Safety of Ships in Icing Conditions

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ABSTRACT

Icing of the above water part of ship poses serious hazard to stability. Icing may occur in high latitudes but also sometimes in other sea routes in adverse weather conditions. Present stability requirement as, for example, in 2008 IS Code, include certain provisions related to icing, but they seam to be inadequate, in particular in view of opening northern sea routes and trends to exploit arctic waters where possibility of icing and its effect on stability must be seriously considered. In the paper physical phenomena related to formation of icing and available data on amount of icing in various areas are considered. Possibility of application of risk analysis to the effect of icing on stability is also discussed

Keywords: *safety of ships, icing, risk analysis*

1. INTRODUCTION

Few years ago within a project sponsored by the Polish Committee for Scientific Research the group of ten experts was assembled consisting of seven ship masters having at least 20 years of service at sea on different types of ships, two scientist involved in stability matters and one experienced naval architects having wide experience in designing different types of ships. The group was charged with the task of assessing the importance of different hazards to stability for different types of ships. The Delphic method was used and the game was arranged. The game did show that the group of experts attached rather high priority (index 4 of the range 0 to 5) to hazard of icing in particular to fishing vessels and smaller passenger ships.

One of the masters having served many years on board passenger ships, produced photos of severe icing that happened during one particular voyage in North Atlantic. One of those photos reproduced below shows how serious threat to stability icing may pose.

At the same time about 300 stability accidents, the data on which were collected from many various sources, including IMO data bank, [IMO 1985] and book of Aksiutin and Blagoveschensky [1975] were analysed and it was discovered that in about 26 cases from the above number of accidents icing was considered as a main cause of capsizing.

Fig.1. Severe icing on m/s Stefan Batory in North Atlantic. (Courtesy of Captain H.Majek)

It is also difficult to imagine, that icing may cause capsizing of ships even in Black Sea, where two fishing vessels capsized because of severe icing in 2002 [Sukhanov et al 2003]. It is clear, that icing is creating severe hazard to stability and must be taken into consideration for ships operating in the areas where icing may occur.

2. STRUCTURAL MODEL OF ICE ACCRETION

Usual way of taking into account the effect of ice accretion on stability is based on very simple and deterministic structural model. It is assumed that certain amount of additional mass of accrued ice is taken on board. The centre of gravity of the ice is assumed to be in the centre of this mass. Because the mass of accrued ice usually is smaller than 10 per cent of the mass of the ship, simplified method of calculation of the new metacentric height and stability levers curve may be used. This is shown in the attached sketch (fig. 2)

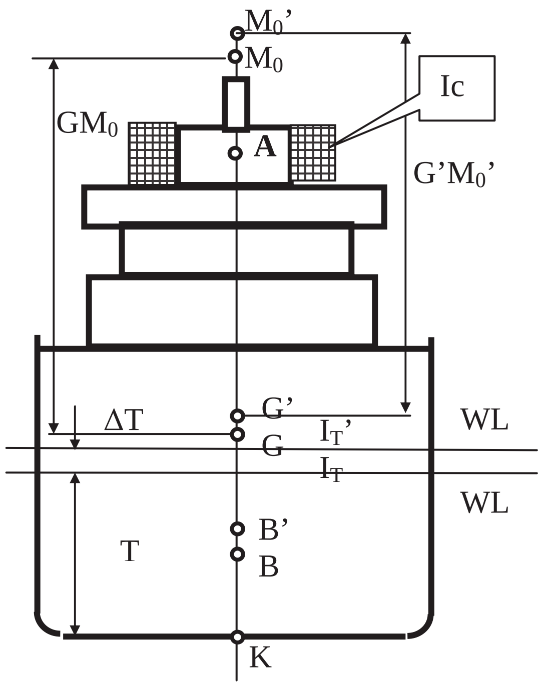

Fig.2. Structural model of the effect of ice accretion

New metacentric height could be calculated by the formula:

$$G'M_0' = GM_0 + \frac{m}{\rho\nabla + m}\left(T + \frac{\Delta T}{2} - KA - GM_0\right)$$

Because when ice is accrued always:

$$KA > T + \frac{\Delta T}{2} - GM_0$$

then the new metacentric height would be always smaller than the original one without icing.

