CONSIDERATIONS REGARDING ICE ACCRETION ON BOARD SHIPS AND THE INFLUENCE ON INTACT STABILITY

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ABSTRACT

Although the aspects of adverse weather conditions encountered during the voyage are continuously studied, the phenomenon of ice accretion on board vessel remain a very important topic of research for those who work in maritime industry. Ice accretion on board vessel, apart from the fact that reduces the ship's maneuverability and makes navigation difficult, also has a high negative influence on intact stability. The importance of this aspect is revealed by the activity of International Maritime Organization which continuously amends the regulations with new recommendations in this respect. The main goal of the present paper is to highlight the main aspects of ice accretion phenomenon and to illustrate the impact on ship's intact stability based on a simulation carried out for a ship in a real loading condition. The simulation carried out revealed very important aspects in respect to ship's stability parameters affected by ice accretion.

Keywords: *ice accretion, ship, intact stability.*

1. INTRODUCTION

The problems and concerns regarding the ice accretion on board ships is not new and is in the agenda of the sub-committee of IMO as a topic of many debates, as a result of casualties occurred and resulted in loss of ships stability or even capsizing.

Ice accretion on board ships is a problem of paramount concern for the owners of the ships that navigate through areas where this phenomenon can occur. Moreover, ice accretion on board ships is a matter of safety. Safety of ship and crew is one of the most important concerns for Master and officers [1].

Casualties of ships involving ice accretion occurred every year and this was the main factor that in 1968 the Inter–Governmental Maritime Consultative Organization started to pay attention for the loss of stability of fishing vessels having the cause of ice accretion. Moreover, the organisation went forward and for the first time, in 1969, the Sub-Committee on Safety of Fishing Vessels was set up, being in charge, among other safety issues, with the recommendations in solving the problems of ice accretion.

As the world shipping was in a continuous development and the commercial ships became larger in size as well as in number, the problem of ice accretion was present as well. Thus, the number of ships involved in casualties and loss of intact stability as a result of ice accretion was on the raise and the concerns of IMO and the safety of it's sub-committee started to appear.

In this respect, the icing considerations on board ships were introduced in the Code on Intact Stability for All Types of Ships Covered by IMO Instruments, since 1975. Moreover, the problem of ice accretion on board ships become a most interested topic over the years and currently is in the attention of many IMO instruments such as Intact Stability Code, Polar Code or Torremolinos Protocol.

Ice deposits on the vessel's decks and superstructures is a real threat to ship's safety that can lead to dangerous situations. Among the recent casualties of lost vessels due to ice accretion it can be mentioned the sinking of two fishing vessels [2], [8]. These and other similar casualties revealed the necessity of understanding the formation of ice accretion on board ships as well as the impact on ships safety.

Thus, the goal of this paper is to analyse the causes and the factors that are influencing the occurrence of ice accretion on board ships as well as the impact on ship's intact stability.

The motivation was born as a result of the fact that loss of ships, resulted in loss of lives, constitutes a problem of safety concern which has to be treated very seriously and must be brought to the attention of those to work in this field.

The aspects of loss of ship stability due to ice accretion are presented in this paper through theoretical as well as practical matters by simulation using real ships in real loading conditions.

The importance of the aspects presented in this paper is given by the fact that it establishes a connection between the environmental factors and the operational factors of the ship that affects its safety. Moreover, the results presented herein can be used as possible guidance for those who work on board ships.

2. CAUSES AND FACTORS OF ICE ACCRETION ON BOARD SHIPS

Formation of ice is not a simple process. The main factors that are influencing ice formation are:

- Weather conditions (atmospheric temperature, sea water temperature, direction and speed of the wind, sea conditions).
- Condition of the ship (loading condition, speed, heading especially in adverse weather conditions).
- Ship's construction (position and size of superstructures and cranes, height of freeboard, type of bow construction, extend of bow flares).

The formation and accumulation of ice on board ships is generated by multiple causes, mainly influenced by the meteorological conditions. Among the most common causes, the following can be mentioned:

- Water droplets (resulted from the water sprayed from the waves), accumulated on different structures of the ship;
- Heavy snowfalls, blizzards, sleet;
- Freezing fog;
- Rain (as a result of freezing in very low atmospheric temperature. In these conditions, rain drops turn into ice accumulations when getting in contact with cold surfaces of different structures of the ship).
- Water shipped on deck.

According to Intact Stability Code 2008 ice accumulations occur as follows [3]:

1. At slow rate, up to maximum 1.5t/h, in the following conditions:

- At any force of the wind but at the range of atmospheric temperature from -1 degree C to -3 degrees C.
- At wind force up to 9 m/s and the atmospheric temperature lower than -4 degrees C.
- During the rain falls, fog or sea mist when the atmospheric temperature falls at low values in a short period of time.

2. At rapid rate, within 1.5t/h and 4t/h, when the wind force is between 10m/s and 15m/s and the atmospheric temperature falls between -4 degrees C and -8 degrees C.
3. At fast rate, when ice deposits are over 4t/h, in the following conditions:

- Wind force over 16m/s and the atmospheric temperature is below -4 degrees C.
- Wind force between 10m/s to 15m/s and the atmospheric temperature drops below -9 degrees C.

