Guide for the Design and Operation of Liquefied Natural Gas (LNG) Carriers

Effective from 1 January 2016

Emirates Classification Society (Tasneef)
Aldar HQ 19th Floor,
Al Raha Beach, Abu Dhabi, UAE
Abu Dhabi, United Arab Emirates

Phone (+971) 2 692 2333
Fax (+971) 2 445 433
P.O. Box. 111155
info@tasneef.ae

GENERAL CONDITIONS

Definitions:

"*Administration*" means the Government of the State whose flag the Ship is entitled to fly or under whose authority the Ship is authorized to operate in the specific case.

"IACS" means the International Association of Classification Societies.

"*Interested Party*" means the party, other than the Society, having an interest in or responsibility for the Ship, product, plant or system subject to classification or certification (such as the owner of the Ship and his representatives, the ship builder, the engine builder or the supplier of parts to be tested) who requests the Services or on whose behalf the Services are requested.

"*Owner*" means the registered owner, the ship owner, the manager or any other party with the responsibility, legally or contractually, to keep the ship seaworthy or in service, having particular regard to the provisions relating to the maintenance of class laid down in Part A, Chapter 2 of the Rules for the Classification of Ships or in the corresponding rules indicated in the specific Rules.

"Rules" in these General Conditions means the documents below issued by the Society:

- (i) Rules for the Classification of Ships or other special units;
- (ii) Complementary Rules containing the requirements for product, plant, system and other certification or containing the requirements for the assignment of additional class notations;
- (iii) Rules for the application of statutory rules, containing the rules to perform the duties delegated by Administrations;
- (iv) Guides to carry out particular activities connected with Services;
- (v) Any other technical document, as for example rule variations or interpretations.

"*Services*" means the activities described in Article 1 below, rendered by the Society upon request made by or on behalf of the Interested Party.

"Ship" means ships, boats, craft and other special units, as for example offshore structures, floating units and underwater craft.

"*Society*" or *"TASNEEF"* means Tasneef and/or all the companies in the Tasneef Group which provide the Services.

"*Surveyor*" means technical staff acting on behalf of the Society in performing the Services.

Article 1

1.1. The purpose of the Society is, among others, the classification and certification of ships and the certification of their parts and components. In particular, the Society:

- (i) sets forth and develops Rules;
- (ii) publishes the Register of Ships;
- (iii) issues certificates, statements and reports based on its survey activities.

1.2. The Society also takes part in the implementation of national and international rules and standards as delegated by various Governments.

1.3. The Society carries out technical assistance activities on request and provides special services outside the scope of classification, which are regulated by these general conditions, unless expressly excluded in the particular contract.

Article 2

2.1. The Rules developed by the Society reflect the level of its technical knowledge at the time they are published. Therefore, the Society, although committed also through its research and development services to continuous updating of the Rules, does not guarantee the Rules meet state-of-the-art science and technology at the time of publication or that they meet the Society's or others' subsequent technical developments.

2.2. The Interested Party is required to know the Rules on the basis of which the Services are provided. With particular reference to Classification Services, special attention is to be given to the Rules concerning class suspension, withdrawal and reinstatement. In case of doubt or inaccuracy, the Interested Party is to promptly contact the Society for clarification.
The Rules for Classification of Ships are published on the Society's website: www.tasneef.ae.

2.3. The Society exercises due care and skill:

- (i) in the selection of its Surveyors
- (ii) in the performance of its Services, taking into account the level of its technical knowledge at the time the Services are performed.

2.4. Surveys conducted by the Society include, but are not limited to, visual inspection and non-destructive testing. Unless otherwise required, surveys are conducted through sampling techniques and do not consist of comprehensive verification or monitoring of the Ship or of the items subject to certification. The surveys and checks made by the Society on board ship do not necessarily require the constant and continuous presence of the Surveyor. The Society may also commission laboratory testing, underwater inspection and other checks carried out by and under the responsibility of qualified service suppliers. Survey practices and procedures are selected by the Society based on its experience and knowledge and according to generally accepted technical standards in the sector.

Article 3

3.1. The class assigned to a Ship, like the reports, statements, certificates or any other document or information issued by the Society, reflects the opinion of the Society concerning compliance, at the time the Service is provided, of the Ship or product subject to certification, with the applicable Rules (given the intended use and within the relevant time frame).
The Society is under no obligation to make statements or provide information about elements or facts which are not part of the specific scope of the Service requested by the Interested Party or on its behalf.

3.2. No report, statement, notation on a plan, review, Certificate of Classification, document or information issued or given as part of the Services provided by the Society shall have any legal effect or implication other than a representation that, on the basis of the checks made by the Society, the Ship, structure, materials, equipment, machinery or any other item covered by such document or information meet the Rules. Any such document is issued solely for the use of the Society, its committees and clients or other duly authorised bodies and for no other purpose. Therefore, the Society cannot be held liable for any act made or document issued by other parties on the basis of the statements or information given by the Society. The validity, application, meaning and interpretation of a Certificate of Classification, or any other document or information issued by the Society in connection with its Services, is governed by the Rules of the Society, which is the sole subject entitled to make such interpretation. Any disagreement on technical matters between the Interested Party and the Surveyor in the carrying out of his functions shall be raised in writing as soon as possible with the Society, which will settle any divergence of opinion or dispute.

3.3. The classification of a Ship, or the issuance of a certificate or other document connected with classification or certificate on and in general with the performance of Services by the Society shall have the validity conferred upon it by the Rules of the Society at the time of the assignment of class or issuance of the certificate; in no case shall it amount to a statement or warranty of seaworthiness, structural integrity, quality or fitness for a particular purpose or service of any Ship, structure, material, equipment or machinery inspected or tested by the Society.

3.4. Any document issued by the Society in relation to its activities reflects the condition of the Ship or the subject of certification or other activity at the time of the check.

3.5. The Rules, surveys and activities performed by the Society, reports, certificates and other documents issued by the Society are in no way intended to replace the duties and responsibilities of other parties such as Governments, designers, ship builders, manufacturers, repairers, suppliers, contractors or sub-contractors, Owners, operators, charterers, underwriters, sellers or intended buyers of a Ship or other product or system surveyed.

These documents and activities do not relieve such parties from any fulfilment, warranty, responsibility, duty or obligation (also of a contractual nature) expressed or implied or in any case incumbent on them, nor do they confer on such parties any right, claim or cause of action against the Society. With particular regard to the duties of the ship Owner, the Services undertaken by the Society do not relieve the Owner of his duty to ensure proper maintenance of the Ship and ensure seaworthiness at all times. Likewise, the Rules, surveys performed, reports, certificates and other documents issued by the Society are intended neither to guarantee the buyers of the Ship, its components or any other surveyed or certified item, nor to relieve the seller of the duties arising out of the law or the contract, regarding the quality, commercial value or characteristics of the item which is the subject of transaction.

In no case, therefore, shall the Society assume the obligations incumbent upon the above-mentioned parties, even when it is consulted in connection with matters not covered by its Rules or other documents.

In consideration of the above, the Interested Party undertakes to relieve and hold harmless the Society from any third party claim, as well as from any liability in relation to the latter concerning the Services rendered.

Insofar as they are not expressly provided for in these General Conditions, the duties and responsibilities of the Owner and Interested Parties with respect to the services rendered by the Society are described in the Rules applicable to the specific Service rendered.

Article 4

4.1. Any request for the Society's Services shall be submitted in writing and signed by or on behalf of the Interested Party. Such a request will be considered irrevocable as soon as received by the Society and shall entail acceptance by the applicant of all relevant requirements of the Rules, including these General Conditions. Upon acceptance of the written request by the Society, a contract between the Society and the Interested Party is entered into, which is regulated by the present General Conditions.

4.2. In consideration of the Services rendered by the Society, the Interested Party and the person requesting the service shall be jointly liable for the payment of the relevant fees, even if the service is not concluded for any cause not pertaining to the Society. In the latter case, the Society shall not be held liable for non-fulfilment or partial fulfilment of the Services requested. In the event of late payment, interest at the legal current rate increased by 1.5% may be demanded.

4.3. The contract for the classification of a Ship or for other Services may be terminated and any certificates revoked at the request of one of the parties, subject to at least 30 days' notice to be given in writing. Failure to pay, even in part, the fees due for Services carried out by the Society will entitle the Society to immediately terminate the contract and suspend the Services.

For every termination of the contract, the fees for the activities performed until the time of the termination shall be owed to the Society as well as the expenses incurred in view of activities already programmed; this is without prejudice to the right to compensation due to the Society as a consequence of the termination.

With particular reference to Ship classification and certification, unless decided otherwise by the Society, termination of the contract implies that the assignment of class to a Ship is withheld or, if already assigned, that it is suspended or withdrawn; any statutory certificates issued by the Society will be withdrawn in those cases where provided for by agreements between the Society and the flag State.

Article 5

5.1. In providing the Services, as well as other correlated information or advice, the Society, its Surveyors, servants or agents operate with due diligence for the proper execution of the activity. However, considering the nature of the activities performed (see art. 2.4), it is not possible to guarantee absolute accuracy, correctness and completeness of any information or advice supplied. Express and implied warranties are specifically disclaimed.

Therefore, except as provided for in paragraph 5.2 below, and also in the case of activities carried out by delegation of Governments, neither the Society nor any of its Surveyors will be liable for any loss, damage or expense of whatever nature sustained by any person, in tort or in contract, derived from carrying out the Services.

5.2. Notwithstanding the provisions in paragraph 5.1 above, should any user of the Society's Services prove that he has suffered a loss or damage due to any negligent act or omission of the Society, its Surveyors, servants or agents, then the Society will pay compensation to such person for his proved loss, up to, but not exceeding, five times the amount of the fees charged for the specific services, information or opinions from which the loss or damage derives or, if no fee has been charged, a maximum of AED5,000 (Arab Emirates Dirhams Five Thousand only). Where the fees charged are related to a number of Services, the amount of the fees will be apportioned for the purpose of the calculation of the maximum compensation, by reference to the estimated time involved in the performance of the Service from which the damage or loss derives. Any liability for indirect or consequential loss, damage or expense is specifically excluded. In any case, irrespective of the amount of the fees charged, the maximum damages payable by the Society will not be more than AED5,000,000 (Arab Emirates Dirhams Five Millions only). Payment of compensation under this paragraph will not entail any admission of responsibility and/or liability by the Society and will be made without prejudice to the disclaimer clause contained in paragraph 5.1 above.

5.3. Any claim for loss or damage of whatever nature by virtue of the provisions set forth herein shall be made to the Society in writing, within the shorter of the following periods: (i) THREE (3) MONTHS from the date on which the Services were performed, or (ii) THREE (3) MONTHS from the date on which the damage was discovered. Failure to comply with the above deadline will constitute an absolute bar to the pursuit of such a claim against the Society.

Article 6

6.1. These General Conditions shall be governed by and construed in accordance with United Arab Emirates (UAE) law, and any dispute arising from or in connection with the Rules or with the Services of the Society, including any issues concerning responsibility, liability or limitations of liability of the Society, shall be determined in accordance with UAE law. The courts of the Dubai International Financial Centre (DIFC) shall have exclusive jurisdiction in relation to any claim or dispute which may arise out of or in connection with the Rules or with the Services of the Society.

6.2. However,

(i) In cases where neither the claim nor any counterclaim exceeds the sum of AED300,000 (Arab Emirates Dirhams Three Hundred Thousand) the dispute shall be referred to the jurisdiction of the DIFC Small Claims Tribunal; and

(ii) for disputes concerning non-payment of the fees and/or expenses due to the Society for services, the Society shall have the right to submit any claim to the jurisdiction of the Courts of the place where the registered or operating office of the Interested Party or of the applicant who requested the Service is located.

In the case of actions taken against the Society by a third party before a public Court, the Society shall also have the right to summon the Interested Party or the subject who requested the Service before that Court, in order to be relieved and held harmless according to art. 3.5 above.

Article 7

7.1. All plans, specifications, documents and information provided by, issued by, or made known to the Society, in connection with the performance of its Services, will be treated as confidential and will not be made available to any other party other than the Owner without authorization of the Interested Party, except as provided for or required by any applicable international, European or domestic legislation, Charter or other IACS resolutions, or order from a competent authority. Information about the status and validity of class and statutory certificates, including transfers, changes, suspensions, withdrawals of class, recommendations/conditions of class, operating conditions or restrictions issued against classed ships and other related information, as may be required, may be published on the website or released by other means, without the prior consent of the Interested Party.

Information about the status and validity of other certificates and statements may also be published on the website or released by other means, without the prior consent of the Interested Party.

7.2. Notwithstanding the general duty of confidentiality owed by the Society to its clients in clause 7.1 above, the Society's clients hereby accept that the Society may participate in the IACS Early Warning System which requires each Classification Society to provide other involved Classification Societies with relevant technical information on serious hull structural and engineering systems failures, as defined in the IACS Early Warning System (but not including any drawings relating to the ship which may be the specific property of another party), to enable such useful information to be shared and used to facilitate the proper working of the IACS Early Warning System. The Society will provide its clients with written details of such information sent to the involved Classification Societies.

7.3. In the event of transfer of class, addition of a second class or withdrawal from a double/dual class, the Interested Party undertakes to provide or to permit the Society to provide the other Classification Society with all building plans and drawings, certificates, documents and information relevant to the classed unit, including its history file, as the other Classification Society may require for the purpose of classification in compliance with the applicable legislation and relative IACS Procedure. It is the Owner's duty to ensure that, whenever required, the consent of the builder is obtained with regard to the provision of plans and drawings to the new Society, either by way of appropriate stipulation in the building contract or by other agreement.

In the event that the ownership of the ship, product or system subject to certification is transferred to a new subject, the latter shall have the right to access all pertinent drawings, specifications, documents or information issued by the Society or which has come to the knowledge of the Society while carrying out its Services, even if related to a period prior to transfer of ownership.

Article 8

8.1. Should any part of these General Conditions be declared invalid, this will not affect the validity of the remaining provisions.

TABLE OF CONTENTS

1 INTRODUCTION

1.1 General

Traditionally LNG Carriers have been owned and operated as part of an LNG project. Changes in the expansion of many existing projects, and the set up of many new projects means that there is a growing market for charter tonnage. In many cases these are long-term charters 20 years, but there is also a growing spot market. This Guide is primarily intended for the technical staff of ship owners or independent consultants, in charge of management and supervision of new LNG construction projects, specification development or maintenance and operation of LNG ships in service. The purpose of this Guide is to identify the main factors that are likely to be of principal concern regarding the design and specification of any new building project. The Guide also highlights the relevant class services offered by Tasneef.

The construction and operation of LNG's has historically been limited to a relatively small number of companies and the development of LNG's design has been linked to operational experience and project requirements. In many cases this development is in addition to regulatory requirements and may not have been fed back into the relevant international codes. Building a LNG without a full understanding of the impact of these additional requirements may result in problems in service with operation, reliability, service life and acceptability. One key element of success of LNG projects has been reliability and therefore redundancy and maintainability, which need to be incorporated into the design.

Due to the expected life of many of these projects and the fact that the vessels are one of the financial assets of the project, like the land based plants, the vessels have been designed and constructed using principles of longevity, ease of maintenance and up-grade-ability. This is borne out by the fact that many LNG's still in service are 30+ years old and operating safely and efficiently with original containment and hull but with new machinery and control systems.

LNG carriers are generally built for an unspecified design life and many of the items in this guide contain the results of current in service experience. Advice to owners when drawing up the specification of new building orders is also given.

The LNG business has also traditionally been very conservative opting for reliability and proven designs, this is why the vast majority of the world LNG is of traditional design with steam turbine propulsion systems. However, alternative propulsion systems and cargo handling arrangements are being proposed and introduced into the industry. This guide also explores some of these alternatives in order to allow the readers to make a considered judgment when developing the specification of a new LNG project.

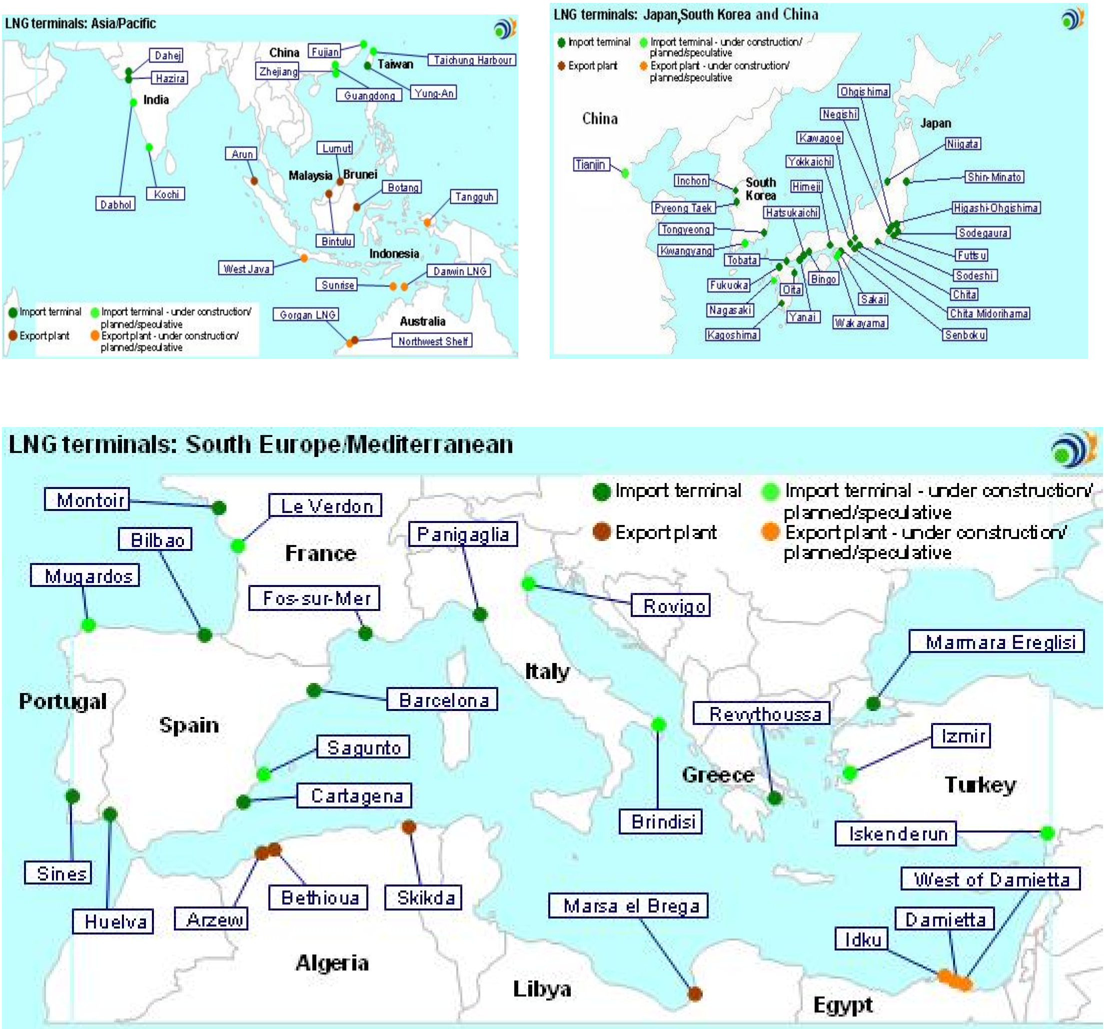
For more information on the history and development of LNG tankers, a good reference is in the Institute of Marine Engineering Science and Technology's paper "The development of Liquefied Natural Gas Carriers – a marine engineering success" by D. R. Cusdin.

1.2 LNG Trade & Fleet

The initial international trade routes for LNG were from Algeria to the UK and Europe and some to the USA. With the discovery of North Sea Gas the trade to the UK stopped, however the trade to Europe continued. With the decline in North Sea Gas and the need for cleaner fuels in the USA the trades to the UK and USA are expanding with Nigeria also becoming a major exporter. The requirements of the UK and USA are one of the drivers for the new and much larger vessels on order from projects like Qatar.

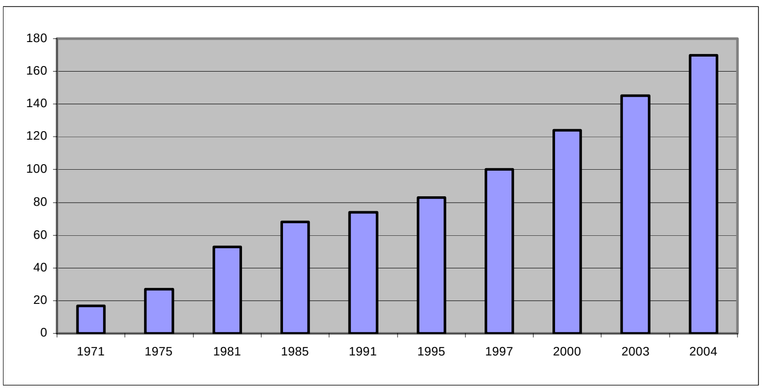
In the Far East Japan has traditionally been one of the biggest importers of LNG from Brunei, Malaysia, Indonesia, Australia and Alaska. Korea, Taiwan and more recently China are also importers.

Figure 1.1: LNG Terminals



The trade in LNG is expanding with Russia, Egypt, Venezuela, India among the countries with plans for LNG in the future. This expansion can be seen in the growth of the world fleet of LNG vessels over the last decade, which has doubled. Currently however there are many LNG vessels sat idle waiting the start up of these projects.

Figure 1.2: LNG Fleet Growth (member of ships)



The size of vessels has also increased with vessels recently delivered over 140,000 m^3, and orders for vessels up to 200,000 m^3 placed with shipyards.

Figure 1.3: Average ship size (m^3)

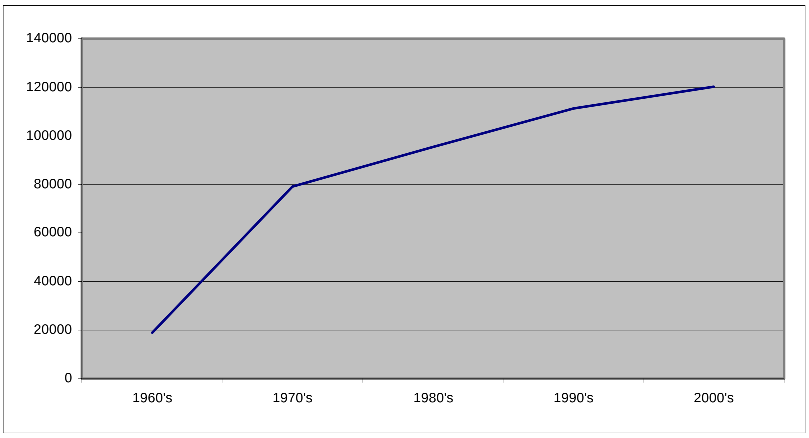
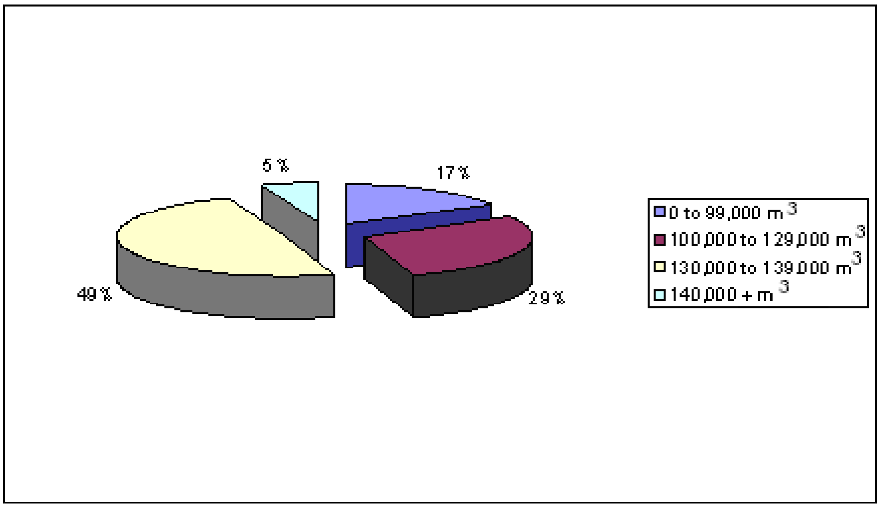


Figure 1.4: Current Fleet Size



1.3 Liquefied Natural Gas

When natural gas is cooled to –162°C at atmospheric pressure it condenses to a liquid called LNG, which is only 45% the weight of fresh water and occupies 1/600 the volume of the gas. It is odourless, colourless, non-corrosive, non-toxic and dielectric. Its composition is mostly methane (at least 90%) plus propane, butane, ethane and heavier hydrocarbons but also small quantities of nitrogen, oxygen, carbon dioxide, sulphur compounds and water. High sulphur content (greater than 30 ppm) may have negative impact on the behaviour of the cargo containment material as INVAR. Liquefying removes oxygen, carbon dioxide, sulphur compounds and water.

