MARITIME

BULK CARGO LIQUEFACTION

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

May 2019

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.

In the last ten years, cargo liquefaction has caused the loss of more than 100 seafarers lives and twelve bulk carrier vessels, and remains the most important safety issue for bulk carriers. Awareness of which conditions may cause cargo liquefaction is essential for the safe operation of bulk carriers, which is why DNV GL issued a first edition of this guidance document in October 2015. The guideline covers both the design and operation of vessels with bulk cargoes that may liquefy. The intention of the 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 groups are ship designers, yards, ship owners and other stakeholders in the shipping industry.

In the May 2019 revision of the guideline, we have taken into account feedback received from many readers and from practical experience gained after the first issue in 2015. Two new paragraphs have been added, 5.8 and 5.9, to better describe precautions to be taken during voyage or in case cargo liquefaction is detected. In addition, parts 4 and 6 have been updated to include the latest developments, including DNV GL's new class notation BCLIQ. We welcome your feedback on these new revisions.

TABLE OF CONTENTS

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 six of the nine vessels were less than ten years old and presumably in good condition. It is also noticeable that there is a strong link to the rainy season in Southeast Asia.

Vessel	DWT	Built	Lives lost	When	Cargo type	Cargo origin
Asian Forest	14k	2007	0	17 July 2009	Iron ore fines	India
Black Rose	39k	1977	1	9 September 2009	Iron ore fines	India
Jian Fu Star	45k	1983	13	27 October 2010	Nickel ore	Indonesia
Nasco Diamond	57k	2009	21	10 November 2010	Nickel ore	Indonesia
Hong Wei	50k	2001	10	3 December 2010	Nickel ore	Indonesia
Vinalines Queen	56k	2005	22	25 December 2011	Nickel ore	Philippines
Sun Spirits	11k	2007	0	22 January 2012	Iron ore fines	Philippines
Harita Bauxite	50k	1983	15	16 February 2013	Nickel ore	Indonesia
Trans Summer	57k	2012	0	14 August 2013	Nickel ore	Philippines
Bulk Jupiter	56k	2006	18	2 February 2015	Bauxite	Malaysia
Alam Manis	56k	2007	1	17 July 2015	Nickel ore	Philippines
Emarald Star	57k	2010	10	13 October 2017	Nickel ore	Indonesia

Table 1 – Liquefaction accidents

Figure 1 – The *Trans Summer* after capsizing (Photo: HKG Flying Service)

2. WHAT IS BULK CARGO LIQUEFACTION?

In this section, the physics behind liquefaction are 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.

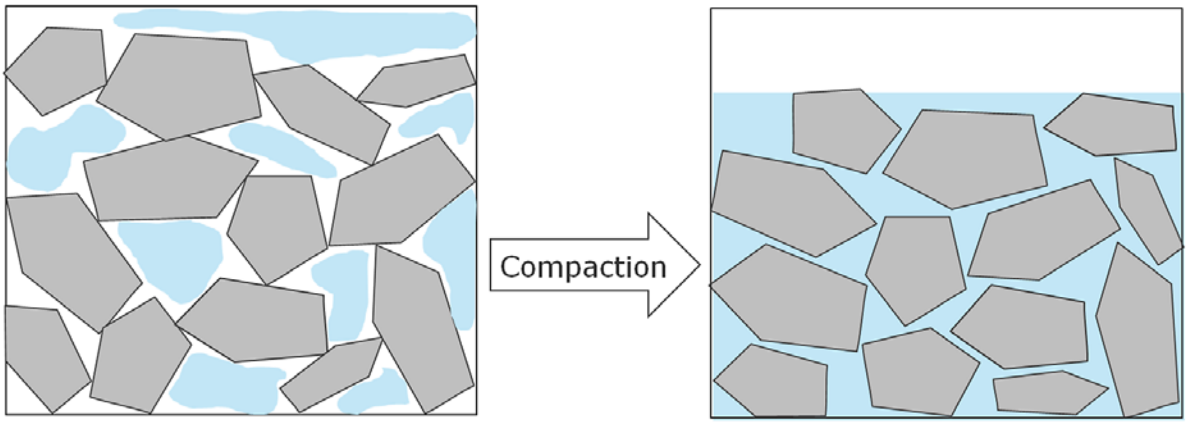

Figure 2 – Liquefaction as a result of cargo compaction

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 – i.e. 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. Furthermore, 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 1 January 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 the 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 the 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 – The 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 the moisture content and the 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, capsizing and structural damage.