Apart from the environmental factors considered above, i.e. atmospheric temperature and wind velocity, another important factor that has to be taken into consideration, for ice accretion problems at sea, is the sea condition.

Apparently, the state of the sea is very close connected with wind velocity but from another point of view is a matter of wave characteristics such as height, period and direction. It is well known from practice that in case of different types of waves coming from more than one direction (such as a combination between sea waves and swell waves) the ship will develop a heavily rolling, generating a larger quantity of sea spray than in the situation of waves of the same height which are coming from the same direction. In icing conditions, the quantity of ice accumulated on board vessels will be higher.

One of the most dangerous situation of icing accumulation on board ships is when the atmospheric temperature decreasing very fast and there are severe sea conditions with high waves and high speed winds [5]. In this situation, large amounts of water sprayed are involved, leading to large ice accumulations all over the ship, especially at high locations. If the situation presented is combined with heavy rain falls, the ice accumulation will become bigger and heavier.

Figure 1 Ship heading in adverse sea and icing conditions [source: author]

Figure 2 Large ice accumulations on board ship [source: author]

3. THE INFLUENCE OF ICE ACCRETION ON SHIP'S INTACT STABILITY

There is no any doubt that ice deposits on board ships have a negative impact on the vessel's stability, seaworthiness and safety. Whenever the vessel is planned to navigate through areas where a high potential of ice accumulation exists, the master should bear in mind that this phenomenon will always affect the intact stability of the ship due to the following effects:

- Ship's freeboard, and implicitly the buoyancy, will degrease due to increasing of displacement as a result of ice deposits on decks, structures, containers, etc. As a result of reduced freeboard the deck will be immersed at a smaller angle of roll.
- Loss of stability, as ice deposits are usually located in high areas on board the vessel, generates a vertical rise of ship's centre of gravity.
- A permanent list of the ship, due to the fact that ice is accumulated more on one side in case of beam winds (the side where the wind blowing and sea water is sprayed).
- Change of ship's trim, as a result of uneven accumulation of ice along ship's length.
- Changes of heeling moment.

When ice accretion occur on board ship, and especially in case of unsymmetrical deposits, will always have the following effects with regard to the intact stability [7]:

- Reduction of initial metacentric height.
- Reduction of all righting levers across the range of transversal stability.
- The ship will become less able to resist heeling by external factors due to reducing of dynamical stability.
- Reduction of the safety range of stability.

A combination of above mentioned effects will dangerously affect the vessel's stability, manoeuvrability, and seaworthiness and if the ice accumulation is in a continuous process and not being possible to be removed, a danger of considerably intact stability failure and the possibility of capsizing will appear.

For the master and officers on board vessels, for the assessment of intact stability in case of ice accretion, the main problem remains the accurate determination of the ice quantity deposited as well as its centre of gravity.

As a recommendation, IMO [3] established that the allowance of ice to be taken into consideration for the assessment of intact stability in icing situations is:

- For open decks – 30kg/sqm.
- For side areas – 7.5 kg/sqm.

In respect of the weight of the ice accumulated on board ships carrying timber deck cargoes, the Intact Stability Code 2008 recommends the following formula for calculation of ice weight [3]:

$$w = 30 \cdot \frac{2.3(15.2L - 351.8)}{l_{FB}} \cdot f_{tl} \cdot \frac{l_{bow}}{0.16L} \qquad (1)$$

where:

f_{tl} - timber and lashing factor = 1.2

L - ship's length in m

l_{FB} - height of freeboard in m

l_{bow} - length of bow flare region in m.

Apart from the information recommended by IMO, the informations regarding the effects of ice accretion on board ships is provided by the stability book of any ship which may navigate through areas susceptible of ice formation.

4. ANALYSIS OF SHIP STABILITY IN CASE OF ICE ACCRETION

For the analysis and assessment of intact stability a real case scenario of ice accretion was used for a real and well documented general cargo ship [6] loaded with timber deck cargo.

The main particulars of the vessel are illustrated in table 1.

Table 1. Ship's main particulars

Length overall	108.210 m
Breadth moulded	15.80 m
Depth moulded	8.10 m
Summer draught	6.624 m
Deadweight	6225.00 t

The vessel was considered in a full loading condition with heavy timber in cargo holds as well as on deck/hatch covers.

The distribution of timber on deck and hatch covers was made as per table.2

Table 2. Distribution of timber on deck and hatch covers

Hatch covers	248 t
Hatch sides	743.6 t

The timber stow was loaded on deck and hatch covers on a length of 80 m and a height of 3.00 m.

Vessel left the loading port with 100% bunkers on board and arrived at discharging port with 10% bunkers on board.

At departure from the loading port, all the intact stability criteria, recommended by IMO for this type of vessel/transport were fulfilled, with an initial metacentric height of 0.80 m.

The stability curve for the departure condition is represented in figure 3.