Tank insulation will not keep LNG cold by itself and LNG is stored as a “boiling cryogen”, that is, it is a very cold liquid at its boiling point for the storage pressure.

LNG is analogous to boiling water, only 260°C colder, the temperature of boiling water does not change – even with increased heat – as it is cooled by steam evaporation from its surface. In the same way, LNG will stay at near constant temperature if kept at constant pressure. This process is known as *auto refrigeration***.**

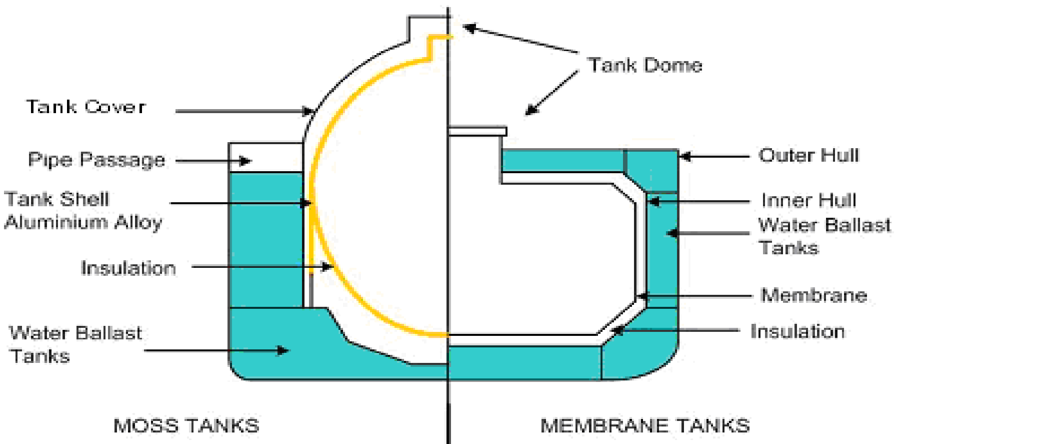
As long as the steam (LNG vapour boil-off) is allowed to leave the kettle (Cargo tank) the temperature will remain constant. If the vapour is not drawn off, the pressure and temperature inside the tank will rise however, even at a pressure of 0,7 N/mm^2 , the temperature will still only be –129°C.

1.4 Containment Systems

There are currently five containment system designs used for new buildings, and designers are working on new ones (Figure 1.5). Three of the designs, Gaz Transport, Technigaz and combined Gaz Transport/Technigaz meet the IGC Code membrane type requirement for double barrier. The other two designs, Moss Rosenberg and IHI use self-supporting tanks which meet the IGC Code Type B requirement of a single barrier, for which it can be demonstrated by failure mode analysis that there can be no catastrophic failure of the containment system.

Suitable care is taken to limit heat ingress through insulation discontinuities , in particular in way of supports; e.g. the Moss tanks foresee an insert of a stainless steel having thermal conductivity lower than aluminium in the supporting skirt.

Figure 1.5: Containment Systems: Main Design Features



MOSS TANKS	MEMBRANE TANKS
Tank :- Heavy rigid metallic High material & fabrication costs	Tank :- Specialised, light construction High material & fabrication costs
Tank capacity 125,000m^3 Ship tank material weight: 4000 tons	Tank capacity 125,000m^3 Ship tank material weight: 400 tons
Insulation : non load bearing relatively cheap	Insulation: rigid load bearing over whole surface high expensive, close to the whole cost of the tank

1.4.1 Spherical

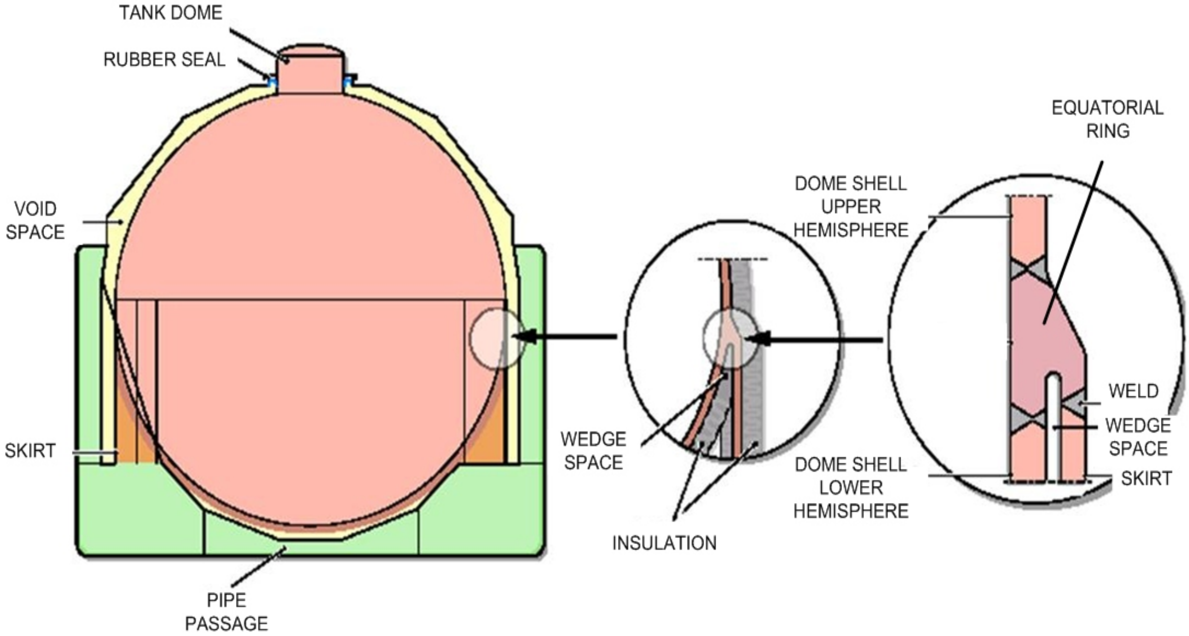
1.4.1.1 Moss Rosenberg

This containment system is supported by cylindrical skirt at equator, allowing deflection to limit bending forces in the tank shell.

The main design features are:

- No secondary barrier - only drip tray
- Self - supporting aluminium sphere (thickness from 30-169mm, weight about 900t)
- Satisfies the 'leak before failure' concept by enabling the leak from a tank to be detected and corrective action taken before a catastrophic failure
- Insulation - PUF foam

Figure 1.6: Spherical: Moss Rosenberg



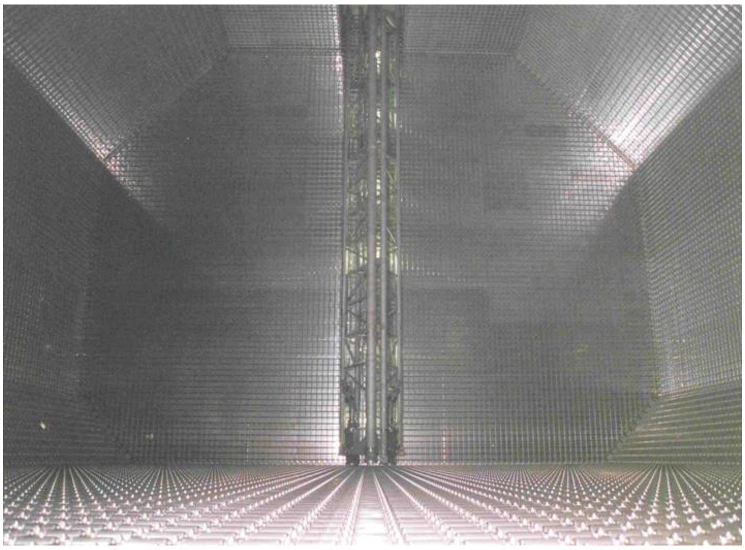
1.4.2 Membrane

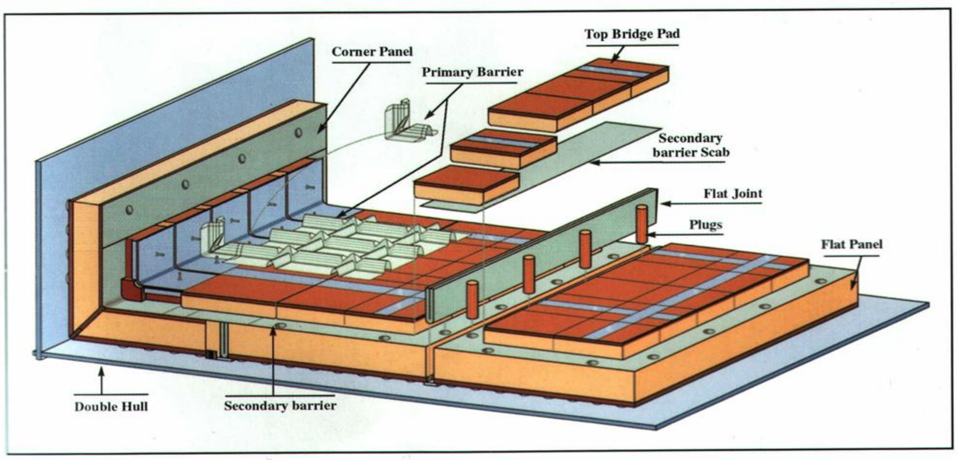
1.4.2.1 Technigaz (Mk III)

The main features of this containment system, made by orthogonal corrugations low carbon stainless steel, are:

- 1.2 mm thick stainless steel ‘waffle’ membrane
- Corrugations absorb the thermal contraction and ship movement stress
- Fibreglass insulation within balsa wood panels bounded by plywood sheets Mk I system (balsa wood now replaced by PVC/PUF foam sections Mk III system)
- Inner balsa wood or ‘Triplex’ laminate provides secondary barrier
- Corrugations and insulation spaces kept inert in service
- Suspended tower framework for pumps, piping etc.

Figure 1.7: Membrane: Technigaz type Mk III





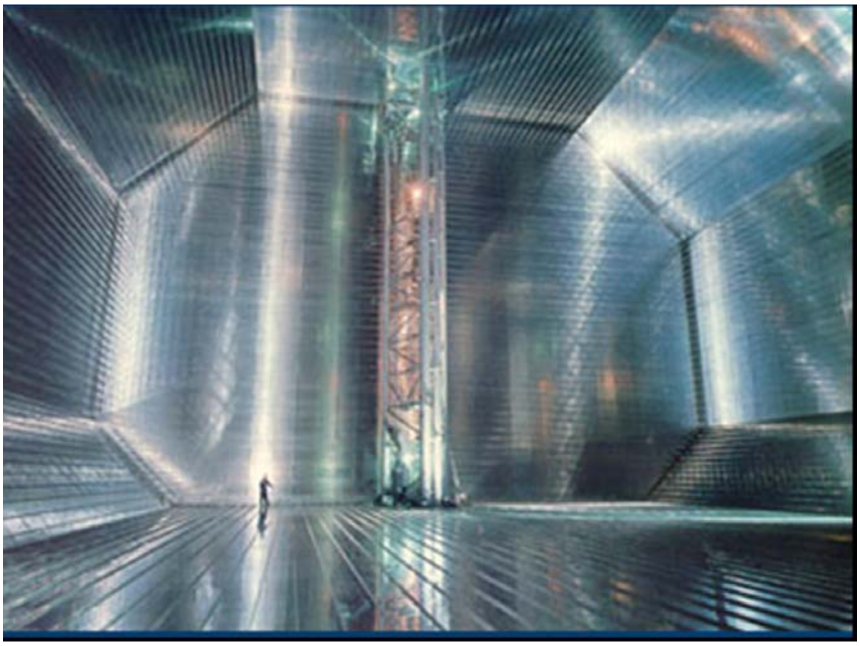
46. Drawing of the Technigaz Membrane Tank System. (GTT.)

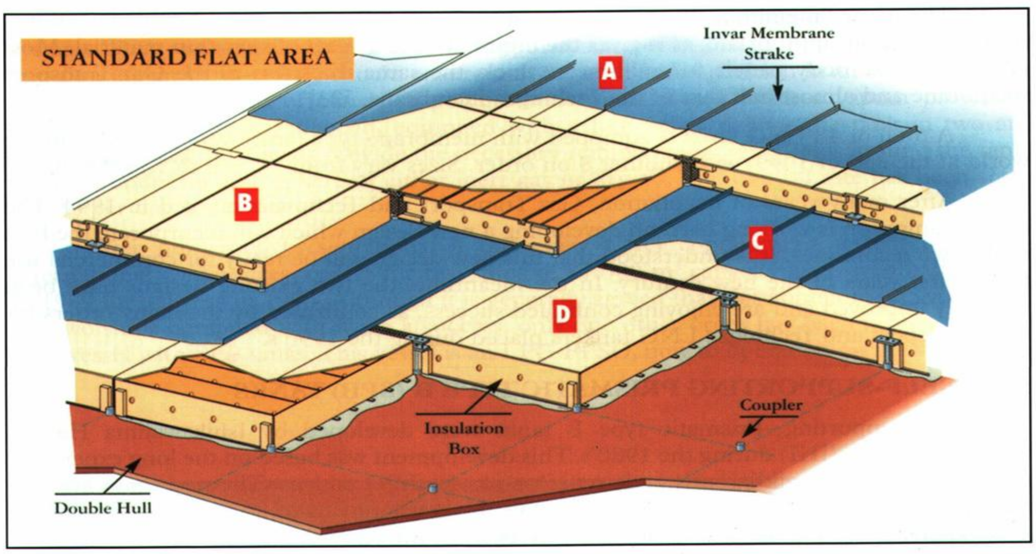
1.4.2.2 Gaz Transport (GT96)

The main features of this containment system, made by flat surface with ridges, are:

- Two 0.7 mm Invar membranes
- No need to compensate for thermal contraction
- Invar - iron-nickel alloy 63% Fe 36% Ni- very low thermal expansion coefficient
- Insulation consists of layers of plywood boxes filled with perlite
- Insulation spaces filled with inert gas in service
- Suspended tower framework for pumps, pipes etc.

Figure 1.8: Membrane: Gaz Transport type GT96





45. Drawing of the Gaz Transport Membrane Tank System. (GTT.)

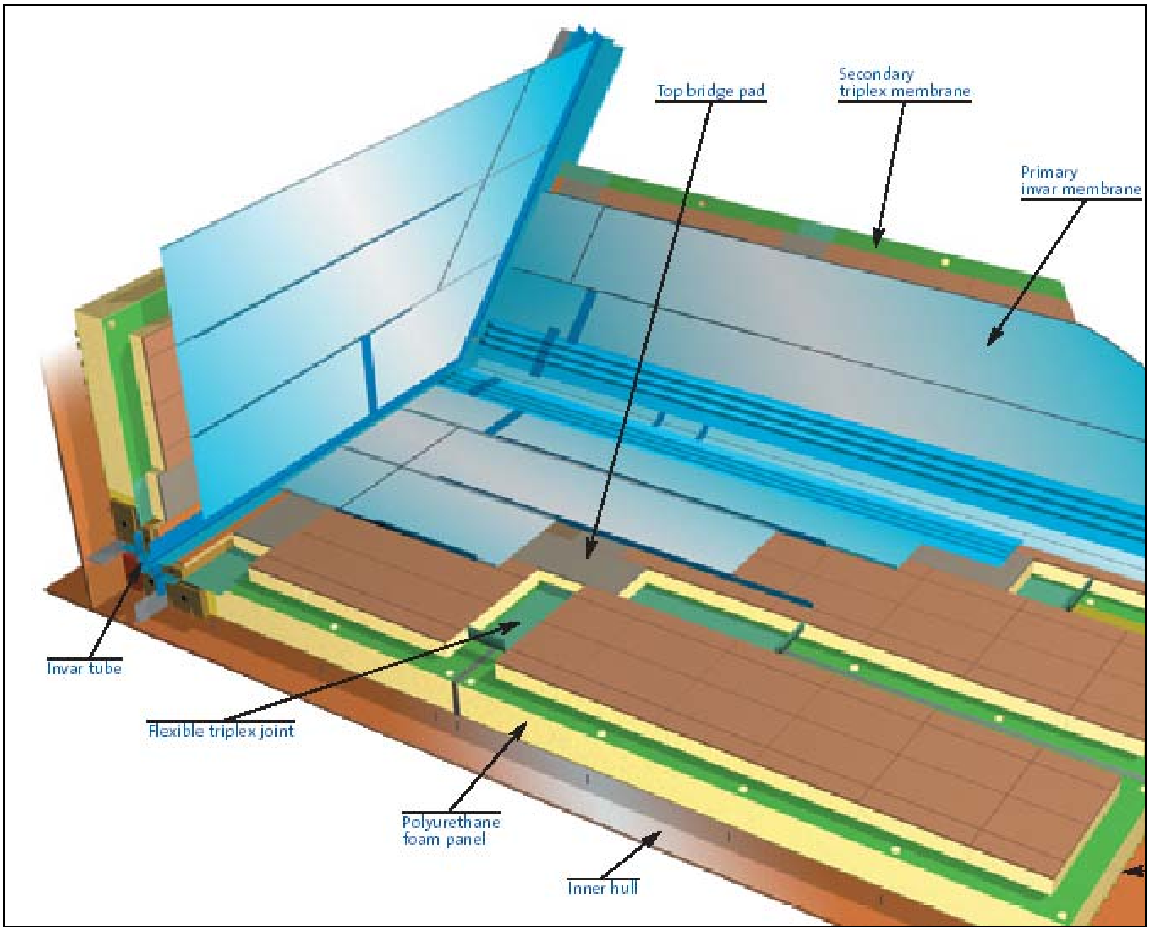
1.4.2.3 CS1

It is a combination of the two systems Mk III and GT96 described in the previous paragraphs.

The main features of this containment system, made by flat surface with ridges, are:

- One 0.7 mm Invar primary membrane (typycal of GT96 system)
- One triplex secondary barrier (typical of MkIII system). The triplex barrier is realised by means of an aluminium foil between two glass clothes and resin
- No need to compensate for thermal contraction
- Invar - iron-nickel alloy 63% Fe 36% Ni - very low thermal expansion coefficient
- Insulation consists of PVC/PUF foam panels
- Insulation spaces filled with inert gas in service
- Suspended tower framework for pumps, pipes etc.

Figure 1.9: Membrane: Gaz Transport Technigaz type CS1

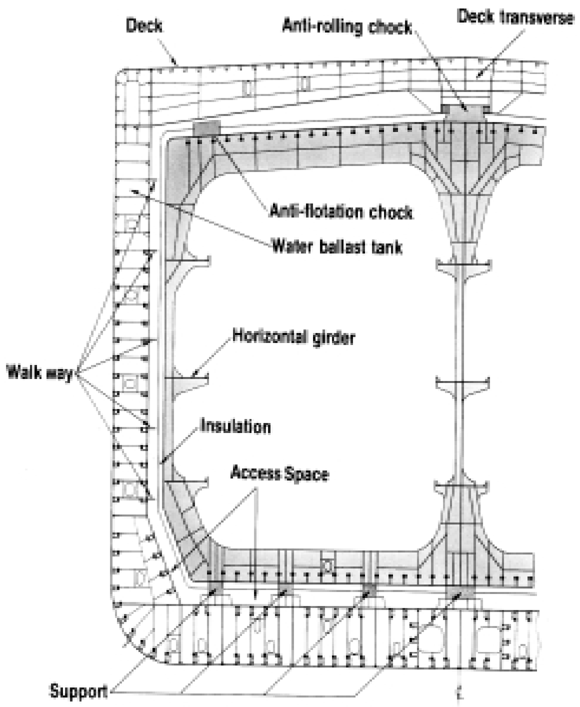


1.4.3 IHI

The main features of this containment system, developed by Ishikawajima-Harima Heavy Industries, are:

- Self-supporting IMO Type B
- Aluminium tanks meeting the leak before fail criteria
- Similar to the original Conch system fitted to the Methane Princess/Progress
- Insulation attached to the outside.

Figure 1.10: IHI

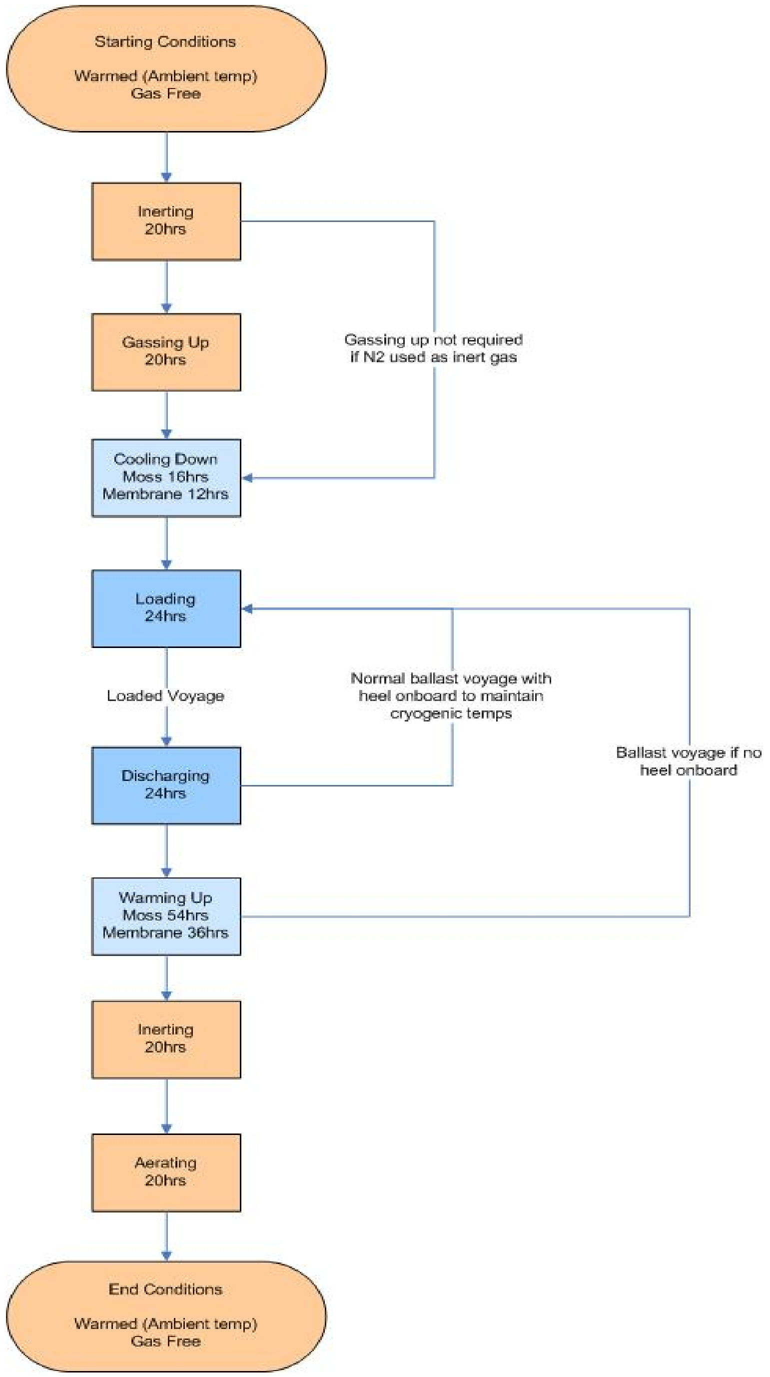


1.5 Operation

1.5.1 Flow-chart

The operations to be commonly considered for LNG are shown in the following flow-chart; the operating times for the various steps are quite different for the various cargo containment systems (membrane systems, Moss system, IHI system):

Figure1.11: LNG Operations



1.5.2 Inerting

Inerting means displace fresh air with dry inert gas:

- Carried out on passage if ship has its own IG generator
- Inerting can also be carried out by using an IG generator barge
- Ship will normally arrive at the loading port fully inerted.

