MARITIME

BULK CARGO LIQUEFACTION

Guideline for design and operation of vessels with bulk cargo that may liquefy

SAFER, SMARTER, GREENER

EXECUTIVE SUMMARY

Liquefaction is a phenomenon in which a soil-like material is abruptly transformed from a solid dry state to an almost fluid state. Many common bulk cargoes, such as iron ore fines, nickel ore and various mineral concentrates, are examples of materials that may liquefy.

If liquefaction occurs on board a vessel, the stability will be reduced due to the free surface effect and cargo shift, possibly resulting in capsizing of the vessel. The ship structure may also be damaged due to increased cargo pressures.

DNV GL has written a guideline for the design and operation of vessels with bulk cargoes that may liquefy. The intention of this guideline is to raise the awareness of the risks of cargo liquefaction on ships and to describe what mitigating actions may be taken to reduce such risks. The target group is ship designers, yards, shipowners and other stakeholders in the shipping industry.

This guideline should not be seen as a complete and exhaustive textbook on liquefaction. Particularly on operational aspects and specific cargoes, more information is available from other sources, especially from the International Maritime Organization's (IMO) mandatory code on bulk cargoes, the International Maritime Solid Bulk Cargoes (IMSBC) Code. Several major protection and indemnity (P&I) clubs, as well as Intercargo, have also issued useful information on this subject. In this guideline the focus is on what mitigating actions may be taken in the design stage, as well as on highlighting conditions that may call for independent, third-party tests to be performed to check and report the actual cargo condition prior to loading.

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1. INTRODUCTION

1.1 BACKGROUND

Traditionally the phenomenon of liquefaction of dry bulk cargoes has not received much media attention. However, liquefaction is now seen as a major hazard for bulk carriers. The topic is receiving increasing attention from all industry stakeholders and from the media.

There are some distinct and disturbing features of accidents caused by cargo liquefaction. First, the accidents happen very fast. The period of time from when liquefaction is detected, if it is detected at all, until the vessel has capsized could in some cases be only a few minutes. This leaves very little time for remedial measures. It also leaves very little time for safe evacuation of the ship, and such accidents are often associated with tragic losses of crew members. Second, it has been observed that an accident on one vessel is often followed by a new accident, or near-accident, on other vessels that have loaded similar cargo at terminals in the same area. The best known example is the loss of the bulk carriers Jian Fu Star, Nasco Diamond and Hong Wei, which occurred during a six-week period in the rainy season of autumn 2010. All of them were carrying nickel ore from Indonesia. Nickel ore is a cargo known to be prone to liquefaction. In total, 44 lives were lost.

Table 1 lists ships of more than 10,000 tons deadweight (deadweight tonnage, or DWT) lost since 2009 where it is suspected that cargo liquefaction was the cause of the casualty. It is worth noting that 6 out of the 9 vessels were less than 10 years old and presumably in good condition. It is also noticeable that there is a strong link to the rainy season in South-East Asia.

Vessel	DWT	Built	Lives lost	When	Cargo type	Cargo origin
Asian Forest	14k	2007	0	Jul 17th 2009	Iron ore fines	India
Black Rose	39k	1977	1	Sep 9th 2009	Iron ore fines	India
Jian Fu Star	45k	1983	13	Oct 27th 2010	Nickel ore	Indonesia
Nasco Diamond	57k	2009	21	Nov 10th 2010	Nickel ore	Indonesia
Hong Wei	50k	2001	10	Dec 3rd 2010	Nickel ore	Indonesia
Vinalines Queen	56k	2005	22	Dec 25th 2011	Nickel ore	Philippines
Sun Spirits	11k	2007	0	Jan 22nd 2012	Iron ore fines	Philippines
Harita Bauxite	50k	1983	15	Feb 16th 2013	Nickel ore	Indonesia
Trans Summer	57k	2012	0	Aug 14th 2013	Nickel ore	Philippines

Table 1 – Liquefaction accidents

Trans Summer after capsizing (Photo: HKG Flying Service)

2. WHAT IS BULK CARGO LIQUEFACTION?

In this section the physics behind liquefaction will be explained in order to increase the awareness of liquefaction and to better understand why and how liquefaction may occur. In addition, the term Transportable Moisture Limit (TML) is introduced, as this is the key parameter in assessing if the cargo is considered safe for carriage.

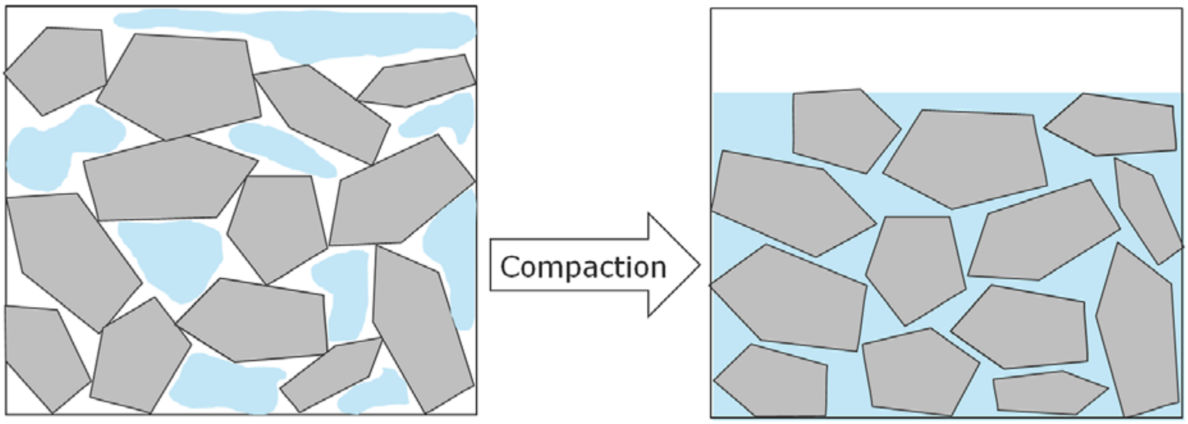


Figure 2 – Liquefaction as a result of cargo compaction

2.1 LIQUEFACTION OF GRANULAR MATERIALS

Liquefaction of granular materials is a well-known phenomenon. There are two prerequisites for liquefaction to occur. First, you need a cargo material with at least some fine particles. Second, you need a minimum moisture level. If one or both of these ingredients are missing, liquefaction is not possible.