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.

To illustrate the effects of cargo liquefaction with free surface effect, an example is provided below which is based on real case experience.

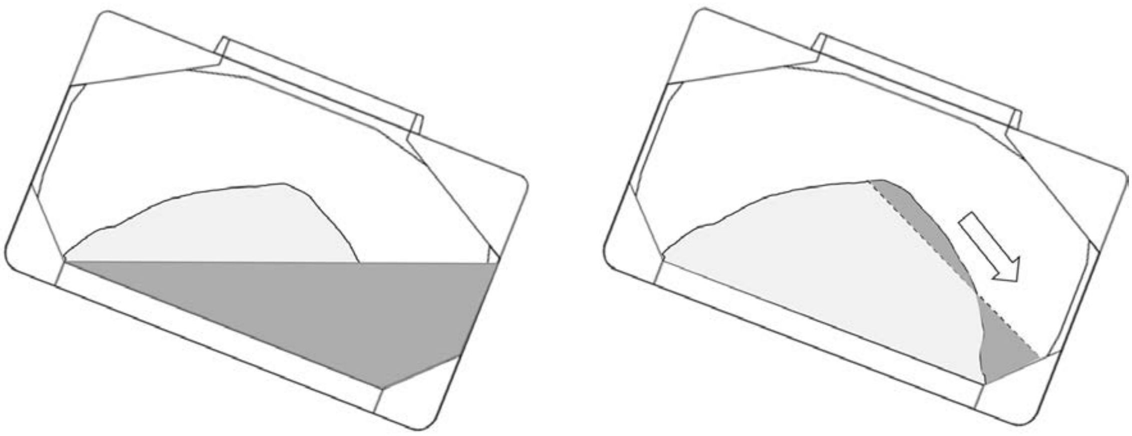

Figure 7 – Liquefaction (left) and sliding (right)

Depending on the design characteristics, standard bulk carriers can retain some sufficient stability with full free surface effect in less than the half of the cargo holds at the same time. Full free surface effect in more cargo holds may result in negative initial stability (GM) and in permanent equilibrium list. In a particular case, the list was about 25 degrees, and the GZ curves indicated that the list can be reduced by ballasting only to 10 degrees on the same side. At around 10 degrees, the vessel will have very little area under the GZ curve and can easily flip to 10 degrees on the opposite side with the risk of cargo shifting and the vessel capsizing.

Further reduction of the list could be achieved only after removing the free surface effect from the cargo holds. The stability in such a condition cannot be calculated and evaluated on the ship's loading computer, so the officers should seek support from shore-based experts. Such cargo failure scenarios have been associated with bauxite cargo. To accurately define the safety margins after cargo liquefaction, every ship and liquefaction case should be evaluated individually.

Another possible scenario is that the cargo flows to one side of the cargo hold with a roll of the ship, but does not completely flow back to the starting point with the subsequent roll. Depending on how many holds the cargo had shifted in, and to what extent, the vessel will develop new equilibrium with large permanent list, and will be rolling more on the heeling side than on the opposite side. The ship may potentially be taking green water on deck, submerging vent heads and hatch covers, which could become a source of progressive flooding. This may increase the rolling and heeling on the listed side, causing more cargo shifting and ultimately resulting in capsizing. Such cargo failure scenarios have been associated with nickel ore cargoes.