1.5.3 Gassing up

At loading port, ship will take LNG liquid from shore at a slow rate:

- This is vaporised to form LNG vapour at about 5°C
- This vapour is pumped into the cargo tanks to slowly displace the inert gas.

This operation is not necessary if N2 is used as inert gas or if the ship, as usual, maintains on passage cargo tanks in N2 atmosphere

1.5.4 Cool down

Prior to loading cargo, the tanks are cooled down slowly by spraying LNG liquid from shore directly into tanks:

- This is necessary to avoid thermal stresses and excess rise in tank pressure due to flash evaporation during bulk loading
- Tank cool down guidelines must be strictly adhered to – cooling down faster than design will damage membranes/spheres
- An average rate would be 10°C per hour, allowing complete cool down in approx. 12 to 16 hours.

1.5.5 Loading

The loading of cargo includes the following phases:

- Gauging
- Line cooling then bulk loading
- Topping off
- Gauging.

1.5.6 Discharging

The discharging of cargo includes the following phases:

- Gauging
- Line cooling then bulk discharge
- Possible stripping
- Gauging.

1.5.7 Warming up

The following phase is about:

- Heel out at discharge port
- Warm tanks gradually with methane vapour, obtained by vaporising LNG left on board after discharge or with heated methane vapour re-circulated into the cargo tank until LNG is fully vaporized.
- Warmed gas usually burnt in ships boilers, or sent to shore if alongside a terminal.

1.5.8 Inerting

The following phase is about:

- Displace methane with dry inert gas.
- Gases passed through ships boilers or sent ashore
- Once methane content less than the acceptable limit forward mast riser may be used.

1.5.9 Aerating

Aerating is about displacing inert gas with dry fresh air.

2 HULL STRENGTH

2.1 General

The considerations in this chapter are based on the criteria for the design of hull structures in the Rules for the Classification of Ships and those in the IGC Codes relevant to the accessibility in the cargo area.

The structural analyses are usually to be carried out during two design phases:

Phase 1: Structural analysis of ship plating and ordinary stiffeners, carried out according to Rules criteria, considering the still water and wave loads induced by the sea and cargoes, and including the hull girder and local strength checks of structural elements versus yielding, buckling and ultimate strength. Phase 1 includes the evaluation of the fatigue life of the structural details, e.g. the connections between ordinary stiffener ends in way of transverse reinforced rings and transverse bulkheads. The effects of the wave induced local and hull girder loads, as well as those due to the relative deflection of the transverse reinforced structures, are to be taken into account.

Phase 2: Structural analysis of primary supporting members, carried out by means of FEM calculations, including a three-dimensional coarse mesh model of the cargo tanks and detailed three dimensional fine mesh models of typical transverse and longitudinal reinforced structures and of the structures in which the global analysis indicates significant stress levels or in localized areas for evaluating the fatigue life of the structural details, e.g. the connections between the various structural elements.

The structural analyses are to verify the following strength parameters:

- **Global strength** of the hull girder that is to be capable of sustaining the design still water and wave loads (bending moments and shear forces) acting in each ship's transverse section, taking into account stresses above the yielding limit and buckling behaviour of compressed elements. This hull girder ultimate strength is evaluated and compared with the extreme loads during the ship's life. In case of Moss Rosenberg containment system, the effects of large deck openings are to be taken into account with respect, in particular, to the possible torsional and warping behaviour and stress concentration in way of the openings corners.

- **Local strength** of structural elements (plating, ordinary stiffeners and primary supporting members) that is to be checked against the most severe combination of stresses due to the hull girder loads, internal pressures induced by the cargo or ballast carried and external sea pressures. In calculating the internal pressures, the inertia effects due to the ship motions are to be taken into account. Ship motions are also to be taken into account when calculating the wave induced sea pressures. The primary supporting members are to be analysed by means of Finite Element (FEM) calculations, taking into account the load distribution and structural interactions between the different elements. Sloshing effects are to be taken into account in the case of partial filling of the cargo tanks.

- **Fatigue life** of structural details, such as the connections between longitudinal ordinary stiffeners and transverse elements and the crossing between primary supporting members, is calculated by means of the Rules criteria and checked against the design values. For the connections between primary supporting members, the fatigue analysis can utilize the results of the FEM calculations.

An example of the application of the above strength check criteria to the design of a 65000 m^3 LNG Carrier, membrane type, is reported in Appendix.

2.2 Net scantling approach

According to the Rules, the local strength checks of plating, ordinary stiffeners and primary supporting members are to be carried out for their *net scantlings*, which means the scantlings that are necessary to sustain the loads acting on the structural elements, without any margin for corrosion. The thickness additions intended to provide the required margin for the corrosion expected during the ship's service, called *corrosion additions*, are then to be added to the net scantlings to obtain the minimum Rules' scantlings according to which the ship is built (Figure 2.1).

The values of the corrosion additions are defined in the Rules for any structural element as those relevant to one-side exposure in the compartment to which the element belongs or which it bounds. In such a way, the corrosive characteristics of the products intended to be transported and the influence of the specific location of each element within the compartment can be explicitly taken into account.

Figure 2.1: Net scantling approach

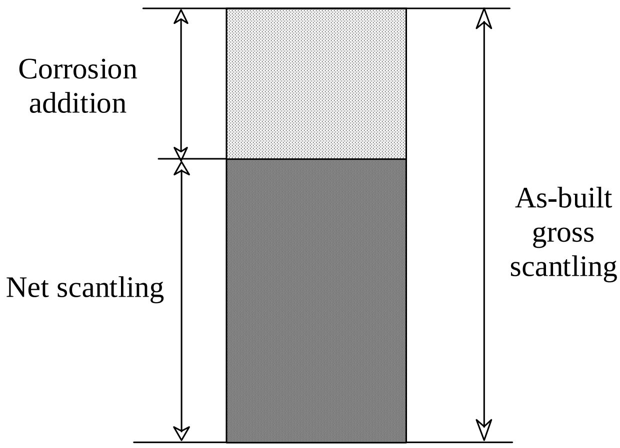


Table 2.1 reports the values of the one-side corrosion additions defined by the Rules (Pt B, Ch 4, Sec 2) for the types and destinations of compartments in LNG carriers. For each structural element, the total corrosion additions are obtained by summing up the one-side additions relevant to the two compartments separated by the element.

Greater values than those defined by the Rules may be adopted, when agreed between the Owner and the Shipyard. Furthermore, the net scantling approach allows the Owner's extras to be clearly identified and taken into account in the course of the class renewal surveys. As these extras do not impact on the strength checks, which are carried out on the basis of the net scantlings, any increase in thickness is 100% available as additional margin against corrosion.

Table 2.1: Rules corrosion additions, in mm, for one side exposure

Compartment type	*General* (1)	*Particular cases*
Ballast tank	1.0	1.25 in upper zone (2)
Cargo tank	0.0	(3)
Accommodation space	0.0	
Compartments other than those mentioned above Outside sea and air	0.5	
(1) General: the corrosion additions are applicable to all members of the considered item with possible exceptions given for upper zones. (2) Upper zone: area within 1,5 m below the top of the tank or the hold. This is not to be applied to ballast tank in double bottom. (3) The corrosion additions specified for the cargo tanks are to applied when requested by IGC Code, 4.5.2.		

2.3 Loading conditions

2.3.1 General

The values of the design still water bending moments and shear forces have great impact on the design of the vessel and consequences on the in-service operations. For these reasons, the loading conditions envisaged at the design stage should be adequately defined to include any possible conditions in which the ship will operate.

According to the Rules, the following loading conditions are at least to be considered:

- homogeneous loading conditions, with all the cargo tanks full, at the ship's scantling draught;
- partial loading conditions;
- ballast conditions;
- arrival and departure loading conditions.

2.3.2 Hull girder design still water bending moments

The design still water bending moment is to cover the envelope of the maximum still water bending moments calculated for the various ship's loading conditions, in order not to limit the ship's flexibility.

At this purpose, according to the Rules, it is considered that the absolute values of design still water bending moments, within 0,4 L amidships, should be taken, in kN·m, not less than:

hogging conditions: $M_{SW\,\min,H} = 15CL^2B\left(8 - C_B\right)10^{-3}$

sagging conditions: $M_{SW\,\min,S} = 60CL^2B\left(C_B + 0{,}7\right)10^{-3}$

C : wave parameter, defined in the Rules as:

$$C = 10{,}75 - \left(\frac{300 - L}{100}\right)^{1{,}5} \quad \text{for } 90 \text{ m} \le L < 300 \text{ m},$$

$$C = 10{,}75 \quad \text{for } 300 \text{ m} \le L \le 350 \text{ m},$$

$$C = 10{,}75 - \left(\frac{L - 350}{150}\right)^{1{,}5} \quad \text{for } L > 350 \text{ m}$$

L, B : Rules length and moulded breadth, in m,

C_B : block coefficient.

At the first design stage, when the still water bending moments are preliminary established, it is recommended be defined in excess by a suitable margin. The margin should range between 0% and 10%, depending on the amount and accuracy of the data available at the design stage and on the number of loading conditions that are considered when evaluating the design still water bending moment.

2.3.3 Partial loading conditions

Dealing with partial loading conditions, sloshing pressure on the plates of the membrane-type or independent LNG tanks deserves a particular consideration at design stage. The sloshing phenomenon is a result of the resonance between the liquid motion in partly filled LNG tanks and the tank motion that comes from the ship's rolling and pitching.

2.3.4 Fore peak tank

Due to its large lever arm, any accidental overfilling or under-filling, also of minor importance, could result into a large increase of the bending moment values, with a possible exceeding of the allowable values, due to the fore end location of the considered tank.

Based on these considerations, IACS has introduced the following requirements in UR S11, applicable to all types of ships:

"Ballast loading conditions involving partially filled peak and other ballast tanks at departure, arrival or during intermediate conditions are not permitted to be used as design conditions, unless design stress limits are satisfied for all filling levels between empty and full.

However, for the purpose of design, it will be acceptable if, in each condition at departure, arrival and any intermediate condition, the tanks intended to be partially filled are assumed to be empty and full."

It is to be noted that, in general, the maximum values of hogging bending moments occur when the ship is in ballast conditions. In these conditions, if the design still water bending moments were defined for a partially filled forepeak tank, a possible overfilling could result into an exceeding of the allowable hogging bending moment. It is also to be noted that, although the forepeak is the tank that maximizes the effects described above, the IACS UR-S11 not only refers to the forepeak tank, but to all ballast tanks.

It is also to be noted that these considerations are only made with respect to the strength aspects. As also recognised by the IACS UR-S11, partial filling of the fore peak tank and of the other ballast tanks is not outlawed and may be adopted, for example, to control the ship's trim, but the necessary precautions have to be taken at the design stage with respect to the hull strength.

2.4 Wave loads

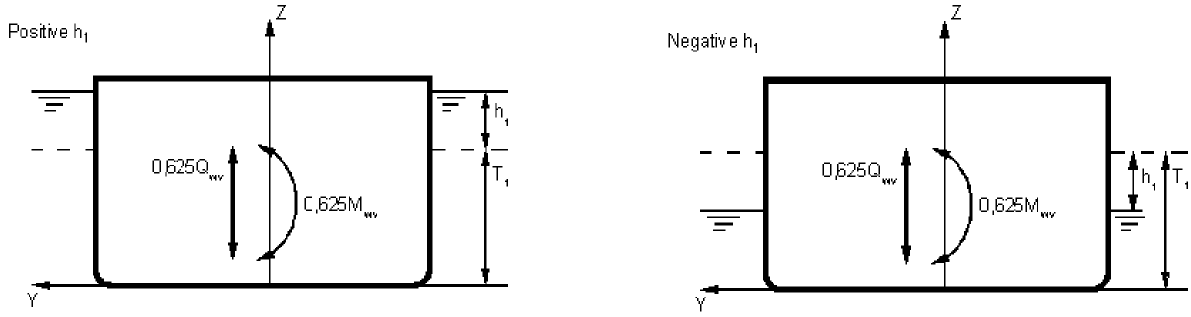
According to the Rules, the wave induced loads, constituted by the sea wave pressures and the inertial loads due to the ship's motion, have to be combined with the still water loads due to the cargo or ballast carried. Both the hull girder and the local loads are calculated by Rules' formulae that simulate the ship's response at sea through the input of her dimensions, hull forms and inertia characteristics.

The wave loads were combined in four load cases "a", "b", "c" and "d". Load cases "a" and "b" refer to the ship in "upright condition", the others in "inclined condition".

Upright ship conditions (see Figure 2.2 and Figure 2.3)

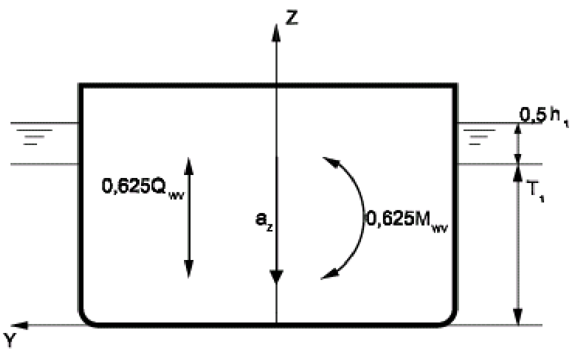
The ship is considered to encounter a wave that produces a relative motion of the sea waterline symmetric on the ship' sides, inducing wave vertical bending moments and shear forces in the hull girder. In load case "b" the wave is considered to induce also heave and pitch motions.

Figure 2.2: Upright ship conditions - Load case "a"



Wave Crest *Wave trough*

Figure 2.3: Upright ship conditions - Load case "b"

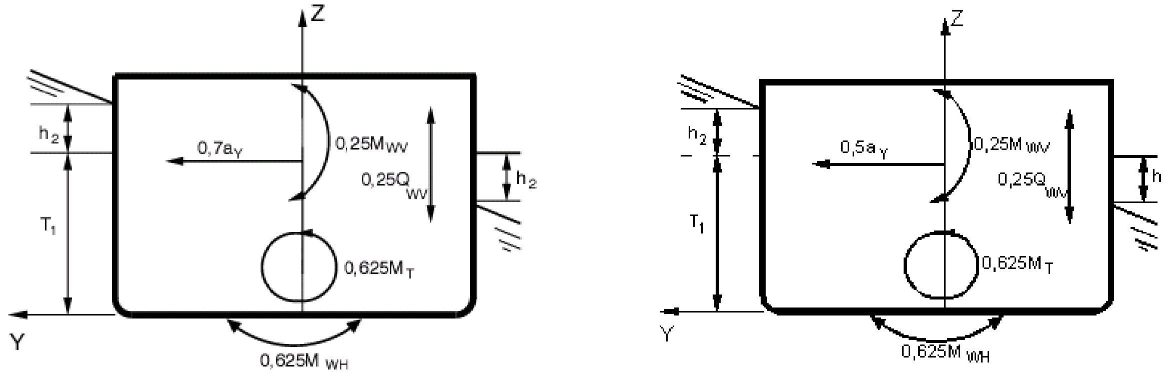


Inclined ship conditions (see Figure 2.4)

The ship is considered to encounter a wave that produces:

- sway, roll and yaw motions;
- a relative motion of the sea waterline anti-symmetric on the ship sides;
- vertical wave bending moment and shear force in the hull girder;
- horizontal wave bending moment in the hull girder;
- in load case "c", torque in the hull girder.

Figure 2.4: Inclined ship conditions, Load cases "c" and “d”



For each load case, the following loads are considered:

- still water loads:
  - hull girder loads,
  - hydrostatic sea pressure,
  - cargo liquid and ballast pressure;
- wave induced loads:
  - hull girder loads,
  - external pressure due to sea loads,
  - inertia pressure, induced on the liquid cargo by the ship’s acceleration.

The wave-induced loads are to be calculated for load cases “a”, “b”, “c” and “d”, on the basis of the following load parameters, relevant to upright and inclined ship conditions:

- Upright ship conditions (load cases “a” and “b”):
  - vertical relative motion h_1 of the waterline on the ship’s side, symmetrical,
  - longitudinal and vertical accelerations, a_{X1} and a_{Z1}.
- Inclined ship conditions (load cases “c” and “d”):
  - vertical relative motion h_2 of the waterline on the ship’s side, asymmetrical, transverse accelerations a_{Y2} at each compartment centre of gravity.

2.5 Rule strength checks

The Rules strength check criteria require the structural elements to be assessed by means of formulae, which represent the checking equations for plating, ordinary stiffeners and primary supporting members. The scantlings of primary supporting members are also to be verified by means of direct calculations and these latter checks may, in turn, affect the scantlings of plating and ordinary stiffeners that contribute to the strength of the primary structures.

With the exception of the hull girder yielding checks defined according to IACS UR's, the structural analysis is to be carried out by considering the net scantlings of each element, without any margin for corrosion, which is then to be added to the net scantlings to obtain the required as-built scantlings. The following strength check procedure is applied:

Figure 2.5: Strength check procedure

Data	Review	Results
Design still water bending moment and shear force at sea and in harbour	**OVERALL LONGITUDINAL STRENGTH** Checking of top, deck and bottom moduli Ultimate strength of the hull girder	Overall bending and shear stress (used for local strength)
Overall bending and shear stress Scantling draught and light ballast draught	**LOCAL STRENGTH PLATING AND ORDINARY STIFFENERS** Transverse sections Transverse bulkheads (all boundaries of compartments checked in full/empty conditions) Forward flat bottom reinforcement Aft and forward structures Engine room structure Superstructures	Thickness of plating Section area and modulus of stiffeners Dimensions and scantlings of brackets
Design loading distributions	**PRIMARY MEMBERS FRAMES, STRINGERS, FLOORS,...** Minimum dimensions from the Rules 3D beam or finite element analysis	Stresses & buckling
Highest loads transferred through the connection	**STRUCTURAL CONTINUITY** Continuity of strength and avoidance of abrupt structural changes Tapering of scantlings	Possible modification of connection design
Full load and ballast conditions	**FATIGUE** Fatigue analysis of longitudinal connections Fatigue analysis of primary members connections	Fatigue life of connection details

The process starts with the checks of the hull girder transverse sections subject to hull girder bending moments and shear forces.

The analysis of the hull girder transverse sections also allows calculating the normal and shear stresses assigned as an input to the analysis of plating, ordinary stiffeners and primary supporting members.

The compression normal stresses and the shear stresses induced by the hull girder loads are used, isolated or combined with those due to local loads, to check the buckling strength of the structural elements, such as, the deck longitudinal ordinary stiffeners, under the combined effect of compression stresses and local loads, by verifying that these effects do not exceed their ultimate strength.

Whilst for plating and ordinary stiffeners the required scantlings can be calculated by means of Rules' formulae, the analysis of primary supporting members can be exhaustively carried out on the basis of the Rules formulae only at a preliminary design stage, or where their arrangement is predominantly fitted in one direction. Such an arrangement is typically adopted for smaller ships. At this purpose, the Rules establish a length limit of 120 m, above which more accurate investigations, i.e. Finite Element (FE) analyses, are to be carried out.

2.6 Finite Element Analysis

The FE models to be used for the strength checks of primary supporting members are generally to extend in the longitudinal direction in way of three adjacent cargo holds, including the central one. Appropriate loads and constraints are applied at the model boundaries, so that the hull girder loads reproduce the bending moment values at the middle of the model and the shear force values in way of the aft bulkhead of the central hold.

The analysis is to address all the structural arrangements in the cargo hold central area. This means that, if the design contemplates different structural arrangements in this area, several FE models should be built in such a way that each arrangement is represented in the models.

In case of Moss Rosenberg or IHI containment systems, where independent cargo tanks are fitted, the structural models should represent the structure of the ship and the cargo containment system, as well as the relevant connection each other. The forces on the tanks are calculated taking into account the ship accelerations as defined in the IGC Code 4.12.

For normal typologies of LNG Carriers, no specific FE models should be created for the aft and fore cargo holds, as, due to the hull shapes, their structural arrangement is stronger than that of the central tank. This is generally true even if the sea pressures and the inertial loads increase towards the ship's ends. However, where the structural arrangements of the aft and fore cargo holds are significantly different from that of the central ones, specific FE models are to be created for these holds.

The geometric accuracy of the model and the level of mesh refinement depend on the strength check that is carried out. For yielding and buckling checks, the FE model should be such as to account for the influence on the stress level of major structural discontinuities. The level of refinement of these models is the fine mesh level, whose characteristics are specified in Pt B, Ch 7, App. 1 of the Rules.

In order to carry out the strength checks, it is not necessary that the whole three-cargo hold model is finely meshed. A procedure that is generally adopted consists in creating the three-cargo hold model with a coarser mesh, loading this model with the sea pressure and inertial loads, as well as the hull girder loads, and deriving from the solution of this model the nodal displacements to be used as boundary conditions for subsequent "fine mesh" analyses of more localised structural areas.

The advantage of this procedure is that the creation of the three-cargo hold model is less time consuming and needs less computer resources. The analysis of this model provides precise information on the most stressed areas, which deserve refined mesh analyses to be carried out in order to assess their structural capability with respect to the Rules criteria. However, some strength checks can also be carried out on the results of the coarse mesh model, provided that the level of geometric accuracy is such as not to alter the actual structural behaviour of the examined elements.

Various cargo and ballast conditions are to be considered to calculate the still water and wave induced loads acting on the FE models. These distributions should be defined in such a way that each one of them is the most critical for each structural area. The result envelope obtained for all the conditions considered allows examining the behaviour of the hull structures under the expected loads.

Figure 2.6: LNG Carrier

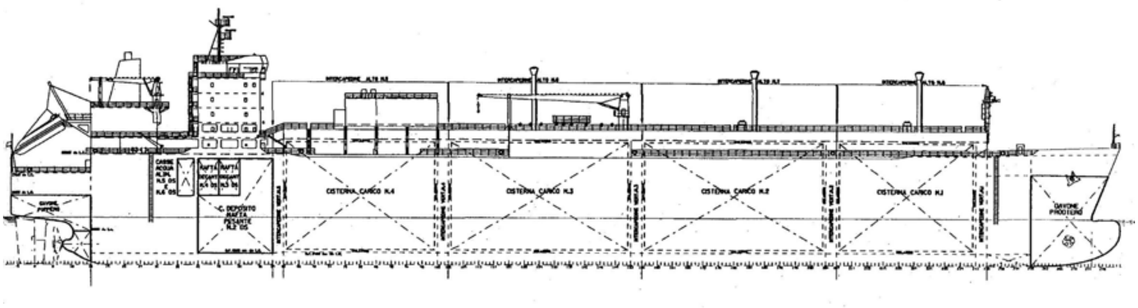
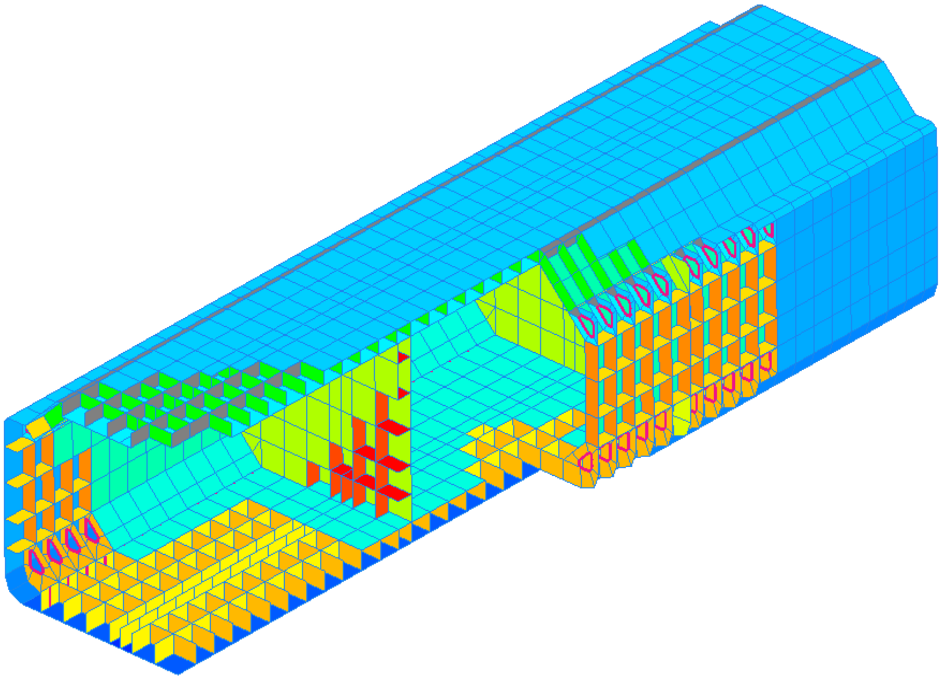


Figure 2.7 shows a typical coarse-mesh three-cargo hold model (for the LNG carrier used as a case study in Appendix).

