ICE CLASS SHIPS
VESSELS AFFECTED PER TOTAL	0.33	0.32
DEFECTS PER TOTAL	0.64	0.56
Anchor	ALL SHIPS	ICE CLASS SHIPS
VESSELS AFFECTED PER TOTAL	0.23	0.20
DEFECTS PER TOTAL	0.38	0.32

APPENDIX B Example of risk table with extracts of some considerations and risk mitigation measures

Component	**Sub component**	**Hazard ~ What if**	**Consequence**	**Existing Safeguards**	**Cons**	**Likeli**	**Comments**
Windlass	Chain wheel (cast item)	Item is over stressed due to extreme temp	Windlass capability lost - ability to raise lower the anchor is lost.	Two windlass's; ability to start main propulsion plant; call for tugs etc	C	3	
	Gear wheel	Item is over stressed due to extreme temp	as above	Two windlass's; ability to start main propulsion plant; call for tugs etc	C	4	
	Shaft	Item is over stressed due to extreme temp	as above	Two windlass's; ability to start main propulsion plant; call for tugs etc	C	5	
	Casing	Over stressed due to temp	Casing cracks with impact on bearing housing and potential loss of windlass	As above & weld repair	C	5	
	Foundation bolt	Over stressed due to temp	Windlass is loose on deck; vibration etc potential for safety issue	Bolting arrangements are designed to take green sea loads	C	3	
Mooring winches	Gear wheel	Over stressed due to temp	Mooring capability lost	Two winches forward & aft, self tensioning winches	C	2	Winches are used significantly more than windlass's hence the difference in the frequency judgement
	Shaft	Over stressed due to temp	Mooring capability lost	Two winches forward & aft, self tensioning winches	C	3	
	Casing	Over stressed due to temp	Casing cracks with impact on bearing housing and potential loss of winch	Two winches forward & aft, self tensioning winches	C	5	
	Foundation bolt	Over stressed due to temp	Winch is lose on deck; vibration etc potential for safety issue	Two winches forward & aft, self tensioning winches	C	3	
Winch motors	Hydraulics piping etc	Over stressed due to temp	loss of pressure boundary and then winch	May be separate hydraulic packs per winch & NRV's e.g. redundant winches	C	5	
	Hoses	Over stressed due to temp	As above	as above	C	1	
	Hydraulic fluid	Hydraulic fluid freezes	Oil freezes & degraded operation	Owners reqs	B	1	Consider giving viscosity advice for hydraulic fluid in cold climate, or heating of fluid