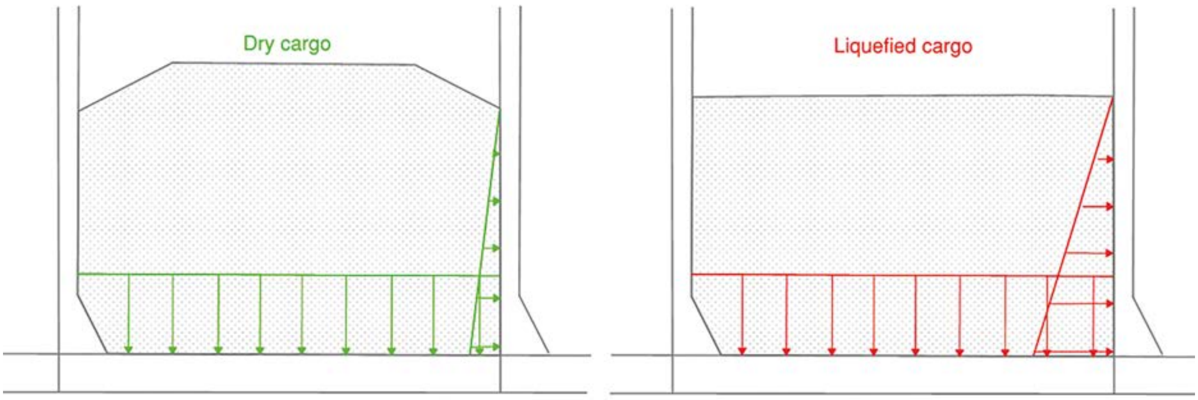

Figure 8 – Pressure on bulkhead

3.2 SLIDING

The sliding of 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.

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 above, 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, in contrast, 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.

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 SUBJECT 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 the 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 82 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 is 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 1 mm, and 50% smaller than 10 mm). The cargo may liquefy if the moisture content exceeds the 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.

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 AND BAUXITE FINES

Bauxite is an aluminium ore, and the world's main source of aluminium. 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 the export of unprocessed ores.

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 is added to the cargo.

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.

In January 2021, an amendment to the IMSBC Code will enter into force, where a new schedule for bauxite which may liquefy, bauxite fines, will be introduced. It is highly recommended to implement the schedules and test procedure as soon as possible.

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

5.2 CARGO NOT LISTED IN THE 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:
The Master should always make sure proper documentation of the cargo is received before loading.

5.3 THE 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 months due to the uniform nature of the cargo.

At the same time, 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:
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.

Guidelines:

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 loading port prior to the start of the 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 the 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 the 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:
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.

Guidelines:

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. At the same time, however, trimming increases the required time and cost for loading.

Guidelines:

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

2. IMSBC Code Section 5 Trimming procedures provides good guidance for trimming different types of cargo.

5.8 LIQUEFACTION DURING VOYAGE

Liquefaction is a phenomenon which could have dramatic consequences and, in most cases, it cannot be dealt efficiently with when at sea. Investigations of cases where ships are suspected to have been lost due to liquefaction indicate that in bad weather, the phenomenon develops very fast. In some of the cases, the time between an initial permanent list of 5 degrees until the vessel had capsized is reported to have been as short as 35 minutes.

Ship and shipping company officers should be familiar with the hazards, the hallmarks and the possible scenarios for cargo liquefaction. They should be prepared to take appropriate actions fast, to minimize the risks and the effects of liquefaction, and to know which actions could save lives of the crew and the ship itself.

Guidelines:

1. Know that liquefaction is most often triggered by heavy rolling (i.e. rough seas, large rolling amplitude and short rolling period).

2. When the ship is loaded with cargo which may liquefy, the route should be carefully planned, and the route plan should be kept updated with respect to the weather forecast so that bad weather which could trigger heavy rolling can be avoided.

3. The rolling period of the ship in the specific loading condition should be known and compared with the frequency of the waves. Rolling should be kept at a minimum, if possible, and the rolling period of the ship should be changed away from the one of the waves to avoid a state of resonance, which accelerates the development of liquefaction.

