ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

ANALYSIS PHYSICAL CHANGE OF LIQUEFY BULK CARGO DURING SEA TRANSPORTATION

M.Sc. THESIS

Canan ŞENDİLMEN DANACI

Department of Maritime Transportation Engineering

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Thesis Advisor: Yrd. Doç. Dr. Münip BAŞ

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

DENİZ YOLUYLA TAŞINMASI SIRASINDA SIVILAŞABİLEN DÖKME YÜKLERİN FİZİKSEL DEĞİŞİMİNİN ANALİZİ

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ARALIK 2015

Canan ŞENDİLMEN DANACI, a **M.Sc.** student of ITU **Graduate School of Science Engineering and Technology** student ID 512131025, successfully defended the **thesis** entitled "**ANALYSIS PHYSICAL CHANGE OF LIQUEFY BULK CARGO DURING SEA TRANSPORTATION**", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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	Prof. Dr. Güler ALKAN İstanbul University	....
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Date of Submission : 27 November 2015
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To my spouse and family,

FOREWORD

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November 2015

Canan ŞENDİLMEN DANACI
Ocean Going Chief Officer

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ABBREVIATIONS

ASTM	**:**The International is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.
BC Code	**:**The Code of Safe Practice for (Solid) Bulk Cargoes (adopted by IMO as a recommendatory code in 1965) aimed to facilitate the safe stowage and shipment of solid bulk cargoes, by providing information on the dangers associated with shipment and instructions on the appropriate procedures to be adopted. This was superseded by the IMSBC Code, which became mandatory on 1 January 2011.
BC	**:**(BC Sub-Committee) The Bulk Cargoes Sub-Committee guided the MSC on matters related to the safe carriage of bulk solids, including those related to cargo shift. This committee was formed in the early 1960's and was replaced by the DSC Sub-Committee in 1995.
CCC	**:**(BC Sub-Committee)The Committee for Carriage of Cargoes and Containers, which replaced the DSC in 2014.
D.W.T.	**:**(Deadweight tonnage): A measure (normally in metric tons) of a ship's carrying capacity, also taking into account fuel, fresh water, crew and provisions.
DSC	**:**(DSC Sub-Committee): The Dangerous Solids and Cargoes Sub-Committee guided the MSC for safety related matters associated with solid bulk cargoes. As of 2013, this was replaced by the CCC. Prior to 1995, cargo shift related matters were submitted to the BC Sub-Committee.
FMP	**:**(Flow Moisture Point): The minimum moisture content at which cargo liquefaction may occur, as determined from test methods specified within the IMSBC Code.
FTT	**:**(Flow Table Test): One of the three methods within the IMSBC Code used to determine the TML of a Group A cargo. It is based loosely on the slump test for cements, used in civil engineering.
Group A	**:**The IMSBC Code's classification for cargoes that may liquefy. These are subject to the mandatory reporting, testing and carriage requirements for Group A cargoes within the IMSBC Code (for example, such cargoes must be shipped at a moisture content.
Group B	**:**The IMSBC Code's classification for cargoes that possess chemical hazards. These are subject to the mandatory reporting, testing and carriage requirements for Group B cargoes within the IMSBC Code.

Group C **:**The IMSBC Code's classification for cargoes that neither liable to liquefy nor to possess chemical hazards. These are subject to the mandatory reporting, testing and carriage requirements for Group A cargoes within the IMSBC Code.

IMO **:**(International Maritime Organization) A sub-body of the UN and the international maritime regulator. Renamed from the Inter-Governmental Maritime Consultative Organization (IMCO) in 1982.

IMSBC Code **:**The International Maritime Solid Bulk Cargoes (IMSBC) Code is the regulatory tool used by IMO to ensure the safe carriage of solid bulk materials. This replaced the BC Code in 2008 and became mandatory on 1st January 2011.

MSC **:**(The Maritime Safety Committee) One of four technical groups within IMO that oversees safety related maritime issues. The BC/DSC/CCC sub-committees guide the MSC on matters related to cargo shift and liquefaction.

P&I Club **:**(Protection and Indemnity Insurance Club) Mutual insurance association that provides a form of marine insurance.

PFT **:**(Proctor/Fagerberg Test) One of the three methods within the IMSBC Code used to determine the TML of a Group A cargo. It is based on the Proctor test, used in civil engineering.

PSD **:**(Particle Size Distribution) The distribution of particles at different size fractions (often expressed as 'percent finer by weight'). The PSD may also be described in terms of grading. A 'poorly graded' soil refers to a narrow distribution (all particles are of a similar size). A 'well graded' soil refers to a wide distribution (there is a range of particle sizes).

PTT **:**(Penetration Test) One of the three methods within the IMSBC Code used to determine the TML of a Group A cargo.

SOLAS **:**The International Convention for the Safety of Life at Sea (SOLAS) is an international maritime safety treaty. It ensures that ships flagged by signatory States comply with minimum safety standards in construction, equipment and operation. The SOLAS Convention in its successive forms is generally regarded as the most important of all international treaties concerning the safety of merchant ships.

TML **:**(Transportable Moisture Limit) A concept within the IMSBC Code that represents the maximum moisture at which a Group A cargo can be safely loaded to prevent liquefaction (TML [% moisture] = 90% × FMP [% moisture]). The TML is determined by test methods, as specified within Appendix 2 of the IMSBC Code.

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ANALYSIS PHYSICAL CHANGE OF LIQUEFY BULK CARGO DURING SEA TRANSPORTATION

SUMMARY

It may seem obvious to say that, today, we live in a global world, and that global economy simply could not function if it were not for ships and the shipping industry. As the world became more developed, proximity to raw materials and to markets became the factors that, shaped the world‘s economy and, in particular, the major trade patterns and shipping routes. Eventually, the great seaborne trades became established, coal from Australia, Southern Africa and North America to Europe and the Far East; grain from North and South America to Asia, Africa and the Far East; concentrated ore from South America and Australia to Europe and the Far East. Shipping is perhaps the most international of all the world's great industries and one of the most dangerous. Recently one of the main dangers at bulk carrier vessels is after loaded as solid bulk cargo become to behave like liquid due to the ship vibration and ship motions during seaborne transportation.

Some these solid bulk cargoes such as concentrated ores, unprocessed nickel ores, iron ore fines and bauxite contain sufficient moisture, then cargo compaction during a voyage can cause liquefaction. This has been known to result in major cargo displacement (cargo shift), causing the vessel to capsize. This has resulted in a number of fatalities. To provide context to this problem, an overview of the key considerations is presented, which includes: a summary of the wide range of factors that influence a cargo's likelihood to shift; the soil mechanics principles that can be used to explain cargo shift; and the regulatory controls that are used to prevent its occurrence during shipment.

Under the requirements of international maritime regulation, primarily the International Maritime Bulk Solid Cargoes (IMSBC) Code, a cargo that may liquefy must be shipped below a threshold moisture content, the ‘Transportable Moisture Limit’ (TML)—as determined from one of three laboratory test methods specified within the IMSBC Code. These concerns, this study has aimed to identify any issues inherent in the TML tests and provisions in the IMSBC Code.

The aim of the this study is analysis physical change of liquefy bulk cargo during sea transportation.

At the first chapter of this study liquefy cargoes are defined. The ship accidents have caused by these cargoes which may liquefy are explained from past to present. Besides, transportable moisture limit (TML) and flow moisture point (FMP) are explained.

At the second chapter of the study, the effect of liquefy cargoes on ship stability, the historical developments about liquefy cargo to prevent loss of lives are mentioned in detail.

At the third chapter of the study, the tests to find moisture and transportable value according to IMSBC Code are explained and the bauxite that origin of Mersin tested by smitulated ship motions and vibrations at laboratory environment and physical changes of bauxite analyzed and observed.

At the last chapter of this study, recommendations are given to minimize the negative effect of liquefy cargoes.

DENİZ YOLUYLA TAŞINMASI SIRASINDA SIVILAŞABİLEN DÖKME YÜKLERİN FİZİKSEL DEĞİŞİMİNİN ANALİZİ

ÖZET

Bugün global bir dünyada yaşıyoruz, açıkça söyleyebiliriz ki global ekonomi gemiler ve denizcilik sektörü olmasaydı olmazdı. Dünya geliştikçe hammadde ve pazarlara yakınlık, dünyanın ekonomisini, başlıca ticaret yollarını ve denizcilik rotalarını şekillendiren asıl faktör olmaya itmeye başladı. Neticede büyük deniz ticaret yolları kuruldu: Avusturalya, Güney Amerika ve Güney Afrika'dan Avrupa ve Uzak Doğu'ya kömür; Kuzey ve Güney Amerika'dan Asya Afrika ve Uzak Doğu'ya tahıl; Güney Amerika ve Avusturalya'dan Avrupa ve Uzak Doğu'ya konsantre cevher taşınmaya başlandı. Denizcilik belki de dünyanın en büyük uluslararası sanayisi ve en tehlikelilerinden biridir. Teknolojinin her geçen gün ilerlemesi ve önemini arttırmasıyla denizcilik sektörü de bu ilerlemeden nasibini almaktadır. Teknolojinin önlenemez gelişmesiyle sayıları artan gemiler, artan deniz trafiği insan hayatına geri dönülmesi imkansız sonuçlara yol açmaktadır; şu da gerçektir ki ticaret var olduğu sürece gemiler de var olmaya devam edecektir. Son yıllarda dökme yük gemilerinde karşılaşılan başlıca tehlikelerden biri de katı olarak yüklendikten sonra seyir halinde gemi vibrasyonundan, dalgaların ve geminin hareketlerinden kaynaklanan nedenlerle sıvılaşabilen yüklerdir. Her ne kadar can ve mal kaybına büyük ölçüde neden olsa da dökme yük gemilerinde sıvılaşabilen dökme yükler konusuna son yıllara kadar gereken önem verilmemiştir.

Yeterli nem içeren, katı dökme yükler örneğin konsantre cevherler, işlenmemiş nikel cevheri, demir cevheri ve boksit madenleri yükün vibrasyonla granüllenmesi sonucunda sefer sırasında sıvılaşabilmektedir. Bunun, yük kaymalarının ve gemilerin alabora olmalarının başlıca nedeni olduğu bilinmektedir. Hatta bu kazaların birçoğu can kayıplarıyla sonuçlanmıştır. Bu soruna çözüm üretmek amacıyla soruna genel bakış içeren anahtar hususlar sunulur, bunlar; yükün kayma olasılığını etkileyen faktörlerin geniş açıdan özetini; yükün kaymasını açıklamakta kullanılabilecek zemin mekaniği prensiplerini; ve sefer sırasında sorunun ortaya çıkmasını önlemek için kullanılan düzenleyici kontrolleri içerir. Sıvılaşabilen bu yükler uluslararası denizcilik kurallarının gerekleri altında, IMSBC kodun belirttiği üç laboratuvar test metodlarından biri ile belirlenmiş alt nem içerik sınırı olan, taşınabilir nem limiti değerinin (TML) altında bir değerde taşınmalıdır. Sıvılaşabilen dökme yüklerin taşınabilir nem limitinin altında olduğunu belirten sertifikalara rağmen alabora olan gemiler denizcilik sektöründe bu sertifikanın yada gemilerin güvenilir olup olmadığı yönünde soru işaretlerini akla getirmektedir.

Bu çalışmanın amacı sıvılaşabilen yüklerin deniz yoluyla taşınması sırasında bu yüklerin fiziksel değişimlerinin analizinin gözlemlenmesi ve çıkan sonuca yönelik önerilerde bulunmaktır. Gelişen teknolojiyle sanayileşmenin artmasında hammadde ihtiyacını irdelersek ileriki yıllarda daha büyük sorunlarla karşılaşmamak adına

sıvılaşabilen dökme yüklere dikkat çekmek ayrıca bu yüklerden kaynaklı can ve mal kaybını azaltmak hatta önlemek için gereken önlemlerin şimdiden alınmasını sağlayabiliriz.

Son olarak M/V Bulk Jupiter gemisinin boksit yükünü taşırken gerçekleşen kazadan dolayı ve Türkiyede boksit madeninin çok miktarda bulunmasından kaynaklı boksit madeniyle geminin hareketlerini ve vibrasyonunu sitimule edilerek bu yükün fiziksel değişimini gözlemek amacıyla testler yapılmıştır. Bu testler neticesinde alınan sonuçlar karşılaştırılarak bir daha bu tür kazaların yaşanmaması için tavsiyelerde bulunulmuştur.

Çalışmanın birinci bölümünde sıvılaşabilen yüklerin tanımlaması yapılmıştır. Bu yüklerin aslında gemilere yüklenirken katı halde oldukları, yeterli nem miktarıyla ve dışarıdan gelen dış etkenlerle nasıl sıvılaşmaya başladığı fotoğraflarla gösterilmiştir. Geçmişten günümüze kadar bu yüklerden kaynaklı gemi kazaları anlatılmıştır. Sadece sıvılaşabilen yüklerden kaynaklı gemi kazalarında kaybedilen canların hiç önemsenmeyecek miktarda olduğu ve bu kazaların hala devam ettiği tablo olarak gösterilmektedir. Ayrıca sıvılaşabilen dökme yükler için çok önemli olan taşınabilir nem limiti (transportable moisture limit) TML ve sıvılaşmaya başlama nem noktası (flow moisture point) FMP tanımları açıklanmıştır.

İkinci bölümde sıvılaşabilen yüklerin gemi stabilitesi üzerindeki etkisine değinilmiştir. Aynı zamanda dökme yük gemilerinin genel olarak stabilitelerini etkileyen faktörlerden bahsedilmiştir. Dökme yük gemilerine yüklenen yüklerin sıvılaşmasının neden kaynaklandığı ve bu dış etkenlerin gemi stabilitesine ne gibi kayıplarda bulunduğu, tekrar kararlı bir gemi haline gelmesi için hangi kuvvetlerin düzeltilmesi gerektiğine değinilmiştir. Ayrıca bu sıvılaşabilen dökme yüklerin gemilerdeki can ve mal kayıplarını önlenmesi için çıkartılan regülasyonlarının tarihsel gelişiminden bahsedilmiştir. Düzenlenen regülasyonların gelişiminden gemilere yüklerin alıcılara ve satıcılara olan yaptırımlarının yıllar geçtikçe değişimleri anlatılmıştır.

Üçüncü bölümde IMSBC Code göre yükün nem ve taşınabilme değerlerinin bulunmasında kullanılan testler anlatılmış ve Mersin ilimizden çıkarılan boksit madeni laboratuvar ortamında gemi vibrasyon ve hareketleri simule edilerek testi yapılmış olan yükün fiziksel özelliğindeki değişimler gözlemlenmiştir. IMSBC Koda göre sıvılaşabilen yüklerin taşınmasında belirlenen nem miktarını üç çeşit test metodu sayesinde belirlenir. Bunlar, the Flow Table Test, the Proctor/Fagerberg test, the Penetration test olmak üzere yükün içindeki nem miktarını belirleyen testlerdir. Mersin ilimizden gelen boksit madeninin fiziksel özelliğindeki değişim bulunmadan önce içerisindeki nem miktarının ölçümü İTÜ Kimya A Laboratuvarında yapılmıştır. Nem miktarını tayin ettikten sonra kuruttuğumuz ve taşınabilir nem limitinin üzerinde olan iki farklı mika kaptaki boksit madenimiz ITÜ Maden Cevher Hazırlama Laboratuvarında geminin hareketlerini ve gemi vibrasyonunu simule edilerek farklı mika kaplardaki boksit yüklerinin fiziksel özelliklerinin değişiminin gözlemi için testler yapılmıştır. Sıvılaşma özelliği gösteren boksit madeni bu testler sırasında sürekli ölçülerek değerler kaydedilmiştir. Tüm çalışma boyunca her ilerleyen saat boksit yükünün fiziksel değişimini gösteren kısa videolar da çekilmiştir.

Çalışmanın son bölümünde ise sıvılaşabilen yüklerin negatif etkilerini minimize etmek ve hatta sıfırlamak için tavsiyeler verilmiştir. Bu tavsiyeler düşünülürken uygulanabilirliği olmayan taşıyan ve taşıtana fazla miktarda ek mali yük getirmeyecek öneriler üzerinde özellikle durulmuştur. Aksi taktirde taşıyanın ve taşıtanın verilen tavsiyelerin yüksek maliyetli oluşundan dolayı, bundan kaçınması söz konusu olabileceği düşünülmüştür. Bu tavsiyeler gemi personeli, eğitimli personel, kargo surveyleri, gemi dizaynırları yada armatörler tarafından yapılabilecek önerileri içermektedir. Maliyet açısından farklılık gösteren bu tavsiyeler can ve mal kayıpları düşünüldüğünde tavsiye niteliğinde kalmayarak en kısa zamanda uygulanmaya geçilmesi yönünden ilk adım olmalıdır. Gerekirse gelecekte sıvılaşabilen yükleri yükleyen dökme yük gemilerinin inşaasının bile değiştirilmesine yönelik çalışmalarda bulunulmalıdır ki başka can ve mal kayıpları yaşanmasın. Bu çalışma geleceğe yönelik yapılacak olan çalışmalara da ışık tutacaktır.

1. INTRODUCTION

Solid bulk cargo means any cargo, other than liquid or gas, consisting of a combination of particles, granules or any larger pieces of material generally uniform in composition, which is loaded directly into the cargo spaces of a ship without any intermediate form of containment [1]. Solid bulk cargoes are categorizes into three groups by IMSBC Code. In figure 1.1, these are: Group A consists of cargoes which may liquefy if shipped at a moisture content in excess of their transportable moisture limit. Group B consists of cargoes which possess a chemical hazard which could give rise to a dangerous situation on a ship. Group C consists of cargoes which are neither liable to liquefy (Group A) nor to possess chemical hazards (Group B).

Figure 1.1 : Group A cargoes that may liquefy (Nickel Ore, left), Group B cargoes that possess a chemical hazard (Sodium Nitrate, right), Group C cargoes that do not liquefy hazard (Iron Ore Pellets, down).

Loading and carriage of some bulk cargoes, the risks associated with liquefaction and the precautions to minimize the risk. Such cargoes may appear to be in a relatively dry granular state when loaded, and yet may contain sufficient moisture to become fluid under the stimulus of compaction and the vibration which occurs during a voyage. A ship's motion may cause a cargo to shift sufficiently to capsize the vessel. Cargo shift can be divided into two types, namely: sliding failure or liquefaction consequence.

This phenomenon can be described as follows:

(i) the volume of the spaces between the particles reduces as the cargo is compacted owing to the ship motion, etc.;

(ii) the reduction in space between cargo particles causes an increase in water pressure in the space; and

(iii) the increase in water pressure reduces the friction between cargo particles resulting in a reduction in the shear strength of the cargo [2].

1.1 Cargo Liquefaction Overview

Cargoes which may liquefy if shipped at a moisture content exceeding their Transportable Moisture Limit (TML). That is, solid cargo has behaved as a liquid, sometimes with alarming results. This event is called liquefaction and leads to stability problems whereby the cargo can shift at sea under the influence of the motion of the vessel and the effect of the vibration. To all intents and purposes, bulk carriers does not design to carry liquid cargo due to the fact that solid cargo lose shear strength and begin to move like a liquid.

Cargoes at risk of liquefaction contain concentrates, unprocessed nickel ores and iron ore fines. These cargoes usually include a part of fine particles, exhibiting low permeability when compacted. Before the loading of bulk carriers, liquefaction cargoes are generally only moderately saturated and may appear ‘‘dry’’. The motion of bulk carriers' loading will result in the cargo compacting whilst forces applied by ships' actions and ships' engine vibrations during navigation. Nevertheless, drainage that is moisture migration can occur, leading to an increase in moisture content in part of the cargo. Under these situations, water can become trapped between the interparticle voids, resulting in an increase in pore-water pressures and a loss of strength. Ships' motions can cause major displacement of the cargo is called ‘‘cargo liquefaction’’.