In a typical cargo that may liquefy, there will be a mix of fine particles and larger particles or grains. In between the particles, there will be a mix of moisture, water and air. When the cargo is in a solid dry state – ie, not liquefied – the particles will be in contact with each other. The frictional force between the particles gives the cargo some physical shear strength. The cargo may be formed to a pile and appears dry.

During voyage, the cargo will be compacted due to ship motions, wave impacts and other vibrations. This means that the space between the individual “grains” of cargo will be reduced. The reduced space will lead to an increased pressure in the water between the grains, since the limited permeability of the cargo due to fine particles prevents drainage of the water. After the compaction, if the amount of water is larger than the space between the particles, the increased pore water pressure will press the particles apart, and the frictional force between the grains will be lost. As a result, the shear strength of the material will also be lost, and the pile of cargo will flow out to an almost flat surface. The cargo is now in a fluid state.

The process is illustrated in Figure 2 above. The box on the left shows a mix of cargo particles, water and air. The particles are in contact with each other and are held together by frictional force. The box on the right shows the situation after compaction. Due to the water pressure, the particles are no longer in contact with each other; the friction is lost, and the cargo is liquefied.

Liquefaction problems involving granular materials are most likely to occur shortly after loading. Further, usually only parts of the cargo will be liquefied at the same time, leading in most cases to partial liquefaction.

The liquefied state is a transient state that normally lasts for a limited time. After a while the cargo again settles into a more compact state, with less possibility for liquefaction.

2.2 LIQUEFACTION OF VERY FINE (NON-GRANULAR) MATERIALS

The liquefaction of very fine, clay-like materials, such as some nickel ores, is principally different from that of granular materials. Nevertheless, the results in terms of hazard for the vessel are comparable.

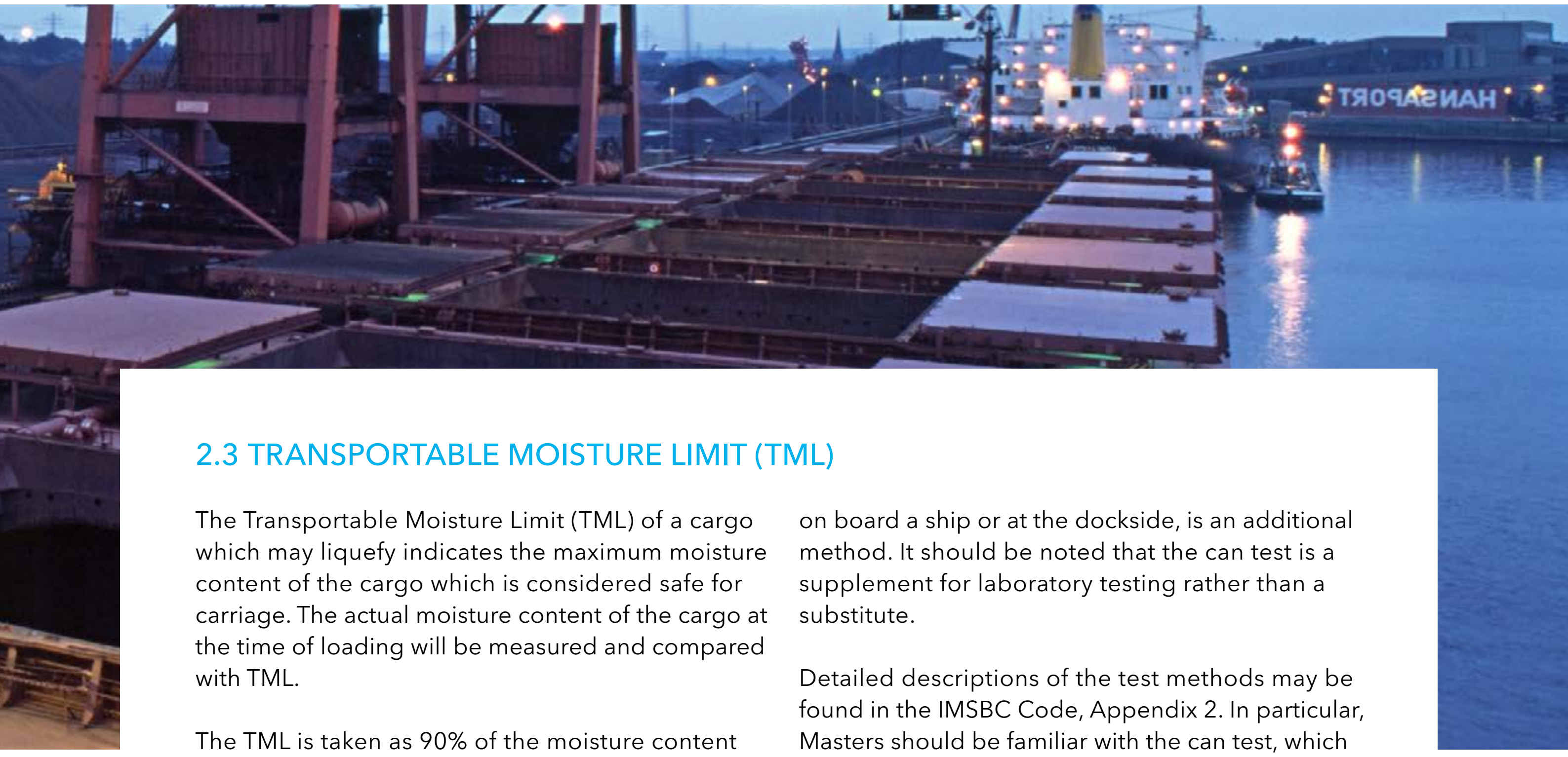
Unlike liquefaction of granular materials, where increased pore water pressure is the trigger, liquefaction of clay-like materials can be seen as a sort of fatigue of the material. After a number of stress cycles due to ship motions, wave impacts and other vibrations, the cohesion and the strength of the material are suddenly significantly reduced. Since a number of stress cycles are required, liquefaction problems may occur several days or weeks after loading.