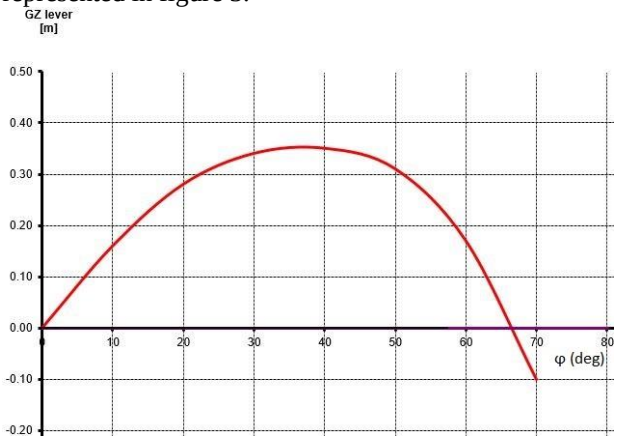

Figure 3 Illustration of righting arm curve for departure condition

Our simulation was carried out for the situation of a planned voyage in winter season in the area with high potential of rain falls and low atmospheric temperatures with the possibility of formation and accretion of ice.

Thus, in the mentioned voyage conditions, the condition of the vessel was changed up to arrival at the discharging port, as follows:

- An added weight of approx. 80 tons of ice. This weight was calculated based on the length and height of the timber stow on deck correlated with the ice allowance recommended by IMO for open decks and side areas.
- An added weight of approx. 100 tons of water absorption for the timber loaded on deck and hatch covers. This weight allowance was taken

into consideration based on the recommendation of IMO Code of Safe Practice for Ships Carrying Timber Deck Cargoes [4].

- A removed weight of 270 t of fuel oil, representing the bunker consumption for the voyage.

Taking into consideration all the above mentioned aspects, which have changed the condition of the vessel during the voyage, the vessel arrived at the discharging port with the stability (righting arm) curve as represented in figure 4 and stability criteria parameters as represented in table 3.

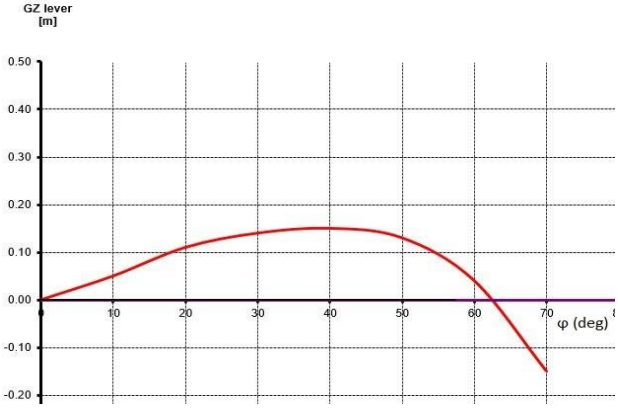

Figure 4 Illustration of righting arm curve for departure condition

Table 3. Illustration of initial and final stability criteria parameters

Criteria	Initial (Departure)	Final (Arrival)
Area 0 to 30 degrees	0.127 mrad	0.063 mrad
Area 0 to 40 degrees	0.191 mrad	0.091 mrad
Area 30 to 40 deg	0.064 mrad	0.036 mrad
GZ at 25 degrees	0.33 m	0.15 m
Angle of GZ max	40 deg	40 deg
GM	0.80 m	0.12 m

Comparing the initial and final stability criteria and parameters, as per table 3, the following analysis can be made:

- Despite the fact that all the criteria representing the area under the stability curve are fulfilled, it can be noted that for the arrival condition, stability decreased almost up to the limit.
- As the recommended value of righting arm (GZ) for 25 degrees is 0.25m, from table 3 it can be noted that this value is below the limit. This aspect revealed the fact that the vessel has a significant loss of stability and the righting moment for arrival conditions having a very low value. In this situation, the vessel is facing difficulties to come in upright condition during rolling.
- As the recommended value for minimum metacentric height (GM) is 0.10 m, from table 3 it can be noted that for the arrival conditions the metacentric height is almost to the threshold value.

Based on the calculations and analysis presented it can be noted that despite the fact that vessel's stability criteria are generally fulfilled, for the arrival conditions there are two very important parameters, righting arm (GZ) and metacentric height (GM) that are very close, or even lower, to the threshold values recommended by IMO. Maritime practice has proved that compliance with stability criteria does not represent any guarantee against capsizing.

The simulation presented emphasized the importance of a very accurate determination of the weights on board vessel, especially for the weight of the cargo loaded on deck. It is well known that in timber carriage on board vessels, the problems in declaring and ascertaining the correct weight of timber is very often encountered. Any error in this sense will highly influence the values of stability parameters which can lead to dangerous situations during the voyage.

5. CONCLUSIONS

This paper presented a very important and actual topic encountered in maritime transport. Understandantig the physics of ice formation and accretion on board vessels is very important not only for those who work on board vessels but also for those who operate and manage the vessels. The analysis presented and the simulation carried out revealed how important is the phenomenon of ice accretion on board vessel and the impact on ship's intact stability. The purpose was to identify a loading condition of a real and well documented ship, where the ice accretion can lead to loss of intact stability during the voyage.

6. REFERENCES

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