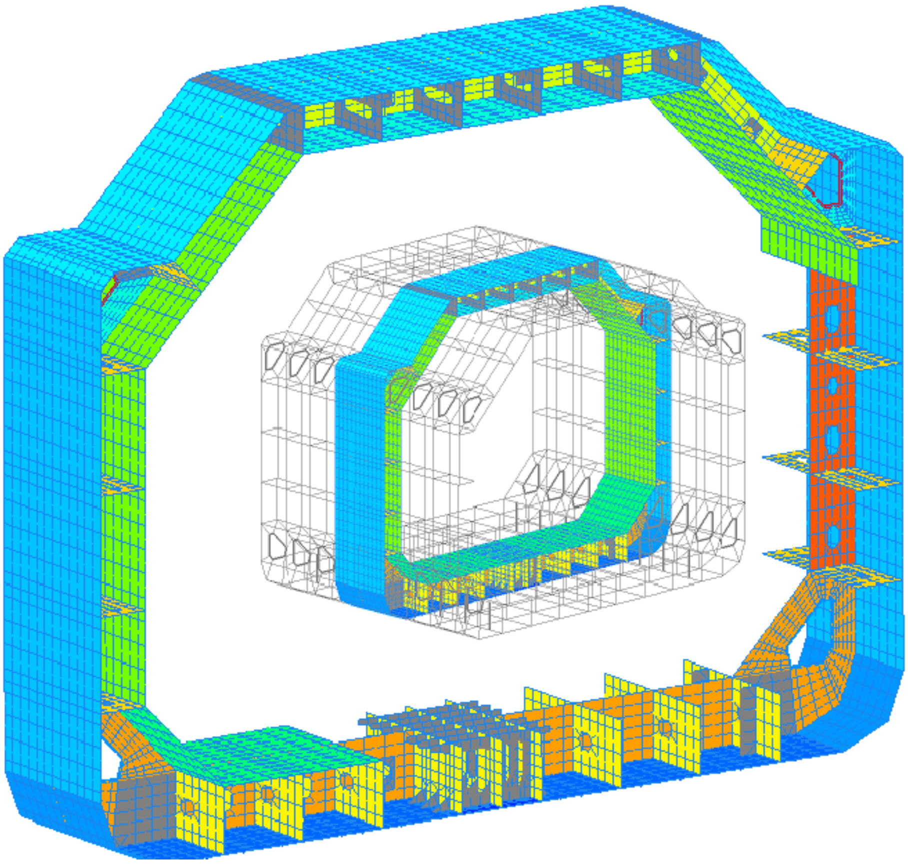
Figure 2.7: Coarse mesh - Finite Element three-cargo hold model



Typical areas of LNG carriers that need to be analysed on the basis of fine mesh models are:

- the transverse web frame ring (e.g. Figure 2.8), including manholes and other openings,
- the connection between side web frames and floors, where manholes are to be fitted for accessibility purposes,
- the structures of transverse bulkheads, whose arrangement depends on the type of ships,
- connections between hopper and top-side tanks with double side structure,
- connections between transverse bulkheads and double side structures.
- for Moss or IHI containment systems, the connections between the tank supports and the hull structures in way.

Figure 2.8: Fine mesh - Finite Element model of a transverse web frame ring



2.7 Fatigue Analysis

2.7.1 General

Fatigue, which may be defined as a process of cycle-by-cycle accumulation of damage in a structure subjected to fluctuating stresses, is one of the factors that mostly contribute to the structural failures observed on ships in service. Though fatigue cracking does not generally result in catastrophic failures, it is responsible for much costly ship repair work.

For welded structures, the fatigue process includes three main phases: initiation, propagation or crack growth and failure.

There are two different types of fatigue:

1. low-cycle fatigue occurring for a low number of cycles, less than $5 \cdot 10^3$, in the range of plastic deformations,
2. high-cycle fatigue occurring for a large number of cycles in the range of elastic deformations.

Fatigue on ship structures is generally of the second type.

There are many factors that affect the fatigue behaviour of ship structures, among others:

- the geometry of the members and weld details,
- materials and welding procedures,
- workmanship,

- loading conditions,
- sea conditions,
- environmental conditions.

The fatigue analysis of welded ship structures requires:

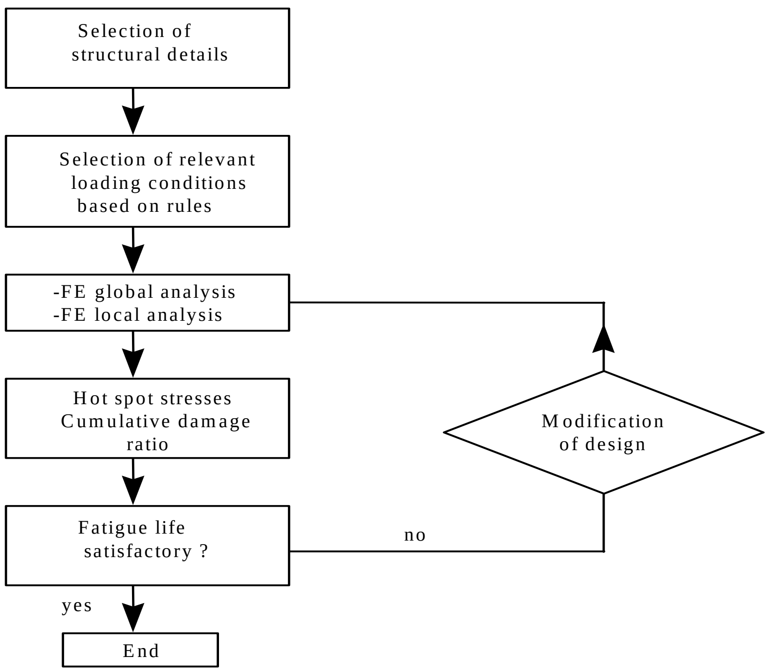
- to determine the demand characterized by the long term distribution of stresses resulting from the action of the various cyclic loads applied on the structure,
- to determine the fatigue capacity of the structure, characterized either by S-N curves or by the fatigue crack growth rate of the material,
- to select a design criterion above which the structure is considered as having failed.

2.7.2 Fatigue procedure

The fatigue analysis procedure described in Figure 2.9 is based on the following assumptions:

- 60% of lifetime in full load condition and the remaining 40% in ballast condition,
- sea conditions are evenly distributed between head seas and beam seas,
- North Atlantic sea state conditions.

Figure 2.9: Fatigue Analysis



2.7.3 Selection of structural elements subject to fatigue

The details to be covered by fatigue analyses (as defined in Pt B, Ch 12, Sec 2 of the Rules for LNG Carriers longer than 150 m) are the following:

1. connection of the longitudinal ordinary stiffeners of side and inner side with transverse primary supporting members (transverse bulkheads and web frames);
2. connection of bottom and inner bottom longitudinal ordinary stiffeners with floors, in double bottom in way of transverse bulkheads;

3. connection of inner bottom with transverse cofferdam bulkhead;
4. connection of inner bottom with hopper tank sloping plates;
5. connection of hopper tank sloping plates with inner side.

In case of Moss Rosenberg or IHI containment systems, where independent cargo tanks are fitted, fatigue strength checks should also be carried out in way of the connections between tank supports and hull primary supporting members.

The fatigue capacity of the above details, represented by their S-N curves, is checked against the long-term distribution of the stresses originated by the various cyclic loads acting on the detail. In general, these stresses are those due to the wave hull girder loads and those induced by the local wave loads. For the connections of side and inner side ordinary stiffeners with transverse bulkheads, the additional bending stresses due to the relative deflections between the transverse bulkheads and the adjacent web frames are also to be taken into account.

The structural models used for these analyses should be quite accurate in order to reproduce the structural behaviour in way of the discontinuity examined and, for this purpose, fine mesh models should be adopted.

The results of FE analyses can provide detailed information for identifying the stress concentration in a complex detail, which depends on the geometry and local scantlings that are to be adequate also with respect to the fatigue strength. This solution should guarantee the structural continuity, avoiding too high stress concentrations that originate from abrupt changes in the structural scantlings or from large modifications of the stress flows.

Different levels of accuracy can be adopted, depending on whether the hot spot stresses are directly obtained from the FE analysis or they are calculated by multiplying the nominal stresses, obtained through the analysis, by appropriate stress concentration factors. In this latter case, the same fine mesh level of refinement as for the buckling and yielding checks is adopted, while in the other case much more refined models should be created for the detail under examination.

2.7.4 Nominal stress procedure

The connection of longitudinal ordinary stiffeners with transverse primary members (web frames or transverse bulkheads) may be analysed by using a bi-dimensional model. In such a case, the calculation is based on a nominal stress procedure. It means that details of a standard library are used, and that relevant stress concentration factors are applied to the nominal stress. The relative displacements between the ends of the ordinary stiffener, due to the deformation of the transverse primary members (transverse bulkheads and transverse web frames), obtained from a Finite Element calculation, are normally to be taken into account in this analysis.

2.7.5 Hot spot stress procedure

Connections other than connections between longitudinal ordinary stiffeners with transverse primary members are normally analysed by using a hot spot stress procedure, in which the stress range is obtained by an analysis using a tri-dimensional Finite Element model.

2.7.6 Improvement of the fatigue life

When the calculated fatigue life is less than the required one, some measures are envisaged to improve the fatigue strength, by improving the design of structural details (generally by reducing the stress concentration factors) and by using improved workmanship methods during building. The following recommendations may be applied:

- systematic analysis of the fatigue life of structural details, by using a simplified nominal stress procedure;

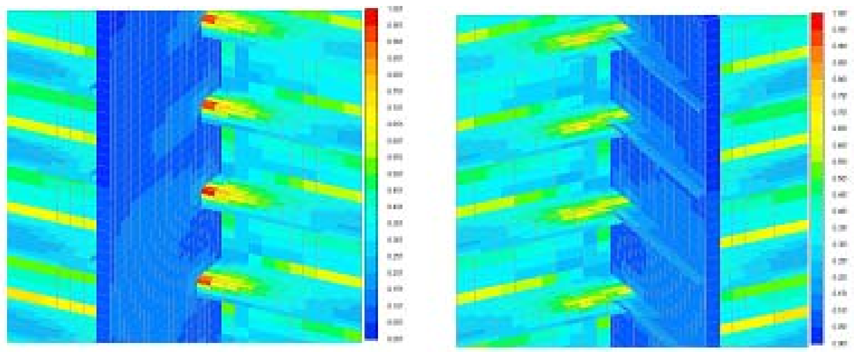
- identification of hot spots, and non-destructive examinations in way of these hot spots;
- improvement of quality control of welding and preparation (permissible misalignments);
- improvement of welding procedures and workmanship;
- modification of the weld geometry by grinding (the rounding of the weld geometry by grinding can increase the fatigue life of about 50%);
- introduction of compressive stresses, for example by hammer or shot peening;
- post weld heat treatment.

The most efficient way to improve the fatigue strength consists in improving the design of the detail. For the connections between longitudinal stiffeners and transverse primary members, the parameters that more effectively control the fatigue strength are:

- the location and the number of brackets (on one or both sides of the transverse primary member) and their dimensions,
- the shape (soft toes) of the flat bars and of the brackets that connect the longitudinal stiffener with the transverse primary member,
- the longitudinal stiffener profile (symmetrical or not).

As an example of the effect of brackets in the connection between longitudinal stiffeners and transverse primary members, Figure 2.10 shows the obtained reduction in stress concentration in such a detail with a bracket compared to a similar detail without bracket.

Figure 2.10: Reduction of stress concentration by means of brackets



2.8 Ultimate hull girder strength

In order to verify that the hull girder is capable to withstand the loads it is subjected to in normal operating conditions, the following longitudinal strength checks are to be carried out:

a) yielding checks, according to the criteria specified in Pt B, Ch 6, Sec 2 of the Rules, (i.e. based on the normal stresses σ and the shear stresses τ induced by the hull girder bending moments and shear forces and on the Rules defined allowable stresses), which account for the longitudinal strength in normal operations and intact conditions,

b) ultimate strength checks, both in sagging and hogging conditions, carried out assuming the following limiting criterion:

$$\frac{M_U}{\gamma_R \gamma_m} \geq \gamma_{W1} M_{WV}$$

In this formula, M_U is the hull girder ultimate strength, calculated according to the procedure in Pt B, Ch 6, Sec 3 of the Rules. M_{WV} is the applied wave bending moment, as defined in Pt B, Ch 6 of the Rules. γ_R, γ_m, γ_{W1} are the Partial Safety Factors defined by the Rules:

γ_{W1} = 1,15

γ_m = 1,02

γ_R = 1,08

2.9 Sloshing

2.9.1 General

Sloshing is the phenomenon caused by periodical motion of free liquid surfaces in tanks causing pressure peaks on their boundaries. This problem has become of particular interest in the design of LNG carriers to meet the request for shipping in partial cargo filling condition.

2.9.2 Rule based sloshing check

When tanks having a regular or usual shape, such as in the case of prismatic shells, are partly filled with liquid cargoes, the risk of resonance is evaluated on the basis of the criteria specified in the Rules. In particular when tanks are designed to be filled at a level d_F $0{,}1H \leq d_F \leq 0{,}95H$, where H is the height of the tanks, the risk of resonance is to be evaluated for the following motions:

- the pitch ship motion and the longitudinal motion of the liquid inside the tank, for upright ship condition, and
- the ship sway and roll motion and the transverse motion of the liquid inside the tank, for inclined ship condition.

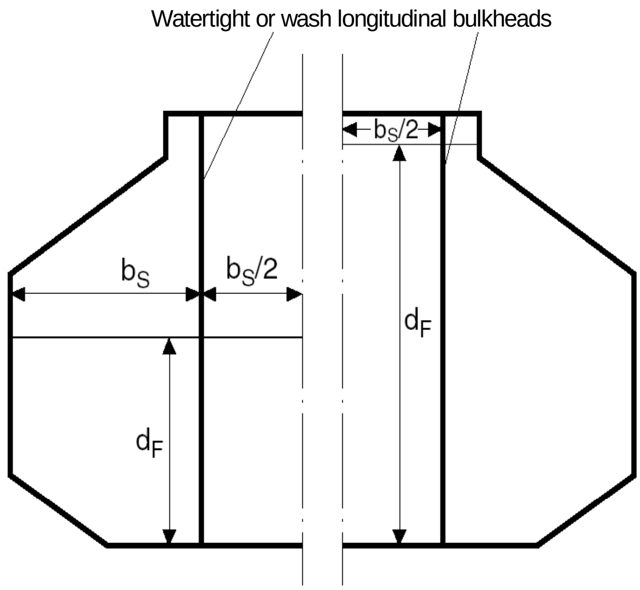
The sloshing pressures are calculated according to the formulae specified in the Rules.

Where there is a risk of resonance in upright ship condition, the sloshing pressure is considered as acting on the transverse bulkheads, which form tank boundaries. If wash transverse bulkheads are fitted, the sloshing pressure is considered as acting on them.

Where there is a risk of resonance in inclined ship condition, the sloshing pressure is considered as acting on the longitudinal bulkheads, inner sides or sides, which form tank boundaries.

In Figure 2.11 it is represented an example of tank design intended to reduce the sloshing pressure on the tank's boundaries, in the case of inclined ship condition, by reducing the free liquid surfaces.

Figure 2.11: Example of tank designed to reduce the sloshing pressures on its boundaries



It is important to highlight that, when there is a risk of resonance, in addition to the sloshing pressure described above, the impact pressure due to the liquid motion is to be considered.

Where there is a risk of resonance in upright condition, the impact pressure due to the liquid motions is considered as acting on:

- transverse bulkheads which form tank boundaries, in the area extended vertically 0,15 H from the tank top;
- the tank top in the area extended longitudinally $0{,}3\,\ell_C$ from the above transverse bulkheads, where ℓ_C is the longitudinal distance between transverse watertight bulkheads.

Where there is a risk of resonance in inclined ship condition, the impact pressure due to the liquid motions is considered as acting on:

- longitudinal bulkheads, inner side or side, which form tank boundaries, in the area extended vertically 0,15 H from the tank top;
- the tank top in the area extended transversally $0{,}3\,b_C$ from the above longitudinal bulkheads, where b_C is the transverse distance between longitudinal watertight bulkheads.

Specific formulae are reported in the Rules to calculate the impact pressure in the above areas.

Once the sloshing and impact pressures have been calculated, the tank scantlings are checked according to the formulae specified in the Rules.

2.9.3 Direct calculation of sloshing pressure

When the shape of the tanks is not regular or unusual, such as when partial wash bulkheads not extending to the tank top are fitted, a more detailed analysis should be carried out to determine the values of pressure acting on the tanks' boundaries. In these cases the sloshing pressures are generally calculated by means of a Finite Element Analysis, according to the following procedure:

1) *Generation of a model for the numerical calculations.* The model should be able to correctly reproduce the global behaviour of the fluid in the considered tank. Particular attention should be paid in the representation of the tank structure boundaries where baffles or obstacles are present which could influence the liquid motions. Dynamic impact loads can be determined by means of a fine mesh, optionally refined in the neighbour of the investigated area.
2) *Tank motions.* The motions imposed to the tank are the cause of sloshing actions, their consideration is therefore of primary importance when performing and analyzing sloshing calculations.
3) *Selection of calculation/test scenarios.* The evaluation of a calculation/test scenario is performed in a step-wise process. The succession of the following analyses leads to the generation of one or more complete sets of calculations or model tests (calculation/test scenarios) for the tank system under investigation:
    a. tanks arrangement on board ship;
    b. selection of the type of analysis (i.e. deterministic or statistical);
    c. initial assessment of the tank resonance frequency;
    d. evaluation of the resonance frequency for a tank configuration.
4) *Determination of the sloshing pressure.*
5) *Analysis of the results,* with particular care to considerations on the values of pressure to be used for structural calculations.

The above procedure is represented in the flow chart of Figure 2.12

Graphical representations of the main results obtained through direct calculation are reported in the examples of Figure 2.13 and Figure 2.14, where the pressure fields due to sloshing into the tanks are shown.

Once the pressure has been calculated as described above, the scantlings of the boundaries of the tanks subjected to sloshing effects are checked according to the formulae specified in the Rules.

Figure 2.12: Sloshing Finite Element Analysis procedure

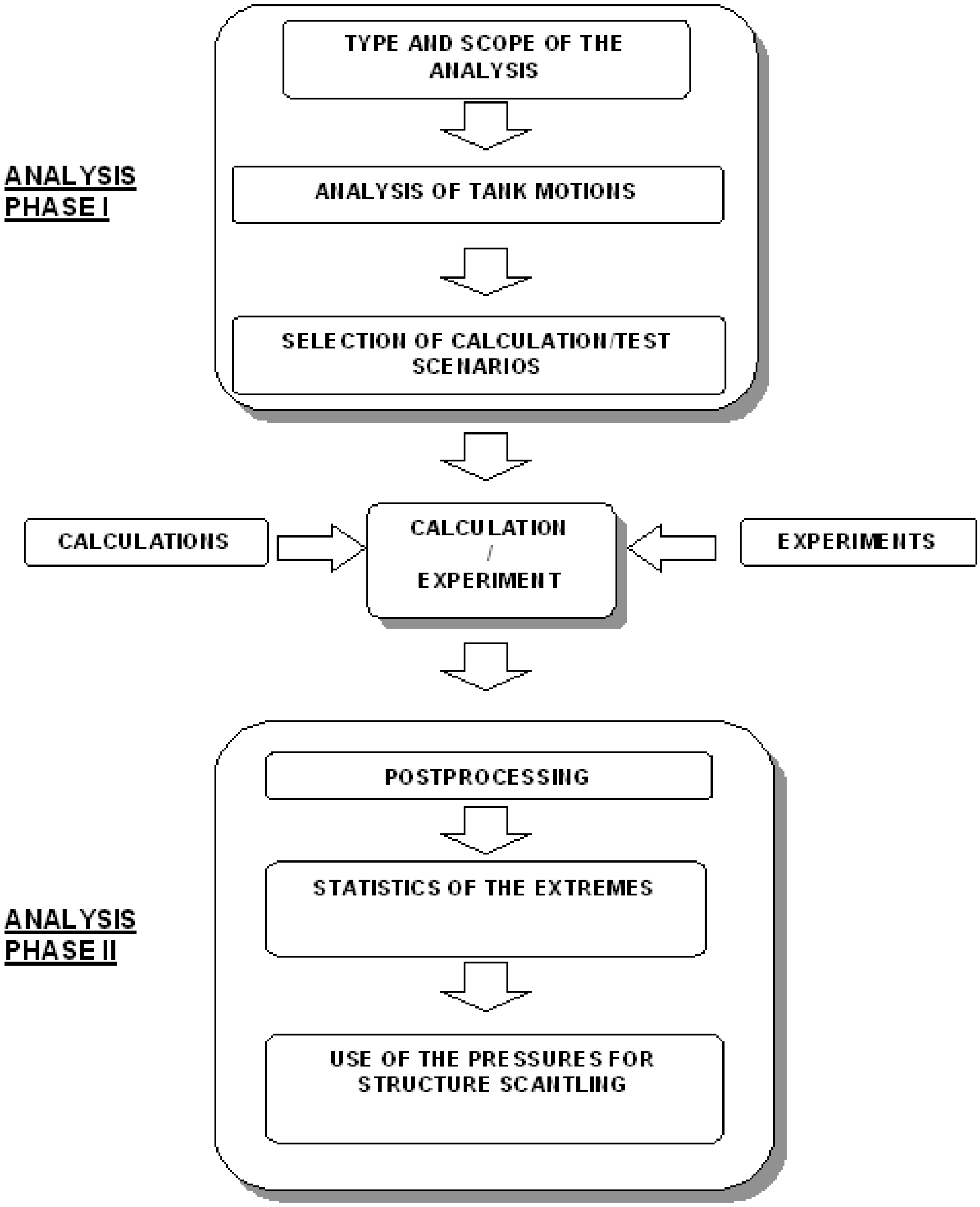


Figure 2.13: Example of 2D pressure and velocity field visualisation

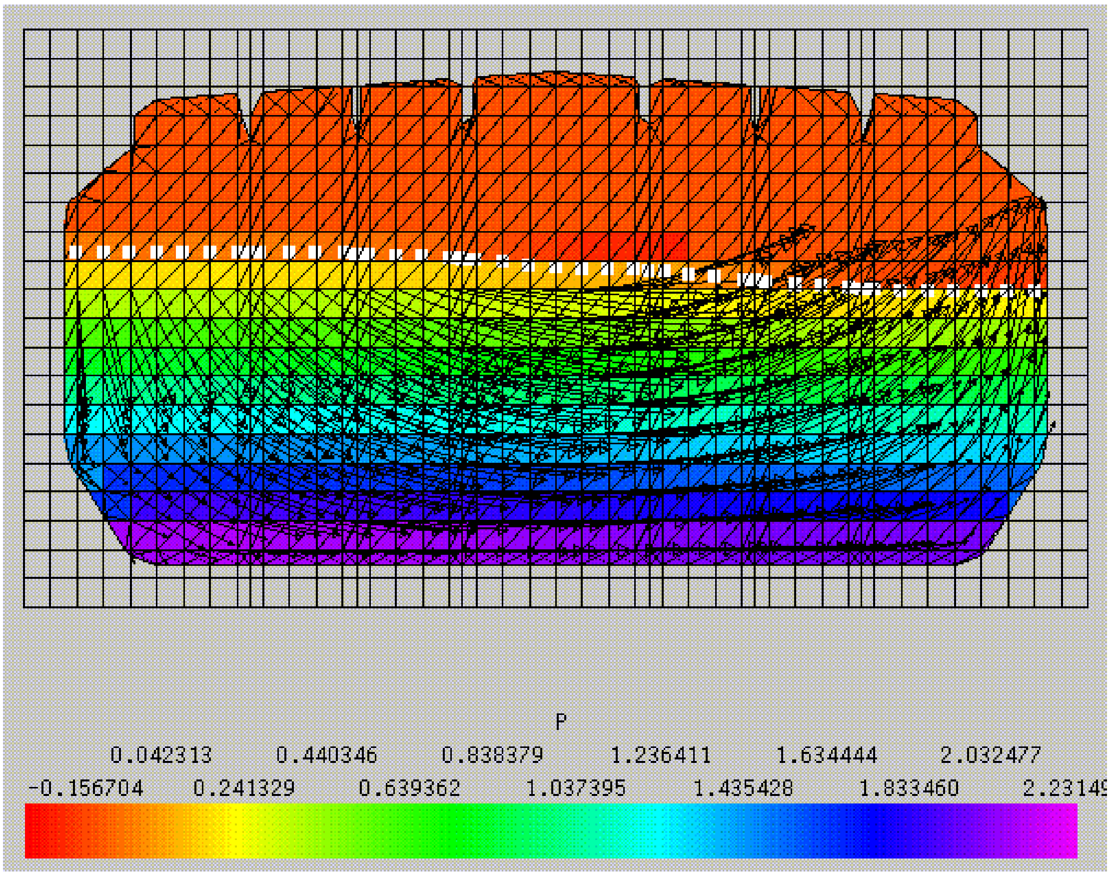
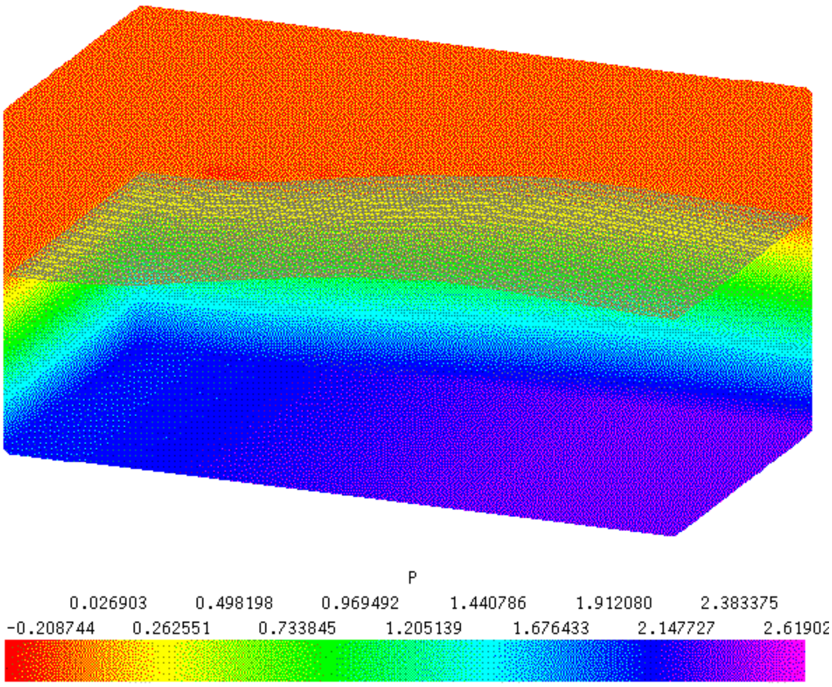


Figure 2.14: Example of 3D pressure field visualisation



2.10 Coating in water ballast tanks

2.10.1 Selection and specification

All dedicated seawater ballast tanks in double hull spaces should be protected by an efficient corrosion prevention system, such as hard protective coating or equivalent. The coatings should preferably be of a light colour. Where appropriate, sacrificial anodes may also be used. (Refer to SOLAS reg. II-1/A.1/3-2, which is compulsory for oil tankers and bulk carriers).