Loading liquefaction cargo can happen in ‘‘dry’’ cargoes if the angle of a vessel rotation is adequate to overcome the frictional and cohesive forces that have in cargo cluster with strength. During voyage, concentrate cargo as nickel ore, iron ore, coal (Group A&C) or zinc concentrate are exposed to sway under ship's rolling, wave impact and engine vibration. However, adequate moisture in concentrated cargo external swawing action as ship's rolling, waves impact and engine vibration can rise water pressure after that the water pressure push cargo particles apart as shown Figure 1.2.

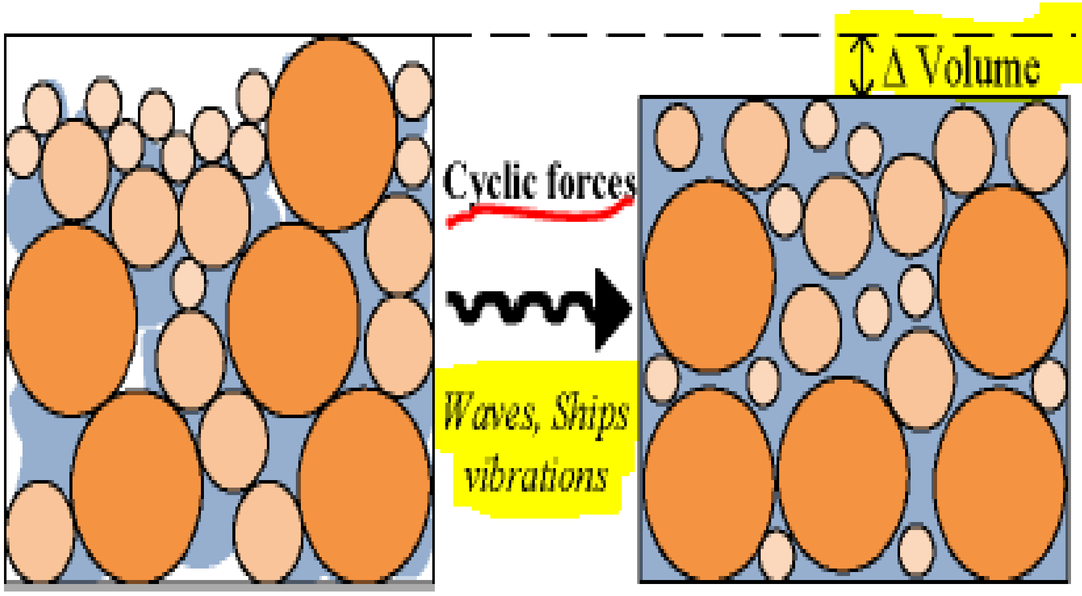


Figure 1.2 : The granules of a partly saturated stable cargo (left) can compact due to cyclic forces. This compaction can led to the movement of water within the voids, resulting in an increase in pore-water pressure and loss of cargo strength between the inter-granular contacts, called ‘‘liquefaction’’ (right). [3]

Under this phenomenon, water contained in the cargo as a result of previously explained action as engine vibrations, ship motions and waves impacts, moves free spaces between the particles upwards. Water can appear on cargo surface which is saturated by moisture and may move along with ship's heeling. At gravitational drainage water, underlying of cargo can also be liquefied. Then all of the cargo in the hold may cause the loss of the stability of the bulk carrier. This circumstance that bring about a particular cargo to shift are complex because of that it is impossible to retrospective analysis. As a consequence of shifting cargo cause capsizing, listing, structural damage, and even fatalities. Because unlike a tanker, the holds of bulk carriers are not designed to transport liquid cargo. Cargo shifting from one side of the hold to the other result in unbalanced vessel as shown figure 1.3. If a bulk carrier are not corrected to unbalanced the list, the casualities are not prevented to capsize.

Since the Bengal accident in 1910 [4], liquefaction has been known to cause capsizing but In January 2011 all the owner of bulk carriers carrying solid bulk cargoes which may liquefy - Group A - apply to mandatory requirement by International Maritime Solid Bulk Cargoes Code (IMSBC Code) [5]. The IMSBC Code requires to obligate the Transportable Moisture Limit (TML) certification before loading of Group A. When determining the TML of cargo, IMSBC Code provides three methods that can be used. These are Flow Table Test, Penetration Test and Proctor/Fagerberg Test. Three test methods are expained in the forthcoming sections.

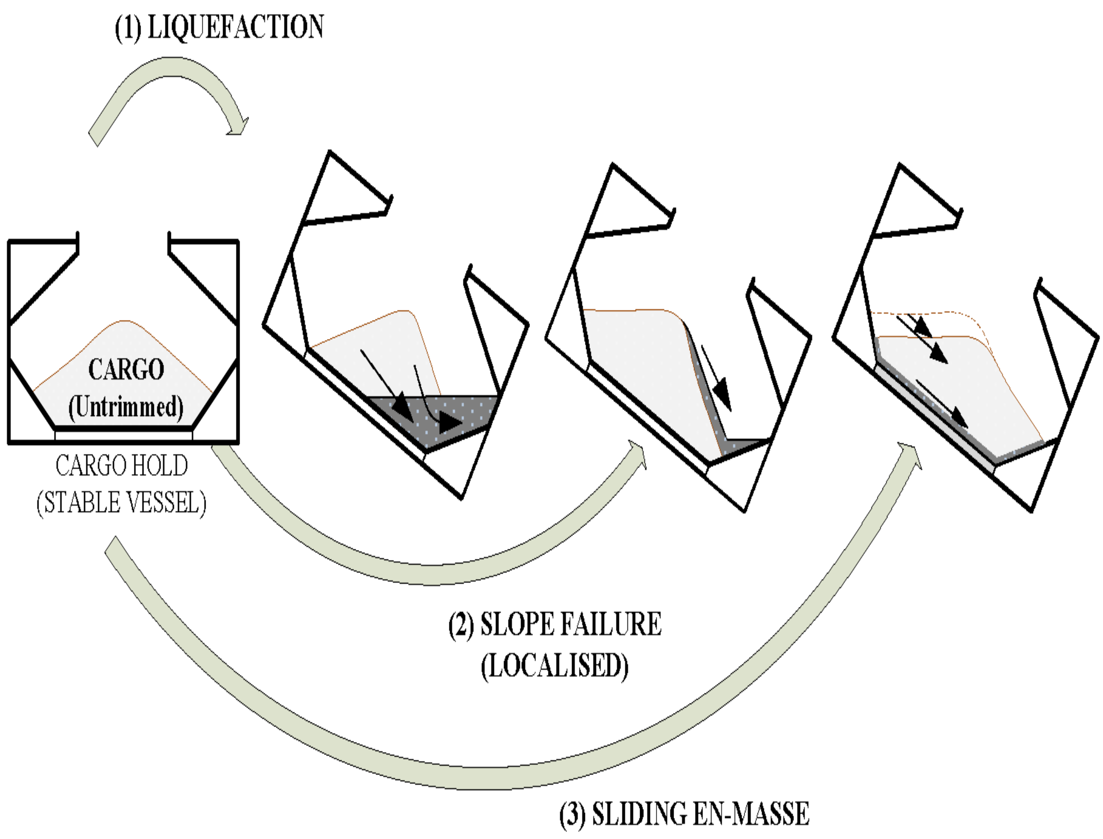


Figure 1.3 : The three different types of cargo shift that occur with a cargo hold. [3]

1.2 Cargo Liquefaction Fatalities (1987 to Present)

Despite the well-publicized potential dangers, it appears that market forces are driving ships to carry cargoes that may liquefy and weak freight markets make it difficult for owners and charterers to pas sup employment opportunities. Although authorities take precaution (with regulation on as SOLAS, IMSBC Code specially after 2011) against the danger of cargo liquefaction, there are many ships become capsized and sink.Between 1987 and 2015, up to 35 solid bulk carriers capsized and 192 lives were lost due to cargo liquefaction. This makes it one of the greatest safety risks in bulk arrier. A detailed Table 1.1 of accidents about cargo liquefaction from 1987 to 2015.

Table 1.1 : Fatalities bulk carrier due to cargo liquefaction. [6]

VESSEL	VESSEL DEADWEIGHT	DATE	LOSS OF LIFE	VOYAGE	CARGO TYPE
Testarosa	66903 ton	Jan 1987	30	The ship foundered in the Atlantic Ocean off Gibraltar to Arquipelago da Madeira	Iron Ore
Mega Taurus	30413 ton	Dec 1988	20	From Philippines to Japon. Capsized while en route	Nickel Ore
Oriental Angel	127300 ton	June 1990	0	New Caledonia Capsized at anchorage area	Nickel Ore
Fin Baltic	Pusher(Finn) and Barge (Baltic)	June 1990	7	From Raahe to Koverhar(Finland). Capsized outside Hanko(Finland)	Iron Ore Conc.
Melete	72060 ton	Sep 1991	25	From Dampier to Wales. Foundered in South Indian Ocean	Iron Ore Fines
Sea Prospect	21297 ton	Sep 1998	10	From Indonesia to Japan Capsized while en route	Nickel Ore
Jag Raghul	64300 ton	Dec 2007	0	From Tanjung Buli, Indonesia to Ukraine	Nickel Ore

Table 1.1 (continued): Fatalities bulk carrier due to cargo liquefaction. [6]

VESSEL	VESSEL DEADWEIGHT	DATE	LOSS OF LIFE	VOYAGE	CARGO TYPE
Wen Qiao	4500 ton	Aug 2007	1	From India to Tianjin, China. Capsized off the Wonsan anchorage, North Korea	Iron Ore Fines
Asian Forest as shown figure 1.4	14400 ton	July 2009	0	Sank in the Arabian Sea 8 miles Southwest of Mangalore, India	Iron Ore
Nasco Diamond	56893 ton	Nov 2010	21	From Indonesia to China. Developed list to port, took water and sank In The Pacific Ocean.	Nickel Ore
Hong Wei	50149 ton	Dec 2010	10	From Indonesia to China. Capsized and sank in the South China Sea.	Nickel Ore
Vinalines Queen	56040 ton	Nov 2011	22	From Indonesia to China. Developed 18 degree list and eventually sank in the Philippine Sea.	Nickel Ore
Harita Bauxite	47450 ton	Feb 2013	15	From Indonesia to China. Developed a list from heavy rolling and engine failure and capsized.	Nickel Ore
Bulk Jupiter as shown figure 1.4	46400 ton	Jan 2015	18	From Kuantan, Malaysia to China. Sank off the coast of Vung Tau, Vietnam	Bauxite

Figure 1.4 : M/V Asian Forest on July 2007 (left), M/V Bulk Jupiter on January 2015 (right). [7], [8]

1.3 Cargo Liquefaction Regulations

The International Maritime Organization (IMO) is specialized agency of the United Nations to responsibility for the safety and security of shipping and the prevention of marine pollution by ships. IMO's main aim is regulate international new regulation. IMO's chief regulatory for solid bulk cargoes, the Internetional Maritime Solid Bulk Cargoes Code (IMSBC Code), is also its key instrument in mitigating the risk of cargo liquefaction. The IMSBC Code involves a number of controls that purpose to assure that at-risk cargoes are loaded at a moisture in matter below that required to ease the progression of pore water pressure cause liquefaction whose termed Transportable Moisture Limit (TML). This is shown equations (1.1) and figure 1.5, the TML is derived from Flow Moisture Point (FMP).

$$TML\ [\%moisture] = 90\% \times FMP[\%moisture] \tag{1.1}$$

Carrying Group A cargoes with bulk carriers are required to mandatory obligation in the IMSBC Code [1]. This includes a mandatory requirement that they are strictly loaded with moisture matter less than TML, determined from laboratory based testing.

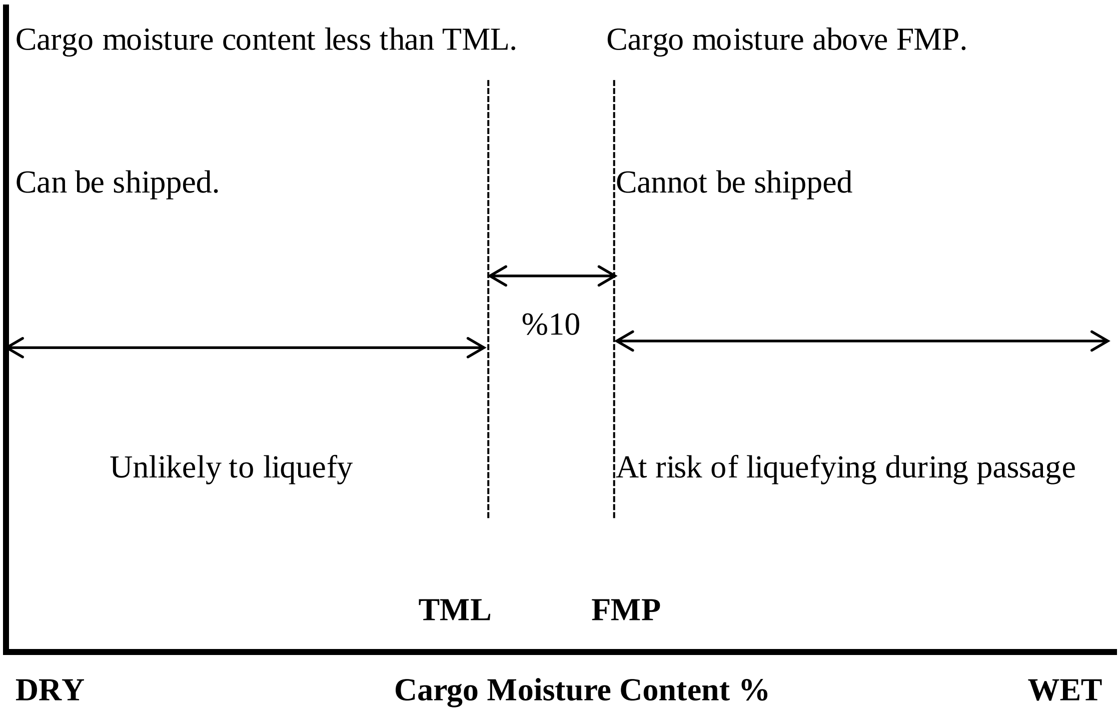


Figure 1.5 : Group A cargoes can only be shipped at moisture contents below TML. FMP represents the moisture content above which cargo may liquefy during overseas transportation. [9]

IMSBC Code ;

(i) help prevent the carriage of cargoes that may be unsafe for shipment, mitigating the risks of loss of cargo, ship and life; but

(ii) impose handling and transportability requirements on Shipper, who delivers the goods to the carrier for merchant vessel, which may introduce commercial risks. For instance, shipper is unable to transport an excessively wet cargo with a moisture content above TML and this can delay shipment. [10]

1.4 The Purpose Of This Study

TML determines if a cargo can be transported, incorrect TML has potential safety and commercial implications. Several studies have found that the TML test methods give unreliable results when testing a given sample of cargo material. There are also concerns if the results reported from the TML test methods accurately represent the liquefaction potential of cargo shipment, given that they are only performed on a small element of cargo material.

These concerns, this study has aimed to identify any issues inherent in the TML tests and provisions in the IMSBC Code. More specifically, the research presented in this thesis has aimed to contribute to an improved understanding of the problem, by:

(i) detailing the different considerations of the cargo shift problem,

(ii) assessing the TML test methods and the associated provisions related to cargo sampling and reporting within the IMSBC Code, and identifying ways to improve the reliability of these test methods and

(iii) exploring the importance of the many other variables that influence a Group A cargo's likelihood of shift, in order to assess whether the TML test methods give an accurate depiction of cargo behaviour.

Requirements and ensure that any views, findings and recommadations presented in this study are of practical relevance, information has been obtained from a broad range of sources and from a variety of experiences. In addition to reviewing conventional literature and undertaking test work, this study has attempted the shortfalls of previous research by incorporating a range of alternative sources of information.

Also this study include:

(i) site visit to recognised testing laboratories videos

(ii) interviews with captains who carried liquefy cargoes

(iii) discussions with leading, influential scientists in the mining, soil, construction engineering field

In this study, the following are the objectives:

- acquire material samples.
- develop a bulk cargo tank model for use in testing and simulation of existing liquefaction problems.
- parametrically investigate the behavior of liquefied cargo (moisture, vibration,.etc.)
- drive proposed solution by means of method of loading/handling/ as well as developing instruction with additional precautions.

- By means of advice, study and propose the navigation parameters and limits, i.e. time, distance, and weather conditions, in order to prohibit the cargo liquefaction.

- disseminate the knowledge and set of recommendations to the maritime sector through seminars, workshops, and publications

2. ACKNOWLEDGEMENT

This chapter provides an overview of liquefy cargo transportation and development of its regulation. Firstly, it presents charactestic of the soil bulk cargo. It then highlights the wide range of ship design and motion to impact cargo liquefaction. Lastly, the chapter mentions the impact of ship stability when cargo become to liquefy and how cargo shift can lead to capsized.

2.1 Development Of Cargo Liquefaction Regulation

Cargo shift and liquefaction have been awaken problem since adoptation of IMSBC Code in 1965, before the Code of Safe Practice for Solid Bulk Cargoes (BC Code), in figure 2.1. Cargo liquefaction has received important interest when happened fatal cargo ship accident between 27th October and 3rd December 2010. [11]

These regulations present many shippers of liquefiable cargoes;

- ❖ The shipper must load liquefaction cargo below the TML
- ❖ The shipper must know and report the characteristic of liquefaction cargo as the moisture before loading in the hold.
- ❖ The shipper must know and report cargo's TML certificate.

Authorities have been working with shipping companies and shippers to improve how to reduce liquefaction risks and prevent capsizing by virtue of cargo liqufaction.

It is a fact that technology is developing day by day; new design vessel will be diffent ours or new cargo liquefaction test will discover in the future. As the world became more developed, proximity to raw materials and to markets became the factors that, shaped the world‘s economy and, in particular, the major trade patterns and shipping routes. Shipping is perhaps the most international of all the world's great industries and one of the most dangerous. Recently one of the main dangers at bulk carrier vessels is after loaded as solid bulk cargo become to behave like liquid due to the ship vibration and ship motions during seaborne transportation.

1958-1960 : Establishment of the Intergovermental Maritime Consultative (IMCO, now IMO)

1960-1964 : Members submit information detailing current practices of determining whether a liquefiable concentrate is safe for carriage to the Sub-Committee for Bulk Cargoes (BCI)

1964 : The first session of the Working Group on Bulk Cargoes is held (BC Sub-Committee). Only concentrate cargo's are considered as ones which may liquefy.

1965 : First Edition of the International Code of Safe Practice for Bulk Cargoes (BC Code, 1965) is published. The Flow table Test is included for determining the TML of a concentrate.

1981 : A method for determining a non-cohesive cargo's angle of repose ('tilt box') is added to the BC Code, to control cargo shift of dry cargoes.

1994 : Two new TML test methods (Penetration Test and Proctor/Fagerberg Test) are included in the BC Code, for testing coarser granular material that is being considered as Group A (e.g. coals)

1995 : The BC Sub-Committee expanded to include dangerous goods and was renamed from BC to the Sub-Committee on Dangerous Goods, Solid Cargoes and Containers (DSC Sub-Commitee)

2008 : The Code of Safe Practice for Solid Bulk Cargoes (BC Code) renamed to be the International Maritime Solid Bulk Cargoes (IMSBC Code)

2008 : The International Maritime Solid Bulk Cargoes (IMSBC Code) is adopted by the Maritime Safety Committee (MSC)

2011 : The IMSBC Code become mandatory (for SOLAS member states)

2013 : A circular (DSC.1/Circ.71) is issued calling for a new schedule for iron ore fines and classifying it as a Group A cargo.

Figure 2.1 : Developments in cargo liquefaction regulation [12-17].