New stability levers could be calculated with the formula (Fig.3):

$$GZ = BN - KG' \sin\varphi$$

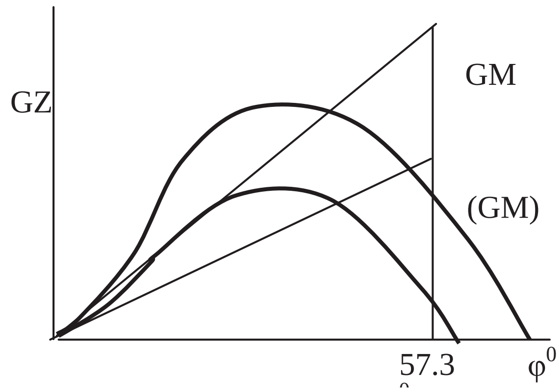

Fig. 3. Reduction of stability levers with icing

Accrued ice will also affect ship motion characteristics in rough sea, particularly rolling periods and deck wetness characteristics but these factors are rarely taken into account when considering problem of icing. The main problem is, however, proper estimation of the mass and centre of gravity of the accrued ice.

3. PHYSICS OF ICE ACCRETION

The physics of ice accretion is very complex and unpredictable phenomenon. Ice accretion depends on many factors as for example on:

- Temperature of air

- Temperature of the upper layer of water

- Wind velocity and direction

- Sea surface condition (waves, current etc)

- Ship speed, course in relation to wind and waves

- Ship characteristics (freeboard, deck and superstructures arrangement, ship motions etc)

Ice may accumulate basically in three different ways

- Freezing rain or drizzle cause thin layer of ice distributed almost evenly over decks, superstructures and rigging including high positioned objects like masts, antennas etc. Layer of accumulated ice increases quite slow, therefore dangerous increase of the position of centre of gravity occurs only when the ship is long time exposed to those effects. Generally this way of accumulating ice is not very dangerous for the ship.

- The second way of accumulating ice occurs when the temperature is at least 9^0 C less than the temperature of water. Freezing fog in contact with cold metal creates thin layer of ice. This usually is close to the waterline and is not very dangerous to the ship.

- The third way of icing is most dangerous. This type of ice accretion occurs when the temperature of air is very low and there is stormy wind and waves. In such situation sprays of water freeze in contact with the hull, decks, superstructures and rigging. It is less likely that sprays are cause icing higher above the water, however. But if at the same time there is heavy freezing rain, then large amount of ice may accumulate high above the water. This is the most dangerous case. The photo in fig. 1 shows how large amount of ice may accumulate on board The photo shows ice accrued on the deck of m.s Stefan Batory in North Atlantic.

In some publications information could be found that at very low air temperatures (below – 180C) this type of ice accretion is not present, because water sprays freeze in air and do not stick to the ship construction. Other observations do not agree with this, however. Four Russian fishing vessels capsized in Bering Sea in 1965 at temperatures between – 200 and -220 C. On "Norilsk" ship heavy icing was observed at temperature -280 C [Aksiutin 1975].

Usually icing does not occur at temperatures of water above +60, but in some cases icing was observed even at water temperature +80C.

The third type of icing occurs most often and when in conjunction with freezing rain is most dangerous. According to data collected by Borisenko [Aksiutin 1986], who analysed about 2000 cases of icing on ships of Russian fleet, frequency of different kinds of icing was as shown in the table 1.

Table 1. Frequency of different types of icing (percent)

	Sprays	Sprays plus rain	Snow	Fog, rain drizzle
Northern hemisphere	89.9	6.4	1.1	2.7
Southern hemisphere	50.0	41.0		9.0

Obviously heavy icing occurs usually only in certain areas. Chart where heavy icing may be expected is included in the IMO IS Code [IMO 2008]. The other chart showing areas in North Atlantic and North Pacific Oceans is reproduced in fig. 4. [Sechrist et al 1989]. However there are known incidents where heavy icing occurred in other areas, even in Black Sea.