It is to be noted that bulb shaped reinforcing members would be better than L shaped ones in this respect.

In case of membrane cargo containment system it is necessary to take all the possible precaution to avoid the necessity, during the ship life, to renew hull plate as well as reinforcing members

The scheme for the selection, application and maintenance of the system should be based on the IMO Resolution A.798(19) and the Tasneef "Guide for the Selection, Application and Maintenance of Corrosion Systems of Ship's Ballast Tanks". Essentially, these guidelines recommend to:

- follow specifications, procedures and related working steps according to paint Manufacturer's recommendations;
- make known the coating specifications to all parties involved in the construction process;
- perform all work in accordance with the agreed specifications by skilled professionals in a safe and workmanlike manner;
- repair coating breakdowns in order to avoid premature decay and deterioration of the coating system;
- program and carry out periodic inspections on coating maintenance during the ship's service.

2.10.2 Coating performance standards

The coating specification should be such that to achieve the coating performance standards given in the Tanker Structure Cooperative Forum (TSCF) "Guidelines for Ballast Tank Coating Systems and Surface Preparation" for a target useful life of 15 years (see Table 2.2).

These standards, based on state-of-the-art information, are not meant to exclude alternative systems or innovative approaches that might be developed and applied in the future, provided that they ensure a performance at least equivalent.

However, in order to prevent premature decay and deterioration of the coating system, it is essential that specifications, procedures and steps followed in the coating application process are strictly applied by the shipbuilder, and that proper periodic coating inspection and regular maintenance during the ship life are carried out by the ship Owner.

TABLE 2.2

Coating System – 15-years Target Useful Life

Item	Requirement	References
Primary surface preparation: Blasting and profile Soluble salt limit	Sa 2½, 30-75 µm <30 mg/m²	ISO 8501, ISO 8503-1/3 ISO 8502-9
Pre-construction primer: Coating type	Ethyl-zinc-silicate	
Secondary surface preparation: Steel condition Pre-washing Salt limit before secondary S.P. Surface treatment After erection Profile requirements Salts after blasting/grinding Dust Abrasive inclusions	Preparation grade P2 Three pass edge grinding Recommended ≤ 30 mg/ m² Sa 2½ on damaged pre-construction primer and welds Sa 2 on intact pre-construction primer, removing 70% of primer Block holding primer acceptable Butts Sa2.5, damages St3 As coating requirement ≤ 30 mg/ m² “1” None as viewed without magnification	ISO 8501-3 Recognized standards ISO 8502-9 ISO 8503-1/3 ISO 8502-9 ISO 8502-3
Painting Requirements: Minimum surface temperature Coating pre-qualification testing Nominal thickness dry film Coating type Number of coats	As per paint Manufacturer’s advice Independent 300 µm dft minimum Light colour epoxy Minimum two full stripe coats followed by two full spray coats	+10°C recommended To be qualified by testing
Anodes: Zinc or Aluminium anodes	As per contract	Installed in accordance with the Rules

The following conditions should cause rejection:

1. excessive sags and runs. Isolated sags and runs, defined as 1 per each 100 m^2 maximum, is permissible
2. pinholes: none permissible
3. air bubbles or air bubble craters: none permissible
4. low DFT (dry film thickness): none permissible
5. too high DFT: none permissible (see sags and runs above for only exception)
6. blistering: non permissible
7. lifting or peeling: non permissible
8. insufficient dehumidification, heating and/or ventilation: none permissible
9. unsafe or poorly erected staging: not permissible
10. poor cleaning, presence of inclusions or invisible contamination in excess of the paint Specification: none permissible.

2.11 Means of access

2.11.1 General

Means of access are needed for the following purposes:

- inspection and maintenance carried out by ship personnel;
- overall and close-up surveys carried out by the Classification Society;
- thickness measurements.

Location and dimensions of permanent means of access, such as elevated passageways, ladders and manholes, are specified by IGC Code and the Rules.

The use of GRP materials is recommended for the passageways due to their corrosion resistant properties as well as cryogenic properties

In the following, the main recommendations for the means of access in cargo area including double hull spaces of LNG Carriers are reported.

2.11.2 Access to spaces in the cargo area

2.11.2.1 Spaces between independent cargo tanks and adjacent hull structures

For the purpose of the requirements in IGC Code 3.5.1 and 3.5.2 relevant to the access to spaces between independent cargo tanks and adjacent hull structures (e.g. Moss and IHI types), the following applies:

1. When the Surveyor needs to pass between the flat or curved surface to be inspected and structural elements such as deck beams, stiffeners, frames, girders etc., the distance between the surface and the free edge of the structural elements is to be at least 380 mm. The distance between the surface to be inspected and the surface to which the above structural elements are fitted, e.g. deck, bulkheads or shell, is to be at least 450 mm in the case of a curved tank surface, or 600 mm in the case of a flat tank surface (see Figure 2.15).
2. If for inspection of a curved surface the Surveyor needs to pass between that surface and another flat or curved surface, to which the structural elements are fitted, the distance between both surfaces is to be at least 380 mm (see Figure 2.16). Where the Surveyor does not need to pass between a curved surface and another surface, a smaller distance than 380 mm may be accepted taking into account the shape of the curved surface.
3. If for inspection of an approximately flat surface the Surveyor needs to pass between two approximately flat and approximately parallel surfaces, to which no structural elements are fitted, the distance between those surfaces is to be at least 600 mm (see Figure 2.17).
4. The minimum distance between a cargo tank sump and adjacent double bottom structure in way of a suction well may not be less than that defined in Figure 2.18. If there is no suction well, the distance between the cargo tank sump and the inner bottom may not be less than 50 mm.

Figure 2.15: Minimum passage over cargo tanks

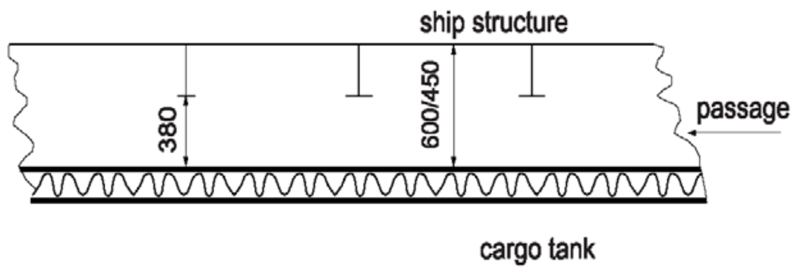


Figure 2.16: Minimum passage between curved surfaces

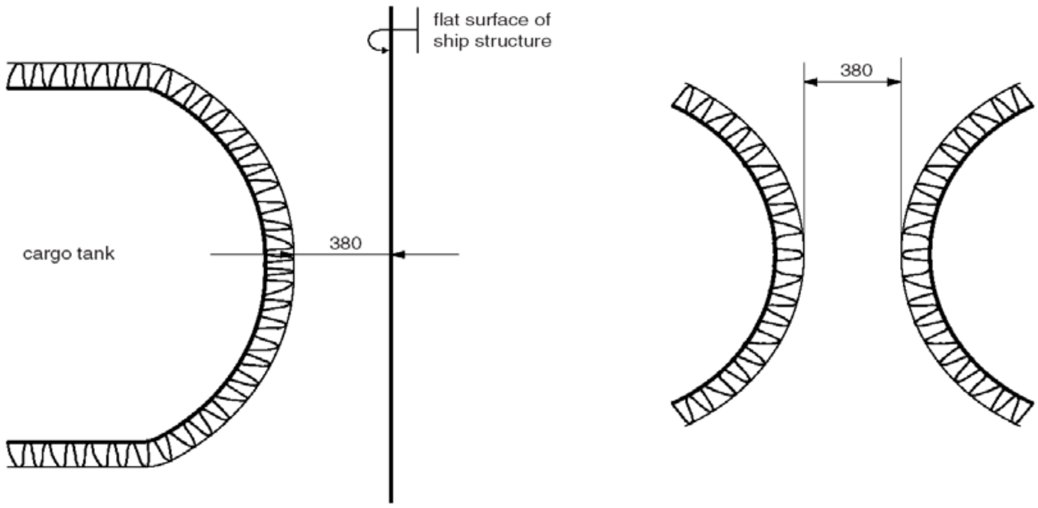


Figure 2.17: Minimum passage between flat surfaces

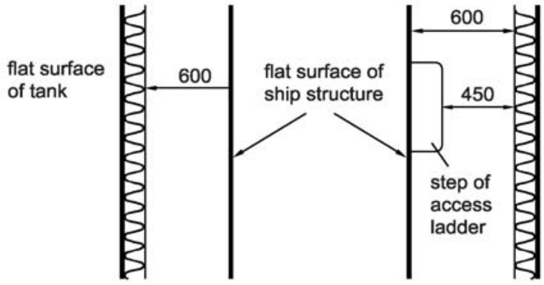
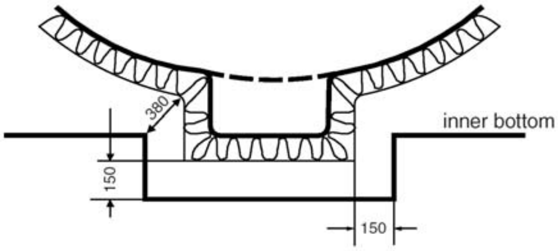


Figure 2.18: Minimum distance of cargo tank sump and inner bottom



2.11.2.2 Passage through hatches and manholes of cargo tanks

For the purpose of complying with the requirements in IGC Code 3.5.3, the following applies:

1. The term "minimum clear opening of not less than 600 x 600mm" means that such openings may have corner radii up to a maximum of 100 mm (see Figure 2.19).
2. The term "minimum clear opening of not less than 600 x 800mm" also includes an opening of the size specified in Figure 2.20.

Figure 2.19: Minimum horizontal hatch size

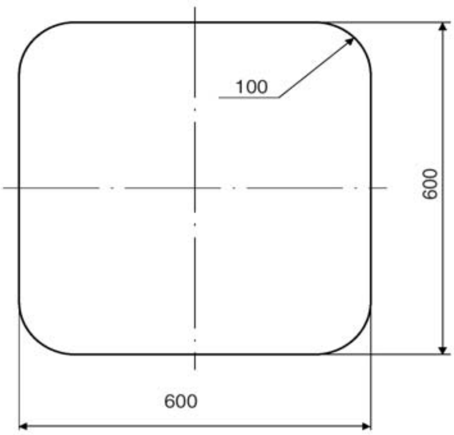
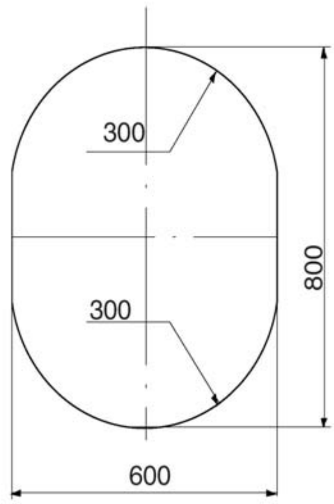


Figure 2.20: Minimum size of manholes



2.11.2.3 Cofferdams and pipe tunnels

- Cofferdams are to have sufficient size for easy access to all their parts. The wide of the cofferdams may not be less than 600 mm.
- Pipe tunnels are to have enough space to permit inspection of pipe. The pipes in the pipe tunnels are to be installed as high as possible from the ship's bottom.
- Access to pipe tunnels through manholes in the engine space is not permitted.

2.11.2.4 Access to spaces in the double hull

In order to ensure proper inspection, maintenance and survey of spaces in the double hull (e.g. water ballast or void double hull spaces), it is recommended to apply the requirements in the SOLAS regulation II-1/3-6, effective from 1 January 2006, and relevant “Technical Provisions for Means of Access for Inspections”, adopted by resolution MSC.158(78), even if they are not compulsory for LNG carriers.

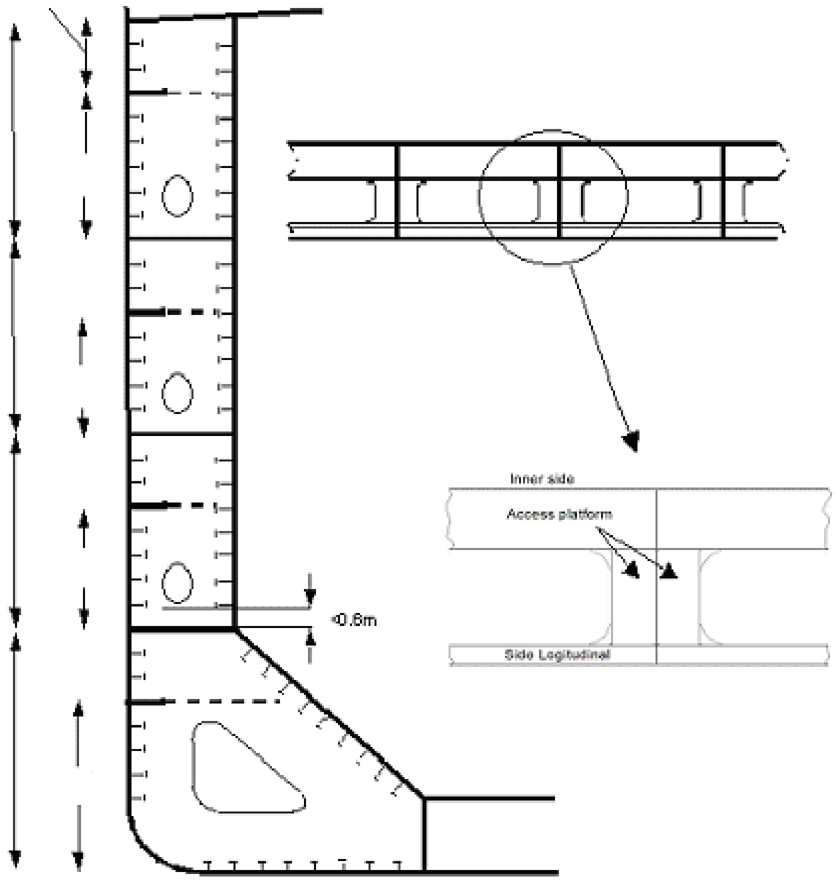
The following aspects may affect the ship’s structural arrangement:

- Longitudinal passageways inside the wing ballast tanks are not requested in the case that maximum vertical clearance between two following stringers does not exceed 6 m. Where that height is larger than 6m, permanent longitudinal means of access should be arranged in order to reach those areas too far to be inspected by means of a portable ladder (Figure 2.21).
- Permanent means of access, such as longitudinal and transverse passageways, should as far as possible be integral parts of the structure of the ship, so that they can contribute to the overall strength of the hull.
- Elevated passageways shall have a minimum clear width of 600mm, except for going around vertical webs where the minimum clear width may be reduced to 450mm, and have guard rails over the open side of their entire length.
- For access through horizontal openings, hatches or manholes, the minimum clear opening shall not be less than 600mm x 600mm.
- For access through vertical openings, such as manholes, in floors, girders and web frames providing passage through the length and breadth of the spaces, the minimum opening shall be not less than 600mm x 800mm at a height of not more than 600mm from the passage, unless gratings or other foot holds are provided.

A sketch showing an example of double hull arrangement complying with the above is shown in Figure 2.21.

It is also highlighted that a detailed structural analysis should be carried out in the hull areas in way of the manholes, in order to minimize the effects of stress concentration at the corners of the holes.

Figure 2.21: Permanent means of access in double hull space



3 FIRE SAFETY

The following aspects, based on current practice, may be considered to complement the current requirements in the IMO IGC Code and the Rules.

3.1 Spray System

A fixed water spray system is normally supplied by a dedicated pump to protect the cargo tank domes, cargo manifolds, compressor houses, Satcom dome, lifeboat embarkation areas, access to the lifeboats and all external bulkheads of the accommodation block.

3.2 Dry Powder System

A dry powder system is fitted to protect the main deck and cargo manifold areas, with two fixed monitors at each manifold and hand nozzles or monitors for the other areas Remote actuation is normally provided from the cargo deck, the cargo control room and the fire control station.

3.3 Gas Detection Systems

Two gas detection systems are normally installed:

- A system based on infrared gas analysers drawing samples from the cargo area, including but not limited to hold spaces, insulation spaces and compressor rooms. All sampling lines are normally fitted with welded or brazed joints.
- A system based on catalytic combustion type detectors for monitoring accommodation, machinery spaces, inert gas line etc. Some detectors are duplicated to provide shutdown gas burning system capability in the event of gas being detected in gas hoods or engine room.
- The following portable instruments are also normally supplied:

Instrument
Combined Meter for Oxygen and Hydrocarbon Gas (LEL) with built-in facility for chemical detector tubes
Chemical detector tubes for above – Carbon Monoxide (50 ppm)
Chemical detector tubes for above – Carbon Dioxide (5000 ppm)
Methane in Nitrogen Meter
Dew Point Meter
Personal Oxygen Meters

3.4 Ballast Tank Pressurization System

Provision should be made for temporary air connection to ballast tanks and means of blanking air vents, so that tanks can be pressurised using salvage air compressors in the event of grounding or collision. Compressors were fitted in the past but generally it is not necessary to provide special hoses or air compressors.

4 CARGO SYSTEM AND EQUIPMENT

4.1 General

The following aspects, based on current practice, may be considered to complement the current requirements in the IMO IGC Code and the Rules.

The cargo system should be designed such that inerting, gas freeing and purging procedures can be carried out with all gases displaced from the cargo system being passed through the vessels boilers. This facility is to be in addition to the normal operating procedures involving venting of gases via a riser.

The following calculations for the cargo containment system should be performed to verify the safety of the system (see also Section 2 – Hull Structures):

- *Thermal stress analysis* for each cargo containment system and each tank size, including the cargo piping system, taking into account expansion, contraction and vessel flexing, such analysis to include transient conditions.
- *Dynamic cargo pressure calculations* based on hull accelerations at sea, indicating local maximum forces.
- *Fatigue stress analysis* due to thermal stress and forces created by dynamic cargo pressures and induced forces from the hull.
- *Sloshing pressure calculations* based on the impact forces born by the cargo containment system due to the cargo free surface movement at sea.
- *Transverse, longitudinal torsional and local hull deflection analysis* indicating stress levels.
- *Local stress analysis* for tank domes and their pipe penetrations as well as pipe supports inside the tank and on the deck.

Any filling restrictions, in any or all of the cargo tanks, must be clearly stated in the Operating Manual.

4.2 Cargo Pumps

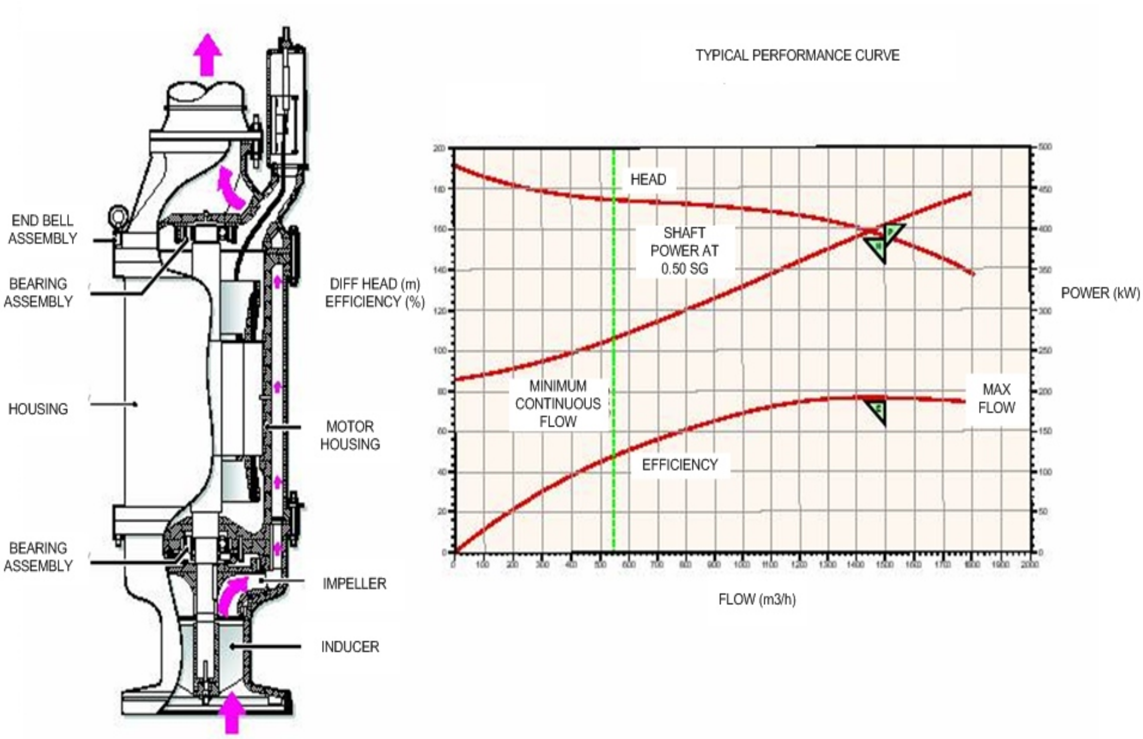
Each cargo tank usually includes two equally sized submerged electric cargo pumps. The pumps are specified to meet the performance requirements set generally by the charterer. Pumps in all cargo tanks should be identical in manufacturer, model and capacity.