2.2 Bulk Cargoes And Group A Cargoes

It may seem obvious to say that, today, we live in a global world, and it is certainly true that international trade among all the nations and regions of the world is nothing new. The history of the world is a history of exploration, conquest and trade by sea. As the world became more developed, proximity to raw materials and to markets became the factors that, above all others, shaped the world‘s economy and, in particular, the major trade patterns and shipping routes. Eventually, the great seaborne trades became established. It is generally accepted that more than 90 per cent of global trade is carried by sea. [17] The shipping of the solid bulk cargoes from the largest portion of overall shipping trade. Lately, transportation raw material's sector has been improving quickly because of Chinese growth. Generally transported by ship as coal, unprocessed or processed ores, grain and sugar. Coal and iron ore are the biggest proportion of dry granular, approximately %60 of total tonnes of bulk solids transported by ship as shown figure 2.2. [10]

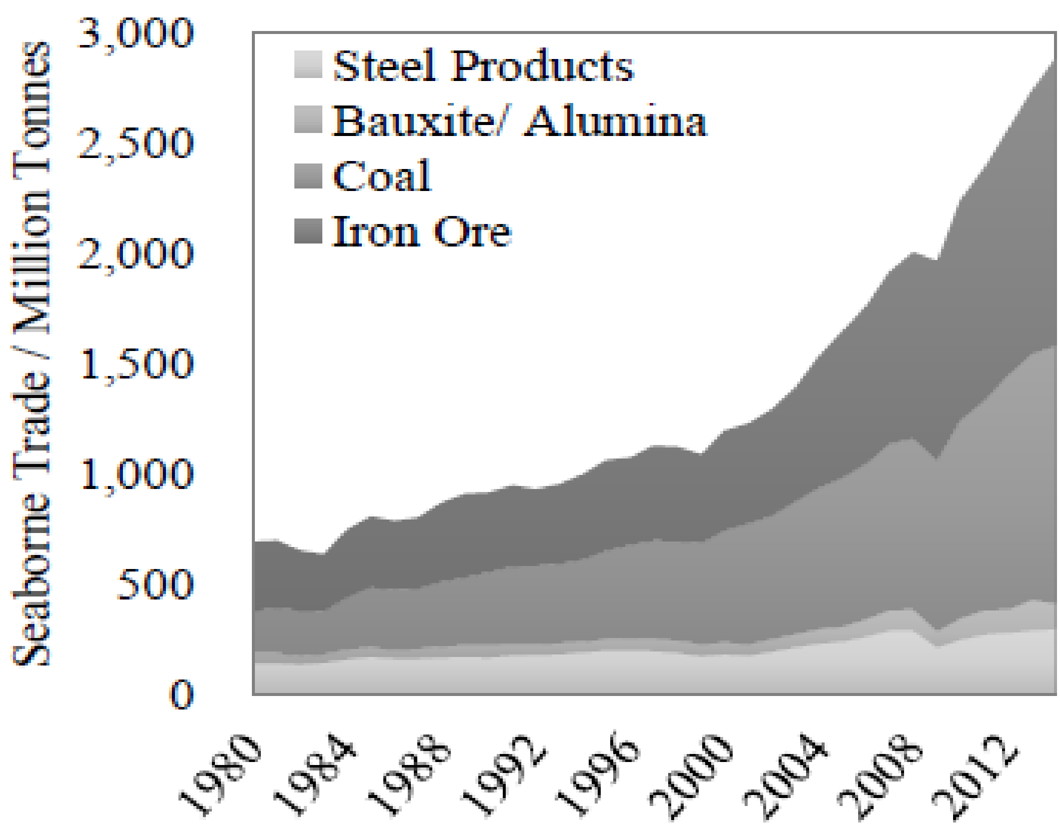


Figure 2.2 : The growth in the four major dry solid bulk cargoes, some of which may liquefy. [10]

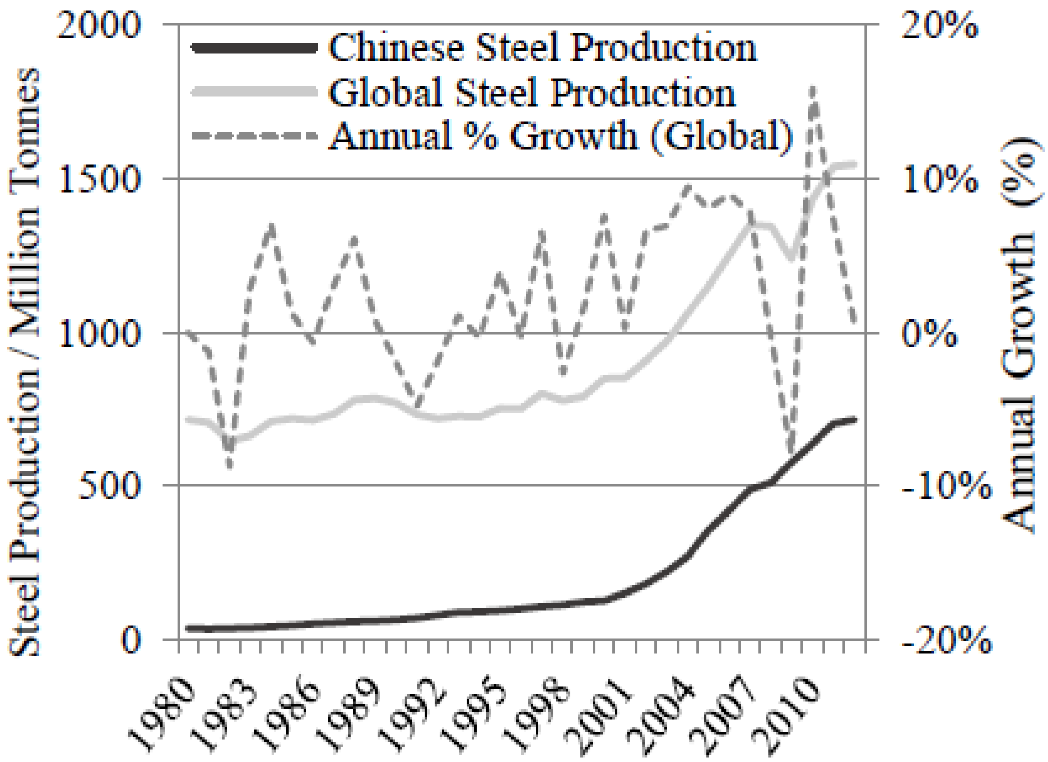


Figure 2.3 : The growth in annual steel production that has driven this increase. [18]

Group A cargoes use to product steel making process such as nickel ores, iron ores, zinc, lead, etc. These cargoes are different than others cargoes due to their chemical and physical properties. Hereinbelow Table 2.1 which lists common Group A cargoes and their typical properties.

Table 2.1 : Major liquefy of solid bulk cargoes and their typical properties. [19]

SOLID BULK CARGO WHICH MAY LIQUEFY	TONNES CARRIED ANNUALLY (APPROX.)	STOWAGE FACTOR m^3/t	SPECIFIC GRAVITY * en bloc	ANGLE OF REPOSE * varies with cohesion/deg	SATURATION /%	INTERNAL FRICTION COEFFICIENT /µ	ANGLE OF REPOSE FROM INTERNAL FRICTION COEFFICIENT =arctan µ
Alumina Hydrate (Group A and B)	201 Mt (2009)	0.933	2.88	31	62.8	0.682	34.3
Bauxite		0.719	2.21	35	37.2	0.816	39.2
Coal (Can be Group A or C)	1114 Mt (2013)	1.145	1.25	41-50	30.2	0.952	39-43.2
Coal Slurry Coke Breeze		1.477	1.25	40.0	45.7	0.8	38.7
Iron Ore Fines		0.4-0.45	3.8-4.6	46-58	34.3-47.0	0.9962-10	41.6
Iron Ore Concentrates		0.375	4.05	47.5	34.5	0.889	41.6
Nickel Ore		0.71	2.9			0.85	
Lead Concentrate		0.31		42			
Silica Sand		0.6	2.62	31.5	36.4	0.727	36
Zinc Concentrate		0.56		35			

Note : Other Group A cargoes (which may liquefy) include Fluorspar, Ilmenite clay/sand, nickel concentrates, some sand, peat moss and a number of other concentrates (no cargo properties could be sourced for these materials.

Particle size distribution is most significant fact for liquefiable cargo due to its influence on packing density and permeability (Fig. 2.4). More specifically, the PSD effects the volüme of voids between particles, the permeability and so that the likelihood for pore-water pressures to develop. The density of particle not only depend on the PSD but also other physical properties like shape, specific gravity, angularity and roughness/smoothnessas shown figure 2.4. [3]

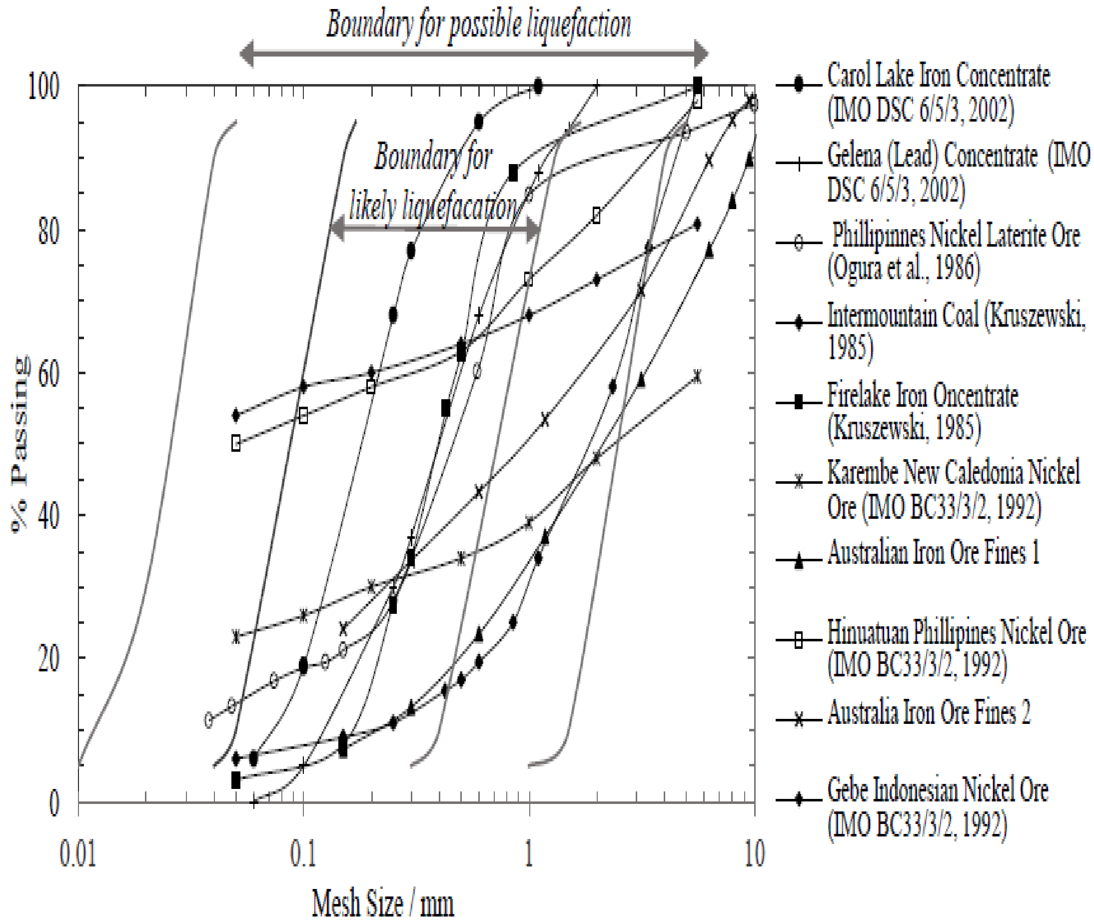


Figure 2.4 : The PSD of various Group A cargoes. Also shown are the boundaries for likely and possible earthquake induced liquefaction presented [20]

2.3 The Bulk Carrier

Since 1950, nearly all solid cargoes are transported by bulk carrier or bulker. Typical bulk carriers are constructed with a single deck, different numbers of holds and different size from small to valemax. Hereinnext page table 2.2, between 1976 and 2006 the average size of carriers increased significantly, from 31,000 d.w.t. to 56,000 d.w.t. [21]

Table 2.2 : Main types of bulk carriers and their dimensions. [22]

SHIP TYPE	SIZE : DEADWEIGHT TONNES	LENGTH (METRES)	NO OF HOLDS
Mini Bulk Carrier	3000-9999 Mini bulker (3-9,999 d.w.t)	100-130	1-3
Handy-Size	10,000-35,000 Handysize(10-35,000 d.w.t)	130-150	5
Handy-max	35,000-49,000 Handymax(35-49,000 d.w.t)	150-200	5
Supra-max	50,000-59,000 Supramax(50-59,000 d.w.t)	200-230	5
Pana-max	60,000-79,000 Panamax(60-79,000 d.w.t)	200-250	5
Cape-size	80,000-199,000 Capesize(80-199,000 d.w.t)	230-270	7
Very Large Ore Carriers	190,000-399,000 VLOC(190-399,000 d.w.t)	270-400	7-9
Vale max/ China max	400,000+ Valemax (400,000+ d.w.t)	362	7

The design of a bulk carrier will have a impact of the potential for cargo liquefaction and shift. In additional, the design of a bulk carrier will influence to include ship's holds and ship's motions.

In order to enable drainage of moisture and prevent the development of free surface water and saturated cargo base, bilges are fitted in ship's holds. There are two bilges located aft and port or starboard side of each hold as shown figure 2.5.

Figure 2.5 : General view of ship's hold (upper) and hold bilges (bottom left&right).

The bulk carrier's hold affects the geometry of pile of loaded cargo in figure 2.6 , influencing its shear resistance. A hold's dimensions can different types of bulk carrier. Most bulk carrier holds are designed so that the lower and topside tanks.

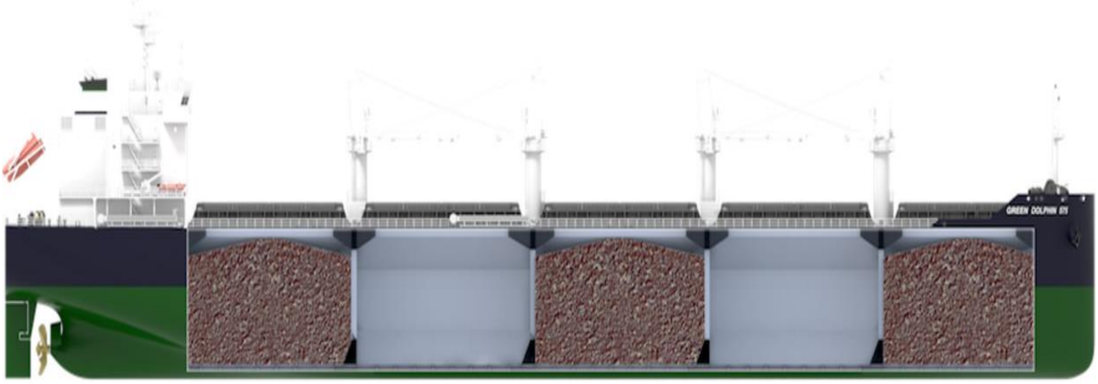


Figure 2.6 : Location of bulk carrier's holds and example of alternate loading. [23]

Heavy cargo, such as iron ore, is often carried in alternate cargo holds on bulk carriers . It is common for large bulk carriers to stow high density cargo in odd numbered holds with the remaining holds empty. This type of cargo distribution will raise the ship's centre of gravity, which eases the ship's rolling motion. When high density cargo is stowed in alternate holds in figure 2.6, the weight of cargo carried in each hold is approximately double that carried in a homogeneous load distribution as shown figure 2.7.

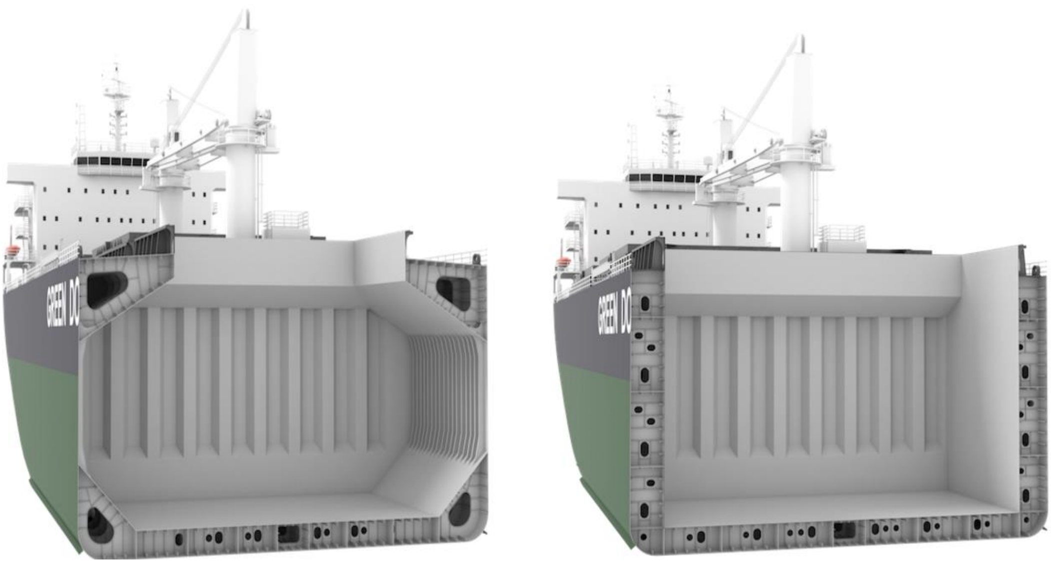


Figure 2.7 : Typical single hull bulk carrier (left), Typical double hull bulk carrier (right). [23]

For high-density cargoes or heavy cargoes the angled lower wing-tank reduce the stresses that is to help reduce the likelihood of slope failure. In low-density or light cargoes the angled topside wing-tanks act void space and help to prevent listing.

Ship's motions are vary for the several types of ship and their loading conditions. Thus, a bulk carrier's motions at sea also depend on the sea-state and ship's behaviour as speed, heading relative to the waves. [24] (see Figure 2.8)

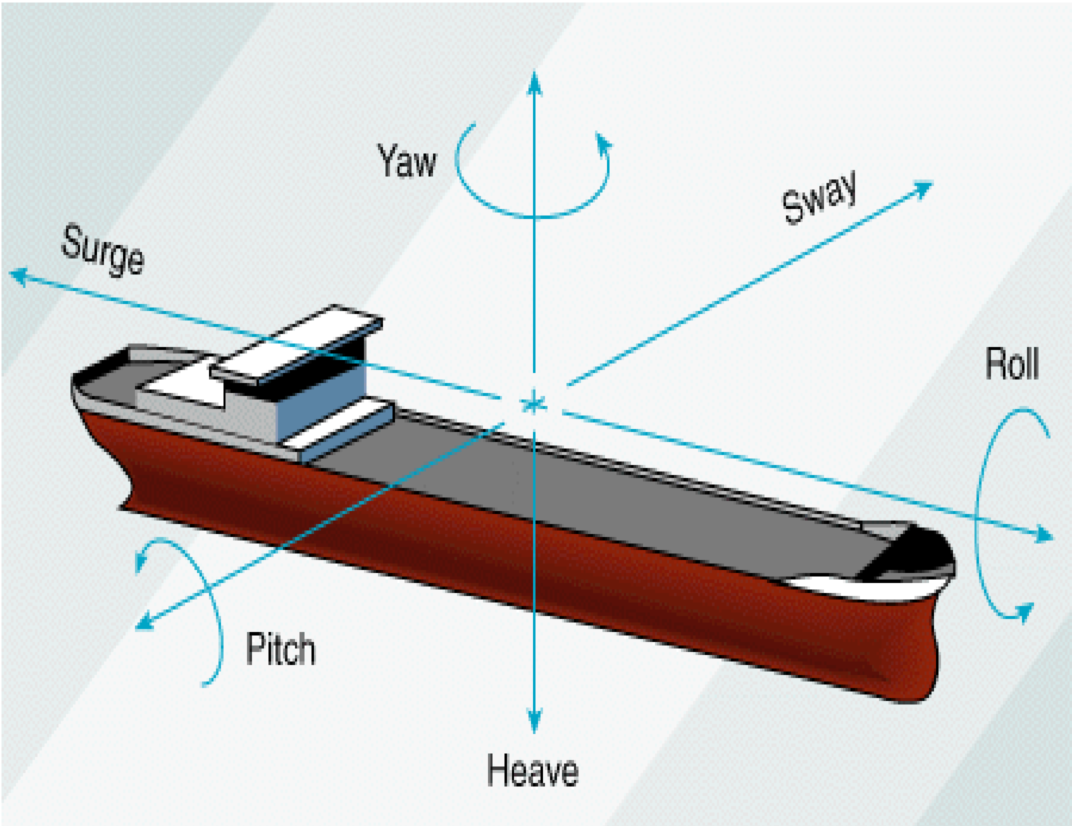


Figure 2.8 : Ship motion with 6 degree of freedom. [25]

Vessel rolling and pitching are typically considered to generate the greatest accelerations on a ship. Accelerations generated by these rotational motions increase with distance from the rolling and pitching axes, and are inversely proportional to the square of the rolling and pitching periods. [26] It follows that each hold on a ship will experience a unique force. Note that any outwardly acting centrifugal accelerations are usually considered of little significance.