Another difference from the liquefaction of granular materials is that liquefaction may happen for all the cargo on board simultaneously. It is also very difficult to stabilize the cargo after liquefaction.

It is important to be aware of the recent amendments to the IMSBC Code for these cargoes. Up until 2015 the Code stated that liquefaction did not occur when the cargo contained very small particles. This sentence was removed with effect from January 1st 2015.

Figure 3 – Dry cargo (Photo: Roxburgh Environmental Ltd)

Figure 4 – Liquefied cargo (Photo: Roxburgh Environmental Ltd)



2.3 TRANSPORTABLE MOISTURE LIMIT (TML)

The Transportable Moisture Limit (TML) of a cargo which may liquefy indicates the maximum moisture content of the cargo which is considered safe for carriage. The actual moisture content of the cargo at the time of loading will be measured and compared with TML.

The TML is taken as 90% of the moisture content that is necessary for liquefaction to be possible, based on laboratory testing. This means that a safety margin is provided to protect against variations in cargo properties and moisture content, and against measuring errors in determination of TML or actual moisture content.

There are currently three recognized laboratory test methods in general use for determining the TML value: The flow table test, the penetration test and the Proctor/Fagerberg test. The modified Proctor/Fagerberg test procedure for iron ore fines is an additional method. As each method is suitable for different types of cargo, the selection of the test method should be carefully considered, either in consultation with local practices or the appropriate authorities.

The "can test", which is commonly used by Masters for approximately determining the possibility of flow on board a ship or at the dockside, is an additional method. It should be noted that the can test is a supplement for laboratory testing rather than a substitute.

Detailed descriptions of the test methods may be found in the IMSBC Code, Appendix 2. In particular, Masters should be familiar with the can test, which is described in the IMSBC Code, Section 8.4.

Figure 5 – Flow table test (Photo: Gard)

Figure 6 – Can test. The picture on the right shows formation of moisture at the surface, indicating that the moisture content may be too high and that more tests are needed to clarify the true relationship between MC and TML for that consignment.

3. WHAT ARE THE RISKS FOR THE VESSEL?

The main risk for a vessel carrying cargo that may liquefy is shifting of the cargo. The shifting may be caused by liquefaction, as explained in the previous section, or by sliding of the cargo. The two processes are different, but the possible consequences are the same: Listing, capsize and structural damage.

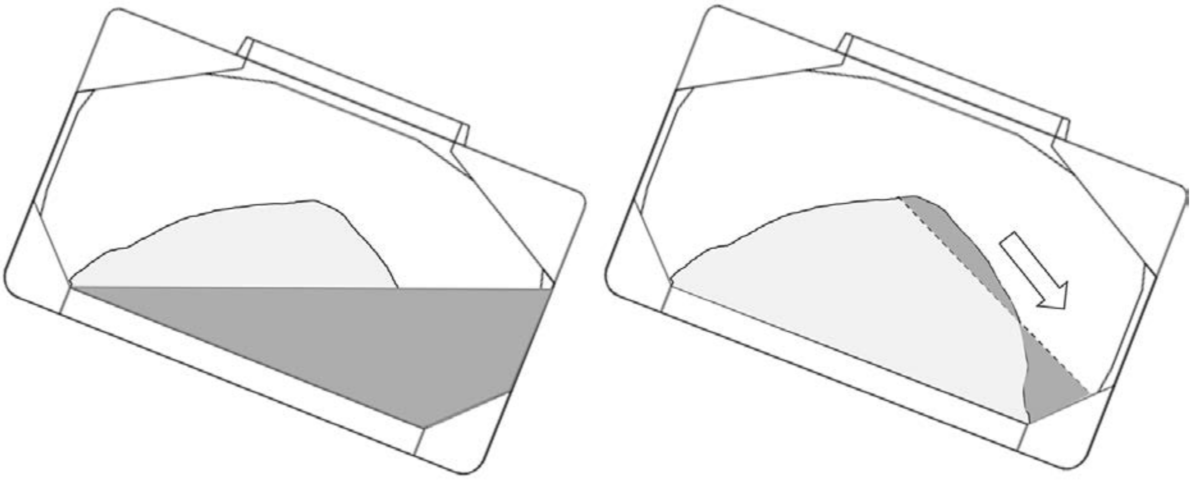


Figure 7 – Liquefaction (left) and sliding (right)

3.1 LIQUEFACTION

As explained in the previous section, the cargo will act as a dense, viscous fluid when liquefied. For standard bulk carriers, the stability becomes critical under such conditions, due to the free surface effect. Most cargoes that may liquefy are relatively dense, so normally only a small part of the cargo hold volume is occupied by cargo. Combined with the relatively wide holds of standard bulk carriers, this leaves a lot of space for the liquefied cargo to move around and cause a high risk of stability problems. The destabilizing effect caused by the free surface may put the vessel in jeopardy.