The pumps should be designed with inducers and bell mouths to give minimum NPSH requirements and to be fully hydraulically thrust balanced in normal service over a wide capacity range (i.e. the pump thrust bearings should carry no thrust during steady state operation). The suction bell mouths shall be fitted with a strainer.

The cargo pumps, pipeline system and starters shall be designed to minimise liquid hammer during starting. In this regard, the cargo pump non-return valves are generally installed in the cargo tank immediately above the pump and sometimes frequency control or soft starters though these can be problematic depending on their design. Operational practice can go a long way to limiting liquid hammer.

All the pumps should be test run at duty point and to establish NPSH in liquefied gas before delivery. It is recommended that for the first pump of the batch, full performance tests should be conducted, such tests being carried out using LNG of similar composition to that which will be encountered in actual service. If the results are satisfactory, this performance test need not be repeated for subsequent identical pumps for the ship or even series of ships..

Figure 4.1: Submerged cargo pump



4.3 Spray Pumps

Normally one spray pump is installed in each cargo tank. Again all pumps should be identical and from the same manufacturer as the cargo pumps. The spray pumps shall be installed as low as possible consistent with maintaining prime so that they may be used for stripping.

The capacity and head of each pump should be determined by the containment design to meet the highest of the following requirements:

- spray cooling all the cargo tanks
- pre-cooling of the liquid lines (if appropriate)
- stripping main cargo pump unpumpables within two hours

The spray pump design should generally be similar to the cargo pumps.

4.4 Alternative Discharge System

In event of failure of both cargo pumps in a tank, alternative means shall be provided to discharge the contents. If an emergency pump is provided then it must be designed so that it can be left in place until a permanent cargo pump repair can be carried out.

In the case of sizing for the emergency cargo pump, the ideal operational solution would be to have it the same size as the main cargo pump so in the event of it being used the same discharge time can be achieved. From a practical point of view, however, it must be remembered that a full size emergency pump will be expensive, very difficult to handle and install, and hopefully never used so there needs to be a balance found.

It is good practice to store the emergency pump on board under proper N2 atmosphere as the presence of moisture could prevent it proper operation at low temperature

4.5 Vapour Return Compressors

Two equally sized electric motor driven centrifugal compressors are normally fitted in the cargo compressor room. The capacity of each should be based on the capacity needed to achieve the times specified for evaporating the unpumpables and warming-up. The compressors need to be suitable for vapour return duties and for warming up duties and be able to handle methane vapour, inert gas or mixtures of both. Undersized compressors will lead to extended times and particularly in the case of cool down, the vessel remaining on the berth longer. For both duties it may be assumed that the maximum capacity can be met by running both compressors in parallel. The most common arrangement uses compressors of radial flow single speed type with integral gearbox unit. Capacity control being achieved by means of inlet guide vane control, though variable speed control has also been fitted on some vessels. Each compressor should be fitted with an independent automatic anti-surge control and safety system. The compressors and associated control systems shall be designed to ensure stable operation in parallel.

The IGC code requires that he motor shall be installed in the adjacent motor room and shall drive the compressor via an intermediate shaft that penetrates the bulkhead through a gas-tight gland. The motor, gearbox and compressor should be mounted on a common bedplate incorporating the gas-tight gland and partial bulkhead, the whole installation being designed to minimise vibration. Sealing of the gas-tight gland should be by means of low-pressure air with a nitrogen back-up.

Magnetic couplings, which would avoid gas tight penetrations and alignment problems, could be employed too.

Consideration is being given to installations using flameproof motors, with the entire compressor/driver unit installed in the compressor room. Provided that all motors are flameproof, such an arrangement will remove the necessity for a separate motor room. Such flameproof motors should be designated Eex d IIB to temperature class at least T4. However this is not yet allowed in IGC Code.

Motors should be double air cooled, using air or fresh water in secondary circuit. HD compressor motors shall be single speed medium voltage but if LD compressors are so large that thyristor speed control is necessary, then such motors will probably have to be 440V or 660V.

The first compressor of each size should be tested with air before delivery and performance curves established, corrected for methane at the designed conditions. Each compressor should then be spin-tested at cryogenic temperatures to verify performance and then dismantled for examination.

4.6 Fuel Gas Compressors

Two compressors generally of equal size are normally installed in the cargo compressor room. The capacity of the compressor needs to take into account the gas burning philosophy.

In the past gas has been cheaper, in some cases considered free when carried on vessels belonging to the LNG exporter and therefore it was generally more economical to burn gas rather than HFO in which case 100% gas burning, or minimum HFO burning was common and it is preferable to have two 100% compressors with one in standby. However, the spot charter market, technological advancements and relative cost gas versus fuel may in the future restrict the burning to the normal boil off of the gas in which case two 50% compressors would be more realistic allowing 100% gas burning if required.

The fuel gas compressors are generally of similar design to the vapour return compressors and ideally from the same manufacturer.

Driving motors, glands and controls are generally as specified for the vapour return compressors.

Provision should be made to allow free-flow of boil-off gas to the boilers with the compressors shut down and isolated. The piping and equipment will need to be sized to accommodate this .

4.7 Gas Heaters

Two gas heaters are usually installed in the cargo compressor room:

- One high duty gas heater, which should be designed to raise the temperature of gas discharged from both vapour return compressors operating in parallel so as to provide the heating requirement to warm up the cargo tanks within the time specified.
- One fuel gas heater, which should be designed to raise the temperature of gas discharged from the low duty compressors at the rated compressor capacity to that temperature needed for 100% gas burning.

The gas heaters may be of the direct steam heated type, with automatic temperature control utilising gas bypass control valves but will need a system of automatic protection against freezing of the condensate side of the heaters.

If the design of the containment system requires a hull heating system (membrane), the heating coils will generally be circulated using glycol-water mixture and an automatic system of control valves, steam heated glycol heater, pumps etc., should be provided. In this case, the gas heaters of the indirect type would be better, circulated by the glycol system. Consideration should also be given to providing an auxiliary electric glycol heater of sufficient capacity to maintain hull temperatures while meeting energy demand of the fuel gas heater under naturally occurring boil-off conditions at sea. The main steam heated glycol heater would be used at times of high demand, such as during loading or when force vaporising.

4.8 LNG Vaporizer

A direct steam heated LNG vaporiser of the shell and tube type will be needed in the cargo compressor room for the following purposes:

- Gassing up the cargo tanks (inert gas purging) within the time specified in the charter party and this requirement shall govern the design capacity of the vaporiser. The design outlet temperature is normally taken as +20°C for this operation.
- Pressurising the cargo tanks for emergency discharge (if appropriate)

The vaporiser is normally started and stopped under local manual control and operated under suitable automatic control for each of the required modes of operation with monitoring facilities in the cargo control room. It is recommended accurate outlet temperature, pressure and flow measurement is provided. The LNG flow to the vaporiser shall be automatically stopped in event of high condensate level or low condensate temperature. A high outlet temperature alarm must be installed.

4.9 Forcing Vaporizer

A forcing vaporiser may be installed depending on the gas burning philosophy. It will be fitted in the cargo compressor room and vaporise LNG supplied by one of the spray pumps via the cargo spray header, If fitted, this unit shall be of sufficient capacity to make up the difference between the energy available from cargo boil-off under normal ballast voyage conditions and the total energy demand at maximum service rating of the main propulsion plant.

The forcing vaporiser shall achieve an outlet temperature similar to that of the vapour header under normal boil off conditions and again normally started and stopped under local manual control. It should have automatic capacity control from 0% to 100% and be integrated with the main propulsion plant control system. Appropriate monitoring facilities shall be provided in the cargo and machinery control rooms to ensure accurate outlet temperature, pressure and flow measurement. A high outlet temperature alarm must be provided. The LNG inlet flow to the unit shall be automatically stopped in case of high condensate level or low condensate temperature.

To avoid the possibility of liquid droplet carryover into the compressor a knockout drum (with internal demister) is fitted between vaporiser outlet and fuel gas compressor suction. Consideration may also be given to alternative arrangements, such as locating the fuel gas heater between the vaporiser and compressor or combining the vaporiser with the heater; in which case the knockout drum could be eliminated.

The installation of only a vaporizer properly sized and operated to satisfy the gassing up, warming up as well as combustion gas production necessities may be considered

4.10 Cargo Compressor Room

The gas compressors, vaporisers, gas heaters and associated controls are installed in a cargo compressor room located towards the after end of the cargo area. The cargo compressor room is provided with a removable connection from the inert gas system.

The design of the room shall incorporate such details as are necessary to deal with the considerable condensation that will be present whenever the ship is operational.

Savealls to contain oil leaks (e.g. from gas compressor gearboxes) shall be installed and shall be constructed so that condensation from pipes and compressor casings does not run into them. The design of the arrangement of components in the compressor room should take into account the necessity of maintenance of the components itself, providing suitable means to isolate the components each other and providing suitable space to facilitate maintenance operation and removal of the equipment.

The design of the compressor room ventilation system has to take proper account of the necessity to remove the amount of N2 generated by the compressors seals, if foreseen.

Figure 4.2: Typical compressor room

4.11 Cargo Piping System

The cryogenic cargo piping system should be constructed from austenitic stainless steel.

Adequate expansion loops or expansion bellows shall be provided in the liquid and vapour piping systems to allow for thermal expansion and contraction of the pipes and for the flexing of the vessel. Any bellows used in the cargo system should be of the multi-wall type with Inconel 825 or austenitic stainless steel flexible elements in the outer layer.

Pipe joints shall be kept to a minimum. The system, including any bellows, shall be welded as far as practical but with sufficient flanges to allow maintenance and removal of equipment. Flange fastenings should be stainless steel 304L or 316L with cut threads.

Fluid velocity in the pipelines in normal service should not exceed 10 m/s for liquid and 30 m/s for vapour.

Means of efficient drainage of the loading arms and manifolds shall be provided. The main liquid lines shall be designed to encourage self-draining toward tanks.

The piping system to be designed to permit warm-up, inerting, purging, cool-down etc. of a single cargo tank with the remaining cargo tanks containing cargo or cargo vapour and without interrupting gas burning. Adequate separation in this condition should be demonstrated. The separation shall be two positive means of isolation such as two valves or a valve and a swing blank but a swing-check valve is not acceptable.

The relief valves fitted to liquid cargo pipelines should discharge independently to either of two cargo tanks, and not to the cargo vent mast. All safety valves in the cargo pipeline system are normally supplied by one manufacturer and provided with means of manual operation.

4.12 Piping Insulation

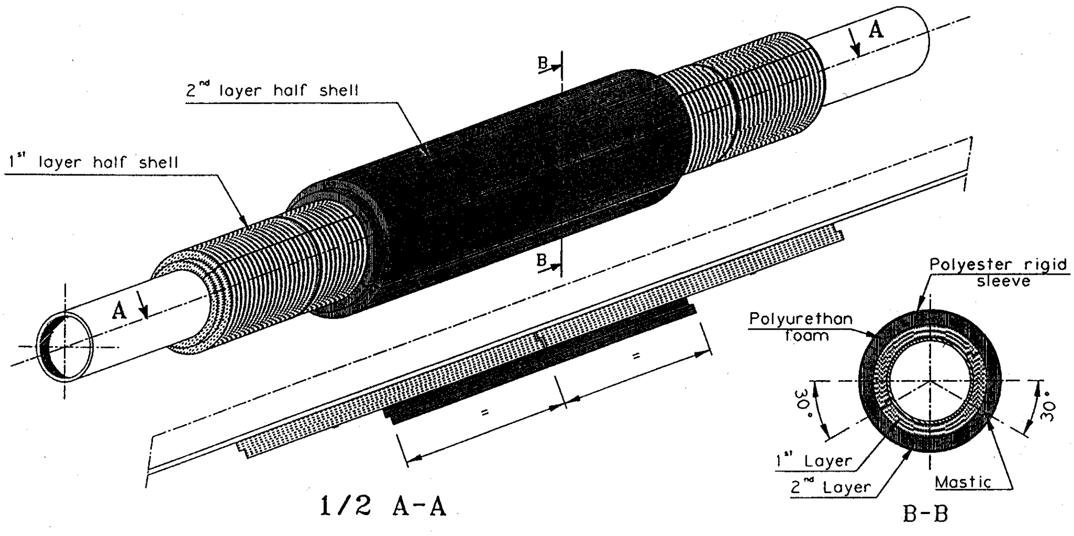
The cryogenic piping system outside the cargo tanks should be insulated with rigid, self-extinguishing polyurethane foam or equivalent, suitable for temperatures up to +80 °C. Two layers should be foreseen; valves, flanges and bellows need not to be insulated (see Figures 4.1 and 4.2). The insulation should be covered with a tough water and vapour tight barrier (e.g. polyester resin reinforced with glass cloth). Particular attention shall be given to thermal expansion and contraction arrangements to prevent ingress of moisture.

The total thickness of the insulation should be such as to limit Boil-Off Gas generated by ship piping during e.g. loading which has impact on the capacity requested by the vapour return compressors (see previous item 4.5). As a guide the total thickness as per table should be used.

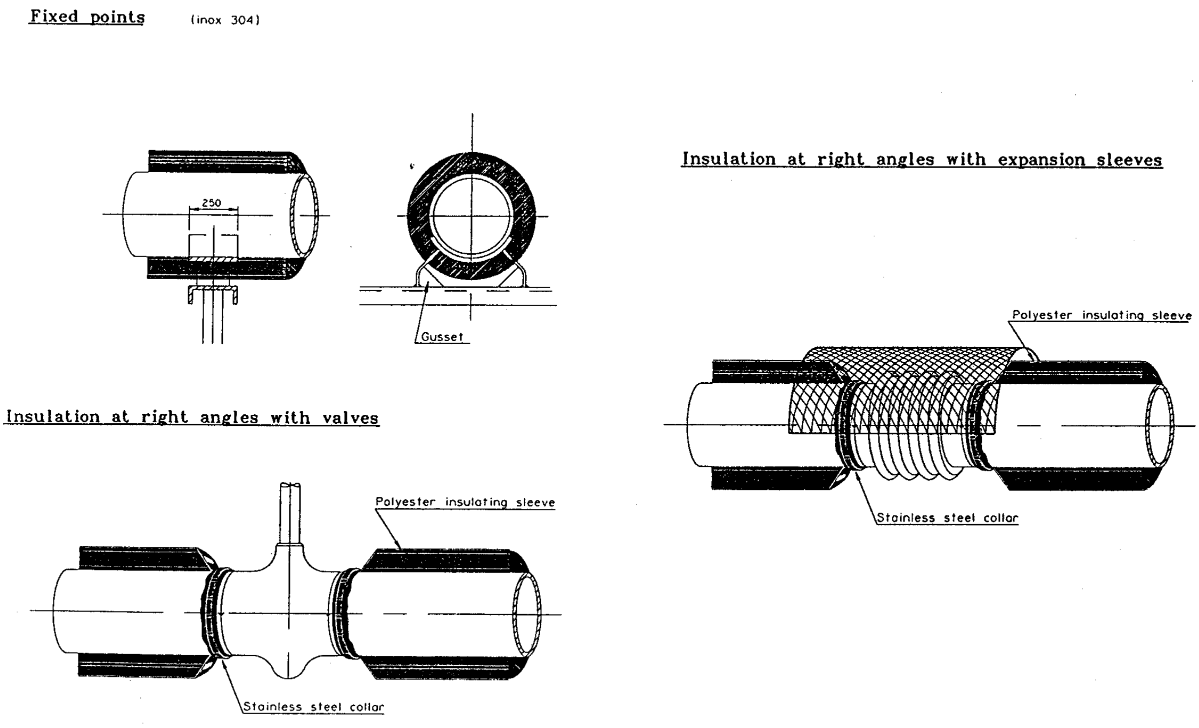
Table 4.1: Piping insulation thickness

Pipe diameter	Liquid line	Vapour line
Up to ND 25 m	30 mm	30 mm
ND 25 mm up to ND 100	50 mm	40 mm
Above ND 100	80 mm	60 mm

Figure 4.3: Cargo piping insulation



Pipe insulation principals



Singular points

4.13 Cargo Manifolds

The cargo manifolds should comply with the latest OCIMF/SIGTTO "Recommendations for Manifolds for Refrigerated Liquefied Natural Gas Carriers". This divides manifold arrangements into three groups, small vessels, medium and large 140,000 m^3 and above. The majority of the world fleet fall into the middle group and until very recently none in the upper size range. The majority of the world's terminals are designed to accept vessels to the OCIMF/SIGTTO category B spacing. However the upper manifold category has an increased strength requirement so the possibility of a manifold with the 'B' spacing and the upper strength should be considered.

Eight manifold strainers with a mesh size of ASTM 60, four for loading and four for discharging should be provided in accordance with the SIGTTO "Recommendations for the Installation of Cargo Strainers on LNG Carriers". Some manufacturers now provide dual strainers.

Cargo reducers are not generally required but adapters should be provided suitable for connecting shore arms having hydraulically operated quick connect/disconnect couplers.

A portable nozzle for emergency cargo jettisoning shall be supplied and stored in way of the manifolds. The nozzle shall be capable of mounting on any liquid manifold, project at least 3 m over the ship's side and provide an outlet velocity of 40 m/s when supplied by two cargo pumps at rated capacity.

Alternatively the jettison system may be located at the stern but care will be needed to passing LNG pipelines around the accommodation.

4.14 Pipe Supports

Pipe anchors are required and should be designed to take the thermal and dynamic loading, including surge pressures, that may be induced in the ship's piping. Fixed pipeline anchors should be designed to avoid point loading and, for this reason, pads are normally interposed between the anchors and pipeline; alternatively, suitably shaped sections of pipeline with increased wall thickness can be employed. "U" bolts shall be of stainless steel.

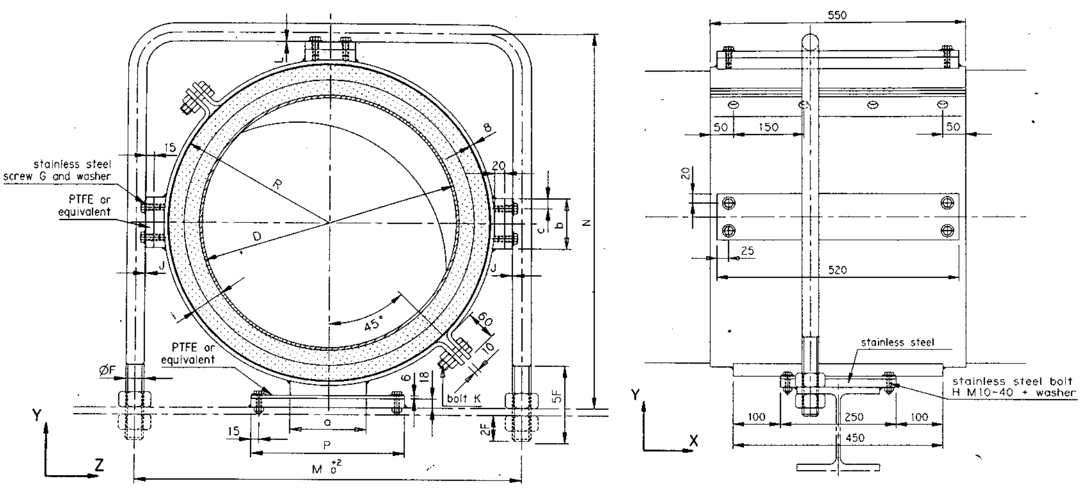
In general, all pipelines on deck and in the compressor room should be installed such that metal to metal contact between the pipe and the ship's structure is avoided by the insertion of suitable pads, chocks or sleeves of PTFE or similar material. The supports should be designed to allow maintenance of the pads in service without hot work. Example of supports showing the above feature are given in Figure 4.3.

In case of ships with Moss cargo tanks and in order to avoid the necessity of maintenance of the said supports which position could be not easily accessible pipe supports of stainless steel construction are preferable.

Calculations should be submitted by the designer which demonstrate the suitability of the design with respect to strength of the supports and stresses in the pipelines under all conditions of operation including transient loads during cool-down. The calculations should also be carried out considering spool pieces both installed and removed.

Where allowed by stress level in the supports, they may be of GRP construction.

Figure 4.4: Pipe supports



4.15 Pipe Testing

Despite IGC Code requirements which allow spot test, all pipe butt welds should be subjected to 100% radiographic inspection or tested by an equivalent method.

Pipe pressure testing shall be by water in the shop and by air or nitrogen on the ship.

After fabrication and testing, the pipes should be internally dried, cleaned and sealed before installation on the vessel.

After the pipelines have been installed, all liquid, vapour, nitrogen, distribution and inert gas pipelines should be blown through with dry air and it is strongly recommended that the main systems is inspected internally by remote controlled TV camera.

4.16 Cryogenic Valves

Valves for cryogenic service will require extended bonnets to avoid freezing of the moving parts. Liquid service valves should have means to relieve pressure caused by liquid trapped in the body. Even if not requested by IGC Code, valves should be "fire safe" to a recognised standard. The manifold ESD valves should be "fire-safe" with metallic sealing (i.e. not reliant on soft sealing materials on the valve seat).

Non-throttling valves should be suitable for bi-directional flow. The soft seals of the valves should be suitable for a temperature range from –163 to +80 °C.

For large diameter valves, special attention should be given to the design of the top flange. Special tightness testing under transient cooling conditions should be conducted. All valves should be designed to permit overhaul in situ.

Wherever possible, valve actuators, manual or powered, should be provided by the valve manufacturer and the whole assembly tested before dispatch from the factory.

Sampling, vent and drain lines on all liquid and vapour lines, which open to atmosphere, should be fitted with double isolating valves.

Materials for handwheels, levers and fittings for all valves and actuators should be selected with a view to their resistance to corrosion.

4.17 Cargo Tank Relief Valves

Each tank should be equipped with two diaphragm relief valves of the pilot operated type. Each relief valve should be provided with a means of manual operation. In the case of spherical cargo tanks, if the chosen means of emergency cargo discharge is by pressurisation of the tanks, then the relief valves shall be provided with a means to allow re-setting in situ.

Suitable means should be provided for installing spade blanks on the inlet side of relief valves in an emergency. These should be provided with a highly visible means of indication when installed.

4.18 Nitrogen Generator

Two equally sized nitrogen generator plants of the membrane permeation type are usually installed within the machinery casing with direct access to the machinery space and to the deck.

The capacity shall be such that one unit shall satisfy all normal service requirements, including normal loading, with a 20% margin. Periods of exceptionally high demand, such as the initial cool down of the cargo system from ambient conditions may be satisfied by two units operating in parallel. The plant should be provided with a buffer tank of sufficient capacity to ensure that the plant shall not start more than once per two hour period in normal operation at sea.

Feed air may be supplied to the nitrogen generator from the engine room compressed air system.

Nitrogen produced by the unit shall meet the specification of the containment system designer but, in any case, shall be dust and oil free and shall meet the following minimum quality requirements:

O_2	≤ 3% volume
Dew Point	≤ –65°C at atmospheric pressure

The plant shall operate fully automatically and shall be arranged for remote control and monitoring from the cargo control room. Discharge flow shall be diverted if the oxygen content exceeds 3% by volume. The discharge of O_2 from membrane filters shall be led to the open deck , at least 3 m above the deck, in a position where no source of ignition exists

4.19 Inert Gas/Dry Air Plant

An integrated inert gas generator/dry air production unit shall be provided for inerting and aeration of the cargo system within the times specified in the contract. The plant shall be located within the machinery casing, in a segregated space having direct access to the machinery space and to the deck. The distillate fuel for the production of inert gas shall be DMA gas oil.

Inert gas produced by the unit shall meet the specification of the containment system designer but, in any case, shall meet the following minimum quality requirements:

O_2	≤ 1% volume
Dew Point	≤ –45°C at atmospheric pressure
CO	≤ 100 ppm vol
SO_2	≤ 10 ppm vol
NO_x	≤ 100 ppm vol
Soot	0 Bacharach

The dewpoint of dry air produced by the unit shall equal that specified for inert gas.

The combustion chamber of the inert gas generator shall be horizontal or near horizontal, so as to avoid potential pollution during start up and in the event of flame failure. No refractory linings shall be employed.