While the compaction of a granular cargo is likely to occur from the contribution of all the ship's motion, it is likely that the forces that lead to transverse cargo displacement are predominantly the result of the rolling motions. That is; however, displacement to the outer edges of a hold is more likely to occur during a moment of roll, where the applied forces acting on the tilted cargo pile.

These are impact holds during voyage:

(i) The initial cargo geometry will depend on the shiploader design and its operator

(ii) The mass of ore loaded into a given hold depends on design of the hold, the stowage factor of that material and its capacity

(iii) The cargo’s initial density will likely be influenced by the deposition characteristics of the ship loader such as drop height, deposition intensity, spread and friction coefficient. [27]

The cargo is usually loaded into each hold in a planned sequence as per the loading plan(see Figure 2.9) Also all holds can load different cargoes each other but, the IMSBC Code applies a blanket rule whereby a Group A cargo is subject to the same conditions of carriage how many holds are filled with cargoes.

The loading or unloading plan should be prepared in a form such as shown below.Worked examples of this form are shown overleaf.
A different form may be used provided it contains the essential information enclosed in the heavy line box.

LOADING OR UNLOADING PLAN Vers: 1	Date:	Vessel:				Voyage No.
Load/Unload Port: TUBARAO / BRASIL	Cargo(es): IRON ORE	Assumed stowage factor of cargo (es 0,4	Balast pumping r 1200 M3 X 2	Dock water densi 1,026 MT/M3	Max. draught available (HW): 14,4	Max. air draught in berth: 21 M
To/from Port: JING TANG / CHINA	Last cargo: ALUMINA IN BULK	No. of loaders/di 1	Load/discharege rate: 3000 MT /H		Min. Draught available (LW): N/A	Max. sailing / arrival draught 14,67

	7	6	5	4	3	2	1
Tonnes	10880	13000	10427	10400	11826	12100	10668
Grade							

Totals:79300 MT

	Cargo			Time		Calculated values				Calculated values			Observed Values		
				required		Draught		Maximum		Air	Draugh		Draught		
Pour No.	Hold No	Tonnes	Ballast operations	(hours)	Comments	Fwd.	Aft	BM*	SF*	draugh	mid	Trim	Fwd	Aft	Mid
1	4	5000,00	PUMP OUT WBT 2P-2S	3	COMMENCE BALLAST OP.	9,71	12,99	76,3	24,8			-3,28			
2	2	5000,00	PUMP OUT WBT 3P-3S	3		10,87	11,43	43,2	29,6			-0,56			
3	6	5000,00	PUMP OUT WBT 4P-4S	4		10,79	11,53	31,7	15,6			-0,74			
4	2	4000,00	pump in apt 240 mt	3		12,35	11,95	41,1	23,2			0,40			
5	6	7000,00	STRIPPING	4		12,17	14,06	62,8	26,3			-1,89			
6	4	5400,00	STRIPPING	4		13,21	14,56	54,6	34,4			-1,35			
7	2	2100,00	STRIPPING	2		14,06	14,32	51,4	34,1			-0,26			
8	2&6	2000,00		1	FOR TRIMMING	14,44	14,51	55,4	38,4			-0,07			
			TOTAL HOURS	24											
	TOTAL	35500,00													

Signed Terminal

NO DEVIATION FROM ABOVE PLAN WITHOUT PRIOR APPROVAL OF CHIEF MATE

Pours to be numbered 1A,1B,2A,2B,etc when using two loaders.

Signed Ship

Abbreviations: PI=Pump in GI=Gravitate In F=Full PO=Pump Out GO=Gravitate Out MT=Emty
All entries within the box must be completed as far as possible.
The entries outside the box are optional.

Figure 2.9 : Cargo Sequence Plan.

2.4 The Bulk Carrier Stability

The displacement of a ship means the weight of the water mass as the ship's underwater body displaces. Archimedes' principle also tells us that the weight of the displaced water mass is equal to the ship's total weight. When properly loaded the ship navigates on a steady course on a quiet and calm day with neither wind nor waves the vessel is in equilibrium. Two equal and along the same manufacturing line directed against each other forces affecting the vessel. One force, lift force Δ, attacks in the depth of focus B and is directed upwards. The second downward force which attacks the ship's center of gravity G is denoted by W.

If the ships pitch is changed (assuming rough sea and wind coming in at the ship side) the equilibrium will be affected while a righting moment that want to straighten the vessel will occur. This part consists of W and the distance Δ GZ from each other. The point M where the lift force cutting the vessel center line, we find meta-center. The distance between point G and point M is called the metacentric height and gives a good picture of the ship's stability (See Figure 2.10 below).

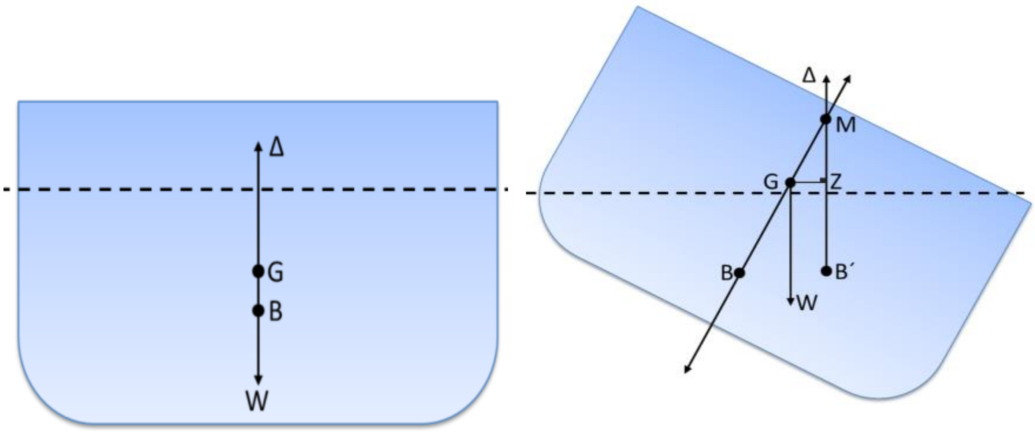


Figure 2.10 : When a stable ship inclines, the buoyancy (B) and the weight (W) acting from the center of gravity (G) work to re-align the vessel. This is typically represented by the righting lever (GZ) (left). If the angle of heel is sufficient, GZ can become negative, and G and W will work to roll the vessel, likely causing capsize (right). [28]

Where M is located depends on what ship's underwater body is shaped at a certain depth. Where G is located depends on how the ship is designed to some extent, but more on how the ship is loaded with cargo. If heavy cargo is loaded on deck the ship's center of gravity G will be displaced upwards.

This means that GM reduces in length. If GM is reduced so will the GZ with the effect that the righting moment becomes smaller which leads to the fact that the ship's stability is impaired.

Metacentre has a direct relationship with a ship's rolling period. A ship with a small GM will be tender which have a long roll period. An excessively low or negative GM increases the risk of a ship capsizing in rough weather. It also puts the vessel at risk of potential for large angles of heel if the cargo or ballast shifts. A ship with low GM is less safe if damaged and partially flooded because the lower metacentric height leaves less safety margin. For this reason, International Maritime Organization specify minimum safety margins for seagoing vessels.

A larger metacentric height on the other hand can cause a vessel to be too stiff ; excessive stability is uncomfortable for ship. This is because the stiff vessel quickly responds to the sea as it attempts to assume the slope of the wave. An overly stiff vessel rolls with a short period and high amplitude which results in high angular acceleration. This increases the risk of damage to the ship and to cargo shift and may cause excessive roll in special circumstances.

In tanks or spaces that are partially filled with a fluid or semi as the tank is inclined the surface of the liquid, or semi-fluid, stays level. This results in a displacement of the centre of gravity of the tank or space relative to the overall centre of gravity. The effect is similar to that of carrying Group A cargoes with water. When an edge is tipped, the water rushes to that side, which loss of stability even capsize.

A ship's stability is often explained by the 'stability curve', which derives information about the righting lever (GZ) for any angle of heel. From curve, a substantial amount of stability information can be obtained, including:

(i) the range of stability;

(ii) the angle of vanishing stability;

(iii) the maximum GZ; and

(iv) the initial GM.

Figure 2.11 shown key characteristics of the curve. It also compares vessel stability before and after a liquefaction event.[29] Their findings showed a bulk carrier exhibits diminished stability post-liquefaction.

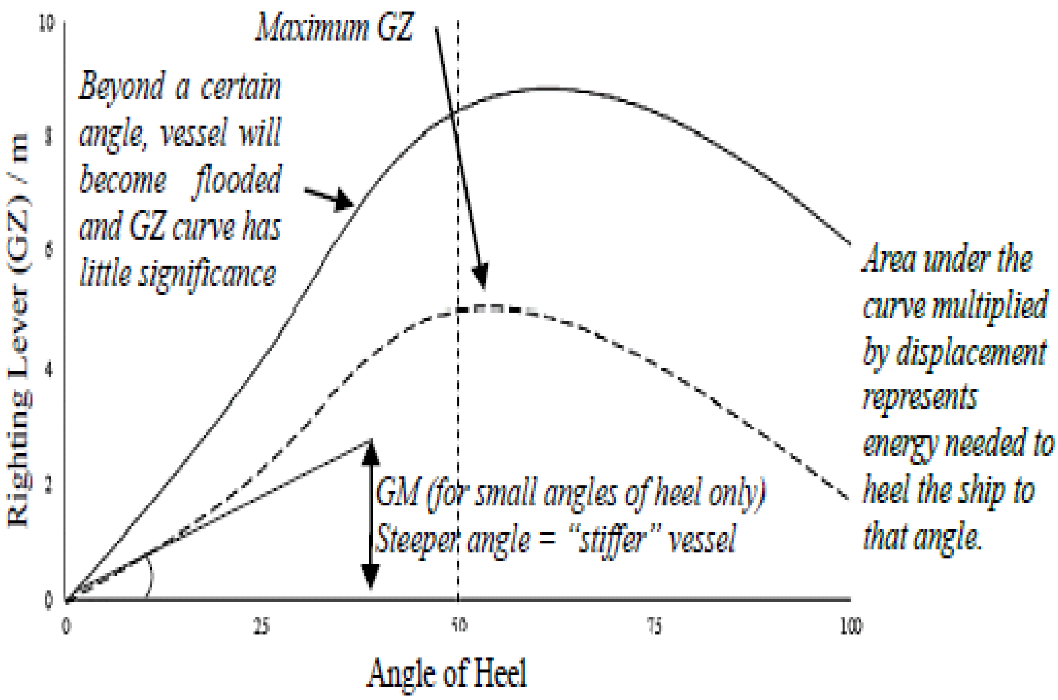


Figure 2.11 : Key features of a GZ stability curve, which shows the calculated effect of liquefaction on GZ for alternate loading of a cargo (specific gravity of 3.6), before *(solid line)* and after *(dashed)* liquefaction. Assumed cargo behaviour or vessel type were not stated. [29]

In the case of transverse cargo shift, stability can be considered in terms of a:

- free surface (whereby the cargo acts like a liquid and stays horizontal to the water line);
- hanging load (whereby centre of gravity remains fixed following a shift); or
- shifting load (whereby a shift may worsen incrementally due to repeated moments of roll) [30].

Each of these will have a different impact on the vessel's stability response. Since cargo shifting develops abruptly, it is hard to prevent the bulk carrier from listing when the master of the vessel identifies characteristic of Group A cargoes and impact of ship stability when cargo liquefaction. Therefore, Group A cargoes' moistures must be tested before the loading in the holds.

3. THE LIQUEFACTION TEST AND METHODS

The shipper must provide the master with confirmation safely transportation for liqufaction cargoes. The shipper's declaration must be involved :

(i) the moisture content of cargo

(ii) the maximum moisture content at cargo to prevent liqufaction (TML).

In figure 3.1 the TML is determined from laboratory-based testing of Group A as per IMSBC Code. These are mainly test method for liquefaction cargoes (see table 3.1) :

- the Flow Table Test (FTT)
- the Proctor/Fagerberg Test (PFT)
- the Penetration Test (PTT)

Other tests have been used to determined the TML of Group A cargoes, but not mentioned in the IMSBC Code, are tests such as the vibrating platform method developed by British Coal [31], a drainage method, produced by Norway [32], and a method using a concrete tester developed in Finland[4] .

Table 3.1 : The IMBSC Code TML test selection parameters and flow indicators.[33]

IMSBC TEST METHOD	RECOMMENED PSD (TOPSIZE)	ALLOWED PSD (TOPSIDE)	SAMPLE PARAMETERS	ENERGY INPUT (COMPACTION) PARAMETERS	INDICATOR OF FLOW /TML
Flow Table (FTT)	0-1000 µm	0-7000 µm	Minimum starting mass= 3X2-3 kg Conical mould volume= 296.6 cm³	Tamper head= 30mm; Tamper pressureXmax cargo depthXg Table drop height= 12.5mm Number of cycles= 50 Frequency= 25 Drops/minute (0.62 Hz)	FMP measured from observed plastic deformation of the cone (convex or concave cone profile) and/or measurement of cone expansion
Proctor /Fagerberg (PFT)	0-5000 µm	>5000 µm if 'extensive investigation for adaptation and improvement is undergone'	Minimum starting mass= ~6kg Proctor mould volume= 1000cm³	Tamper head= 50 mm Drop height= 20 cm Hammer mass= 350 g *No cyclic load	TML determined from intersection of the compaction curve with the 70% saturation line.
Penetration (PTT)	0-10 mm for small cylinder, 0-25 mm for large cylinder		1,700 cm³ or 4,700 cm³	Vertical vibration frequency 50 or 60 Hz Acceleration: 2g nms= 10% Vibration Time: 6 min.	FMP measured penetration depth >50 mm penetration is considered flow.

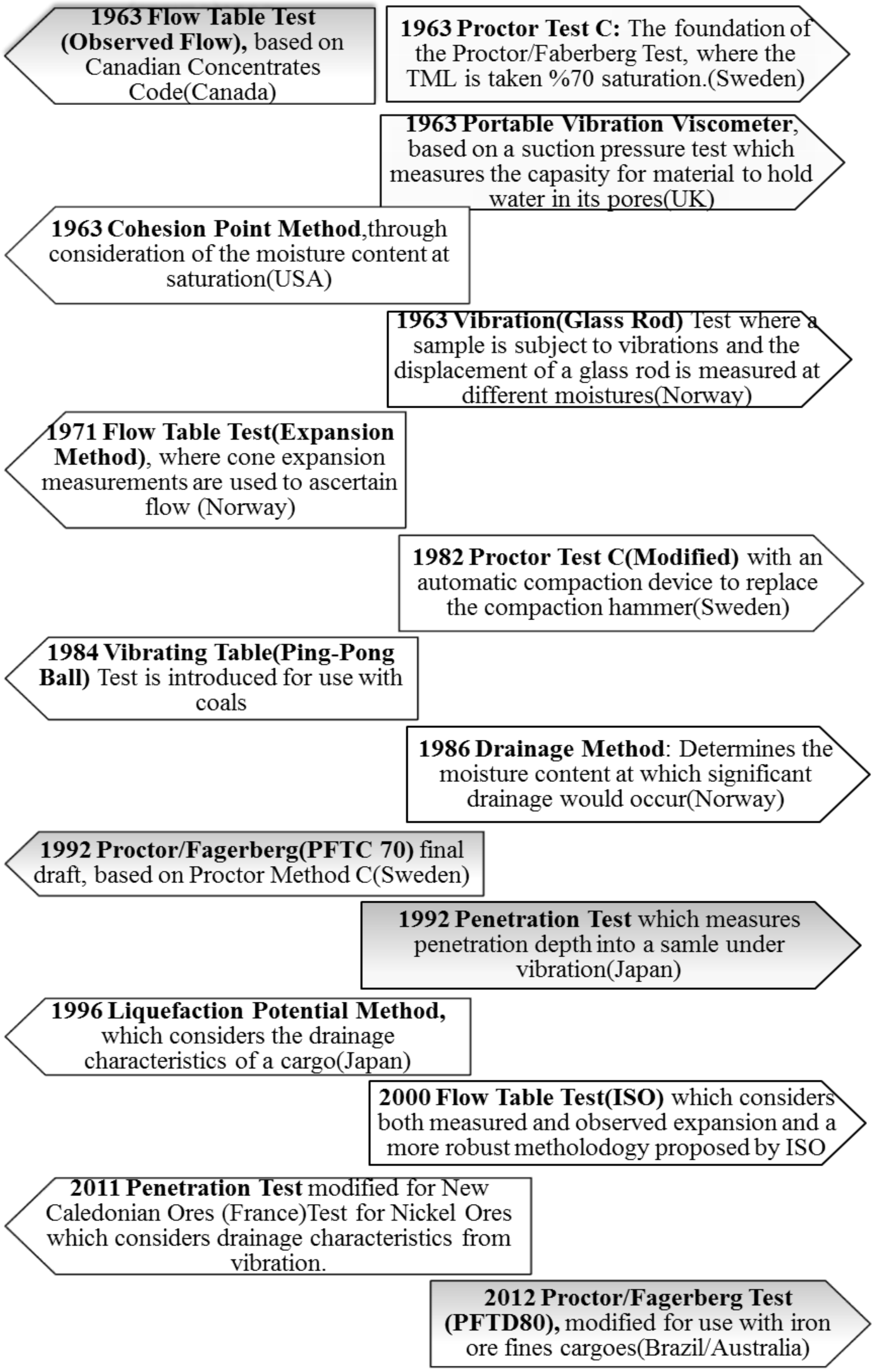


Figure 3.1 : A timeline showing various methods developed to ascertain if a cargo is safe for carriage, including the TML test methods. Most of these were proposed to IMO for use internationally. Some were never adopted and some have been adopted for use only on certain cargo types. [34-40]

3.1 The Flow Table Test (FTT)

The Flow Table Test has been commonly used in the cement industry to test hydraulic cement since 1983 with the release of ASTM C230/C230M Standard Specification for Flow Table for use in tests of Hydraulic Cement. It can be traced back to 1971 when it was used to test Portland-Cement and as far back as 1952 when it was used to test Magnesium Oxychloride Cements. [41]

The early BC Code included a modified procedure, created by Department of Mines and Technical Services in Canada that can be used to determine the TML of bulk cargoes using the Flow Table Test procedure as given in the 2012 IMSBC Code, which also references apparatus (see in figure 3.2) used in ASTM C230/C230M-08 Standard Specification for Flow Table for use in tests of Hydraulic Cement.