Another possible scenario is that the cargo flows to one side of the cargo hold with a roll, but does not completely flow back to the starting point with the next roll. The vessel may then experience a progressively increasing heel angle, which may result in a sudden capsize.

The possible structural damages are related to the fact that the pressures exerted on non-horizontal cargo hold boundaries, such as transverse bulkheads, are higher for a liquid than for a dry bulk cargo.

Typically the pressures are increased by a factor of two or three. This is illustrated in Figure 8 below, where pressures on the inner bottom and transverse bulkhead are shown for dry cargo and liquefied cargo respectively.

On ore carriers the stability is normally not critical, since the longitudinal bulkheads limit the width of the cargo hold. The structural strength, on the other hand, may be more serious than on conventional bulk carriers, due to the higher filling in the cargo hold and because the cargo hold boundaries are not designed to withstand flooding.

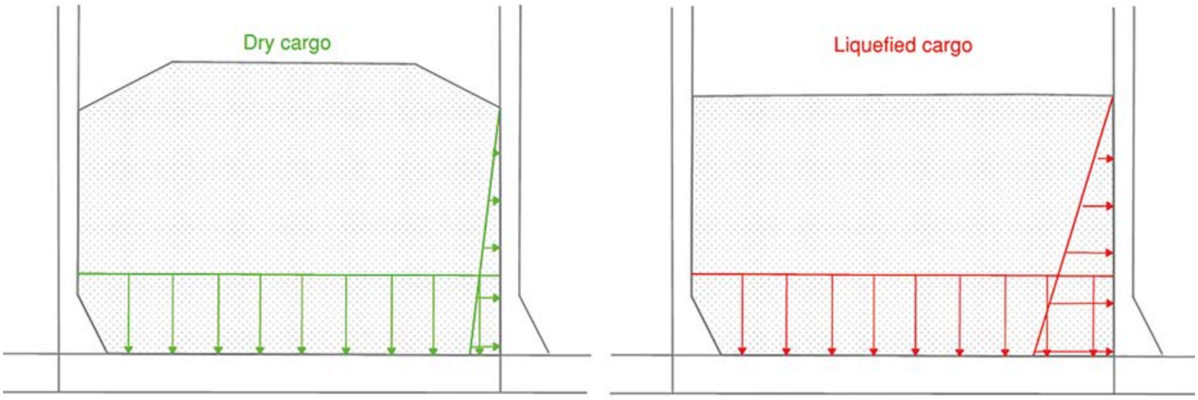


Figure 8 – Pressure on bulkhead

3.2 SLIDING

Sliding of the cargo is not exactly the same as liquefaction, but could be considered as a related phenomenon. Sliding may occur in untrimmed cargo holds during heavy rolling if the inherent cohesion, or "stickiness", of the cargo is too low. To illustrate the concept of cohesion, we could use sand as an example. Damp sand is quite cohesive and can be used to make sandcastles with steep or even vertical sides. Dry or very wet sand has almost no cohesion and cannot be used for sandcastles, as any steep slopes will collapse.

Similar to sand, the cohesion of many bulk cargoes is also dependent on the moisture level, and both too dry and too wet cargoes could be prone to sliding. Due to moisture migration, the surface may dry out and a wet base at the bottom may be formed, leaving both top and bottom with low cohesive strength.

4. WHICH CARGOES ARE TO LIQUEFACTION?

4.1 IMSBC CODE GROUP A

In the IMSBC Code, the cargoes have been divided into three groups. Group A consists of cargoes that may liquefy. Group B are cargoes with a chemical hazard. Group C cargoes are neither liable to liquefy nor to possess chemical hazards.

The majority of the Group A cargoes are various types of mineral concentrates. Fortunately there have not been many incidents related to these cargoes in recent years, most likely because the cargoes are uniform in nature, and the properties and condition are well controlled.

Several types of unprocessed ore cargoes are also classed in Group A. Such cargoes have been linked to a number of tragic accidents. The most common and dangerous of these cargoes will be described in more detail in the following sections.

In addition, Group A includes various other cargoes that will not be described in this guideline. For an exhaustive list of Group A cargoes, reference is made to IMSBC Code Appendix 1.

4.2 NICKEL ORE

Nickel ore is arguably the most dangerous of all bulk cargoes, suspected of claiming the lives of 81 seafarers since 2010. The number of fatalities is horrific when taking into account that the nickel ore trade only amounts to approximately 2% of the total bulk cargo trade.

The largest exporters of nickel ore have traditionally been Indonesia and the Philippines, but since the Indonesian ban on export of several types of unprocessed ores in January 2014, the Philippines has by far been the largest exporting country. The vast majority of nickel ore is shipped to China, where it is used for making stainless steel. The trade has grown rapidly in the last decade, from 6m tons in 2005 to 80m tons in 2013, and is now among the largest "minor bulk" cargoes.

There are several reasons for why liquefaction is such a huge problem for nickel ore. Nickel ore is dug from open pit mines. It is an extremely low-grade ore, with nickel content as low as 1%. The remaining 99% is fine-grained, almost clay-like soil. Since the ore is dug from open pits, it may be very wet in the monsoon season. Wet, fine-grained material is prone to liquefaction. To make things worse, most of the mines are located in very remote areas, which makes TML testing difficult.

Figure 9 – Nickel ore liquefaction on a bulk carrier

SUBJECT

4.3 IRON ORE FINES AND IRON CONCENTRATE (SINTER FEED)

Iron ore fines are iron ore with a large proportion of small particles (10% smaller than 1mm, and 50% smaller than 10mm). The cargo may liquefy if the moisture content exceeds TML.