The plant shall be arranged for fully automatic operation. Starting shall be performed under local control and equipment shall be provided to allow remote control and monitoring from the cargo control room.

Where regenerative dryers are installed, facilities shall be provided to allow regeneration in the absence of a supply of steam in order to allow the unit to produce dry air in the event of the vessel being laid up. Where refrigerated dryers are installed, Refrigerant 410A or other non-ozone depleting refrigerant shall be used.

The possibility to use nitrogen from a source not installed permanently on board (e.g. a portable generator or an IG barge could be considered, taking into account that the use of inert gas is limited to certain operational phases of the ship (e.g. dry docking).

4.20 Alternative Arrangements

An arrangement by which the requirement for an inert gas generator is deleted and replaced by larger capacity nitrogen may be considered as an option. An example is:

- The inert gas plant with associated scrubber, cooling system, fuel system, fire protection etc., replaced by a simple air dryer unit with blowers providing dry air at Dew Point ≤ –45°C at atmospheric pressure.
- The total capacity of the nitrogen generators increased so as to provide sufficient nitrogen flow at 95% purity for cargo tank inerting operations.
- The large capacity nitrogen plant will allow nitrogen to replace instrument air throughout the vessel, reducing duplicated pipe work and eliminating the need for separate instrument air receivers, instrument air dryers etc.

4.21 Ship to Ship Transfer

It has been common for ship to be able to transfer cargo to, or receive cargo from, another ship. The following equipment has usually been provided and stowed on board:

- one set of the necessary flexible cryogenic transfer hoses and adapters, together with suitable support devices, of a suitable size to permit easy handling,
- one set of the necessary cables to link the ESD systems,
- a lightweight gangway for transfer of personnel,
- in some cases a suitable connection to both the cargo and emergency switchboards with one set of electric cables to allow the supply of electrical power to or from another ship for the operation of hydraulic power packs, instrumentation, etc.

It should be noted that for the majority of ships with this equipment it has never been used, and for those which have used it, it has been as a test or exercise, not an emergency.

4.22 Custody Transfer System

An approved Custody Transfer System (CTS) is needed to measure cargo volume, temperature and pressure according to the requirements of cargo sellers, buyers and the fiscal authorities in exporting and importing countries.

Two independent level measuring systems shall be installed in each tank. There is however provision for one only in the IGC Code provided it can be maintained externally. It must be considered the operational and regulatory implications should a single system fail. It is common for a primary system to be radar gauged for level measurement. These systems should be of the automatic calibrated type.

Each cargo tank shall be provided with temperature sensors at a minimum of five levels for the purpose of determining cargo temperature for the CTS. The distribution of the sensors shall be subject to Owners approval. Two sensors are to be installed at each level – one working and one spare – each sensor being separately cabled back to the control cabinet.

Each cargo tank shall also be provided with a system for absolute pressure measurement for CTS purposes.

The CTS shall take signals from the primary level gauges and shall automatically and continuously calculate cargo volumes corrected for trim and list, based on the certified tank tables. The system shall allow draught readings to be input manually if necessary. The CTS shall also process the cargo temperature and pressure signals from the sensors in each tank to provide reports of cargo loaded or discharged to suit the commercial requirements of the charterers.

The CTS system shall also output cargo data to the cargo control system for monitoring purposes.

The entire system, including the calibration of the tanks, shall be certified by an independent sworn measurer approved by the Owner.

The accuracy of the systems shall be equal to or better than the following:

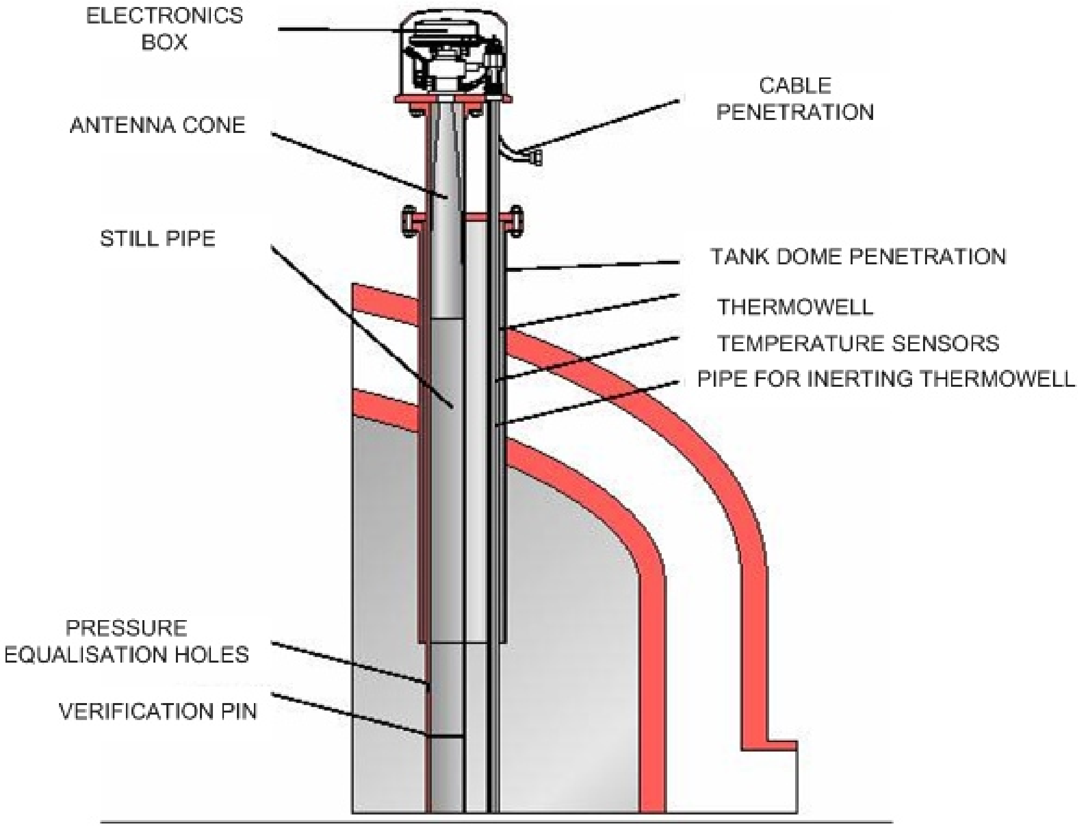
Level (primary system)	± 7·5 mm over full tank height
Level (secondary system)	± 7·5 mm over full tank height
Temperature	± 0·2°C over the range −165°C ~ −145°C ± 1·5°C over the range −145°C ~ +40°C
Pressure	1% of span over the range 800 ~ 1400 mbar

The primary level gauging system shall provide alarm level signals for low level and normal filling level, the latter also providing a signal to close the filling valve.

Each cargo tank shall be fitted with two additional independent high level sensors of the capacitance type. One at a level slightly below normal filling level for alarm purposes, the other slightly above normal filling level to provide a signal to the emergency shut down system. If capacitance pot type are fitted then consideration should be given to fitting dual sensors at each level, one in service one spare.

The custody transfer system should comply with standards such as ISO 13888 and G.I.I.G.N.L (Groupe International des Importeurs de Gaz Naturelle Liquefié).

Figure 4.5: Typical Radar Gauging Arrangement



4.23 Cargo ESD System

The cargo emergency shutdown (ESD) system, required by the IGC Code, may be part of the main distributed control system.

The fusible links in the cargo area are generally of the electric thermal fuse type.

Three types of ship/shore link system are in general use:

- An optical fibre link system (compatible with the Furukawa/Sumitomo system) and incorporating ESD and telephone functions
- An electric link system compatible with European LNG terminals, utilising Pyle-National connectors and incorporating ESD and telephone functions, or Far Eastern terminals using Miyaki connections
- A pneumatic link, utilising Nitta-Moore connectors.

4.24 Ship Shore Communication System

The following facilities are needed when the vessel is alongside LNG terminals:

- A '*Hotline*' call telephone installed on the central control console, providing voice communications with shore control room via the optical fibre link system
- A pushbutton telephone installed via sockets in the central control room, providing communications to the terminal's internal telephone network via the optical fibre and electric link systems
- A pushbutton telephone installed via sockets in an acoustic booth located in the control room area, providing communications to the shore public telephone network via the optical fibre and electric link systems

- A telephone socket for fax communications installed in the central control room area and connected to shore via the electric link system
- A sound powered telephone installed in the central control room, providing emergency communications to the shore terminal via the electric link system.

Even if the use of the same ship-shore link for both EDS and communication as well as optical fibre link would be preferable, the ship is to be prepared to face shore facilities which are, at the time being, different each other. At present no international standards for ship-shore interface systems exists.

5 PROPULSION MACHINERY

5.1 General

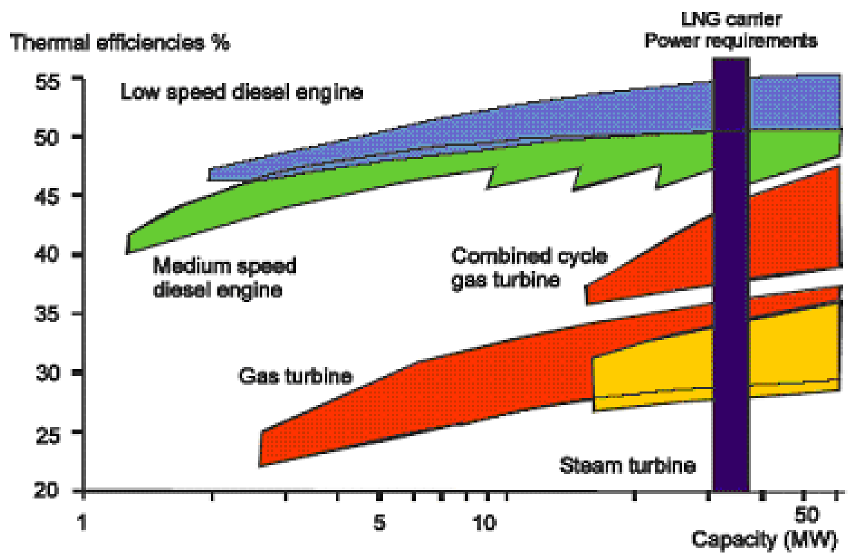
The LNG Industry has been seen as a conservative one when it comes to choices of propulsion. Reliability and maintenance has been the key driver, however a shortage of manufacturers combined with a shortage of qualified steam engineers are leading to new designs and developments.

Some of these that have been tried in the pioneering days of LNG transportation and subsequently withdrawn are now being reviewed with the advancements in technology. There are now vessels on order with new propulsion systems.

Below is a brief overview of those tried, those available and those being considered.

The following diagram shows the thermal efficiencies for the different systems (MAN B&W):

Figure 5.1: Thermal efficiencies of prime movers



5.2 Steam Turbine

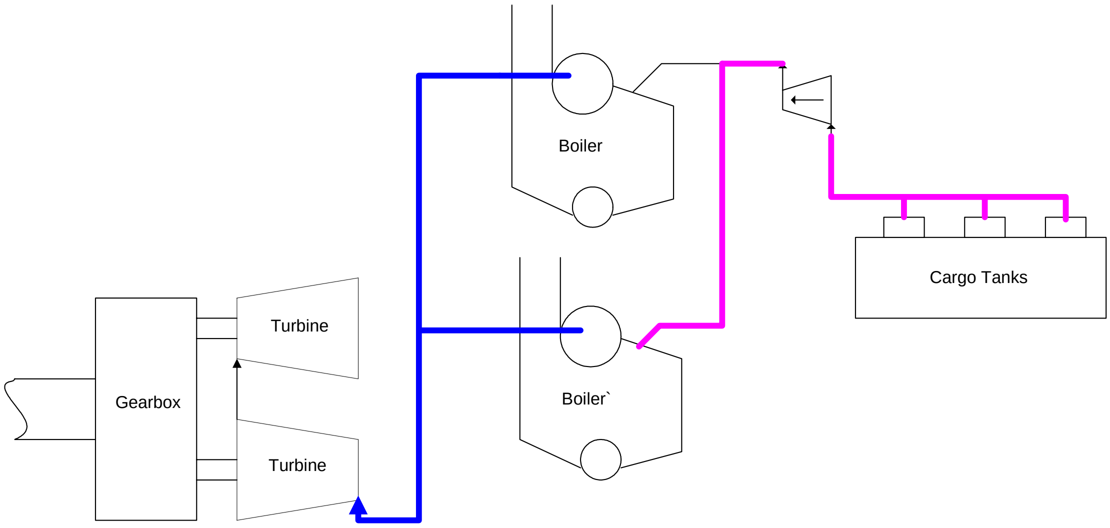
Up until recently and with the exception of a few prototype vessels all LNG Carriers have been steam turbine driven.

Table 5.1

For	Against
Ease of boil off disposal	Efficiency low
Reliability	Lack of boiler and turbine manufacturers
Limited maintenance between dockings	Lack of steam engineers
Ready for use in port	

Figure 5.2: Steam Turbine and gearbox

Figure 5.3: Traditional Steam Plant Layout



5.3 Low Pressure Dual Fuel Diesel Engines

One vessel (MV Havfru) was built with this arrangement, which has subsequently been taken out of service.

Table 5.2

For	Against
Engine thermal efficiency Availability of engineers	Restricted power ratings due to knock Time needed out of service between docking for maintenance Extra means needed to handle boil off

Figure 5.4: MV Havfru

Figure 5.5: Low Speed Dual Fuel System

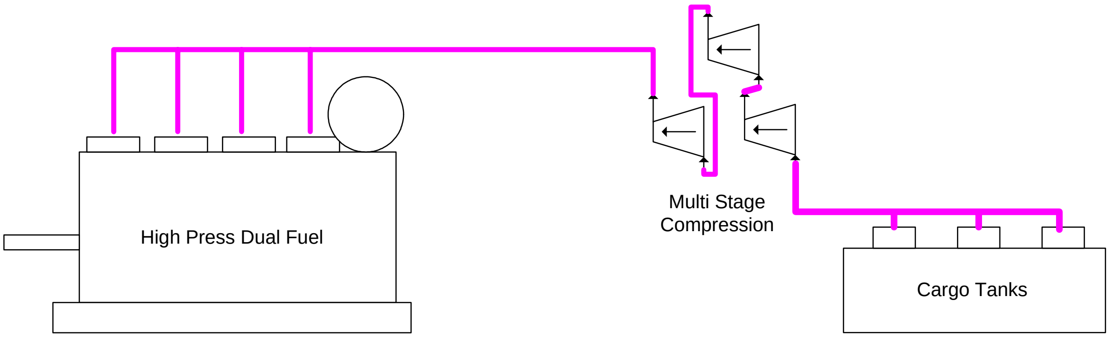
5.4 High Pressure Gas Injection Diesel Engine

No LNG carriers have been built with this system.

Table 5.3

For	Against
Engine thermal efficiency Knock power problem eliminated Availability of engineers	High power requirement to drive gas compressor (6%) 100% boil off use not possible Time needed out of service between docking for maintenance. Extra means needed to handle boil off

Figure 5.6: High Pressure Dual Fuel Engine



5.5 Dual Fuel Slow Speed

Mitsubishi have an engine like this running in a shore installation but no vessels have been fitted yet.

Table 5.4

For	Against
Engine thermal efficiency Availability of engineers	Strict maintenance schedule Cost of spares greater than a steam turbine Time needed out of service between docking for maintenance Extra means needed to handle boil off

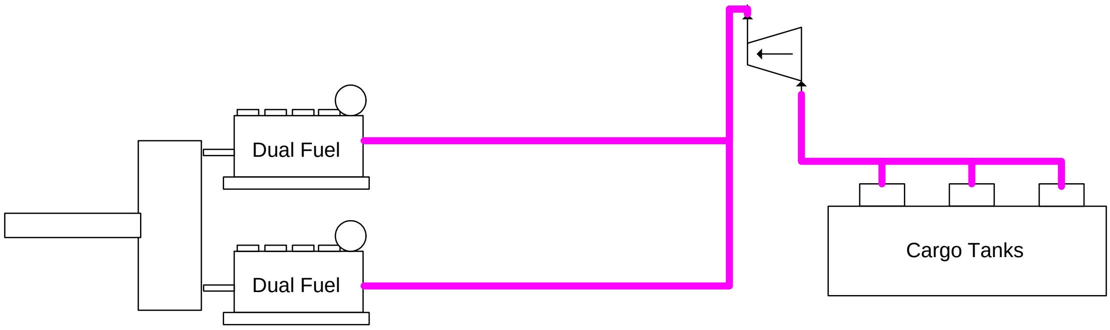
5.6 Dual Fuel Medium Speed Direct Coupled

No vessels have yet been fitted with this arrangement.

Table 5.5

For	**Against**
Redundancy if two or more engines coupled through a gearbox Availability of engineers	Not as efficient as slow speed diesel Extra means needed to handle boil off Time needed out of service between docking for maintenance

Figure 5.7: Dual Fuel Medium Speed Engine



5.7 Dual Fuel Diesel Electric

Gas de France has recently taken delivery of an LNG vessel with this arrangement and there are now a few vessels on order in Korea, the arrangement gaining popularity.

Table 5.6

For	Against
Higher efficiency than steam turbine Redundancy Flexibility of configuration Availability of engineers	Maintenance required for diesel

Figure 5.8: Wartsila DF Engine

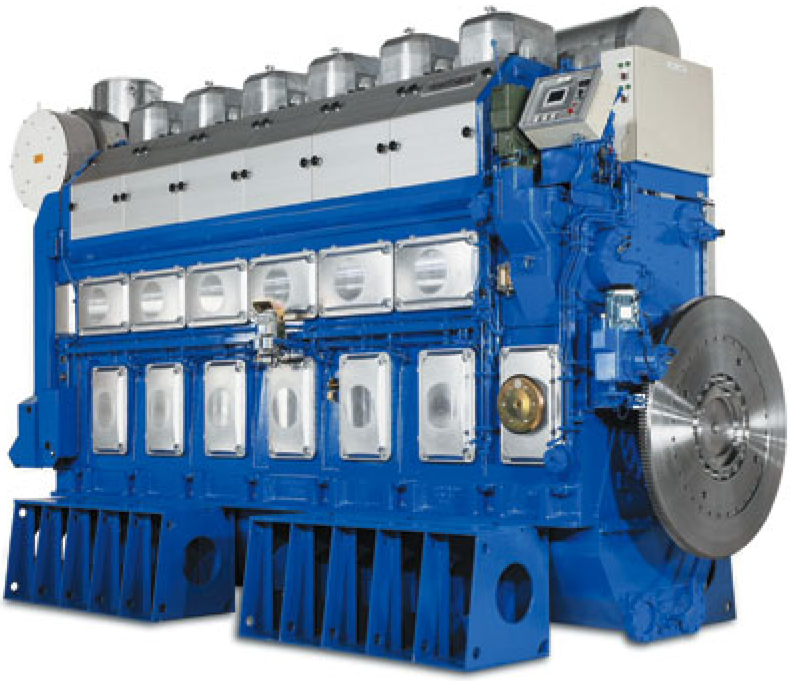
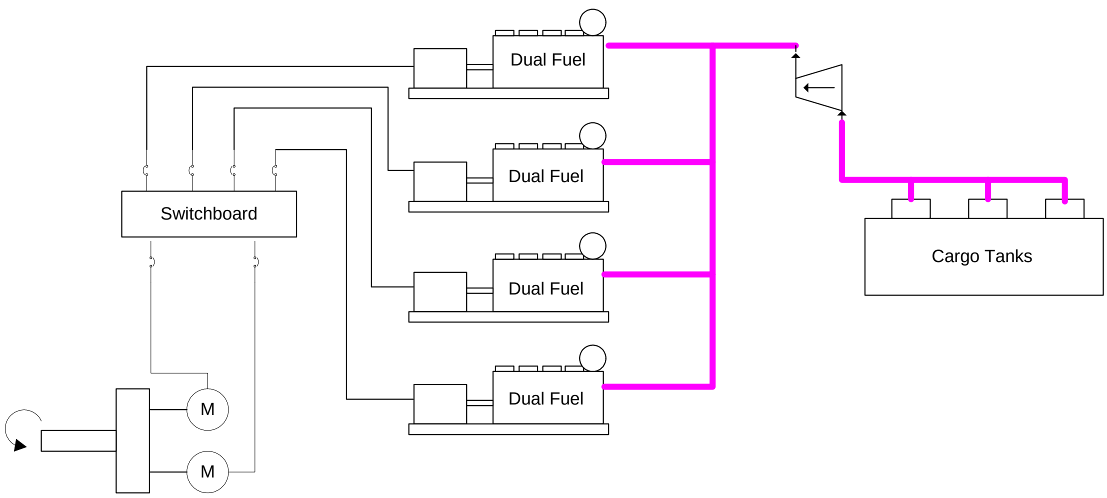


Figure 5.9: Typical Dual Fuel Diesel Electric Layout



5.8 Slow Speed Diesel with Reliquifaction

There are a number of designs available but none yet in service, the only ships fitted with LNG reliquifaction plants have either had them removed, LNG Lagos, Port Harcourt, or the other trial fitted to a steam turbine vessel does not use it regularly due to the power and complexity of the system.

Table 5.7

For	Against
Conventional Slow Speed Diesel Thermal efficiency high Availability of engineers	Maintenance required Power requirements very high for reliquifaction plant (estimated 20~30% of the boil off as fuel)

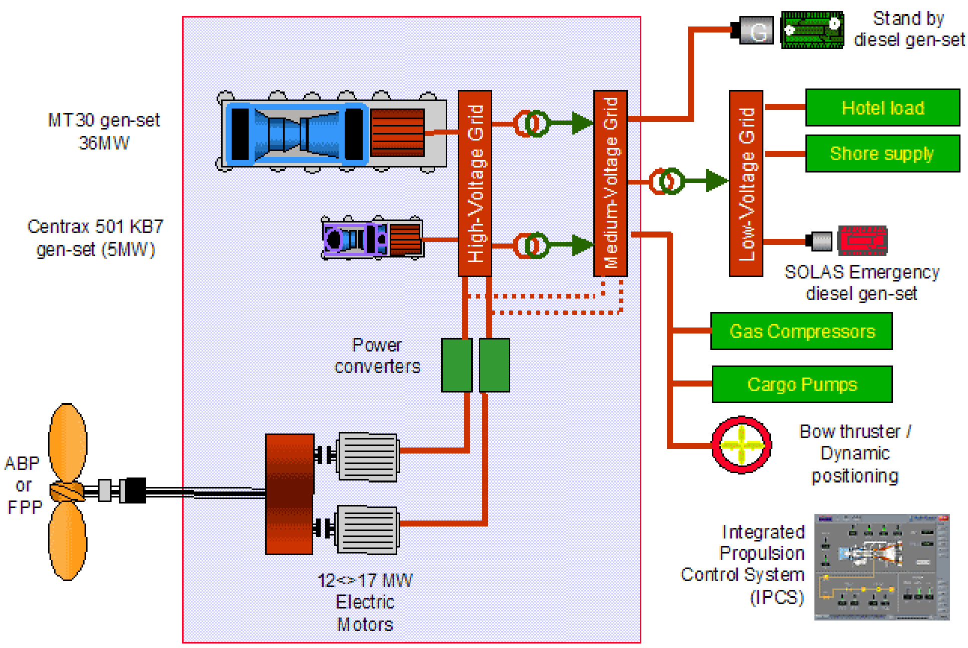
5.9 Gas Turbine

There has been one vessel fitted with a gas turbine but was re-engined. There are however again a number of designs available based on gas turbine electric configuration. A 'father a son' arrangement with the smaller gas turbine rated to give in port electrical power for discharge and the combination of the two to give MCR power.

Table 5.8

For	Against
Reliability Redundancy and flexibility similar to Table 5.6 Long maintenance periods High power to volume, increased cargo capacity	Efficiency between steam and diesel

Figure 5.10: Gas Turbine Electric (Rolls Royce)



6 APPENDIX: EXAMPLE OF ANALYSIS OF A LNG CARRIER (MEMBRANE TYPE)

6.1 General

The scope of this appendix is to present the results of an analysis aimed to investigate the structural behaviour of a LNG carrier, membrane type, according to the requirements in the Rules as well as in relevant IACS Unified Requirements.