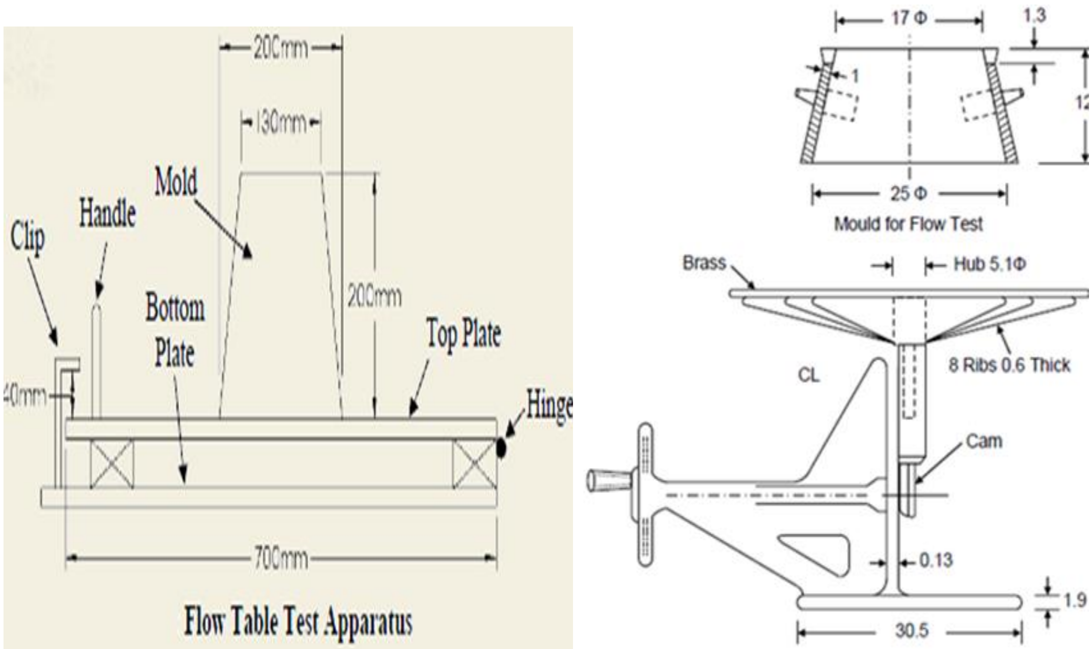


Figure 3.2 : The Flow Table Test Apparatus' Dimensions [42]

The flow table is generally suitable for mineral concentrates or other fine material with a maximum grain size of 1 mm. It may also be applicable to materials with a maximum grain size up to 7 mm. It will not be suitable for materials coarser than this and may also not give satisfactory results for some materials with high clay content. If the flow table test is not suitable for the material in question, the procedures to be adopted should be those approved by the authority of the port State.

The Flow Table Test apparatus is placed a conical shaped mould on the centre of the Flow table. The mould is filled and the material is compacted in three stages as shown table 3.2. In the first stage the mould is filled to one third its height then compacted uniformly with an adjustable tamper. The second and third stages are similar tamping actions are performed, respectively.

Table 3.2 : Additional measurements for the flow table test that are commonly recorded are as follows:

Measurement	Description	Possible Interpretation
Height	Measurement from the top of the sample to the base.	If the sample is not breaking up (as described below), a reduction in height could indicate the sample is slumping and therefore could indicate plastic deformation.
Top Width	Measurement of the diameter of the top of the sample.	When plastic deformation of the sample occurs it is common to see a reduction in the diameter of the top of the sample. This measurement is sometimes hard to take if the sample contains coarse particles.
Middle Width	Measurement of the diameter of the middle of the sample.	Although not accurate if a datum is not available, when plastic deformation of the sample occurs the middle of the sample may expand or contract at a consistent rate.
Base Width	Measurement of the diameter of the base of the sample.	When plastic deformation of the sample occurs the base of the sample will expand at somewhat linear rate. This measurement is see to be the most important and therefore the average of four points around the base is commonly taken.

After compaction is complete and excess material has been struck off with a straightedge, the mould is then carefully removed. Immediately after the mould is removed the Flow Table Test is raised and dropped up. This Flow Table Test procedure is repeated at different moisture contents (see figure 3.3).

Figure 3.3 : Observations on the The Flow Table Test to find TML.

For each incremental moisture content tested on the FTT, the identification of flow was assessed by three methods, namely:

(a) Visual observation;

(b) Measurement of cone base expansion; and

(c) A combination of both visual observation and cone expansion.

For iron ore, the FMP/TML occurred at 12.6%/11.3% as shown table 3.3. This was determined by observation of flow only; there was insufficient test material available for comprehensive assessment using expansion measurements, see table 3.4 and figure 3.4.

Table 3.3 : TML obtained by the FTT using different methods of flow identification, namely (A) observed; (B) measured; and (C) a combination of both observed and measured (described below).

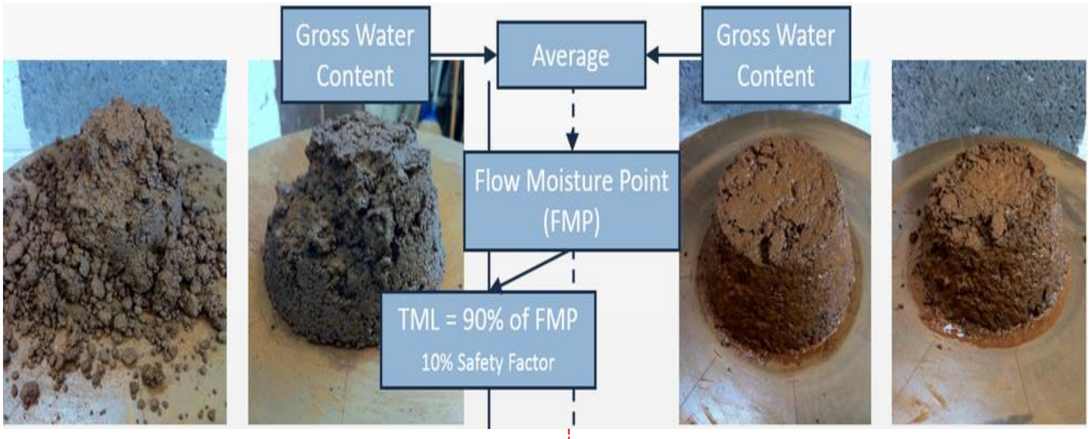
METHOD OF DETERMINATION FMP	FMP / TML % MOISTURE,BY │ DRY MASS
(A) Observed plastic deformation	20.7% / 18.6%
(B) Measured value: >3 mm expansion	20.7% / 18.6%
(C) Measured value: IMSBC Code intersection method	21.5-22.8 / 19.3-20.5%
(D) ISO 12742:2007 (both observed and >3 mm considered)	20.7% / 18.6%

Table 3.4 : Some observations, with relevant interpretations, that may be useful to note when performing the flow table test are as follows:

Observation	Description	Possible Interpretation	Image
No Measurable Edges, Breaking Up or Crumbling	When there are no edges because the sample has broken up (base, top, height, etc.)	This could indicate the sample is not showing plastic deformation, therefore it is under the flow moisture point. This is because the sample has most likely broken up because of insufficient friction between the particles. More moisture is most likely needed in order show plastic deformation. It also could indicate the particles within the sample are too coarse or uniform to show plastic deformation.	
Moving	With each drop of the flow table the sample moves or jumps.	If after 50 blows the sample is still showing this characteristic, it is most likely indicating that the sample is under the flow moisture point, but if after a number of successive drops of the table this characteristic changes, it could indicate that the sample is over the flow moisture point. This is because as pore pressures within the sample alter the density and degree of saturation it can force moisture to the surface and this is when plastic deformation may begin to occur. When the sample is jumping or moving it indicates there is no cohesion of the sample to the flow table top and when there is no cohesion between the particles the sample usually does not show plastic deformation.	

Table 3.4 (continued): Some observations, with relevant interpretations, that may be useful to note when performing the flow table test are as follows:

Observation	Description	Possible Interpretation	Image
Bleed Water	When free moisture is being expelled from the sample during dropping the flow table.	This is a good indication that the same is very close to the flow moisture point. It does not indicate whether it is over or under the FMP, but with the addition of other observations and measurements it can be determined.	
Pulsing	This is when with each drop of the flow table the sample appears to pulse slightly (expand and contract).	This is a good indication that there are excess pore pressures building up within the sample. Excess pore pressures can produce a reduction in the shear strengthof the sample and may eventually cause it to show plastic deformation. Additional observations and measurements are needed to prove if this is the case.	Not illustrate
Smearing	Smearing of moisture and fine particles from the sample on the flow table flow table top.	Although it is a good note to take, this is not necessary a good indication of whether the sample is showing plastic deformation or over/under the flow moisture point. This is because depending on the sample and amount of fines, smearing may occur well below the flow moisture point.	Not illustrate
Seepage of Moisture from Mould	When moisture from the sample seeps from the base of the flow table mould while tamping compacting the sample.	Although it is a good note to take, this also is an indication of whether a sample is is going to show plastic deformation or whether it is over/under the flow moisture point. This indicates that there free moisture within the sample. Free moisture indicates the sample is close to saturation where it is likely to more liable to show plastic deformation	Not illustrate



I	II	III	IV	V
Not measurable	Not measurable	Slight break up	Excess water	Water from base
Breaking up	Crumbling	Jumping	Smearing	of mould while
Crumbling	No Edges	Measurable but	Measurable	tamping
No Edges	Jumping	no difference	with slight	Excess water
		Smearing	difference	Smearing
				Measurable with
				significant
				difference

Figure 3.4 : Example stages of Flow Table Testing on a sample of Iron Ore Fines.

Determining the TML of Group A cargoes using the Flow Table Test is the most demanding test on the operator. The operator has to visually determine whether or not the sample is above or below the Flow Moisture Point. Visually being able to determine the FMP of coarser samples can be difficult as coarse particles breaking off can obscure the operator’s view when trying to observe plastic deformation of the sample. Therefore with same laboratory and same operator the repeatability of the test is perfect, while against other laboratories. The repeatability of the test can be improved with more detailed procedure in figure 3.5. The Flow Table test is used determining the TML of ore concentrates and coals.Also according to IMSBC Code, it lists coal, metal ore, iron ore concentrate and lead ore concentrate. In the scope of [43] it states This international standard specifies a flow-table method for determination of the TML of copper, lead and zinc sulfide concentrates, which may liquefy during transport.

Flow Table Test (FTT): IMSBC Code Procedure

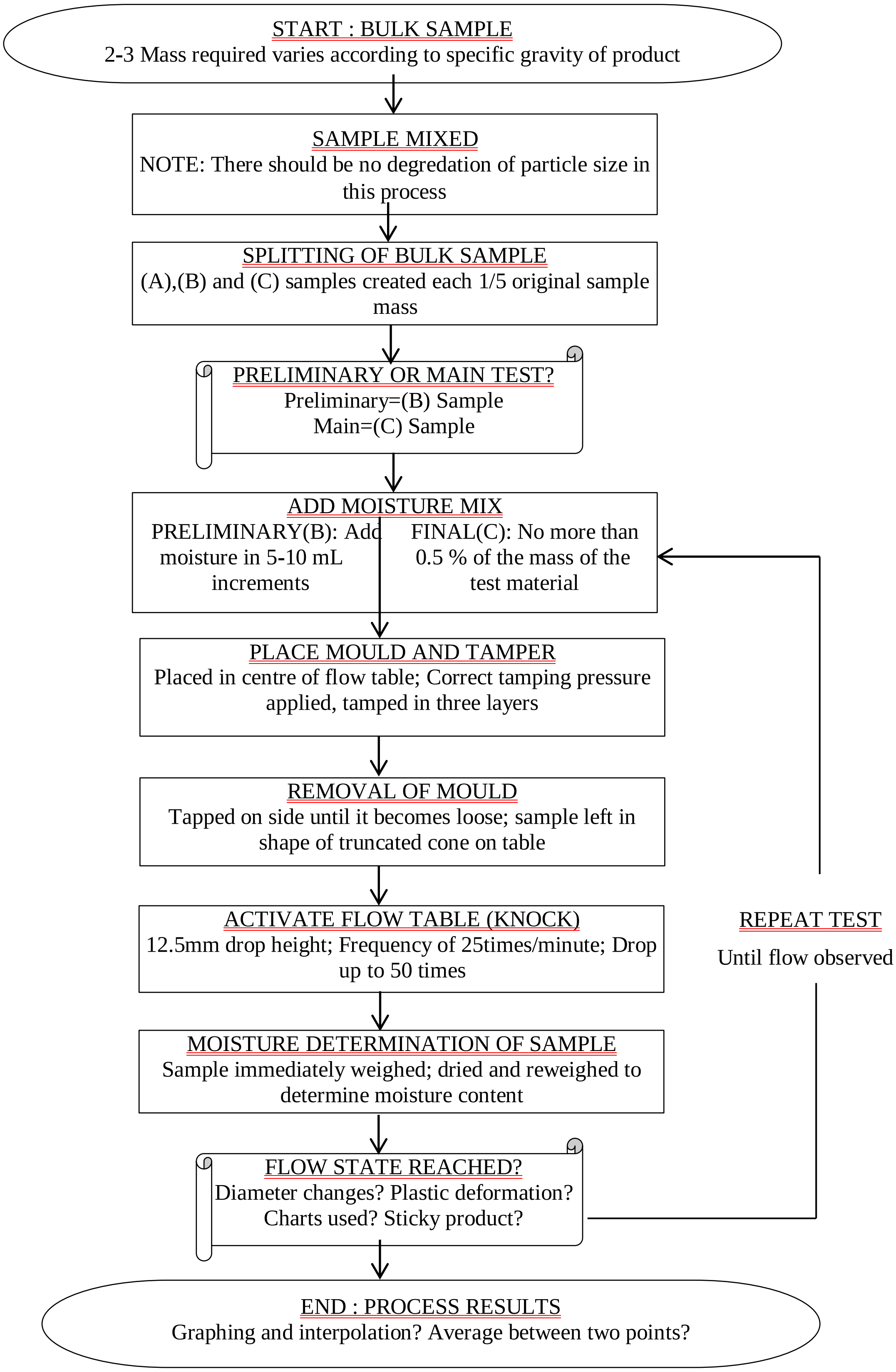


Figure 3.5 : Flow diagram representation of the FTT Methodology

3.2 The Proctor/Fagerberg Test (PFT)

In the 1930's, Proctor proposed a test method, commonly called the 'Proctor Test', whereby changes in density are measured at a range of moisture contents. From this, a compaction curve and the optimum moisture content (OMC) can be determined as shown figure 3.6, corresponding to the maximum dry density. Proctor's work focused primarily on soils from 1933 to 1948.

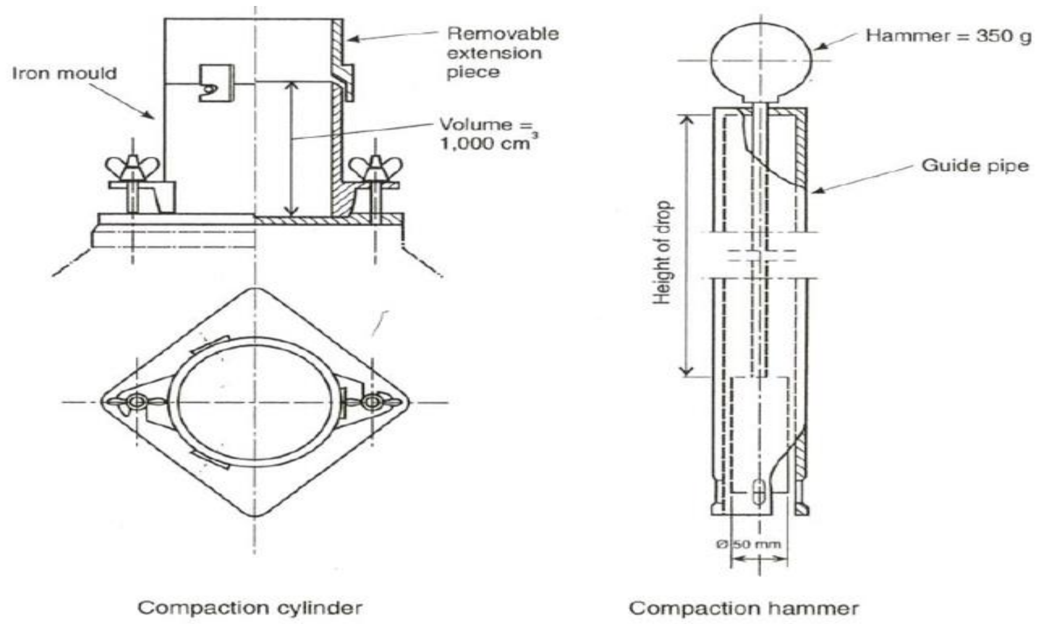


Figure 3.6 : The Proctor/Fagerberg Test apparatus parts and dimensions. [44]

The Proctor/Fagerberg test was first published in Stockholm in 1962 by Bengt Fagerberg and Kjell Eriksson as part of a committee established by the Swedish Mining Association and several Scandinavian mining companies. Fagerberg (1965) later performed research to extend the Proctor Test for application to solid bulk cargoes. The relationships between the void ratio, moisture and degree of saturation were explored for a number of shipped mineral concentrates. Fagerberg found that the minimum void ratio which corresponds to the OMC occurred at, or just above, the intersection of compaction curve and the 70% saturation line. It was therefore proposed that 70% saturation could be considered the safe moisture content at which a material could be safely carried on a vessel. The committee was given the task to develop a simple method for determining the critical moisture content (CMC) of individual cargoes. The test method is based upon use of the Proctor apparatus developed in soil mechanics and was adopted by the International Maritime Organization, for use in the IMSBC Code, between 1991 and 1998.

In 2013 and 2014 the Proctor/Fagerberg Test was modified for use with Iron Ore Fines (IOF) and Coal, respectively.

The Proctor apparatus consists of a cylindrical iron mould with a removable extension piece the compaction cylinder and a compaction tool guided by a pipe open at its lower end the compaction hammer as shown figure 3.7. Scales and weights and suitable sample containers. A drying oven with a controlled temperature interval from 100^{o}C to maximum 105^{o}C. This oven should be without air circulation. A suitable mixer. care should be taken to ensure that the use of the mixer does not reduce the particle size or consistency of the test material.(see figure 3.8) Equipment to determine the density of the solid material, for example a pycnometer.

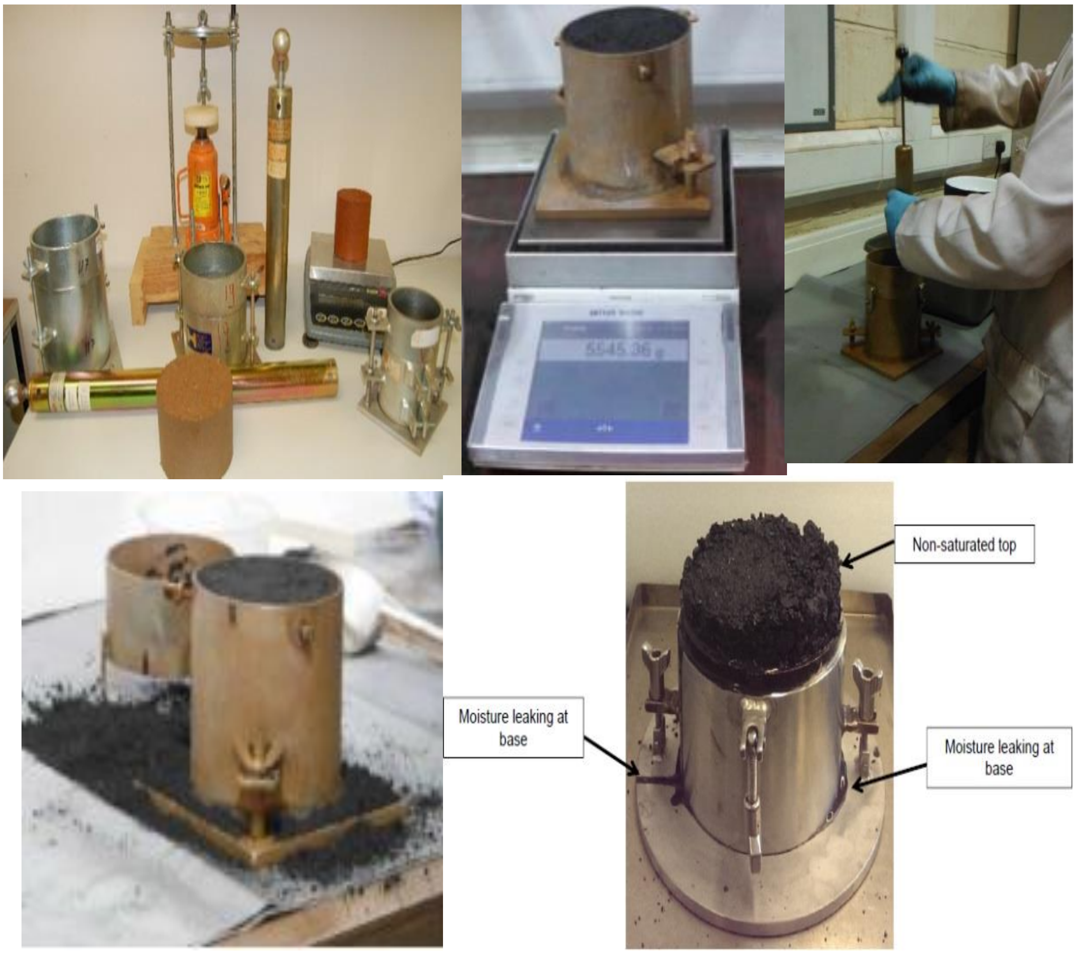


Figure 3.7 : Observations on the Proctor/Fagerberg Table Test to find TML.