For example extreme icing was observed on two Russian fishing vessels in Black Sea on 9th December 2002. Both ships capsized and foundered. Synoptic situation at that time was as follows: because of suddenly changing air circulation over eastern part of Black Sea, layer of cold air came over this part and air temperature drops down from +100C to −180C in 24 hours. Strong wind of about 35 m/s velocity called “Bora” occurred. Icing on both vessels started fast increasing and as all attempts to remove it failed, it was not possible to save the vessels [Sukhanov et al 2003]. According to data provided by Aksiutin (1986) heavy icing may be expected in periods and areas as shown in the table 2.

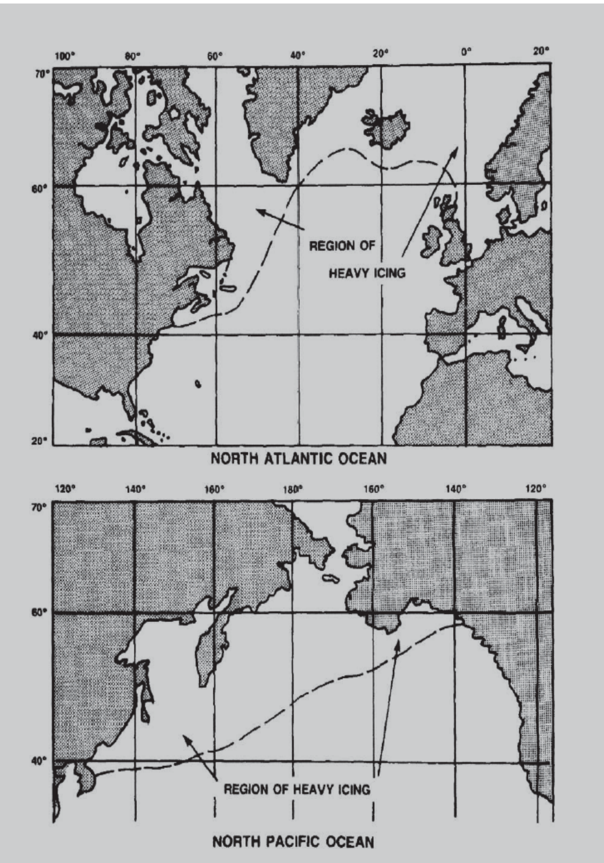

Fig. 4. Chart of areas where icing may be expected [Sechrist et al 1989].

Table 2. Areas and periods where heavy icing may be expected [Aksiutin 1975]

Area	**Period**
North-west Atlantic Ocean,	15 Dec-15 March
Norway and Greenland Sea	15 Dec-31 March
Northern Atlantic Ocean	15 Dec-15 April
Barents Sea	1 Jan - 15 March
Baltic Sea	15 Dec-
Baffin Sea	1 Dec-31 March
New Foundland area	1 Jan - 15 March
Bering Sea and Okhock Sea	1 Dec- 29 Feb
Japan Sea	1 Dec- 29 Feb
North-West Pacific Ocean	15 Dec-31 March
Karsk and , Laptiev Sea	15 June -15 Nov
Chukock Sea	15 June -15 Nov
East Siberian Sea	15 June -15 Nov

As icing depends on air temperature and wind velocity some data were published showing how fast layer of ice accumulates with increasing wind velocity and decreasing temperature. The diagram showing icing dependence on air temperature and wind velocity developed in Japan is reproduced in fig. 5 [Sawada 1962].

Similar diagrams were developed by Overland et al [1986] and also by the US Navy [1988]. Rate of ice accretion depends on the water and air temperature and on the wind velocity. According to Mertins [1968] who on the basis of 4000 observations in North Atlantic area, with the temperature of water 00C and air temperature -60C discovered that the ice accumulation may be 7 to 14cm in 24 hours.

