

THE IMPACT OF BULK CARGOES LIQUEFACTION ON SHIP'S INTACT STABILITY

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The article presents very important aspects of the liquefaction of bulk cargoes, loaded on board ships, that can lead to loss of ship's intact stability with severe consequences on ship's safety as well as safety of crew. Among practical methods for assessment the liquefaction process of bulk cargoes on board ships, recommended by international maritime codes that covers the transport of solid bulk cargoes at sea, the article expose a possible method for determination of ship's heeling moment due to liquefaction of cargo and the probability of cargo shifting due to liquefaction process.

Keywords: bulk, liquefaction, safety, stability, capsizes, heeling, free surfaces.

1. Introduction

The transport of bulk cargoes has an important share over the commodities transported on board vessel all around the world. The development of bulk carrier ships was kept in the trend of the quantity of bulk cargoes transported and today the constructed bulk carriers reached the boundary of 400, 000 tons deadweight capacity.

Every bulk cargo has their particular proprieties that are influencing the transport on board vessel. This fact is related in the International Maritime Solid Bulk Cargoes Code issued by IMO [1]. Apart from the already known proprieties of bulk cargoes, like self-ignition or explosion, part of the bulk cargoes are susceptible to liquefaction. In the dependence of degree of mobility, based on the dimensions of internal particles, the bulk cargoes that are transported on board vessels can be divided in two categories:

- First category includes bulk cargoes with small particles, like grain or sand, which are moving gradually after the ship is heeled.
- The second category includes high density bulk cargoes, like nickel ore and iron ore, which moving, suddenly, as a caving of a mountain, in ship's hold. Moving of bulk cargoes starts as soon as heel angle of the ship is almost equal with angle of internal friction of particles.

Many alarms was raised, [2], [3], in relation with the severe consequences of the bulk cargoes liquefaction on board vessels over safety and stability of ships.

The objective of this article is to point out the risks involved in the process of bulk cargo liquefaction and to describe the impact on ship's safety and intact

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stability based on a number of observations related to loss of ships associated to this matter. Over the recent years, an increased number of vessels lost their intact stability due to cargo liquefaction. Part of them developed large angles of list whilst others unfortunately capsized. The below table illustrate the casualties happened in the last decade that involved severe ship stability failure, like capsizing, due to cargo liquefaction, as stated in [4].

Table 1

Casualties of ship stability failures related to liquefaction of cargo

| Date of incident | Vessel | Cargo loaded | Type of incident | Location |
|------------------|-----------------|---------------------------|------------------|---------------------------------------|
| 1988 | Mega Taurus | Nickel ore | Capsize | Indonesia |
| 1998 | Sea prospect | Nickel Ore | Capsize | Indonesia |
| 18/05/2005 | Hui Long | 11,245 tons of Fluorspar | Capsize | West of Sri Lanka |
| 08/2009 | Hodasco 15 | 6,000 tons of Iron ore | Capsize | Malaysia |
| 09/09/2009 | Black Rose | 23,000 tons of Iron ore | Capsize | Few miles out of Paradip port (India) |
| 17/07/2009 | Asian Forest | 13,000 tons of Iron ore | Capsize | Mangalore (India) |
| 21/10/2010 | Jian Fu Star | 43,000 tons of Nickel ore | Capsize | West of Taiwan |
| 10/11/2010 | Nasco Diamond | 55,150 tons Nickel ore | Capsize | East of Taiwan |
| 03/12/2010 | Hong Wei | 40,000 tons Nickel ore | Capsize | South of Taiwan |
| 21/11/2011 | Bright Ruby | 25,000 tons Iron ore | Capsize | South of Taiwan |
| 25/12/2011 | Vinalines Queen | 54,000t nickel | Capsize | South China Sea |

2. The liquefaction process of bulk cargoes

Usually, the cargo is mined and stored in often quite simple facilities that provide no protection from the environment. The cargo may be wet, when mined, or becomes wet, when left in open storage areas.