4. As much as weather and safety permit, the surface of the cargo in all holds should be periodically checked for signs of change (i.e. surface collapse, flattening of cargo piles, cargo shifting, accumulation of water on top of the cargo). A record of findings should be kept and compared with previous checks and findings to trace any changes. If changes and abnormalities or liquefaction in one or several cargo holds are noticed, help from shore-based experts should be sought to evaluate the risks and to develop a plan of action. Seeking a sheltered area for the ship is recommended.

5. When the vessel rolls, the list and the rolling parameters should be monitored. If the ship develops any permanent list and/or is rolling asymmetrically, this may be an indication of liquefaction in progress. The crew should be alerted and aware of possible scenarios.

6. If liquefaction of bulk cargo is confirmed, the crew should prepare and stay ready to leave the vessel on short notice until the situation is brought under control or the decision to leave the ship is taken. The course of navigation should be adjusted to minimize the roll movement.

7. An evaluation of whether it is safe to remain on board or not, as well as actions, should be taken in accordance with company's safety procedures (Safety Management System) for such situations.

8. Support and advice should be sought from shore-based experts regarding whether it is possible or not to improve the vessel's condition and how. For such support, emergency response services of class societies (e.g. ERS™ from DNV GL) can be contacted around the clock. Another alternative for support could be marine and cargo survey companies.

It is recommended that all shipping companies operating bulk carriers should have the respective standard operational procedures for handling cargo liquefaction in their Safety Management System.

5.9 DNV GL INVOLVEMENT

DNV GL class and advisory services have built up extensive understanding of the effects and risks of the liquefaction phenomenon on ships. DNV GL's Emergency Response Service (ERS™) has been involved in many liquefaction and liquefaction-related cases and post-liquefaction studies. ERS™ engineers have also helped resolve difficult cases involving vessels halted in port with cargo TML problems.

Guidelines:

1. Emergency Response Services (e.g. ERS™ from DNV GL) can provide fast support and specific advice in cases of cargo liquefaction.

2. Enrolment of bulk carriers in ERS™ can ensure the crew receives critically important support in decision-making with respect to cargo liquefaction.

6. DESIGN GUIDELINES

SPECIALLY CONSTRUCTED OR FITTED CARGO VESSELS

6.1 CERTIFICATE OF FITNESS

The general rule is that cargo with moisture content above the 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 the TML and moisture content is not required and because wet cargo does not have to be rejected.

Guidelines:

1. Specially constructed or fitted ships need approval from the flag state.
2. The IMSBC Code specifies high-level requirements for specially constructed or fitted ships.
3. The DNV GL class notation BCLIQ provides practical requirements for stability and strength, fulfilling the high-level requirements of the IMSBC Code.

In the following two sections, the applicable stability and strength criteria of the BCLIQ notation are described. 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 a fully liquefied condition in which 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.

The second scenario is the shifting or sliding of the cargo, as shown in Figure 12. 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.

Ships intended to carry cargoes that do not resettle in a stable state after liquefaction, e.g. nickel ore, shall satisfy SOLAS damage stability requirements with all cargo in all cargo holds in a liquefied state.

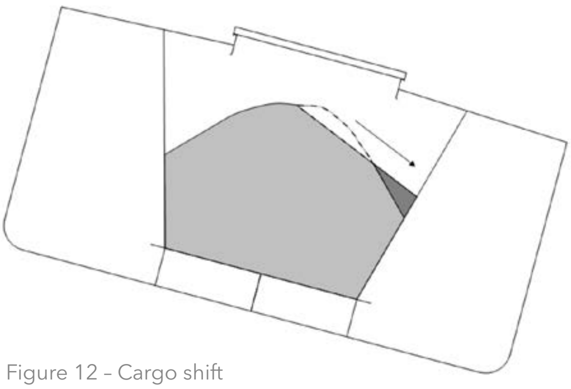

Figure 12 – Cargo shift

6.3 HULL STRENGTH EVALUATION

In the evaluation of structural strength, only the fully liquefied 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 is assessed by finite element analysis. The typical findings for such analyses are described in the two next sections.