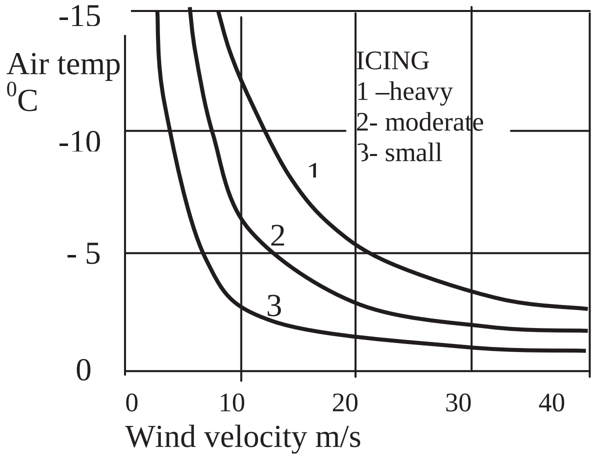

Fig.5.Icing dependence on air temperature and wind velocity.[Sawada 1962]

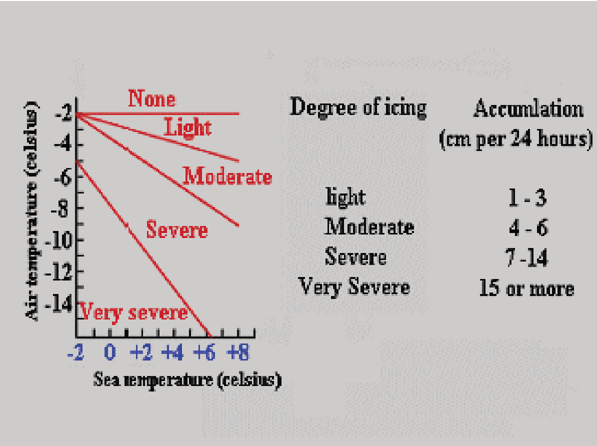

Fig 6. Nomogram for estimation of icing in North Atlantic for wind force 9-10^{0}B [Mertins 1968]

Mertins [1968] produced also diagrams for prediction of icing in relation on air and water temperatures and on wind force. One of these diagrams for wind force 9 -100B is reproduced in fig.6.

4. CURRENT CRITERIA OF ICING

Problem of icing is considered currently in several IMO instruments, for example in the IS Code, Polar Code, Torremolinos Protocol and in some other documents. The requirements and recommendations included there are not repeated here; they may be easily found in those documents, in particular in the 2008 IS Code, Chapter 6 and Annex 2 [IMO 2009] and they are not very different in other IMO documents.

The basic requirements for fishing vessels consist of specification of certain amount of accrued ice on exposed surfaces of weather decks and on projected lateral areas on each side of the vessel above the waterplane.

In most IMO instruments the recommended amount of accrued ice is:

- 30 kg/m2 of open weather decks, and gangways;
- 7.5 kg/m2for projected lateral area of each side of the vessel above the water plane.

In several national recommendations different values of accrued ice per square meter of open decks and projected lateral areas are recommended, but in general those values are not very different from the above.

In mid-eighties of the last century at the time when first edition of the IS Code was considered at IMO, many delegations pointed out that the above values are underestimated because 30 kg/m2 practically means 3 cm thick layer of ice. After discussion, however, it was decided that adoption of higher values in certain regions was left to the decision of national Administrations.

Aksyutin and Blagoveschensky [1975] pointed out that thickness of layer of ice as recommended in the IS Code was widely different from values observed in different regions. In 1000 observed cases of icing they analysed, thickness of accrued ice was greater than recommended by IS Code for fishing vessels:

In Baltic Sea by 76%
In Bering Sea by 71%
In Okhock and Japan Sea by 60%

The actual mass of accrued ice exceeded the mass calculated according to the recommendation of IS Code

In Barents Sea by 270%
In Okhock Sea by 200%
In Bering Sea by 360%
In Baltic Sea by 1000%

According to the same observations calculated position of the centre of gravity of accrued ice was usually 20 to 60 % higher than calculated according to IS Code recommendation which had important effect on stability characteristics of the vessel. There are many similar data available showing that ice accretion in certain conditions may by much larger than recommended by IS Code. This was duly noticed by the IMO Subcommittee, however finally it was decided to leave the decision in respect of the amount of accrued ice in hands of the national administrations.