The location of these mines is in countries and areas where generally the facilities and infrastructure are under development and where the climate and weather leads to frequent large rainfalls. The areas with high profile problem and where many casualties related to liquefaction of bulk cargoes occurred are India (for iron ore fines), Philippines, Indonesia and New Caledonia (for nickel ore), areas affected by the Monsoons in summer months. However, the problem is prevalent in all the countries where the humid climate is present. Moreover, the issue can arise anywhere where fine particle mineral cargoes are mined and stored in exposed areas.

Cargoes such as iron ore fines, iron ore concentrates, nickel ore, fluorspar, certain grades of coal, pyrites, sinter/pellet feed and others have all given rise to liquefaction associated problems. Those cargoes are fine grained cargoes that are containing fine particles and moisture, although they need not be visibly wet in appearance, are at risk of liquefaction process.

During loading on board vessels, the cargoes are usually in their solid state, the particles are in direct contact with each other and, therefore there is a physical strength of resistance to shear strains. The liquefaction process appears when in a fine grained cargo the spaces between cargo grains are filled with both air and water. The problem occurs in mineral cargoes of predominantly fine particles, mined and stored in conditions which allow the soaking up of large amounts of water which is then retained, with minimal drainage or evaporation occurring.

Mineral cargoes can turn into muddy slush if the amount of moisture (typically water) is too high. Whilst at sea the cargo is subject to forces due to the engine vibration and motions of the vessel as well as waves impact. This leads the forces to cause the inter-grain spaces to contract resulting in compaction of cargo. If compaction is such that there is more water inside the cargo than there are spaces between the particles, the water in the spaces between particles is subject to a compressive force but as it is a liquid, it cannot be compressed. The water pressure inside the cargo can rise sharply and press the particles apart. Where enough moisture is present, the reduction in inter-grain friction due to the ship's motion and vibration can be sufficient to cause the cargo flow like a liquid, i.e. to liquefy.

3. Problems associated with liquefaction of bulk cargoes

The most significant consequence for the vessel resulting from liquefaction is cargo shift, cargo flow to one side of the ship with a roll one way but not completely return with a roll the other way, progressively leading to loss of stability. This may produce dangerous angles of list (Figure 1) and in some instances the resulting loss of stability can be such that the vessel and the lives of those onboard are lost.

The heavier the cargo, the effect of shifting of cargo and heeling the ship will be more acute. The impact of such unpredictable cargo behaviour on the ship motion is not easy to assess, first of all because the dynamic characteristics of the liquefied bulk are not well described in the literature and furthermore is not well understood at present time. In the meantime, it is sufficient to say that this is a highly undesirable situation from a ship stability point of view. Depending on mode and speed of loading, cargo geometry can have multiple peaks and plateaus. Unlike liquid cargo the mechanics of such moisture laden cargo in the ship's hold

is rather complex where the water drains into the hold bilges inducing mixing prospects with the cargo due to the ship dynamics such as vibration.

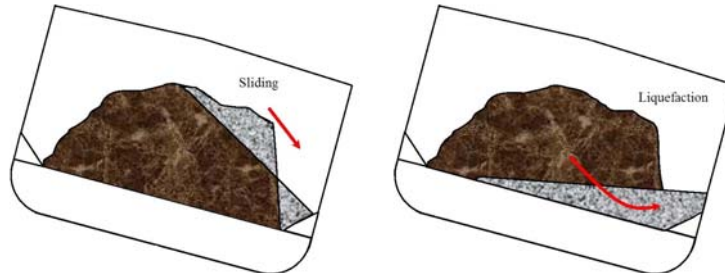


Fig 1. Developing of list due to cargo liquefaction

However, with condition unfavorable, separated water migrates to the surface and forms scattered puddles. This results in lower strata compaction with increased draining resistance and loose surface cargo with presence of water.