A representation of the IMSBC Code PFT methodology is show in the form of a flow diagram in Figure 3.9. As for the FTT, ambiguities are inherent within this methodology and this diagram.

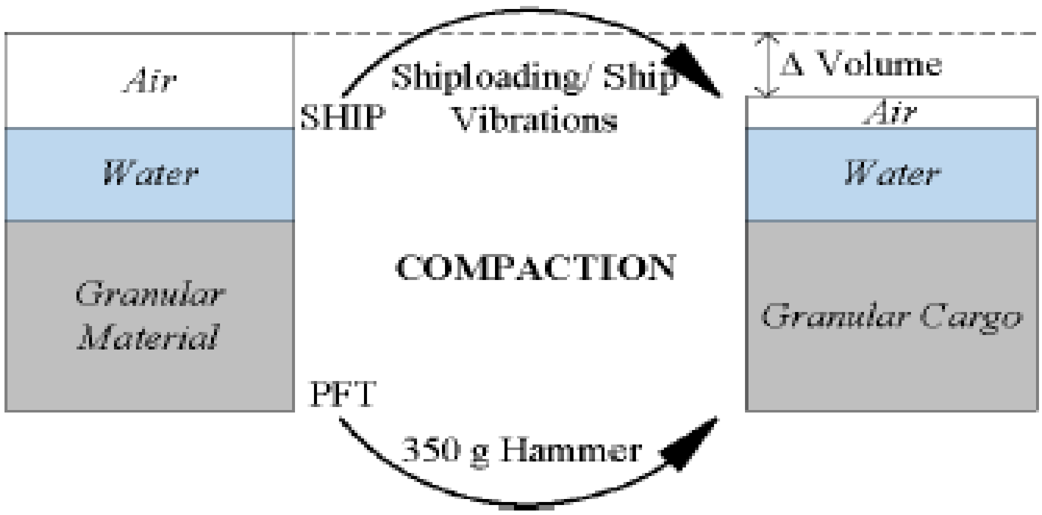


Figure 3.8 : Analogy between compaction in the PFT and compaction in a cargo [33].

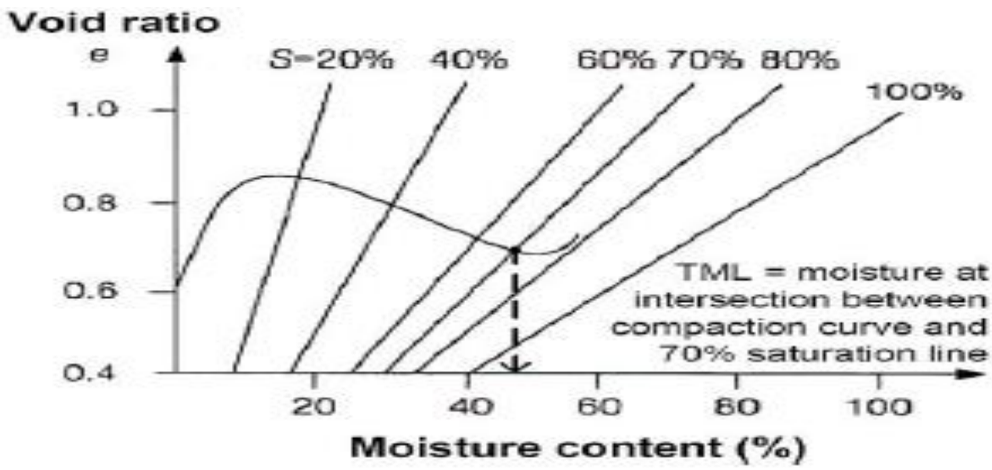
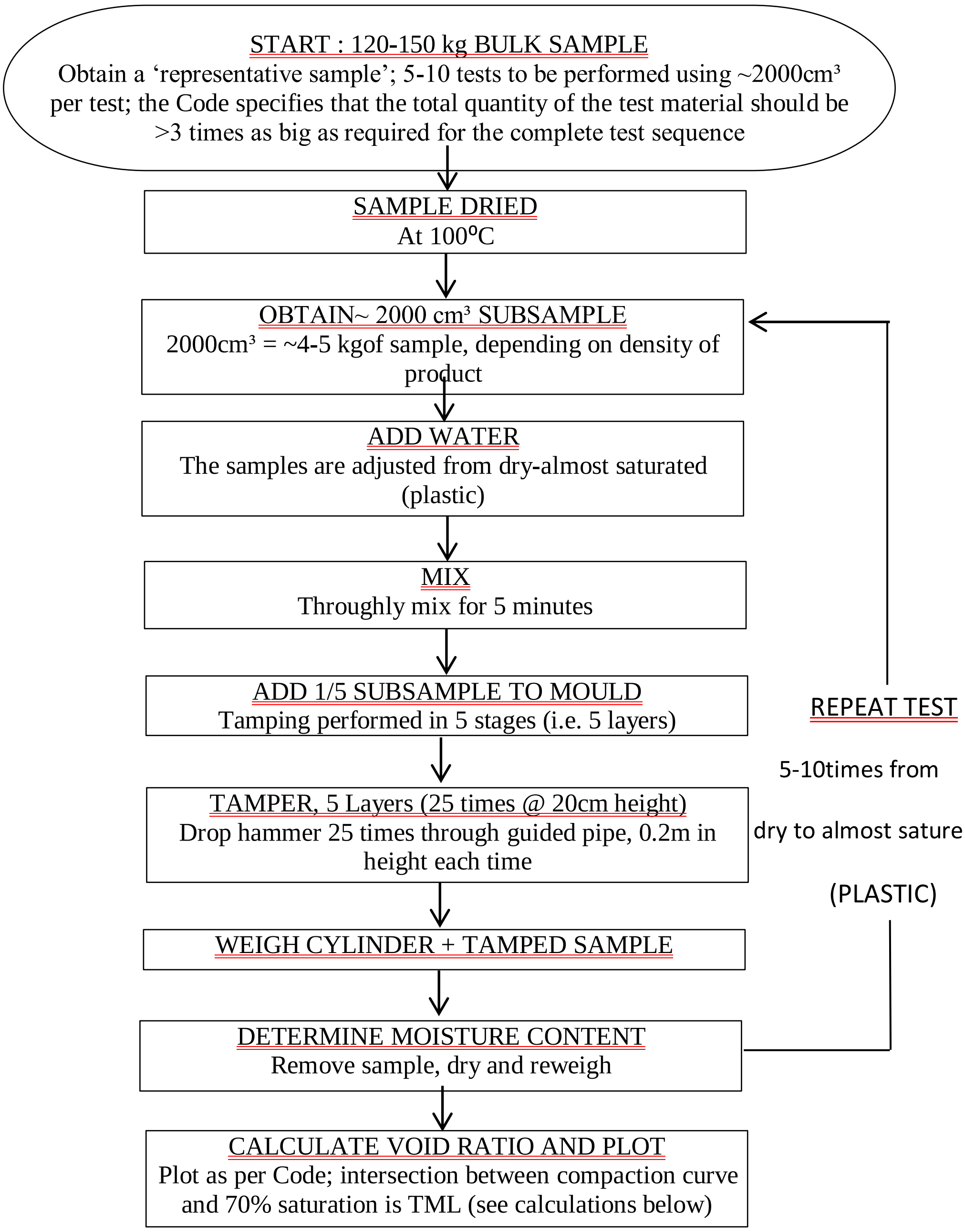


Figure 3.9 : Determination of the TML of a solid bulk material from the Proctor/Fagerberg curve [33]

Efficaciously, the Proctor/Fagerberg Test is rarely used. Hereinnext page figure 3.10, the test equipment is more specialised, difficult to manufacture, is more expensive and is challenging to calibrate by inexperienced personnel. Nonetheless, the Proctor/Fagerberg Test generally gives lower TML results than the other methods. Thus, the Proctor/Fagerberg Test is thus unlikely to be favoured shippers, when deciding which test to use.

Proctor Fagerberg Test (PFT): IMSBC Code Procedure



Measured Properties	
Variable	Symbol
Mass Empty Cylinder	A
Mass Cylinder with Tamped Sample	B
Mass Wet Sample	C=B-A
Mass Dry Sample	D
Mass Water	E=C-D
Volume of Cylinder	1000 cm³

Calculations		
Variable	Symbol	Calculations
Density	d	d
Dry Bulk Density	y	y=D/100
Net Water Content (%volume)	e_v	e_v=E/Dx100xd
Void Ratio(vol voids/vol solid)	e	e=G_5/y-1
Degree of Saturation(%volume)	S	S= e_v/e
Gross Water Content	W^i	W^i=E/Cx100
Net Water Content	W	W=E/Dx100

Figure 3.10 : Flow diagram representation of the FTT Methology.

3.3 The Penetration Test (PTT)

The Penetration Test was started to use in Japan at the research institute of marine engineering for detecting the TML for coal. It was approved by IMO between 1991 and 1998, to detect the TML of ore concentrates and coal.

The Penetration Test apparatus is involved placing a cylindrical mould for sample with four layers. The cylinder mould is changable size from 1700 cm^3 to 4700 cm^3. Each sample layer is compacted with an adjustable tamper thus the sample is level. It is indicated tamping pressure prior to vibrating. After compaction is complete the mould is attached to a vibration table [45] called name the Penetration bit as shown figure 3.11. The penetration bit is operated frequency 50-60 Hz. The mixed in a bowl Group A cargo are taken subsamples three times. One subsample is used to get the initial moisture content and other two subsamples for the preliminary test. The Penetration test is obtained the nearly moisture content where the depth of mixed in a bowl Group A cargo. Also the Penetration Test will be greater than 50 mm which called the flow moisture point.

Figure 3.11 Observations on the Penetration Table Test to find TML.

According to IMSBC Code, the Penetration Test can be completed in two days. One day is needed to accomplish the preliminary test, aproximately the Flow Point. The second day is needed to scale the Group A cargoes that were dried out during the Penetration Test and calculate the Transportable Moisture Limit.The Penetration Test uses measurements to detect if the flow moisture point has been figured out and not necessary the operator to explain visually if the flow moisture point arrived. The test is repeatable between operators and laboratories as long as the same procedure is used, see in table 3.5. Varying the settings on the vibrating table can cause significant differences in the results and more investigation is needed to determine if the initial compacted density, produced by the tamper, effects the resulting TML.

Table 3.5: Major alternative TML test methods

TEST NAME	OVERVIEW OF THE TEST METHOD
The Portable Vibration Viscometer (Norway, 1964)	Based on the 'Suction Pressure Test', the Portable Vibration Viscometer was developed to determine the flow properties of a slurry material at sea. It measured the forces holding water into the pores and indicated the capacity of a material to retain water, under vibration. This test gave a 'Go' or 'No-Go' (not a TML) depending on whether a slurry flowed and touched an electrical contact switch, within a set time (IMO BCI/7, 1964; IMO BCI(II)/Conc/12, 1964; IMO BC/Conc/6, 1964).
The Cohesion Point Method (U.S.A, 1964)	This method considered the saturation moisture of cargo and then deducted a 2.5% absolute safety factor to obtain the water content at maximum cohesion (termed the 'cohesion point'). Saturation moisture was determined by addition of a known amount of water to the sample, and letting it stand for 15 minutes (US Coast Guard, 1959; IMO BCI/7, 1964).
The Vibration (Glass Rod) Test (Norway 1964)	This test worked in a similar principle to the PTT. An FMP was obtained by applying an uncontrolled vibration to the sample within a small bottle (i.e. only suitable for fine concentrates) and the penetration depth of a glass rod was measured with time. The turning point of the penetration depth and moisture content curve indicated the moisture content at maximum cohesion (i.e. the FMP). The rate of the curve provided insight into the speed at which a concentrate may lose cohesion after maximum moisture has been exceeded (IMO BC/Conc/6, 1964; IMO BC/Conc/13, 1964; IMO BCXIV/4, 1972).
The FTT Expansion Method and the 'Characteristic Moisture Content' (CMC) (Norway, 1971)	In order to address the subjectivity associated with the FTT, Norwegian researchers investigated the effect of varying table knocks (20, 50, 100, 200 and 400) on cone expansion. They found that the turning point of all curves corresponded to the same moisture content and that this corresponded well to when 'plastic deformation' was observed. They termed this the Characteristic Moisture Content (CMC) and suggested that the TML be taken from a lower safety margin of 0.97-0.98 times the CMC as this method consistently gave lower results than other TML tests (Kvalheim et al., 1971; IMO BCXV/4(a)/2), 1971; BCXIV/4, 1972; BCXV/Inf.3, 1973; BCXIX/6, 1978).

Table 3.5 (continued): Major alternative TML test methods

TEST NAME	OVERVIEW OF THE TEST METHOD
Proposed Method to Determine the Liquefaction Potential (Japan, 1992)	This method intended to determine whether a cargo was likely to liquefy during transit (i.e. a Group A Cargo) based on two criteria: (i) PSD; and (ii) drainage characteristics. If the cargo contained a sufficient portion of fine particles, and the degree of saturation after drainage was over 70% (determined from a specified test whereby a sample is saturated and allowed to drain for a fixed time), then the material would be classified as one that may liquefy, and further TML testing would be necessary (IMO DSC2/12/1, 1997; IMO DSC3/11/2, 1998; IMO DSC3/11/5, 1998; IMO DSC4/5/4, 1999; IMO DSC4/5/5, 1999; IMO DSC6/5/3, 2001).
Penetration Test for New Caledonian Nickel Ores (France, 2011)	This research presented a modified version of the PTT for use with New Caledonian Ores. Major modifications included increasing: (i) the penetration bit diameter to 20 mm (from 15 mm); (ii) the penetration bit weight to 1500 g (from 177 g); and (iii) the fail criteria to 80 mm penetration (from 50 mm). Also, they proposed a 'surface confinement disk' be used to prevent material creeping to one side of the container, to control erroneous penetration (IMO E&T17/5/1, 2012).
A Study on Safe Operation of Nickel Ore (Jian-Ping, W., 2011)	In research aimed at assessing the safe shipped moisture content for nickel ores, these researchers presented a new TML test in which vibration (20-50 Hz) is applied to a cargo sample that has been compacted into a cylindrical tube (d = 150 mm, h = 1200 mm) for 1-3 hours. Moisture analysis was then carried out in ~100 mm layers through the tube and moisture content of each layer is then plotted against height. At moisture contents approaching the flow point a wet base layer is formed and a turning point is observed on the plot, taken as the FMP. They found that the gradient of the turning point can provide insight into a material's absorbing capacity (Jian-Ping, W., 2011).
The Proctor/Fagerberg Test D80 for Iron Ore Fines (Brazil and Australia, 2013)	Through a research project undertaken jointly by Rio Tinto, BHP Billiton and Vale, it was found that for the PFT on iron ore fines, the minimum void ratio (i.e. point of optimum compaction) occurred between 90-95% saturation; and that the density within the Proctor mould from the PFT was unrepresentative. They proposed that S=80% be taken as the intersection condition and that a 150 g hammer be used (replacing the 350 g hammer). These modifications increased TML by around 1% absolute. This new method was adopted within the schedule for iron ore fines (IMO DSC18/INF.12, 2013; IMO DSC.1 /Circ.71, 2013).

3.4 The Liquefaction Test Methods Materials

The two different type of iron ore, bauxite and lead concentrate were tested during this study. Various of Group A cargoes were obtained from different of locations around Turkey. In addition, this study was tested the samples of Group A cargoes with suitable particle size according to IMSBC Code procedure listed for TML in the 2012 as seen Table 3.1.

3.4.1 Magnetite iron ore

Magnetite is type of oxides of iron in the form natural as shown figure 3.12. It is formulated Fe3O4 in chemistry, is involved 72.4% Fe. The classical magnetite iron ore concentrate is much than 0.1% phosphorus, 3–7% silica and less than 3% aluminium. Banded iron formations (BIFs) are sedimentary rocks containing more than 15% iron composed predominantly of thinly bedded iron minerals and silica (as quartz). Banded iron formations occur exclusively in Precambrian rocks, and are commonly weakly to intensely metamorphosed. In figure 3.13, banded iron formations may contain iron in carbonates (siderite or ankerite) or silicates (minnesotaite, greenalite, orgrunerite), but in those mined as iron ores, oxides (magnetite or hematite) are the principal iron mineral.[46]

Figure 3.12 : Magnetite iron ore at stockpile [47].

Banded iron formations are known as taconite within North America. Magnetite iron ore has much lower ore than hematite iron ore. Nonetheless, magnetite iron ore must be concentrated prior to using it. Magnetite is also the most magnetic mineral in the world. An ancients days, the first time property of magnetism discovered by the virtue of small pieces of magnetite iron ore which has called lodestone. Additionally, obtaining iron from hematite ore can produce a great deal of carbon emissions, and the process for magnetite is much less harmful.

Figure 3.13 : Magnetite iron ore at mine [47].

Magnetite iron ore is generally mined in the United States (Minnesota&Michigan) in Eastern Canada and North Sweden. At the present time, magnetite banded iron ore is largely mined in Brazil which is generally exported to Asia and there are many magnetite iron ore industry in Australia.

3.4.2 Hematite iron ore

Hematite iron ore is a mineral and is chiefly mined iron ore as shown figure 3.14. Its name comes from Greek for blood, haima, due to reddish color. It is formulated Fe2O3 in chemistry, is involved 69.9% Fe. Hematite iron ore is found abundance on Earth as the most mined in Brazil, Australia and Asia. It is a common rock-forming mineral found in sedimentary, metamorphic, and igneous rocks at locations throughout the world.

Hematite iron ore has advantage like magnetite is its high content. Thus, hematite iron ore extraction process is much less costly and time consuming. In additional, while hematite iron ore only goes through one time of screening and crushing, magnetite has additional round of processing. Due to the high density of hematite relative to associated silicate gangue, hematite beneficiation usually involves a combination of beneficiation techniques.

Figure 3.14 : Hematite iron ore at stockpile [48] .

One method relies on passing the finely crushed ore over a slurry containing magnetite or other agent such as ferrosilicon which increases its density. When the density of the slurry is properly calibrated, in figure 3.15 the hematite will sink and the silicate mineral fragments will float and can be removed.[49]

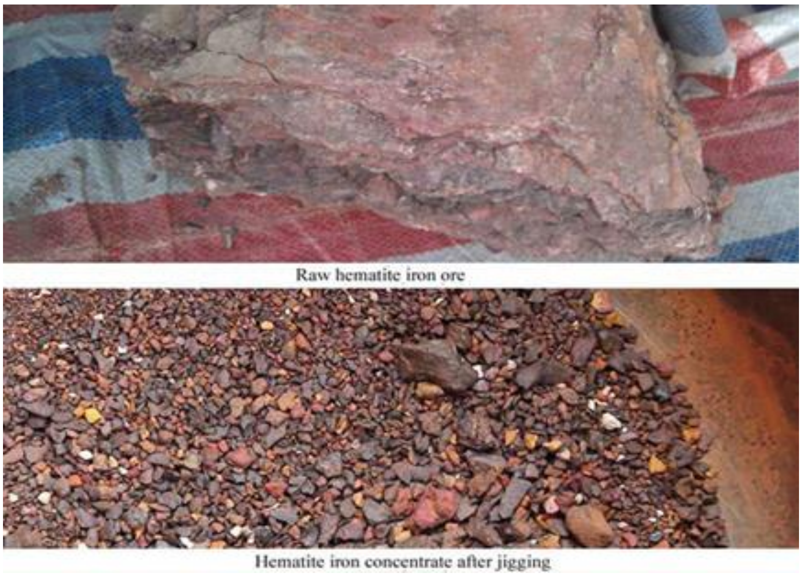


Figure 3.15 : Raw hematite iron ore , hematite iron concentrate after jigging [48]

Most ore is now produced in China, Australia, Brazil, India, Russia, Ukraine, South Africa, Canada, Venezuela, and the United States, see figure 3.16. Hematite has a wide variety of other uses, but their economic significance is very small compared to the importance of iron ore. The mineral is used to produce pigments, preparations for heavy media separation, radiation shielding, ballast, and many other products.