Guideline:
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 shall be assessed. The liquefaction design loading conditions are considered intact conditions, meaning that no permanent deformations of the ship structure are acceptable.

6.4 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:
According to DNV GL's 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 are reduced, which makes the vessel less suitable for carriage of low-density cargoes. In addition, the steel weight and construction cost 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:
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.

6.5 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 Section 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 to conventional bulk carriers.

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 the standard nomenclature. The areas of special attention are described in more detail below.

Longitudinal bulkheads

The lateral pressure load is significantly higher on plates and stiffeners of the longitudinal bulkheads, which means the scantlings will normally have to be increased.

Guidelines:

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.

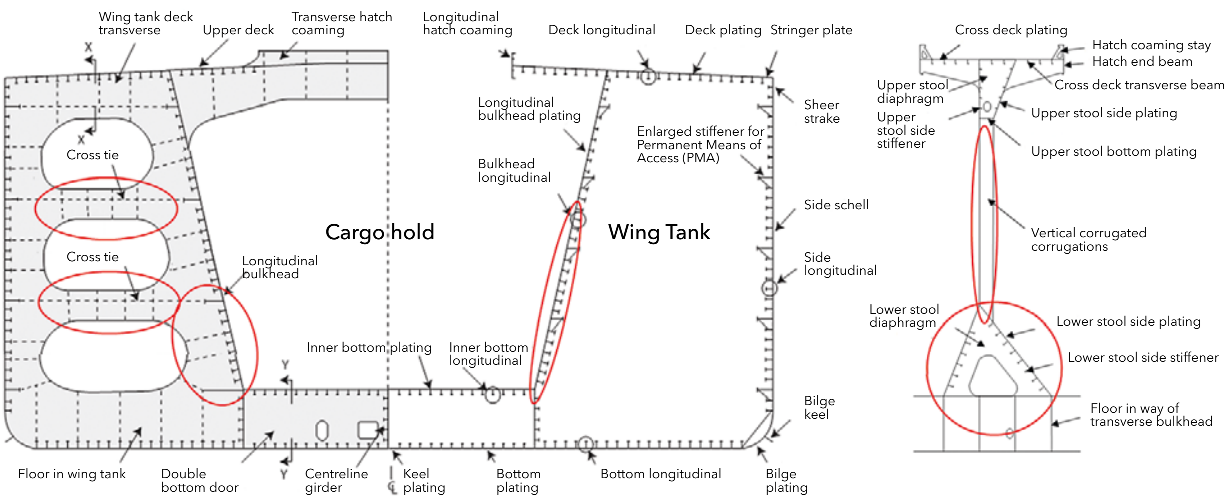

Figure 13 – Ore carrier: areas of special attention

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.

Guidelines:
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.

Transverse corrugated bulkheads

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

Guidelines:
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 the filling height is illustrated in Figure 14, where the total force on the bulkhead is shown in a light red colour.

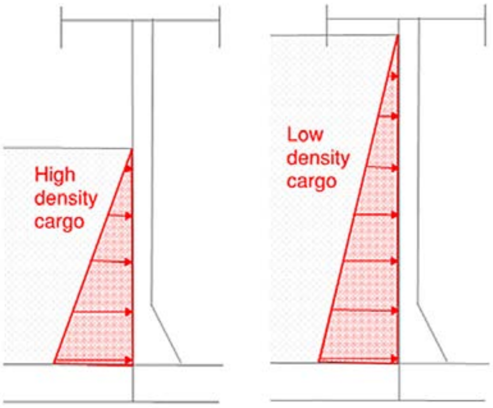

Figure 14 – Force on bulkhead

6.6 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 the 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 (SoC) with the IMSBC Code after a thorough review of the relevant structural drawings and stability calculations. The SoC is based on a set of stability and strength criteria, as described in the previous sections.

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DNV GL
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