Bulk carriers are not designed to carry liquid or semi-liquid cargoes, and when this process happens, it can cause stability problems that in many cases have led to vessel's capsizing and sinking. Small lists, due to de-ballasting, create surface water flow, truncating peaks / collapsing cargo and thus can result in huge sudden dangerous movements of the ship. Large liquefaction can happen in mere minutes and adversely affects the shipment, operationally as well as commercially, and can lead to severe casualty beyond ship's control. Moreover, as large liquefaction is initiated at loading port it gets aggravated during the voyage and may persist during discharging.

Same aspects may be encountered in case of multi-purpose ships with cargo hatches covered by pontoons. Despite the fact that vessel completed loading in upright position, during maneuvering the pontoons the vessel develop a small list which correlated with flowing of cargo can result in sudden increased listing angle with dangerous consequences.

4. Determining the limit value of the problem and additional heeling moment

It is well known that once the liquefaction process is present and the ship is rolling and additional heeling moment appears. The magnitude of the additional heeling moment is influenced by two important factors: the form of free surface developed due to liquefaction and the amount of cargo that is shifting. In order to determine the limit value of the phenomena of liquefaction it is very important to determine the shifting of cargo. This problem can be mathematically approached by solving a system of quasi-linear partial differential equations for the components of cargo particles' velocity.

Thus, the problem is treated in an approximate manner based on the following assumptions [5]:

- It is considered a compartment that is developing rolling motions (relatively to an axis that represent the intersection of the plane of compartment with the free surface of the cargo) with a certain frequency - ω_R - and amplitude - α - connected in conditions as $\psi < \alpha$;

$$\omega_R \ll \sqrt{\left(\frac{2g}{b \cdot \alpha}\right)}; \quad (1)$$

$$\alpha = \min\left(\arctg 2\left(\frac{h-d}{b}\right), \arctg\left(\frac{2d}{b}\right)\right).$$

where, b and h are the breadth and height of the compartment, d is the depth of bulk cargo in the compartment and ψ is the angle of internal friction of the cargo particles.

- The cargo is considered homogenous and is exposed to a two-dimensional movement.

For the mathematical expression of the solution are considered three Cartesian coordinate system with the origins placed on the compartment's axis of rolling and can be stated as follows: - a system fixed in space, xOy ;

- a system x_1Oy_1 fixed in the compartment;

- a system x_2Oy_2 that is moving together with the cargo and where the axis Oy_2 is similar with the level of cargo and the axis Ox_2 is along the internal normal to the level of free surface.

The description of the cargo movement is obtained by solving the following limit value problem in the space occupied by the bulk cargo:

$$\begin{aligned} \frac{dv_x}{dt} + \frac{1}{\delta} \left(\frac{\partial \xi_x}{\partial x} + \frac{\partial \varepsilon_{xy}}{\partial y} \right) &= 0; \quad \frac{dv_y}{dt} + \frac{1}{\delta} \left(\frac{\partial \varepsilon_{xy}}{\partial x} + \frac{\partial \xi_x}{\partial y} \right) = 0; \\ \frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} &= 0; \end{aligned} \quad (2)$$

$$(\xi_x - \xi_y)^2 + 4\varepsilon_{xy}^2 = \sin^2 \phi (\xi_x + \xi_y)^2; \quad \frac{2\varepsilon_{xy}}{(\xi_x - \xi_y)} = \frac{\frac{1}{2} \left(\frac{\partial v_x}{\partial y} + \frac{\partial v_y}{\partial x} \right) \pm \frac{\partial v_x}{\partial x} \operatorname{tg} \phi}{\frac{\partial v_x}{\partial x} \pm \frac{1}{2} \left(\frac{\partial v_x}{\partial y} + \frac{\partial v_y}{\partial x} \right) \operatorname{tg} \phi}.$$

In order to obtain the solution of the differential equations (2), it is compulsory to submit the resulted values to limiting conditions:

- of the free surface of cargo, calculated from the relation

$$F_s = y \sin \beta_1 + x \cos \beta_1 - \gamma = 0, \quad (3)$$

where β_1 is the angle of the axis inclination to horizontal plane Oy_2 and γ is the elevation of free surface. In this respect, there must be fulfilled the condition:

$$\frac{dF_s}{dt} = 0. \quad (4)$$

- on the cargo that came into contact with the compartment's surface, calculated from the relation $F_c(x, y, t) = 0$. (5)

$$\text{In this respect must also be fulfilled the condition } \frac{dF_c}{dt} = 0. \quad (6)$$

The non-linear limiting values of the problem, stated in relations (2) – (6) can be reduced in two simple problems if some assumptions are taken into consideration. First assumption is based on the possibility to calculate the components of cargo particles velocity vector and the form of free surface whilst the second assumption is to determine the stressed condition of cargo for the aim of a quasi-static approximation.

The stresses of cargo particles can be expressed, based on the bulk medium mechanics, as $\xi_x, \xi_y = \rho\xi(1 \pm \sin\phi \cos 2\theta)$;

$$\varepsilon_{xy} = \delta\xi \sin\phi \sin 2\theta, \quad (7)$$

where, the functions ξ and θ are written as

$$\xi = \xi^{(0)} + \xi^{(1)}; \theta = \theta^{(0)} + \theta^{(1)}. \quad (8)$$

In the above equation, the superscript zero is corresponding to the values obtained in a quasi-static approximation while the superscript one indicates the dynamic surplus to those values.

The functions $\xi^{(0)}$ and $\theta^{(0)}$ are calculated from the following time derivative equations

$$(1 + \sin\phi \cos 2\theta^{(0)}) \frac{\partial \xi^{(0)}}{\partial x} + \sin\phi \sin 2\theta^{(0)} \frac{\partial \xi^{(0)}}{\partial y} - 2\xi^{(0)} \sin\phi (\sin 2\theta^{(0)} \frac{\partial \theta^{(0)}}{\partial x} - \cos 2\theta^{(0)} \frac{\partial \theta^{(0)}}{\partial y}) = 0$$

$$\sin\phi \sin 2\theta^{(0)} \frac{\partial \xi^{(0)}}{\partial x} + (1 - \sin\phi \cos 2\theta^{(0)}) \frac{\partial \xi^{(0)}}{\partial y} + 2\xi^{(0)} \sin\phi (\cos 2\theta^{(0)} \frac{\partial \theta^{(0)}}{\partial x} + \sin 2\theta^{(0)} \frac{\partial \theta^{(0)}}{\partial y}) = 0 \quad (9)$$

The equation (8) has the solution in the form obtained by Sokolovsky [8] as follows $\xi = \frac{x + y \operatorname{tg} \beta_1}{\cos^2 \phi} (1 - \eta)$;

$$2\theta = \beta_1 + (\kappa - 1) \frac{\varepsilon}{2} - \kappa \arcsin \frac{\sin \beta_1}{\sin \phi}; \quad (10)$$

$$\eta = \sin^2 \phi + \kappa \cos \phi \sqrt{(\sin^2 \phi - \sin^2 \beta_1)}.$$

Based on equation (10), the expressions for the stresses developed inside the bulk cargo can be written as $\xi_x, \xi_y = \rho g(x + y \operatorname{tg} \beta_1)(1 + \sin^2 \phi)$;

$$\varepsilon_{xy} = -\rho g(x + y \operatorname{tg} \beta_1) \sin \phi \cos \phi. \quad (11)$$

To solve this problem it is important to take into consideration the fact that the bulk cargo has a discontinuous movement inside the oscillating compartment, due to the fact that the phases of movement relatively to the compartment alternate with phases of relative unit.