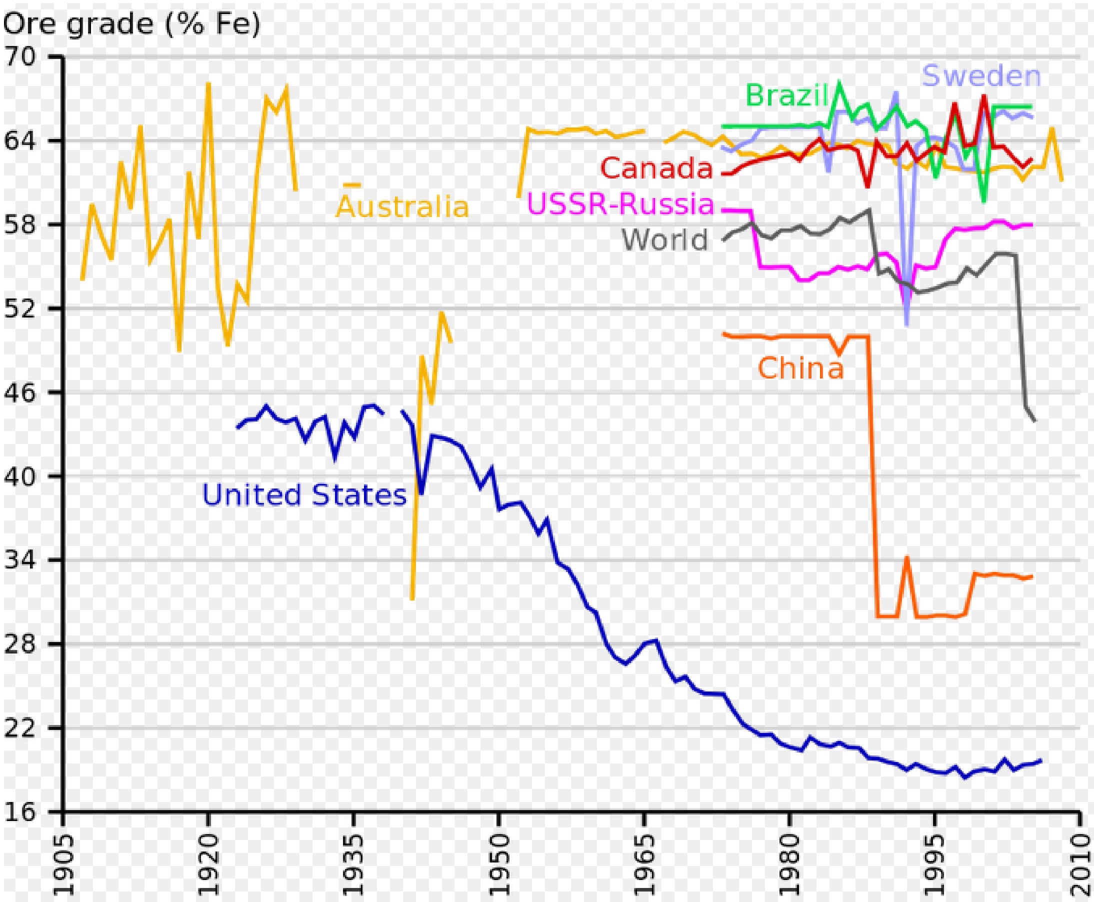


Figure 3.16 : Evolution of the extracted iron ore grade in different countries (Canada, China, Australia, Brazil, United States, Sweden, USSR-Russia,world). The recent drop in world ore grade is due to big consumption of low grade Chinese ores. The American ore is upgraded between 61% to 64% before being sold. [50]

3.4.3 Bauxite

Bauxite is the principal aluminium ore for example in figure 3.17 . It is formed as a residual product over millions of years by chemical weathering of rocks containing aluminium silicates. It was first discovered in France in 1821 and has since been found in many locations around the world. Hydro has interests in two bauxite mines in Brazil.

Bauxite occurrences are widespread mostly in tropical areas where there has been intense weathering to generate bauxite but, resources are tightly held by a few competitors. Bauxite usually occurs in a thin layer (typically 2 to 5 meters) near or at the surface.

Figure 3.17 : Bauxite at loading port before shipment.[51]

The layers are usually mixed with various clay minerals, iron oxides and titanium dioxide. It is the iron that gives bauxite a deep red color as shown figure 3.18. Worldwide bauxite production is about 250 million tonnes and has been growing at an annual rate above 5% for the past decade driven largely by Chinese demand growth. Bauxite is a mixture of minerals that contain various concentrations of hydrated aluminum oxides as well as impurities. The primary ore minerals are gibbsite (alumina tri-hydrate), boehmite and diaspore (alumina monohydrates).

Figure 3.18 : Bauxite at stockpile before shipment.[51]

Gibbsite-rich bauxite is preferred as it can be refined at lower digestion temperatures than the other types of alumina bearing minerals. Bauxite is usually reddish-brown but can also be white, tan, and yellow, depending on the type and concentration of iron minerals present. It also has a wide range of textures, but is typically dull to earthy in luster and can look like clay or soil.

Bauxite is usually covered by an overburden of several meters of rock and clay, which must be removed before the bauxite can be recovered. Then, the bauxite is transported to crushing or washing plants, before it is transported for processing. The aluminium industry is also preparing to use ores other than bauxite in the future. Research to develop extraction processes from other minerals is ongoing, and in the future we envision using more recycled metal, from buildings.

Every year, the worldwide use (see figure 3.19) of new land related to bauxite mining is 40-50 square kilometers. However, after the mining operations have been completed in one area, it is normally re-vegetated with local species.

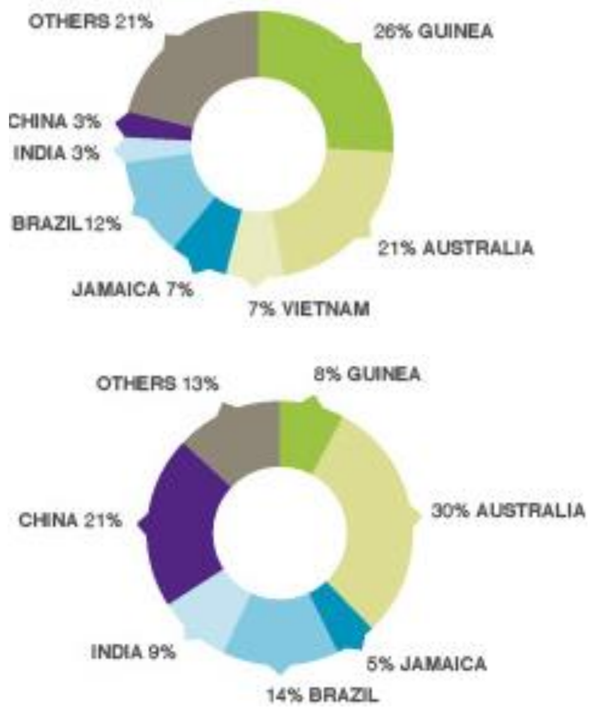


Figure 3.19 : World production (up) and reserves (down) of bauxite[52]

The world's bauxite reserve is 25 billion tons (base reserve is about 34 billion tons) where 23 billion tons are minable. Australia has 24% percent of world bauxite reserves where Brazil has 12%, Guinea has 24%. Turkey has 45 million tons of visible reserve where probable reserve is total of 97 million tons. 46 million tons of total reserves are minable (according to table 3.6).

Table 3.6 : Numbers for 2010's total proven bauxite reserves x 1,000 tonnes [53].

Country	Mine production		Reserves	Reserve base
	2010	2011 (est.)		
Guinea	17,400	18,000	7,400,000	8,600,000
Australia	68,400	67,000	6,200,000	7,900,000
Vietnam	80	80	2,100,000	5,400,000
Jamaica	8,540	10,200	2,000,000	2,500,000
Brazil	28,100	31,000	3,600,000	2,500,000
Guyana	1,760	2,000	850,000	900,000
India	18,000	20,000	900,000	1,400,000
China	44,000	46,000	830,000	2,300,000
Greece	2,100	2,100	600,000	650,000
Iran	—	500	—	—
Suriname	4,000	5,000	580,000	600,000
Sierra Leone	1,090	1,700	180,000	?
Kazakhstan	5,310	5,400	160,000	450,000
Venezuela	2,500	4,500	320,000	350,000
Russia	5,480	5,800	200,000	250,000
United States	30	N/A	20,000	40,000
Other countries	2,630	2,600	3,300,000	3,800,000
World total (rounded)	209,000	220,000	29,000,000	38,000,000

In 2009, Australia was the top producer of bauxite with almost one-third of the world's production, followed by China, Brazil, India, and Guinea. Although aluminium demand is rapidly increasing, known reserves of its bauxite ore are sufficient to meet the worldwide demands for aluminium for many centuries.[54] Increased aluminium recycling, which has the advantage of lowering the cost in electric power in producing aluminium, will considerably extend the world's bauxite reserves.

3.4.4 Wilfley and deister table

Wilfley and Deisher shaking table are generally used to concreate ores by mining engineer as shown figure 3.20. The wilfley table is one among the gravity concentration unit operation that separate minerals or other bulk material of different specific gravity by their relative movement in response to gravity and other forces. Usually Wilfley tables are used for the concentration of different heavy minerals such as chromite, iron and beach sand including different plant tailings.

The separation performance of Wilfley table depends on both feed characteristics and operating parameters associated with the equipment. Feed characteristics include particle size, density distribution, volumetric flow rate and solid concentration.

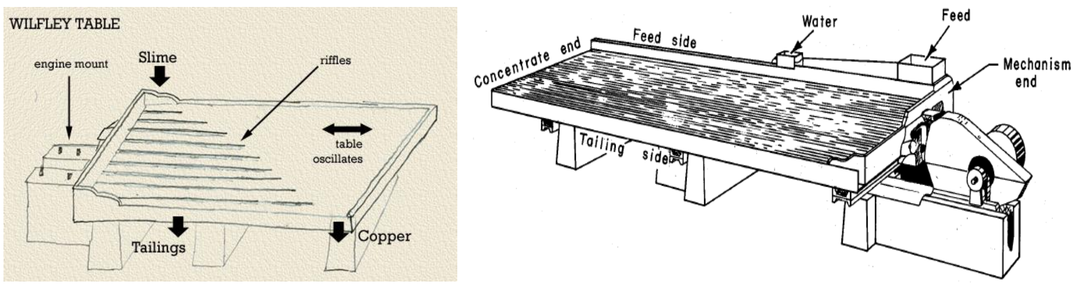


Figure 3.20 : Wilfley Table (left), Deister Table (right)[55],[56]

Similarly the operating parameters include wash water flow rate, deck tilt angle, shake amplitude, shake frequency, splitter position and side tilt angle [57, 58, 59]. Wilfley table has been used to recover celestite ore [60] and also for the beneficiation of low grade manganese ore [61]. When gravity concreation with mines, there have been several variable measurement on the shaking tables; but this study is used to them to aim in different way. Wilfley and deister shaking table are compound eccentric which are used to create variable frequency and rapid throwing motion on the table, longitudinally or latitudinally. In addition, wilfley shaking table is adjusted for rake as listing ships. (see figure 3.21 & 3.22)

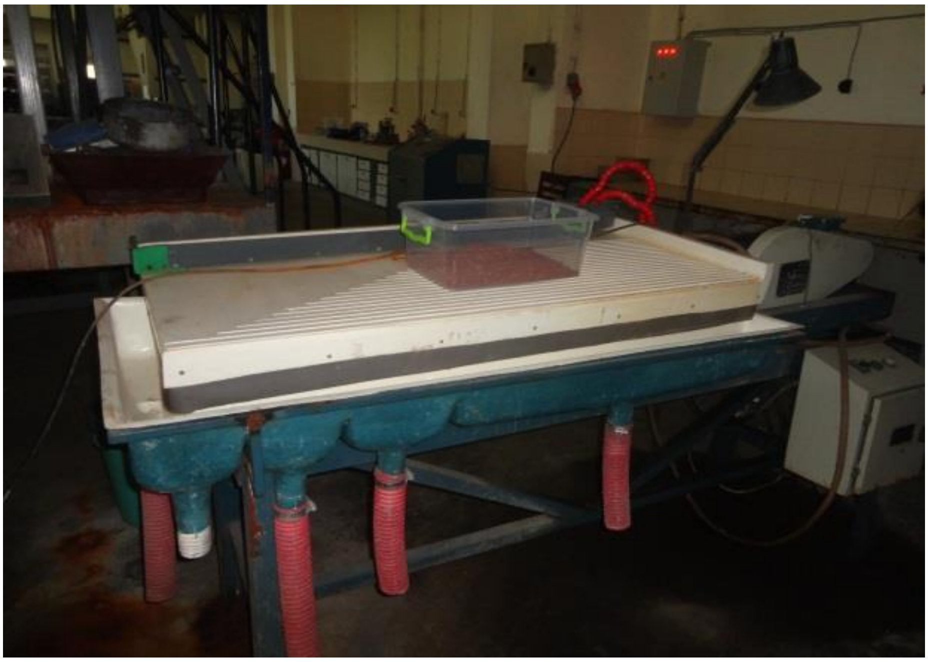


Figure 3.21 : Wilfley shaking table with dried bauxite moisture content less than 1 percent

Figure 3.22 : Deister shaking table with bauxite TML 8.9 percent (right).

This study consists of shaking tables that is driven to move as desirable, from low to medium frequencies.A rectangular tank's size is 0.23m X 0.34m X 0.15m (width X lenght X height). The dimensions of the rectangular tank are intend to accord a Panamax bulk carrier that is mounted maximum frequency. The rectangular tank is made from non-coloured plexiglass of 20 mm thickness.

Plexiglass is enduring material than glass due to medium frequencies. Plexiglass tank is more visible than sheeting tank. Thus, Plexiglass tank which is why this study is used it for test.

3.5 Used Materials And Procedure Of Test

Although the findings on variability of the TML test methods was described in the previous issue, if implemented, improve the reliability of TML results obtained within and amongst TML testing laboratories, there is little evidence available to indicate their accuracy. That is, the ability of these methods to accurately predict the likelihood for a cargo to liquefy during a voyage is not quantified and TML may have significant financial and safety implications.

The current approach to cargo stability assumes that for a given cargo there is a critical moisture content, the FMP, above which a Group A solid bulk cargo could liquefy and so become unstable, but below which the cargo is stable. A simplified analogy between the TML test methods and cargo behaviour is represented in Figure 3.5.1. In reality, assessing the potential for cargo liquefaction and dangerous cargo shift is much more complex than shown figure 3.23, due to the many dynamic variables that that influence actual cargo behaviour, but which are not captured within TML testing.

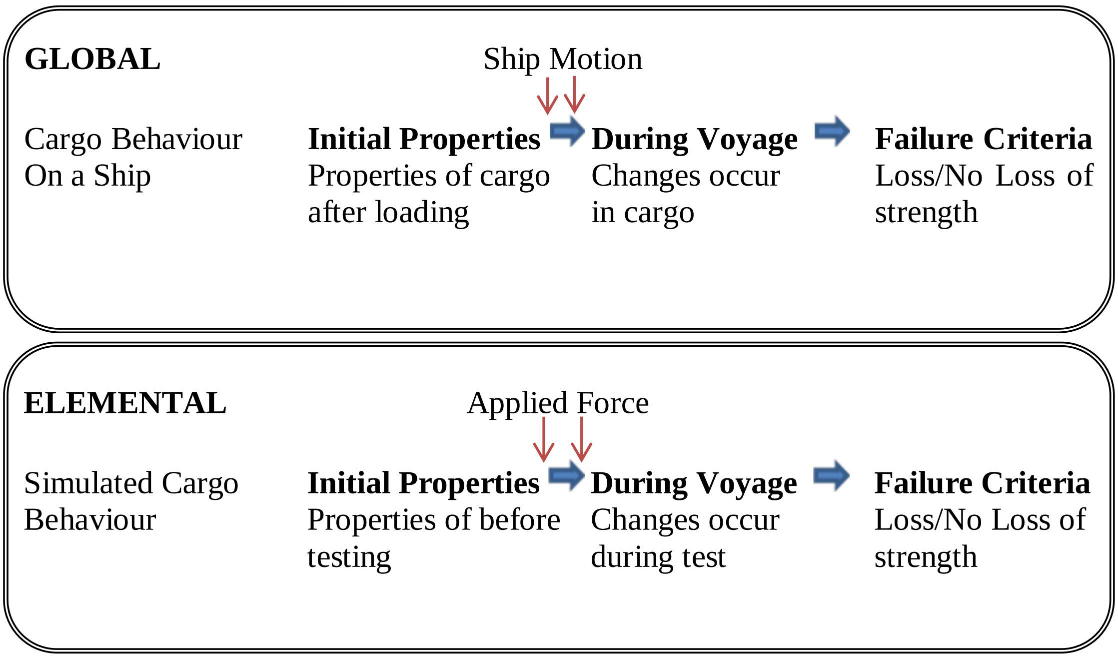


Figure 3.23 : Simple comparison between cargo shift and small scale testing.

This section explores these variables in relation to the TML test methods and summarises previous work that has aimed to asses cargo behaviour. It then suggests apossible approach for assesing the changes in physical properties in Group A cargo during transportation by sea.

In order to asses if the results devired from elemental test-work accurately represent the global cargo behaviour, it is necessary to give consideration to those variables that lead to cargo compaction, a loss of strength and in the worst-case, dangerous cargo shift.

Prior to starting test bauxite is characterised high quality diasporic which have consisted of 50-57% Al_2O_3, 20-26% Fe_2O_3, 2-10% SiO_2, 2-3% TiO_2, 10-12% LOI. Particles size of bauxite is between 0 mm and 10 mm according to XRF analyses at mining laboratory. All these characteristic features about cargo are unique for a given cargo consignment, influence the strength of the material and additionally its resistance to shift during passage.

Initially, bauxite was delivered from Mersin mining on 26th of October 2015. After bauxite was taken at the Faculty of Mines of ITU, investigation of bauxite was commenced at the department of the Chemistry of ITU. Prior to starting test, bauxite was known its moisture content but bauxite have different particles size between 0.1 mm and 10 mm so that mesh (no 18) was conducived to seperate not bigger 0.47mm particles size that is determined quickly moisture content, in figure 3.24.

Figure 3.24 : Analysis of bauxite moisture content at the Chemistry Lab A of ITU.

When obtained particles size (0.47mm) of bauxite, the dimensions of three pieces of petri dished glasses were 100mm X 15mm (height x diameter)which were different tare weighs. The tare of respectively petri dished glasses were 49.19g, 49.45g, 52.10g, was written their tare weigh on the theirs side of the labels. (see figure 3.25)

Figure 3.25 : The measurement of the tare weight of each of petri dished glasses.

In figure 3.26, 10 grams of bauxite were placed in to each of the petri dished glasses. After then all petri dished glasses put into drying chemistry oven at 115^0C to investigate their moisture content according to general chemistry theory.

Figure 3.26 : 10g bauxite is to be put into oven for determination MC.