Iron ore fines have been associated with several accidents in recent years, as can be seen in Table 1 in Section 1.1. A contributing factor to the accidents is believed to be that the cargo has been wrongly categorized as normal iron ore, which, according to the IMSBC Code, is cargo that poses no liquefaction risk. In a response to this, Australia and Brazil fronted an initiative to the IMO to amend the IMSBC Code with an individual schedule for iron ore fines, and also with a modified TML test procedure. The mandatory entry into force of the amended IMSBC Code is January 1st 2017, but it is strongly recommended to implement the amendments as soon as possible.

Iron concentrate (sinter feed) is iron ore that has been processed to increase the content of iron. The material is very fine-grained, and even though it is a different kind of cargo than iron ore fines, technically speaking, it possesses the same risk with regard to liquefaction.

Figure 10 – Iron ore fines before and after liquefaction (Photo: Gard)

Figure 11 – Australian bauxite mine

4.4 BAUXITE

Bauxite is an aluminium ore, and the world's main source of aluminium. The bauxite is mined in open-pit mines, then converted to alumina (aluminium oxide), which is in turn further processed to pure aluminium by electrolysis.

Bauxite is considered one of the most important bulk trades. The main importer is China. Until January 2014 Indonesian bauxite accounted for approximately two-thirds of the Chinese imports, but China has been sourcing bauxite from other locations since the Indonesian ban on export of unprocessed ores.

It may be confusing that bauxite is listed under Group C cargo in the IMSBC Code, meaning that it poses neither chemical nor liquefaction risks. It is important to know that this listing only covers relatively dry and relatively coarse-grained bauxite. If the bauxite has a large proportion of powder, or if the moisture content is above 10%, the cargo is potentially unsafe, and more information about the cargo should be gathered (See Section 5.1).

Normally bauxite is shipped without any processing; however, in some cases the ore is sieved before shipping to remove large lumps. Sieving involves using high pressure water to force the ore into rotary sieves. In addition to increasing the portion of fines, water will be added to the cargo. Both these factors increase the risk of liquefaction.

The risks of loading fine-particled bauxite cargo are high on the agenda in the shipping industry. David Tongue, Secretary General of Intercargo, said: "What is normally considered a Group C cargo may have the potential to behave like a Group A cargo when that cargo's specified characteristics are not maintained, especially when cargoes with higher levels of fines and moisture beyond those specified in the IMSBC Code are presented. The IMSBC Code states that 'many fine-particled cargoes, possessing sufficiently high moisture content, are liable to flow. Thus any damp or wet cargo containing a proportion of fine particles should be tested for flow characteristics prior to loading'."

Shipowners, operators and charterers should exercise extreme care when dealing with any cargo that has the potential to liquefy, and Intercargo reiterates the importance of caution being the best policy. If there is any doubt whatsoever as to the authenticity or content of the cargo declaration, Intercargo strongly advocates the use of independent tests to check and report the actual cargo condition prior to loading.

P&I clubs are also voicing their concerns and issuing recommendations for their members, emphasizing that shipowners should be alert to any cargoes which possesses flow properties when wet or contain a high proportion of fine particles.

5. OPERATIONAL GUIDELINES

In this section the most common causes for liquefaction-related incidents are described, along with DNV GL's guidelines for mitigating actions.

5.1 WRONG CARGO NAME

The name of the cargo should be described by using the Bulk Cargo Shipping Name (BCSN) as detailed in the IMSBC Code. Sometimes shippers use trade or commercial names instead. The trade or commercial name may be used as a supplement to the BCSN, but must not be used as a substitute. The consequence of not using the proper name could be that the risks of the cargo are not correctly detected.

Guideline:
1. **The Master and shipper/operator should always make sure the cargo is correctly identified before loading.**

5.2 CARGO NOT LISTED IN IMSBC CODE

If the cargo is not listed in the IMSBC Code, such as bauxite with high moisture content, the shipper must provide the competent authority of the port of loading with the characteristics and properties of the cargo. Based on the information received, the port authority will assess the acceptability of the cargo for safe shipment. After consulting with the port of unloading and the flag state, the loading port authority will provide to the Master a certificate stating the characteristics of the cargo and the required conditions for carriage and handling of this shipment.

Guideline:
1. **The Master should always make sure proper documentation of the cargo is received before loading.**

5.3 TML

In order to get reliable TML values, representative samples of the cargo have to be tested in laboratories, as explained in Section 2.3. For shippers of processed mineral concentrates, this is usually not a problem, since it is sufficient to do testing every sixth month due to the uniform nature of the cargo.

On the other hand, in case of unprocessed ore cargoes, such as iron ore fines, bauxite or nickel ore, it may be difficult to get the cargo tested in a suitable lab. The properties of the cargo may vary significantly, so every cargo being shipped should be tested. TML testing is a specialized task, and worldwide there are not many competent and independent laboratories. In some of the main ore exporting countries, there are few or none such labs. The testing problem is amplified by the fact that many mines are not easily accessible due to their remoteness. It is therefore difficult for independent surveyors or experts to visit the mines and take samples of the cargo. The mines usually have their own laboratories, but it is questionable whether all of them are properly equipped or whether the procedures of the IMSBC Code are always followed.

It is the responsibility of the shipper to declare the cargo as a liquefaction hazard and provide a TML certificate. Unfortunately it is difficult for the Master to verify or independently assess the TML value other than with the highly inaccurate can test, as mentioned in Section 2.3. The Master should be updated on any known problems with a specific cargo. In addition, it is recommended to appoint an independent surveyor or cargo specialist for advice.

Guideline:
1. **It is recommended to appoint an independent surveyor or cargo specialist for advice.**

5.4 MOISTURE CONTENT PRIOR TO LOADING

The shipper has to present a declaration of the average moisture content of the cargo before loading. In this process there are many potential sources of error, and again the unprocessed ore cargoes are most vulnerable.