The magnitude of values, in the phase of relative movement, represents the solution of the linearised limit value problem as

$$\dot{v}_x + (1 + \sin^2 \phi) \frac{\partial \xi^{(1)}}{\partial x} - \frac{1}{2} \sin 2\phi \left(\frac{\partial \xi^{(1)}}{\partial y} - \frac{\partial (2\xi^{(0)} \theta^{(1)})}{\partial x} \right) + \sin^2 \phi \frac{\partial (2\xi^{(0)} \theta^{(1)})}{\partial y} = 0;$$

$$\dot{v}_y - \frac{1}{2} \sin 2\phi \left(\frac{\partial \xi^{(1)}}{\partial x} + \frac{\partial (2\xi^{(0)} \theta^{(1)})}{\partial y} \right) + \cos^2 \phi \frac{\partial \xi^{(1)}}{\partial y} + \sin^2 \phi \frac{\partial (2\xi^{(0)} \theta^{(1)})}{\partial x} = 0;$$

$$\frac{\partial v_x}{\partial x} + \frac{\partial v_y}{\partial y} = 0; \quad (13)$$

$$\frac{\partial v_x}{\partial y} + \frac{\partial v_y}{\partial x} - 2 \operatorname{ctg} 2\phi \frac{\partial v_y}{\partial y} = 0.$$

The solution of the equations (12) and (13) fulfils the limit conditions (4) and (6). The dynamic heeling moment developed due to shifting of bulk

cargo can be calculated from the equation $M = \sec(\phi - \beta) \sum_{-\infty}^{\infty} M_m e^{im\omega_R t}$;

$$M_m = b \cdot f_m \left(\frac{b}{2} \operatorname{ctg} \eta_m \frac{b}{2} - \frac{1}{\eta_m} \right). \quad (14)$$

$$\text{where, } \eta_m = \frac{1}{2} \operatorname{ctg} \phi m^2 \omega_R^2 / g \quad (15)$$

and f_m is the Fourier's coefficients of function $f(t)$ expansion into series

$$f(t) = -\sec(\phi - \beta) = \sum_{-\infty}^{\infty} f_m e^{im\omega_R t}. \quad (16)$$

5. Bulk cargo shifting probability due to heeling of ship

This problem may be solved by estimating the degree of stability of cargo volume by a stability margin coefficient [9] in a form of

$$C_{sm} = \frac{\int_{y_0}^y Rdy}{\int_{y_0}^y \Omega dy}, \quad (17)$$

where, Rdy is the retaining force acting along the collapse line of cargo and Ωdy is the ordinary shearing force.

Due to the fact that the coefficient C_{sm} is a function of the form of collapse line of cargo, the solution of the problem is to determine the curve implementing the minimum of the function.

The probability of collapse the bulk cargo mass is determined as a probability of rolling ordinate which is same with the heel angle corresponding to $C_{sm} = 1$ and reveals that the cargo is at the limit of equilibrium situation. The probability of rolling ordinate can be assimilated as a probability of function representing the heeling angle that exceeds over a certain given level of heeling angle.

A more accurate assessment of the probability can be obtained by the methods of Markovian processes theory, where the ship's rolling motion with shifting of cargo is given by a component of six dimensional Markovian process and the probability of cargo collapse is calculated from the integral

$$P(t) = \int_{-\infty}^{\infty} \dots \int_{-\chi^*}^{\chi} f(t, \chi_1, \dots, \chi_6) d\chi_1 \dots d\chi_6, \quad (18)$$

where, χ is the heeling angle and χ^* is a certain given level of the heeling angle.

The probability that the rolling amplitude χ_m will exceed the angle χ^* of the limit equilibrium of cargo is given by the relation

$$P(\chi_m > \chi^*) = \exp\left(\frac{-\frac{1}{2}\chi^{*2}}{\Delta\chi}\right), \quad (19)$$

where, $\Delta\chi$ is the variation function of rolling.

6. Practical methods for assessment the liquefaction of bulk cargoes

The main reference for any ship operator or ship Master when considering whether a cargo is likely to liquefy is the IMO International Maritime Solid Bulk Cargoes Code, named IMSBC Code. The dangers associated with commonly shipped cargoes are listed within the Code Group A cargoes, which are those that are likely to liquefy. Any cargo listed as Group A, should be shipped and carried strictly in accordance with the provisions of the IMSBC Code. The definitions,

tests, and precautions in the Code for cargoes that may liquefy are widely associated with metal ore concentrates, for which their application is relatively straightforward. The general framework for the carriage of all cargoes is contained in the SOLAS Convention, Chapter VI-Carriage of Cargoes. However, the Code itself warns in Section 1.2.1 that schedules for individual cargoes are not exhaustive. It may be that some cargoes, which can liquefy, that are not included in the Code.