5. OPERATIONAL FACTORS

Safety of ships in situations where icing occurs depends greatly on operational factors, first of all on possibility to remove accrued ice. In several IMO recommendations in this respect included, for example, in the IS Code, there is operational guidance on how to behave in situations when icing occurs, on how to prepare the vessel and what kind of equipment for removal of accumulated ice should be on board. Such operational guidance is essential for safety of the vessel but in real life quite often in cannot be observed.

Removal of excessive ice accumulating very fast in in bad weather, particularly if the vessel is weathering against the wind, cannot be accomplished because access to the forward part of the ship is too dangerous. Moreover in modern ships the number of crew members who could be employed in this work is much smaller than it was in older times. This particularly applies to small container ships and ships carrying deck load of timber. In fishing vessels having low freeboard in stormy weather deck is constantly flooded by the waves and if covered with ice, slippery. Therefore access there is risky. According to current requirements in relation to icing, assessment of safety in icing condition was left to the judgement of national Administrations. The requirements concerning values of accrued ice as, for example in the IS Code, seem to be roughly applicable to icing at comparatively mild weather conditions. There is nowhere, however, guidance on how to perform risk analysis for ships sailing in areas where heavy icing might occur.

6. EVENT TREE AND FAULT TREE FOR DANGEROUS ICING

Branches of event tree and fault tree for dangerous icing are shown in figs 7 and 8.