Guideline:

1. In order to determine the average moisture content, the samples have to be representative of the whole shipment. This means that the entire cargo has to be available at the load port prior to start of loading. It is also important that samples are taken from the full depth of the stockpile.

2. For ore cargoes the properties and moisture content may vary significantly. It may be required to state, by hold, moisture content levels. If the variations are so large that the cargoes are considered as different types of cargo, the moisture content should be given separately for each cargo type. This is the case even if the cargoes are mixed in the same cargo hold.

3. The interval between testing for moisture content and loading the cargo must be as small as practicable, and may in no case be more than seven (7) days. In case of rain between the time of testing and loading, tests must be conducted again.

It is sometimes reported that the guidelines mentioned above are not adhered to. As with TML, it is difficult for the Master to verify or independently assess the moisture content, other than when the cargo is so wet that the moisture can be seen on the surface in the form of wet mud or puddles. However, especially during monsoon season or other periods with heavy rain, the Master should be vigilant. Again, it is recommended to appoint an independent surveyor or cargo specialist for advice.

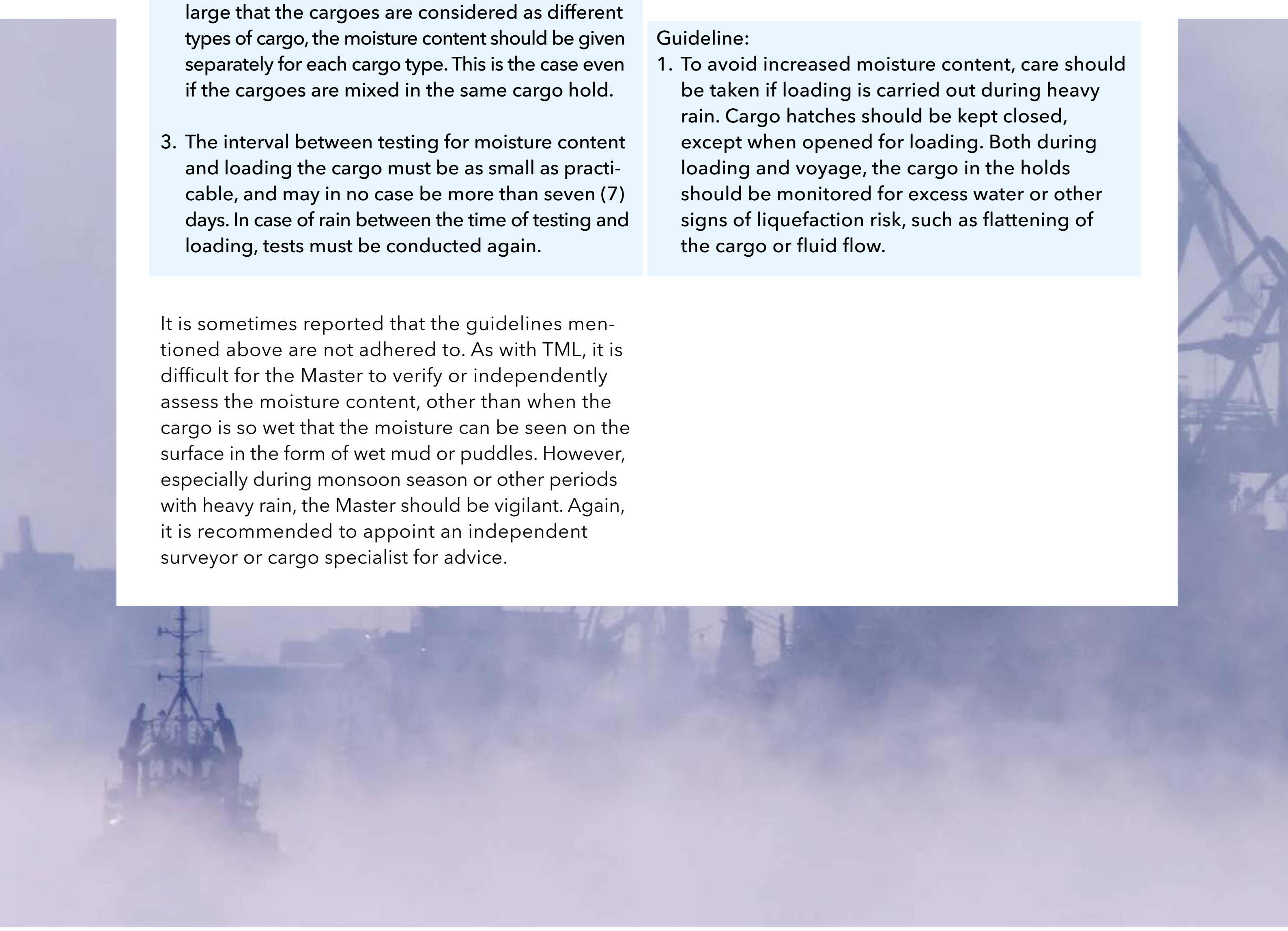
5.5 INCREASED MOISTURE DURING LOADING AND DURING VOYAGE

Even if a reliable measurement of the moisture content is provided before loading, there are still some areas of concern regarding moisture content. Needless to say, the moisture content will increase in case of heavy precipitation during loading. If barges are used for transportation of the cargo from the stockyard to the ship, rain and waves may add water.

During the voyage the moisture content may vary due to drainage and possible water ingress into the cargo hold. Even if the average moisture is below TML, there may be local variations in the cargo pile due to moisture migration. The moisture from the top layer is likely to migrate downwards, resulting in an increasing moisture level towards the bottom of the hold. This may cause partial liquefaction or sliding of the cargo.