There are two important proprieties of such kind of cargoes that have to be taken in consideration when loading on board vessels: Flow Moisture Point (FMP) and Transportable Moisture Limit (TML). Flow moisture point is the maximum water content, expressed as a percentage, at which a sample of cargo will begin to lose shear strength. Cargoes with moisture content beyond FMP may be liable to liquefy. Transportable moisture limit is defined as 90% of the FMP. The major factor that increases the moisture content in the cargo, above TML, is the rain during storage in open space or during transit from the mines to the port, in open top train wagons, barges, or conveyors. Sampling and testing procedures for bulk cargoes that may liquefy should be carried out according to international standards such as the test procedures described in Appendix 2 of the IMSBC Code.

From the ship operators and Master's perspectives the important figures for the laboratory to determine are the TML of the representative sample of the cargo to be loaded and its actual moisture content. In order to find the TML the laboratory must first determine the FMP of the sample. After determining the FMP the moisture content of the cargo is obtained by drying samples of the cargo in accordance with section 4.6.4 of the Code. If the moisture content of the cargo sampled is below the TML then the cargo should be safe to load. Loading a cargo above at or near its FMP represents an unacceptable high risk for vessels and for this reason a safety margin is allowed, this gives the TML.

Liquefaction process may occur unpredictably at any time during the voyage in cargoes loaded with moisture content in excess of the FMP point. In some situations, cargo have liquefied and caused catastrophic cargo shift almost immediately on departure from the loading port, in other situations liquefaction occurred several weeks after uneventful sailing. While the risk of liquefaction is greater during heavy weather, in high seas, and while under full power, there are no safe sailing conditions for a cargo with unsafe moisture content. Even in relatively calm conditions on a vessel at anchorage or proceeding at low speed, liquefaction can occur unpredictably.

The problem is how reliable is the information received by vessel's Master from the local shippers and authorities as the cargo presented for shipment is compliant with IMSBC Code. It is not unusual for shippers to present incorrect or, at best, inadequate cargo documentation. Many alerts have been issued regarding

Brazilian sinter feed cargoes whereby Brazilian shippers have been wrongly declaring these cargoes as non-hazardous cargoes or namely Group C cargoes (i.e. neither liquefy nor possess chemical hazards) under the IMSBC Code.

In other cases, certificates were presented stating only that a cargo of ore bulk material was tested “*in accordance with the IMBSC Code, and passed successfully*”. The cargo’s alleged average moisture content was recorded without the corresponding TML and FMP values, and of course, unless those values are known, the moisture content is meaningless. Casualties have shown that the current testing and certification regime for these cargoes may be inadequate and reliance on shipper’s certificates alone should be avoided. Given such lapses, it is unsurprising that cases of liquefied cargoes and listing or capsized ships are still regularly seen.

The poor compliance of some shippers with testing and certification requirements that are stated under IMSBC Code and designed to ensure that cargoes are loaded only if the moisture content is sufficiently low to avoid liquefaction occurring during the voyage, looks to be one of the main cause of the casualties. However, the causes of casualties is probably a mixture of understanding of the problem, and inadvertent or, occasionally, deliberate misrepresentation of the true nature of the cargo by shippers or by others.

From the investigation reports of the casualties, resulted also that not every Master or Chief Officer was aware of the problem or of the simple “can” or “shake” test that can be performed to check the risk of cargo liquefaction, despite the fact that the test is described in IMBSC Code. The facts revealed that Masters are often not aware of what information they are entitled to receive from shippers under the IMBSC Code; nor are they fully aware of their rights under international carriage of goods conventions to reject or land unsafe cargo. Only in few cases, Masters seem to abrogate all responsibility for checking whether or not the cargo being loaded on board is safe.