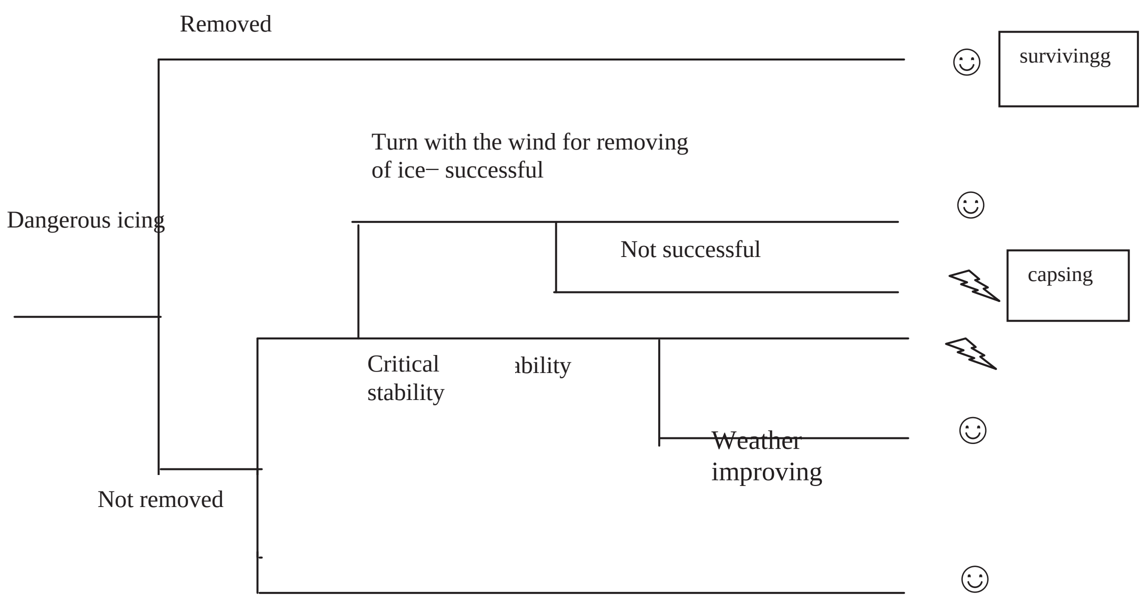

Fig.7. Branch of event tree for heavy icing

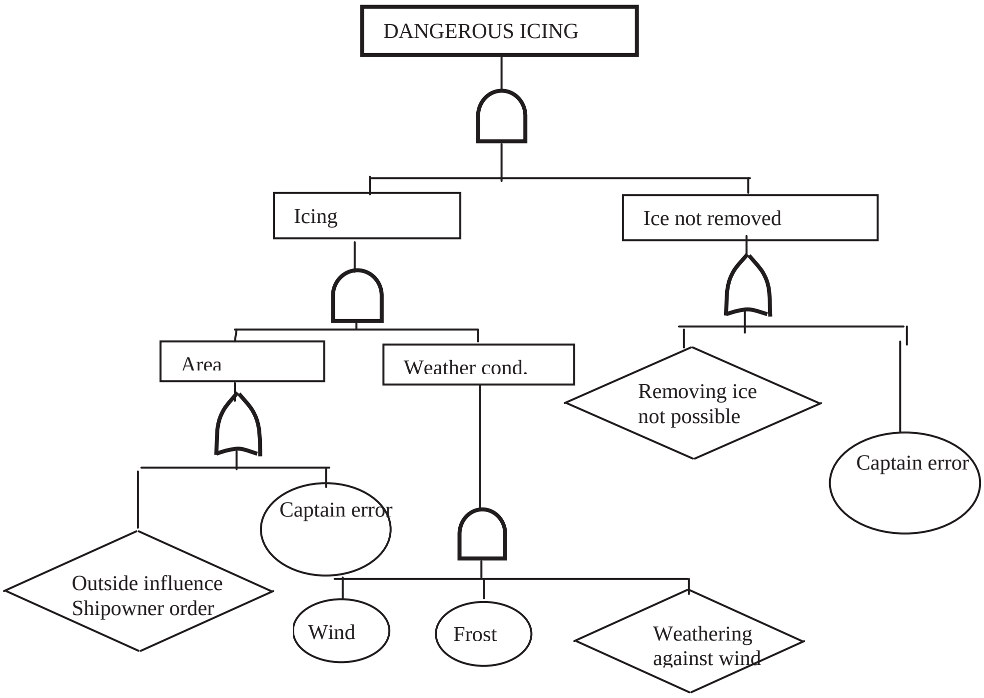

Fig.8. Branch of fault tree for dangerous icing

They may help national Administrations when performing risk analysis in order to assess safety of a ship intended to operate in areas where heavy icing might occur. Risk analysis should include scenarios that may cause loss of stability and in all cases reduction of metacentric height and stability levers due to ice accumulated should be taken into account.

In the risk analysis scenarios of ship motions in areas where icing is possible should apart from hazards from icing take into account hazards from wind and waves. Scenarios where human error is taken into account should be also considered. Ice accumulated should be removed as fast as possible. However it is not always possible. As mentioned above there are many situations when ice removal is risky or not possible at all. For example, if in stormy weather ship is weathering against the wind and ice is accumulated in the front part of the ship, manoeuvre to turn the ship with the wind in order to make access to front part possible is too dangerous. This is taken into account in fault tree shown in fig. 8.

Obviously two factors should be present if icing would be possible: firstly vessel should operate in area where icing is possible and secondly weather conditions must be such, that formation of icing may occur. Both factors are taken into account in the fault tree shown in fig. 8. The situation that the vessel would be in the area where icing occurs depends on the route, therefore on the decision of shipowner but it may depend on the decision of the master who ignored danger and decided not to avoid area where icing may occur.

The difficult part of the risk analysis is attribution of probabilities to particular events in the fault tree and assessment of the probability of top event which is dangerous icing. Probably the only method would be assessment by experts having enough experience in operating ships in areas where icing occurs. In the example shown in fig. 9 probabilities were taken as example values. In the exercise performed that was mentioned in the introduction and where Delphic method was used the conclusion was that the probability of dangerous icing that may lead to capsizing was of the order of 10^{-7} (hourly) or 10^{-3} (ship and year). It seems, however, that this probability is underestimated and based mainly on the experience of one ship master who served on large passenger ship operating on North Atlantic route.