Guideline:

1. To avoid increased moisture content, care should be taken if loading is carried out during heavy rain. Cargo hatches should be kept closed, except when opened for loading. Both during loading and voyage, the cargo in the holds should be monitored for excess water or other signs of liquefaction risk, such as flattening of the cargo or fluid flow.



5.6 VESSEL MOTIONS AND GM

The metacentric height of the vessel should be carefully considered when carrying cargoes that may liquefy. An excessive GM value results in shorter rolling periods and high accelerations which may trigger liquefaction.

Guideline:

1. If the loading condition and the structural strength of vessel allow it, the centre of gravity of the vessel could be raised by ballasting the top wing tanks or by loading the cargo in a non-homogeneous pattern.

2. Weather routing is recommended in order to avoid excessive motions.

5.7 TRIMMING OF LOAD TO AVOID SHIFTING/SLIDING

Trimming the cargo is a well-known method for reducing the risk of cargo shift or cargo sliding. In addition, the stability and the weight distribution are improved. On the other hand, trimming increases the required time and cost for loading.

Guideline:

1. When carrying cargoes that may slide, the cargoes should be trimmed as necessary to ensure that they are reasonably level.

6. DESIGN GUIDELINES

SPECIALLY CONSTRUCTED OR FITTED CARGO VESSELS

6.1 CERTIFICATE OF FITNESS

The general rule is that cargo with moisture content above TML may not be loaded on board. However, in the IMSBC Code there is an allowance made for carrying such cargoes on specially constructed or specially fitted ships. These ships are constructed in such a way that they remain stable and afloat even if the cargo liquefies or shifts. Such ships have better operational efficiency, since testing for TML and moisture content is not required and because wet cargo does not have to be rejected.

Guideline:

1. Specially constructed or fitted ships need approval from the flag state.

2. The requirements for such ships are not well specified in the IMSBC Code, other than that the vessels are to have permanent structural boundaries or specially designed portable divisions to confine any shift or liquefaction of cargo.

3. It is also clear that the stability and structural strength have to be specially considered.

In the following two sections, the applicable strength and stability criteria are described, based on DNV GL's procedure. It should be emphasised that the flag states may set different or additional requirements.

6.2 STABILITY EVALUATION

When assessing the stability of a specially constructed or fitted vessel, two different scenarios are to be investigated.

The first scenario is shifting or sliding of the cargo, as shown in Figure 12 below. The cargo in all holds is shifted at an angle of 25 degrees, creating a fixed heeling moment. In this condition the vessel fulfils the IMO Grain Code criteria.

The second scenario is a fully liquefied condition where the cargo behaves as a liquid. It is assumed that the cargo in all holds is liquefied and therefore has a free surface effect. In this scenario the vessel satisfies the criteria of the IMO Intact Stability Code. It is not required to check the damage conditions originating from SOLAS II-1 Reg. 9 (double bottom) and ICLL Reg. 27 (reduced freeboard) together with liquefaction conditions. These damage conditions should be checked independently without considering liquefaction.

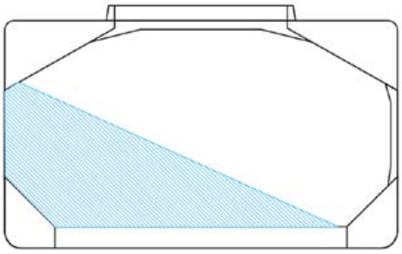


Figure 12 – Cargo shift

6.3 HULL STRENGTH EVALUATION

In the evaluation of structural strength, only the liquefaction scenario needs to be investigated. In this condition the pressure on the vertical cargo hold boundaries is significantly increased. When calculating the cargo pressure, the cargo is assumed to behave as a heavy liquid, as described in Section 3.1.

The yield and buckling strength of the structure should be assessed by finite element analysis. This may be performed in combination with an automatic buckling check, in accordance with DNV GL Class Rules. The typical findings for such analyses are described in the two next sections.

Guideline:

1. The design conditions must be based on the most severe operational cargo conditions in the loading manual. Harbour conditions need not be assessed. The possibility of liquefaction occurring in only one cargo hold or simultaneously in two or more holds should be assessed. The liquefaction design loading conditions are considered intact conditions, meaning that no permanent deformations of the ship structure are acceptable.

2. It could be argued that liquefaction should be considered an accidental load, since liquefaction is an unwanted incident. Normal design philosophy for accidental load cases is to allow some buckling, indentations and other deformations, as long as the overall integrity of the vessel is maintained. However, designing vessels on such a basis would not allow the owner to load cargo with moisture content above TML on a regular basis; it would only ensure a safety margin to handle liquefied cargo if liquefaction were to happen by accident. It is therefore recommended to consider the load as an extreme load, but not as an accidental load.

6.4 DNV GL INVOLVEMENT

DNV GL may assist in several phases in the development of specially constructed or fitted vessels:

Phase 1:
Establish the necessary background documentation required for the design as basis for requesting approval from the flag state. The DNV GL advisory department has extensive experience with both the required hull strength assessment and the stability calculations, and may support designers and shipyards in this phase.

Phase 2:
Obtain approval from the flag state. The DNV GL Class department may assist by issuing a statement of compliance with the IMSBC Code after thorough review of the relevant structural drawings and stability calculations. The statement of compliance will be based on a set of stability and strength criteria, as described in the previous sections.

6.5 SPECIAL CONSIDERATIONS FOR BULK CARRIERS

Investigations on conventional bulk carriers (with no centreline bulkhead) confirm their vulnerability in the event of cargo liquefaction. The effect on the free surface from the liquefied cargo becomes very critical for wide holds. The cargo-shifting scenario is obviously equally severe for wide cargo holds.