7. The way forward

Masters should carefully consider the potential risks involved in carrying such cargoes and the impact of their properties on ship intact stability. Ship’s officers should closely check the condition of cargo before loading, whenever is brought alongside vessel, and should continue monitoring the condition throughout loading operations. Even when the cargo appears to be dry, the moisture content may be in excess of TML, but in cases when the cargo appears to be wet, the experience evidenced that moisture content was above TML. A negative result from the “Can Test” as described in IMSBC Code does not mean that the cargo is safe for shipment, but in case of a positive result from such test, where moisture is visible, is no doubt that further laboratory testing is required.

In this context, Masters should strictly follow the recommendations stated in the IMSBC Code related to certification requirements for the cargoes which may liquefy and ascertain that the cargo is suitable for sea transport. When considering the carriage of such cargoes Master should never start loading operations prior being in possession of certificate of moisture content and TML. In cases that the certificate is provided it should be closely checked in order to ensure that is issued from a reliable source. In many cases these certificates are issued by the mining companies and are subject to risk of incorrectness because those companies are acting on behalf of shippers. Although the burden of certification is placed by IMSBC Code on the shipper, the information contained in certificates may be incorrect due to various reasons like: failure to correctly analyse the samples, use of facilities not geared to properly test the samples, or the test samples not being properly representative of the cargo to be loaded.

A possible solution as stated in [10] may be the introduction of longitudinal hold divisions that can reduce considerably the risks of cargo shift. The problem is that they have to be of high strength having in view the massive forces expected on these divisions. Additionally, these divisions will interfere with loading and unloading operations. In this context, the existing ships have to be modified for such duties and this fact will involve costs that will not be probably agreed by owners, even if the vessel is chartered for long period of time. Therefore, ships that intend to carry cargoes prone to liquefaction must be specially designed, such as sludge carriers, and operated to be fit for this purpose. Probably, this is the step that maritime community has to take in this moment through concerted efforts of all parties involved.

8. Conclusions

This paper has considered the risks involved as well as the methods of assessment the liquefaction of bulk cargoes on board ships. The risks involved were defined as the severe consequences of the liquefaction on ship's safety where the described method of assessment the heeling moment as well as the probability of cargo shifting is indicated as a viable alternative solution for prevention of ship's stability loss.

The experimental investigation is performed in order to understand the behaviour, stresses and friction of the mineral particles and it is necessary in order to predict and to control the shifting of bulk cargoes as well as heeling of the ship.

In view of the liabilities risks described, the Masters refusal to load the cargo can be the last resort. An effective measure which may be taken in consideration could be the request of attendance of a supercargo or expert to examine the cargo before it is accepted and prior loading on board vessel, as well as to supervise the loading and liaise to vessel's Master.

The main problem is that the knowledge on the behaviour of liquefied cargo and its impact on ship safety are still quite limited. A certain fact is that the ships are not fitted to load and transport bulk cargoes that liquefy and not very much can be done to rectify the situation even on a temporary basis.

In the future, to prevent the catastrophes resulted from the liquefaction of mineral cargoes transported on board vessel it is necessarily the raising of risk awareness of shipowners, charterers and their crews as well as their training and qualifications.

The potential consequences of loading a mineral bulk cargo that is unsuitable for carriage due to moisture content have to be seriously evaluated and taken into consideration and the vigilance when dealing with these cargoes should never be relaxed.

It is very important the familiarity with the IMBSC Code and the awareness contained in its Annexes by all the parties involved in such transports but especially for vessel's Masters. As a precautionary measure, always has to bear in mind that some cargoes do not appear in the IMBSC Code but these cargoes may be subject to liquefaction process. Thus, the best way to ensure protection of crew and safety of ship is that the provisions and advice of the IMBSC Code are followed all the times and being vigilant before, during and after loading.

A thorough knowledge and understanding of the properties of the cargo carried with regard to role played on ship's stability, in a static and dynamic sense, is essential for the safety of ship, crew, cargo and environment.

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