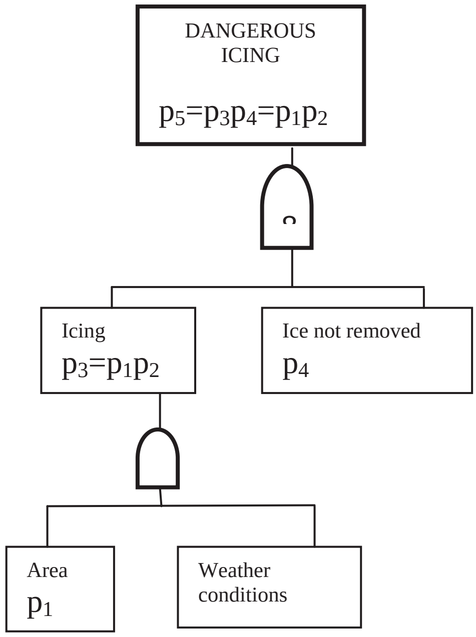

Fig. 9. Simplified fault tree for calculation of probabilities

Estimation of the probabilities in the fault tree in order to assess the top event probability is rather difficult and probably should be made by experts having sufficient experience of navigating in areas where icing might occur It is doubtful if general accessible data on icing in areas in question are available, although national Administrations may have their own data. However with expanding navigation in arctic routes international recommendations are certainly needed.

7. CONCLUSIONS AND RISK CONTROL OPTIONS

From the point of view calculation of stability characteristics in icing condition poses no problems. For the majority of ships navigating around the world hazard of icing does not exist at all or may appear with such small probability that it is not taken into account. It is essential, however, for ships navigating in northern or southern seas, especially important for fishing vessels. For those vessels risk control options should be considered. Those options include preventive options as well as mitigation options. (Fig.10).

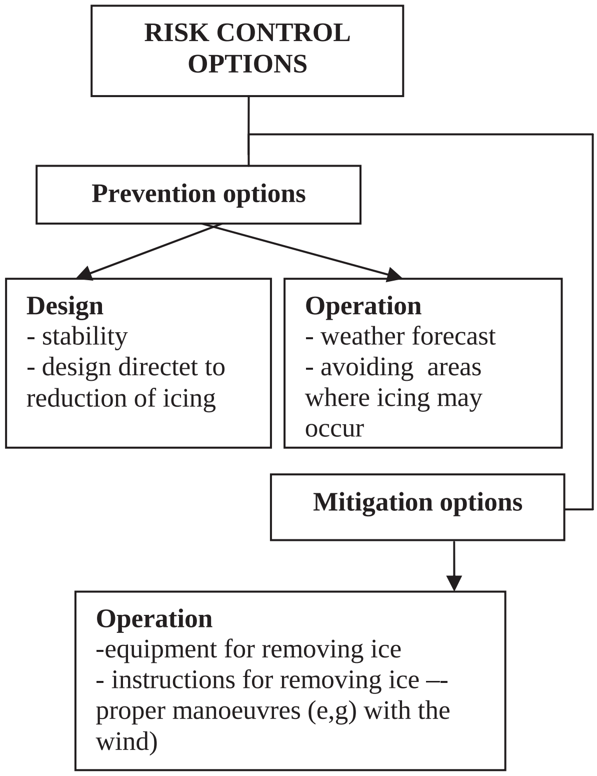

Fig. 10 Risk control options

Prevention options are mainly related to ship design including stability and suitable design of decks and superstructures intended to reduce possibility of accumulation of ice. Mitigation options are related to the possibility of removing ice and safe manoeuvring in stormy weather.

Current requirements of the IS Code related to icing include mostly recommendations and guidance for skippers of fishing vessels for ensuring survival of icing that may be valid also for other types of ships. However recommended values of ice accretion seem to be underestimated. Risk analysis performed should allow adoption of more diversified values of ice accretion in different areas. Also it may allow to take into considerations risk control options

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