Guideline:

1. **According to DNV GL experience, arranging longitudinal bulkheads to narrow the holds is the only feasible way of obtaining sufficient stability to withstand cargo liquefaction for a conventional bulk carrier.**

Unfortunately there are significant drawbacks of such longitudinal bulkheads on a bulk carrier. The most important is that the cargo hold volumes will be reduced, which makes the vessel less suitable for carriage of low-density cargoes. In addition, the steel weight and construction cost will increase.

Conventional bulk carriers are designed for a wide variety of cargoes with different characteristics, such as density and angle of repose. Modern bulk carriers are also designed to withstand accidental flooding of the cargo holds. In addition, the filling height of cargoes that may liquefy is often quite low due to the relatively high density.

Guideline:

1. **The structural consequences of cargo liquefaction are generally minor for bulk carriers. This means that the hull strength is usually not a critical area of concern when assessing cargo liquefaction.**

6.6 SPECIAL CONSIDERATIONS FOR ORE CARRIERS

For ore carriers the situation is different than for bulk carriers. These vessels, which are typically arranged with longitudinal bulkheads, will normally be capable of meeting relevant criteria applied for the cargo failure conditions as described in 6.3. This is a consequence of the fact that the maximum breadth of the cargo hold versus the ship's breadth is low in comparison with the conventional bulk carrier.

Due to the high filling level of the holds, the hull may need considerable strengthening in order to comply with the hull strength criteria for cargo liquefaction. Figure 13 below shows the areas which require special attention for a standard ore carrier, together with standard nomenclature. The areas of special attention are described in more detail in the next paragraphs.

6.6.1 Longitudinal bulkheads

The lateral pressure load will be significantly increased on plates and stiffeners of the longitudinal bulkheads; the scantlings will therefore normally have to be increased.

Guideline:

1. **The stiffeners are supported by the web frames in the wing tank, and the increased loading will result in high shear stress in the lower part of these web frames. Thicker plating or steel with a higher yield point may be required.**

2. **The cross ties will experience higher compressive forces, and pillar buckling has to be checked. The stress level may also be above the yield stress, requiring increased strength.**

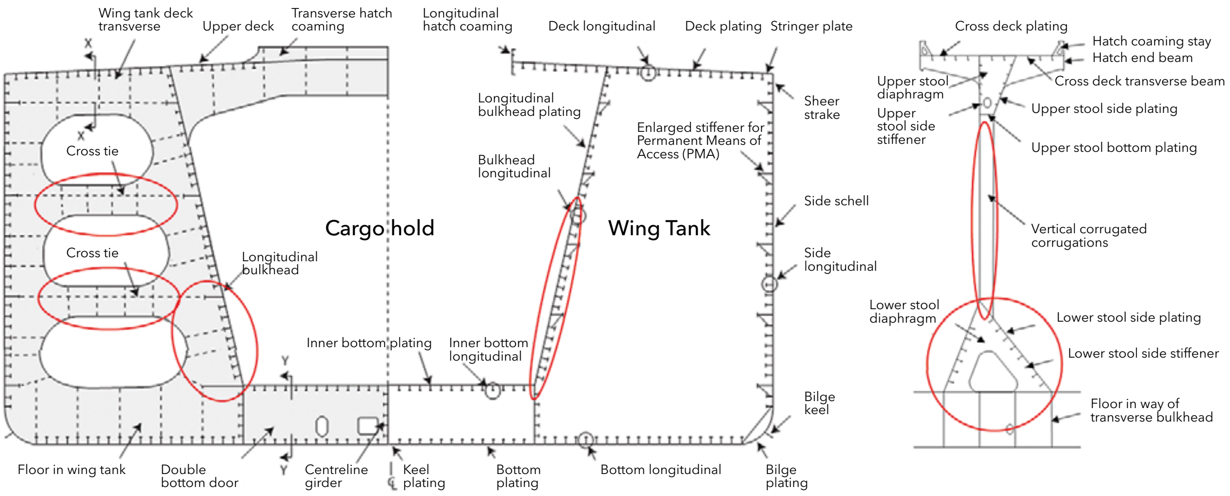


Figure 13 – Ore carrier: Areas of special attention

6.6.2 Lower stool

For the plates and stiffeners on the lower stool in way of the transverse bulkhead, the situation is similar to that for the longitudinal bulkheads.

Guideline:
1. The pressure is increased, and the scantlings need to be increased accordingly.
2. The diaphragms inside the stools may need reinforcements, depending on the initial scantlings.

6.6.3 Transverse corrugated bulkheads

The strengthening of the transverse corrugated bulkheads is very much dependent on the relevant loading conditions.

Guideline:
1. If the vessel is designed for only homogeneous loading conditions, the structure has to be checked for the worst condition, which in this case is liquefaction in one hold and no liquefaction in the neighbouring hold. In this case the pressure from the liquefied cargo will only partly be counteracted by the cargo pressure from the neighbouring cargo hold.
2. If the vessel is designed for multiport conditions or other conditions with uneven filling or even empty holds, this effect will not be present.
3. The filling height of the cargo is important, especially for the corrugations. For low density cargoes, the filling height is higher, which means that the total force on the corrugations will be larger. The centre of pressure is also less favourable when considering corrugation bending. The effect of filling height is illustrated in Figure 14 below, where the total force on the bulkhead is shown in light red colour.

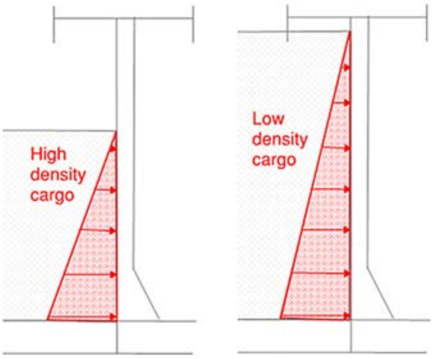


Figure 14 – Force on bulkhead

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Design: Maritime Communications ID: 890116