All petri dished glasses were checked their weigh step by step 1 hour later, 3 hour later and 6 hour later end of the moisture content test nearly 3.3%. The weigh of bauxite were 58.87g (MC: 3.2%), 59.11g (MC: 3.4%), 61.77g (MC: 3.3%), for example see in figüre 3.27. Major considerations in an assessment of the finding moisture content is changing each of bauxite in the petri dished glasses weigh hour to hour and using desicator glass to trap moisture.

Figure 3.27 : Measuring the weight of the bauxite after storing into desicator.

For this experiment all of bauxite were dried completely in drying chemistry oven until MC less than 1% due to finding answer how their physical properties of bauxite can change. In other words, prior to loading, a cargo is characterised by unique granular properties and moisture content. The act of ship loading causes compaction of the material that cause an initial state within the hold. In this state in figure 3.28, the cargo can be considered as nearly homogenous and is characterised by material properties such as bulk density, initial degree of saturation, in addition to the geometry. Each of factors effect the cargo liquefaction indeed dangerous cargo shift so that this study initially was the aim to minimize the margin of the error.

Figure 3.28 : The mineral processing laboratory at the Faculty of Mines ITU.

A rectangular tank's size is 0.23m X 0.34m X 0.15m (width X lenght X height) and added to 3 kilograms of bauxite with angle of reponse like loading with a grab in a Panamax bulk carrier's hold. One of the rectangular tanks was tested MC < 1%, the other rectangular tanks was tested that water was added to dried bauxite involving MC < 1% weigh up to 10 percent (300ml) and also TML 8.98 percent.(see figure 3.29) Thus, this study is explained how to change physical of bauxite, if it have moisture content.

Figure 3.29 : Measuring of the 3000g of bauxite and angle of repose before experiment.

The moisture content of less than 1 percent in bauxite was put on wilfley shaking table, bauxite containing the value of 8.9% TML was put on deister shaking table to observe how to influence physical of bauxite with same frequence, time slot and condition, in figure 3.30.

Figure 3.30 : The bauxite less than 1 percent moisture place on wilfley shaking table (left), The bauxite involving 10 percent MC place on deister shaking table (right).

The initial moisture content of the less 1 percent in bauxite by heating it in a furnace was not physically any changed except angle of repose whereas the MC value 10 percent of bauxite was liquefied when exposed to sway 1 hour.(see in figure 3.31)

Figure 3.31 : The appearence of bauxite with different moisture content exposed to vibration after 1 hour (left-less1%), (right 10%)

There is a critical moisture level below which cargo behaves almost like a solid; in the sense that it follows rectangular tank's motion without flowing, no matter what the external frequency value or time slot is so that after swaying from low to medium frequency. However, the value of 10 percent MC in bauxite after the critical moisture content reached, two apparence occur after swaying 1 hour: i) Bauxite had a small heap wits its peak at the centre of free surface, ii) Bauxite had a small amount of the water appears at each side of the rectangular tank.(see in figure 3.32)

Figure 3.32 : The appearence of bauxite with different moisture content exposed to vibration after 1 hour (left-less1%), (right-10%)

After swaying 3 hours later, the first experiment of rectangular tank in bauxite less than 1 moisture content, similarly to after swaying 1 hour, was behaved like a solid too, basically following rectangular tank's motion. The level of 8.9 percent TML in bauxite after swaying 3 hours later, there was water diffusion the entire cargo body through the formation of moisture layers, leading to a jelly like motion of the cargo. (see in figure 3.33)

Figure 3.33 : The appearence of bauxite with 10% moisture content exposed to vibration after 3 hour

After swaying 7 hours later, bauxite property afore behaving solid (MC 10%) was completely fluctuated to noticeable shift of a portion of cargo to the sides of the rectangular tank. It is unquestionable fact that bauxite was not behaved a solid which was exactly homogenous mixed cargo called dangerous liquefaction or unstoppable cargo shift, as shown figure 3.34.

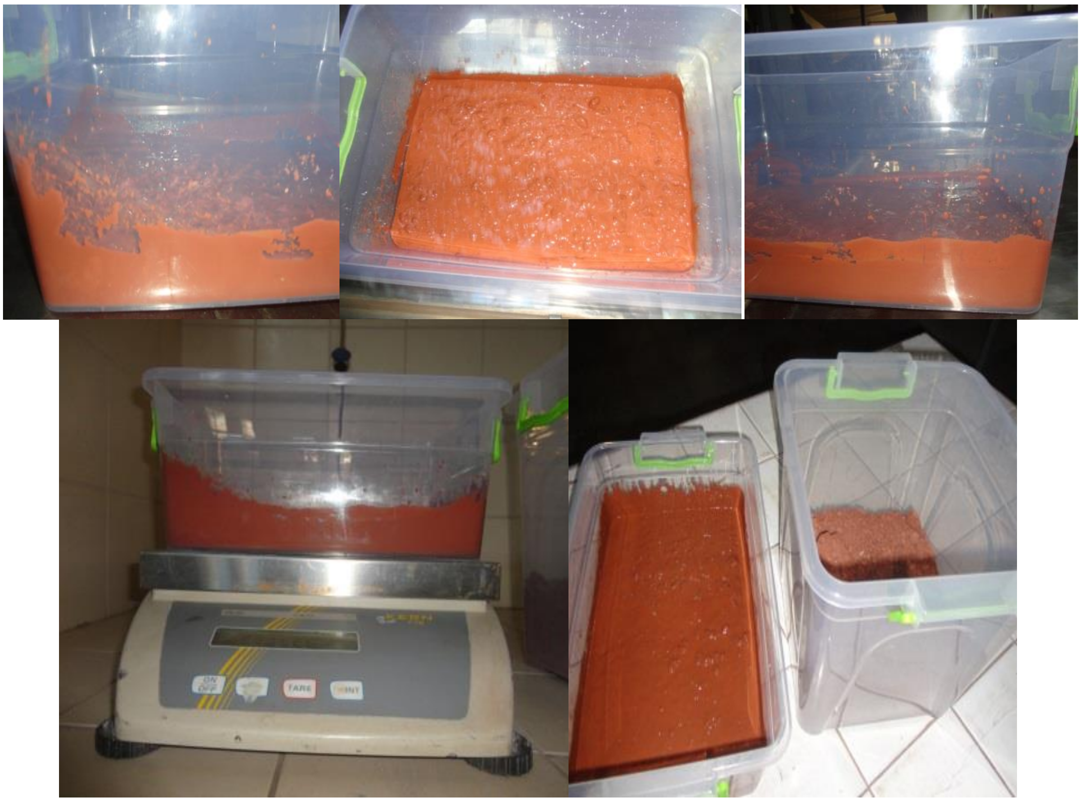


Figure 3.34 : The appearence of bauxite with 10 percent MC exposed to vibration after 7 hour, right bottom less 1 percent moisture content (no change).

In accordance study with that the effect of the deister or wilf shaking table on the rectangular tank's motions in bauxite's behaviour are twofold. Firstly, they cause cargo compaction that either i) facilitates the development of pore-water pressure, reduction of effective stress and reduction in strength (wet cargo); ii) increases cargo strength due to increased relative density and particle inter-locking, leading to more dilation on shearing (non-homogerous dry and wet cargo).

Secondly, given this adopted state of cargo compaction, it is the ship's transverse motion that cause dangerous displacement to outher edges of the hold and leads to a list. More specifically, these transverse motion impart shearing forces on the cargo from gravity when tilting the pile to horizontal and these can overcome the cargo's resistance to shear.

4. CONCLUSIONS

Solid bulk cargoes called Group A such as concentrates, unprocessed nickel ores, bauxite and iron ore fines contain adequate moisture, then cargo compaction and moisture migration during sea transportation can end up development of pore-water pressures and liquefaction. This has been known to result in dangerous cargo shift and vessel capsize, even causing a number of fatalities over the years like M/V Bulk Jupiter.

The IMSBC Code highlights as the principal regulatory tool for preventing cargo shift and cargo liquefaction. The IMSBC Code requires that cargoes with potential to liquefy during seaborne transportation, or Group A cargoes, be shipped at a moisture content below the TML. The TML is determined by laboratory based testing, as per the methodologies specified within the IMSBC Code. The TML results given by these test methods are one of the most important components of the IMSBC Code. Firstly, this is due to the fact that they intend to prevent liquefaction and for this reason loss of life, ship and cargo. Secondly, they also introduce an upper moisture limit at which cargoes can be shipped. An inaccurate TML result that is too high can demonstrate a safety risk, while a TML result that is too low can incorrectly restrict the ability to ship that cargo. Both the problem of liquefaction and its regulation have significant safety and commercial inferences.

The bauxite containing different amounts of moisture in this experiment was explained physical changes that have given influence. This study was worked with samples of dry and wet bauxite, having moisture content that is commonly found when such bauxite is transported by sea. The focus of our study with ship motion that the bauxite showing solid feature by changing the physical properties of liquefaction with a high moisture content.

Actually, the dried of bauxite involving moisture content less than 1, there was no physical change of bauxite behaves like a solid, but stability change occured angle of respose. The bauxite which MC is 10 percent after simulated ships motions bauxide behave like liquid that its influences explained at section 3 above.

4.1 Recommendations Of Cargo Liquefaction By Seaborne Transportation

Cargo liquefaction is now one of the most significant factor in lives lost at sea for most bulk carriers. During the general safety level of modern bulk carriers has been substantially improved over the last decades, recent accidents have been demonstrated that cargo liquefaction remains a major safety issue . Since 2009, at least six ships of more than 40,000 dwt have been lost to suspected liquefaction of cargo. For latest example of MV Bulk Jupiter accident 18 lives lost voyage from Kuantan, Malaysia to China which sank off the coast of Vung Tau, Vietnam.

Below recommendations to reduce the risk of liquefaction include by directly Master or shipper/owner of ship in person:

a) Make sure that shipped cargo is correctly identified and properly documented, the master should always assure the cargo is correctly identified by shipper before loading.

b) Ensure the time interval between testing for moisture content and loading is no more than seven days and that retesting is done in the event of rain.

c) Appoint an independent surveyor and performing a can test or similar to verify the moisture content loading in a non-homogeneous pattern.

d) Raise the center of gravity by ballasting the top wing tanks, provided loading condition and structural strength allows for it, and trimming as necessary to ensure cargoes are reasonably level.

Below recommendations to reduce the risk of liquefaction include by educated crew onboard or labours/cargo masters:

According to figure 4.1, filters can be installed into the bilges of cargo holds as filtering elements, to improve a possible drainage of water from cargo. Firstly, a strainer should be placed inside the well-cleaned cargo holds' bilges. An appropriate size of canvas should be spread at the top of strainer. There should be three different size of stone chips for the most effective drainage of water. Biggests will be poured for the first layer and smallers will follow. The top of the filter should be closed by metalic cover.

Figure 4.1 : The preparation of hold bilge before loading liquefy cargo.

During voyage drained water will be pumped out by chief officer when water sounding at each bilge reach 30 cm or more. Thus, the water, liquifed from the cargo due to ship motions and vibration, will be discarted and ship stability will be protected. During the voyage bilge alarm must be open and should be checked before loading to asure that it is functioning. Moreover, hold bilge soundings should be checked and recorded daily, for instance in figure 4.2.

Vessel:			Voyage from:	Tubarao	To	Jingtang	
Hold No:	4						
	Port Bilge Well				Starboard Bilge Well		
Date & Time	pH Value	Sounding (cm.)	Total Pumped Out Volume (cbm)	Date & Time	pH Value	Sounding (cm.)	Total Pumped Out Volume (cbm)
1		0	0	1		0	0
2		0	0	2		0	0
3		0	0	3		0	0
4		0	0	4		0	0
5		0	0	5		0	0
6		0	0	6		0	0
7		5	0	7		9	0
8		5	0	8		46	1.0 m3
9		13	0.4 m3	9		48	1.1 m3
10 0800lt		8	0	10 0800lt		49	1.1 m3
11 2030 lt		12	0.3 m3	11 2030 lt		35	0.8 m3
12 0800lt		2	0	12 0800lt		42	1.1 m3
13 2015lt		10	0.3 m3 (after pump out sounding found 0)	13 2015lt		48	1.1 m3 (after pump out sounding found 1
14 0820lt		3	0	14 0820lt		35	0.8 m3 (after pump out sounding found 0

Figure 4.2 Example of recommended vessel's hold bilges observation log (hold no 4). As seen liquefaction commenced at 7th day of voyage.

82000 dwt bulk carrier pumped out drained water that liquefied iron ore during voyage from port of Brasil Tobarao to port of Jingtang China. During 1,5 month voyage vessel faced 10 beaufort force weather at South of Africa 3 days and around 10 days rolled and pitched heavily due to rough swells. However, voyage completed without any problem. As seen at figure 4.2 totally 470 mt water discharged by chief officer. At the arrival port while discharging cargo was seen not wet or liquefy.

Below recommendations to reduce the risk of liquefaction by ship design for future:

New specialized bulk ore carrier vessels should be designed for the liquifed cargo like OBO vessels. An OBO vessel (Ore / Bulk / Oil) is a vessel which can carry cargo in both liquid and dry form, and a typical use is alternation between transportation of crude oil and coal in figure 4.3. Opposite of OBOs this new design vessel will carry only bulk ore cargoes.

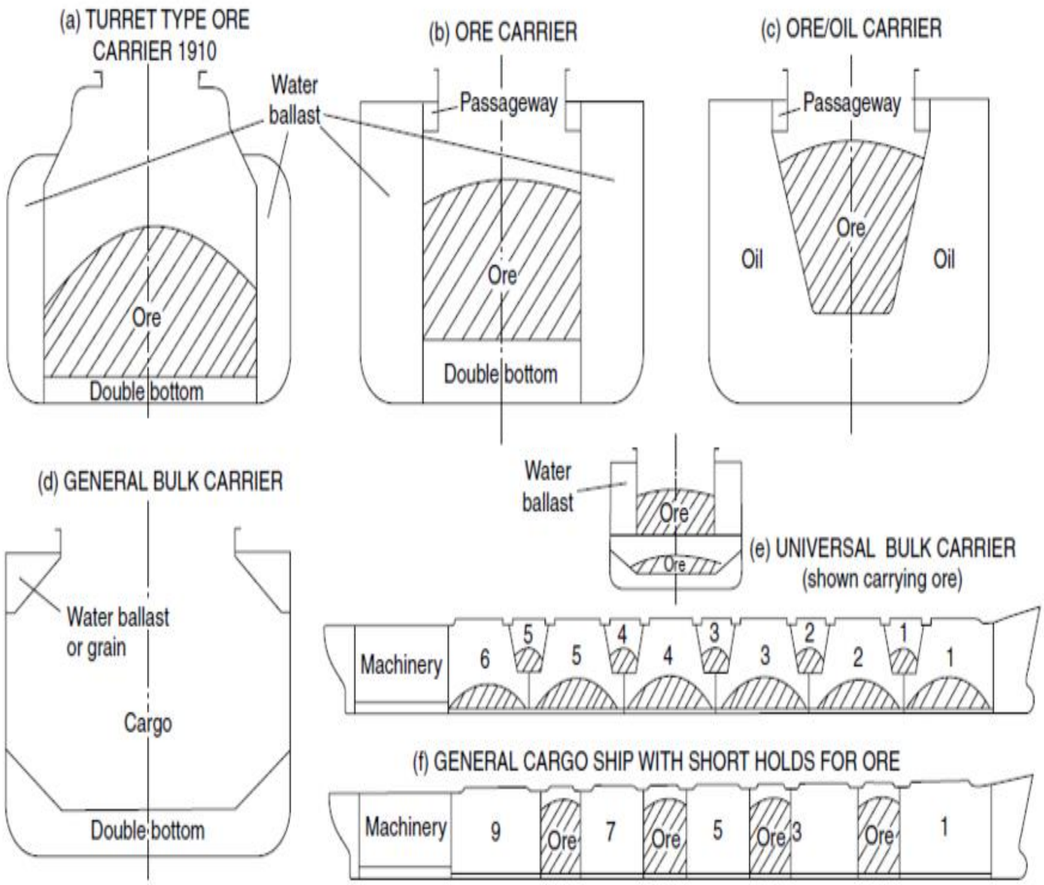


Figure 4.3 : Different type of ore carriers holds.[62]

Investigations on conventional bulk carriers 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. As shown below figure in 4.4 ore specialized ore carrier vessels' hold will have narrow cargo space. This will reduce GM, even if cargo liquefy during seaborne transportation will not effect the ships' stability and reduce the free surface effect obverse of present other bulk carrier vessels.

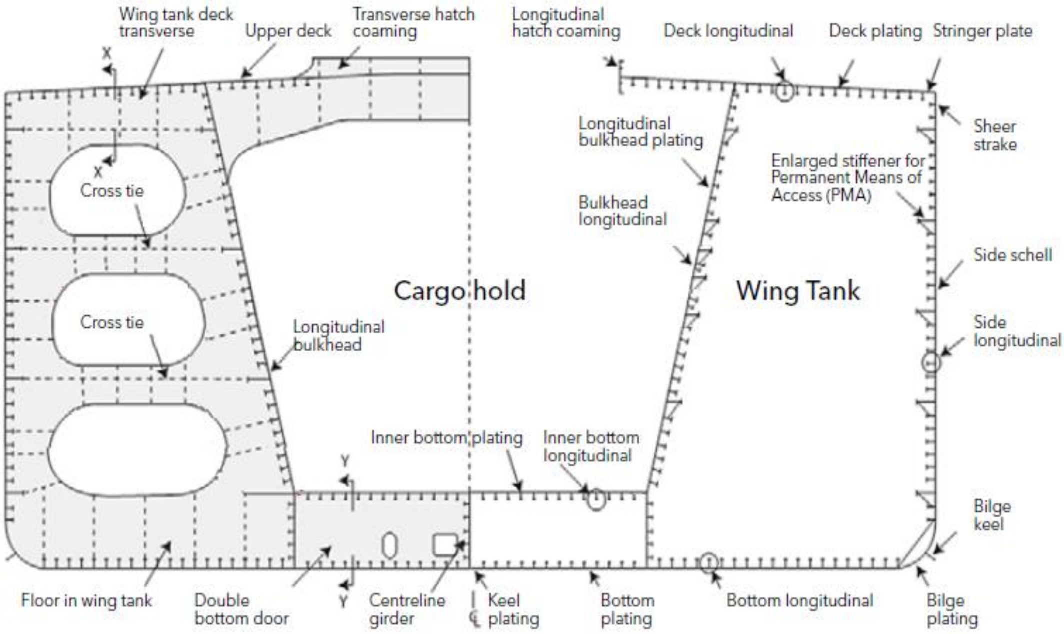


Figure 4.4 : New design ore carriers' hold plan[63]

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. Despite of all these, carry liquefy ore cargoes essential on specialized ore carrier vessels to prevent loss of lives.

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Company	Vessel	Type	DWT	Rank	Duration
Safi Holding	Arif Amca	General Cargo	11082	Chf Off	2 months
Armador Shipping	CS Cihan	General Cargo	8700	Chf Off	5 months
Armador Shipping	Vatan L	General Cargo	9700	Chf Off	5 months
Harren & Partner	Hanse Explorer	Super Yatch	50 m	Chf Off	4 months
Harren & Partner	CFS Pacora	Container	12000	Chf Off	4 months
Armador Shipping	CS Cihan	General Cargo	8700	Chf Off	6 months
Turkon Lines	Selma Kalkavan	Container	12000	2nd Off	3 months
Turkon Lines	Fürth	Container	12000	2nd Off	3 months
Turkon Lines	Serap K	Container	12000	2nd Off	6 months
Yasa Hold.	Yasa H Mulla	Bulk Carrier	52000	2nd Off	6 months
Nemtas A.S.	Karşıyaka	Bulk Carrier	47000	3rd Off	7 months
Nemtas A.S.	Nemtas 1	Bulk Carrier	52000	3rd Off	6 months
Nemtas A.S.	Nemtas 1	Bulk Carrier	52000	Deck Cadet	7 months
Mes Line	Captain Zaman	Passenger	1200 passenger & 300 vehicles	Deck Cadet	7 months