The following structural analyses have been carried out on the ship under consideration:

- Analysis of the midship transverse section in way of cargo and ballast holds, in order to carry out the strength checks of hull girder, plating and ordinary stiffeners, performed by means of the Tasneef LH2D™ software program, implementing all Rules strength criteria.
- Three-dimensional FEM analysis of primary supporting members in the mid-ship area, by means of Tasneef LH3D™ software program, which assigns the Rules defined loads to the FE model and automatically performs the required Rules' strength checks.
- Three-dimensional FEM analysis of web frames in way of openings, in order to check the stresses in the web frame plating around the opening.

The case study considered is referring to the design of a 65000 m^3 LNG Carrier whose characteristics are described in Table 6.1.

In this ship, the cargo containment is obtained by means of membrane non-supporting tanks, which consist of a thin layer supported through insulation by the adjacent hull structure. The membrane is designed in such a way that thermal and other expansion or contraction is compensated for without undue stressing of the membrane.

Table 6.1: Main characteristics of the ship considered

Deadweight [t]	35 760.6
Length of scantling [m]	203.7
Breadth [m]	33.90
Draught (scantling) [m]	9.50
Draught in ballast condition [m]	6.11
Moulded Volume (at scantling draft) [m^3]	51100
Block coefficient (at scantling draft)	0.779
Max. design still water bending moment (Sagging) [kN·m]	-1 325 898
Max. design still water bending moment (Hogging) [kN·m]	1 528 365

6.2 Applied loads

The values of the applied wave load parameters, calculated for the mid-ship area, are summarised in Table 6.2.

Table 6.2: Wave load parameters for LNG Carrier

Ship condition	Load parameter	Value	
		Full load	Ballast
Upright ship condition	h_1, in m	6.091	
	a_{X1}, in m/s^2	0.980	0.902
	a_{Z1}, in m/s^2	2.351	
Inclined ship condition	h_2, in m	6.595	
	a_{Y2}, in m/s^2	2.712	2.662
	a_{Z2}, in m/s^2	0 for holds 0.365 for ballast tanks	

6.3 Hull girder, plating and ordinary stiffeners strength

The plating and ordinary stiffeners belonging to the mid-ship section have been checked against the following Rules' criteria:

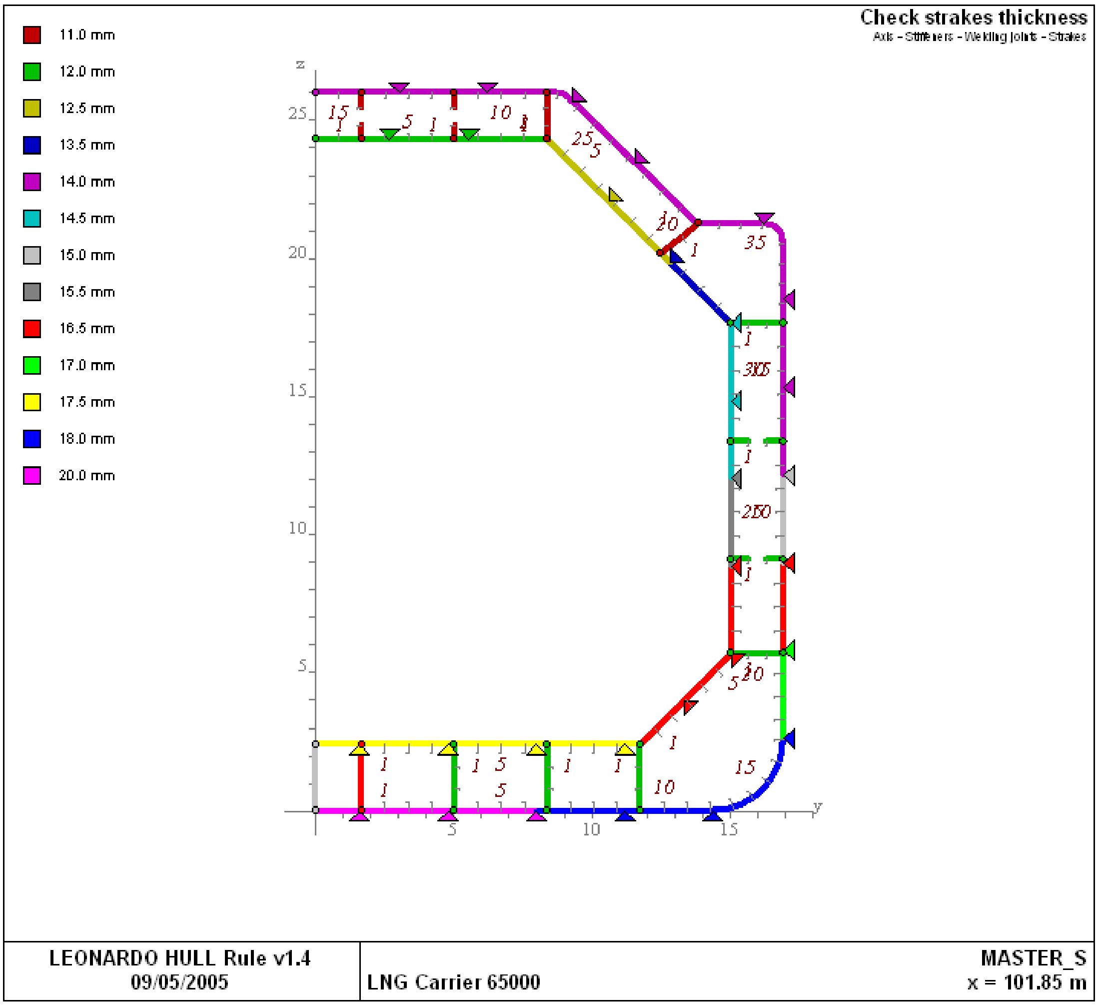
- yielding and ultimate strength of the hull girder;
- strength of plating under local pressures combined with the hull girder loads;
- yielding and ultimate strength of ordinary stiffeners under local pressures combined with the hull girder loads;
- buckling strength of plating and ordinary stiffeners subjected to the in-plane stresses induced by the hull girder loads;
- fatigue strength of structural details, discussed in detail in 6.6.

The values of hull girder loads are summarised in Table 6.3.

Table 6.3: Hull girder loads (amidships)

Hull girder load	Value
Hogging still water bending moment, in kN·m	1 528 365
Sagging still water bending moment, in kN·m	-1 325 898
Hogging wave bending moment, in kN·m	2 041 360
Sagging wave bending moment, in kN·m	-2 243 828
Horizontal wave bending moment, in kN·m	836 108
Wave shear force, in kN	21 029

Figure 6.1: Midship section – Plating and longitudinal ordinary stiffeners from the software program LH2D™



A summary of the main results of the structural analysis are shown in:

- Figure 6.2 and Figure 6.3 for the hull girder strength,
- Figure 6.4, for plating,
- Figure 6.5, for ordinary stiffeners.

Results of the fatigue strength checks are discussed in 6.6.

Except for the results relevant to the hull girder ultimate strength in Figure 6.3, where the hull girder ultimate capacity is directly compared with the extreme bending moment, the other results are expressed in terms of usage factors, i.e. the ratios between the Rules required value and the offered ones. This means that a ratio greater than 1.0 indicates non-compliance with the Rules requirements.

The results shown in the following figures indicate that the hull girder strength and all the plating and ordinary stiffener scantlings satisfy the Rules.

Figure 6.2: Hull girder yielding check results

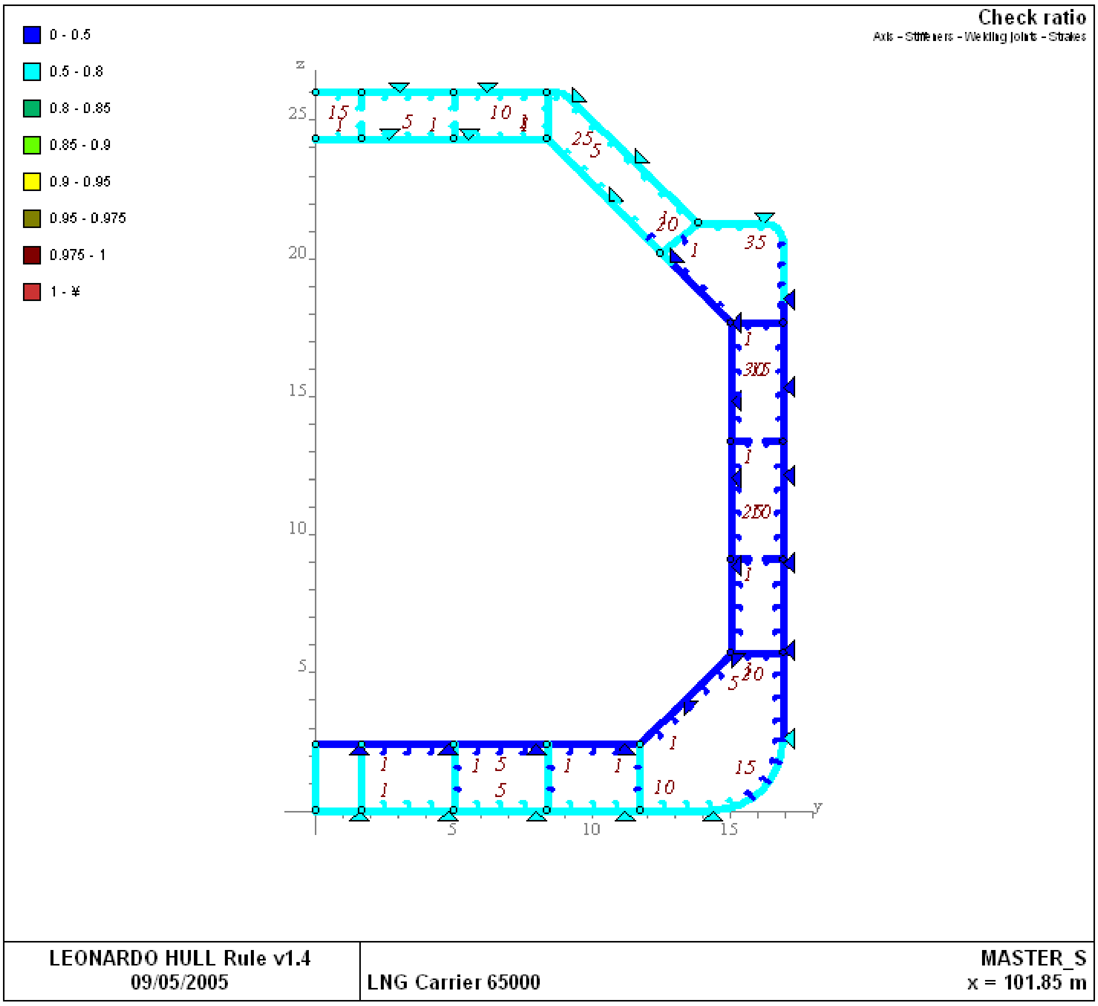


Figure 6.3: Hull girder ultimate strength check results

Ultimate strength check
(rule calculation)

Calculation options

Scantling:	Net
Solution:	Standard control
Moment:	Fixed horizontal/vertical curvatures ratio
Ratio:	0.00

Bending moment (kN.m)	Mu	Ultimate	Applied	%
Hogging	7 605 935.	6 904 443.	3 875 930.	56.14
Sagging	- 5 593 867.	- 5 077 948.	- 3 906 300.	76.93

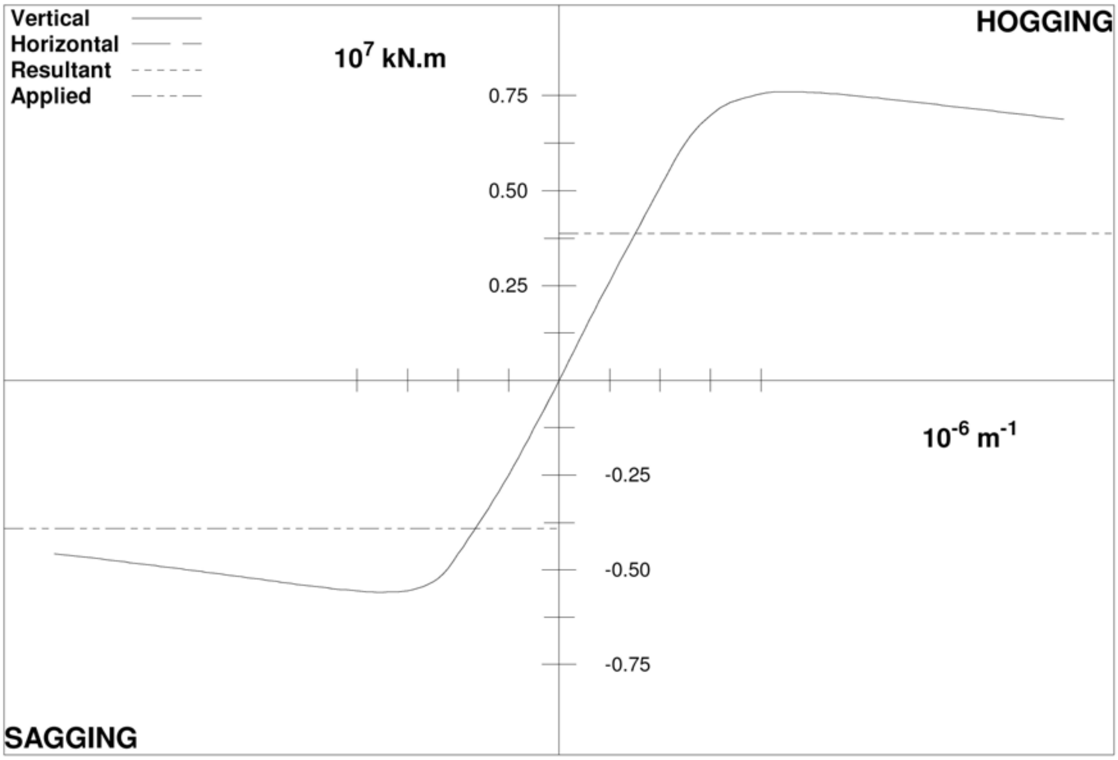


Figure 6.4: Plating strength check results

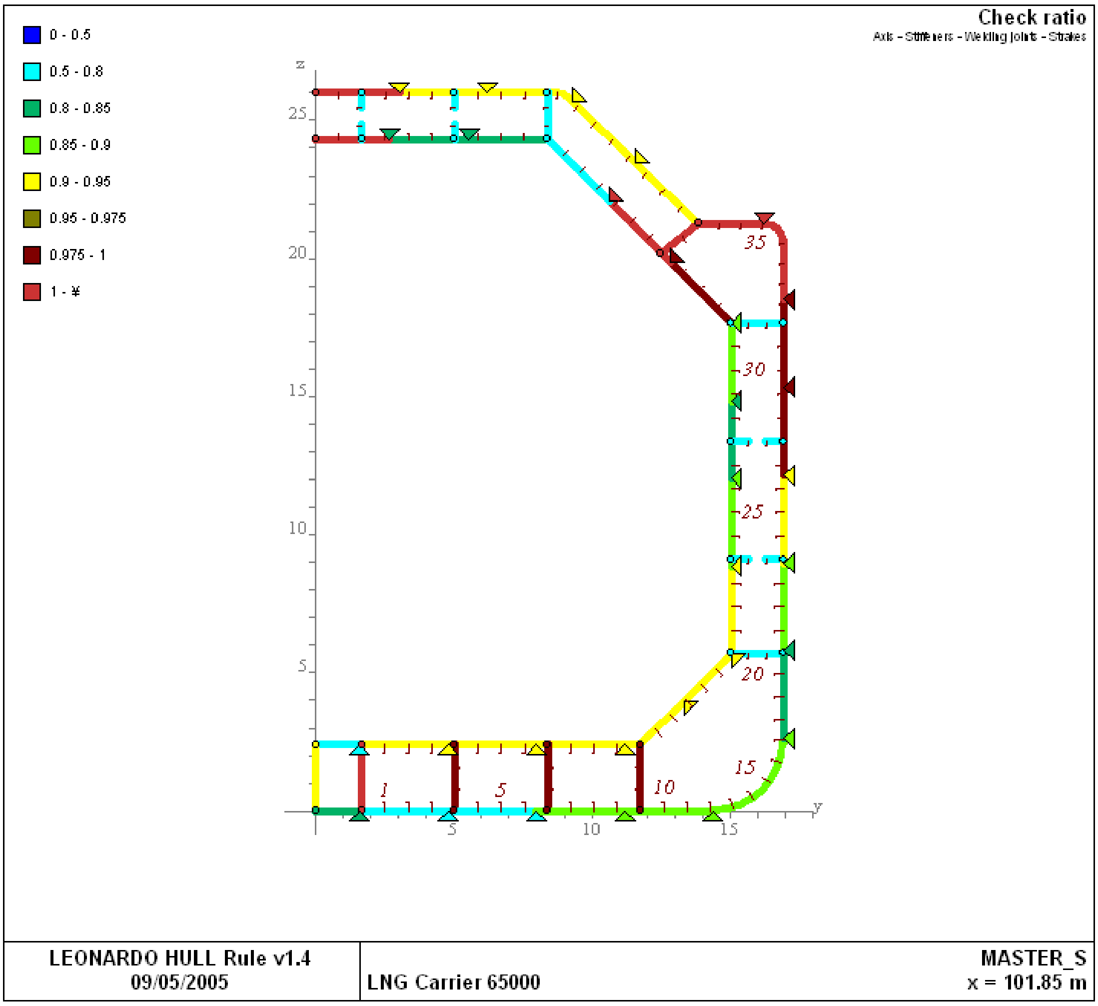
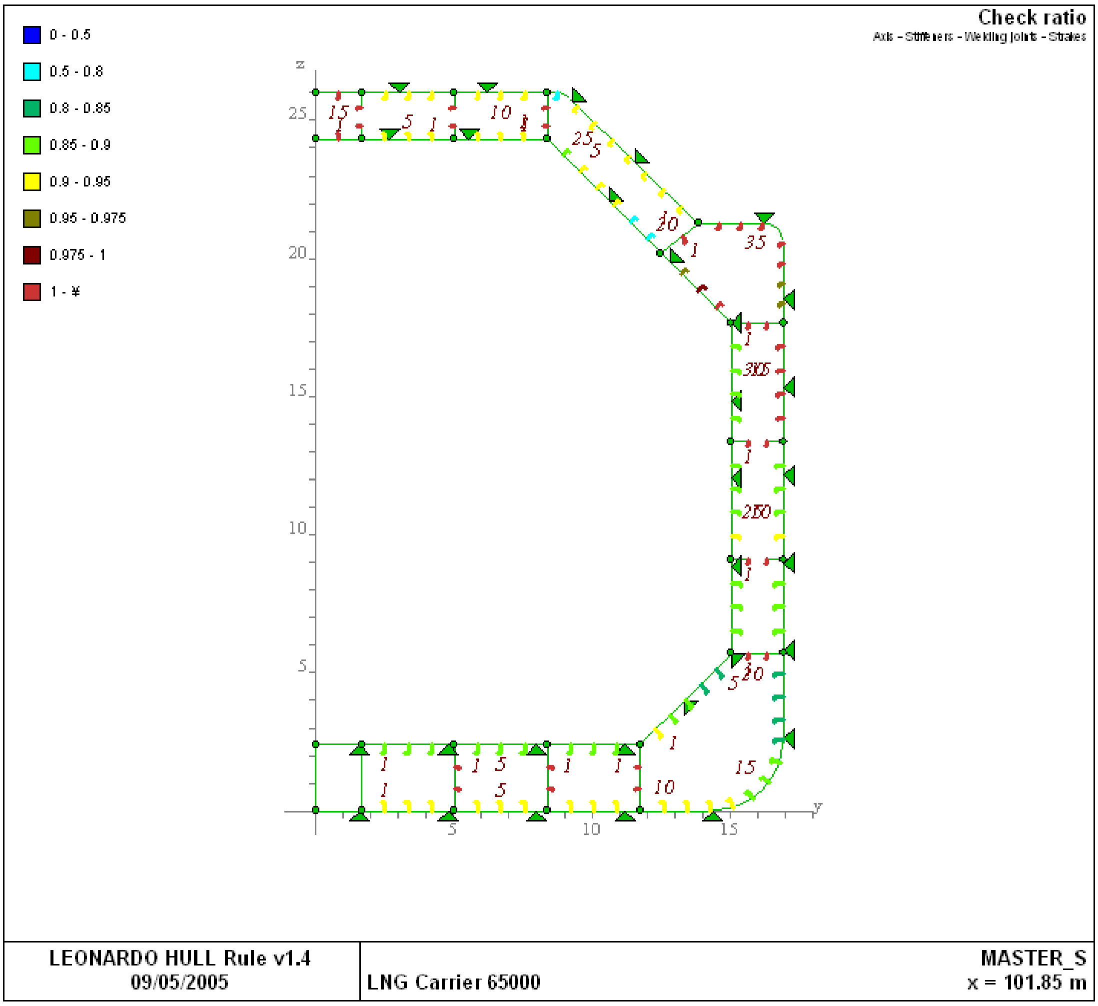


Figure 6.5: Ordinary stiffeners strength check results



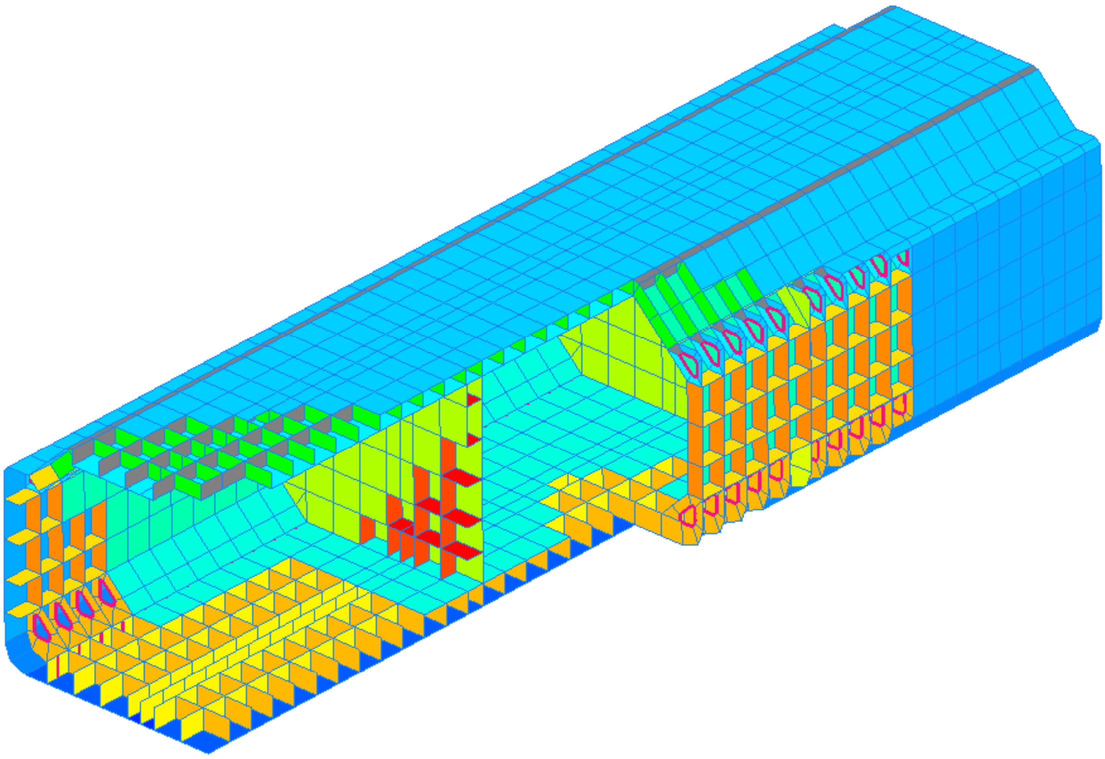
6.4 Strength of primary supporting members

The hull structures in way of cargo holds represented in the structural model are shown in Figure 6.6. Each model element represents the corresponding structural element in terms of geometric and mechanical properties, such as thickness, stiffeners geometry and yielding stress obtained from the ship's drawings.

The hull non-modelled parts (i.e. those forward of hold 2 and aft hold 4) are taken into account through adequate loads and constraints at the model boundaries.

More in detail, the fore end section of the model is considered as being fixed and equilibrium forces have been applied, for each load case, at the aft end section, at which symmetry constraints were also imposed. This is to obtain, in certain sections of the model, the hull girder loads stated in the Rules for each one of the loading conditions considered.

Figure 6.6: Global 3D structural model for the FEM analysis

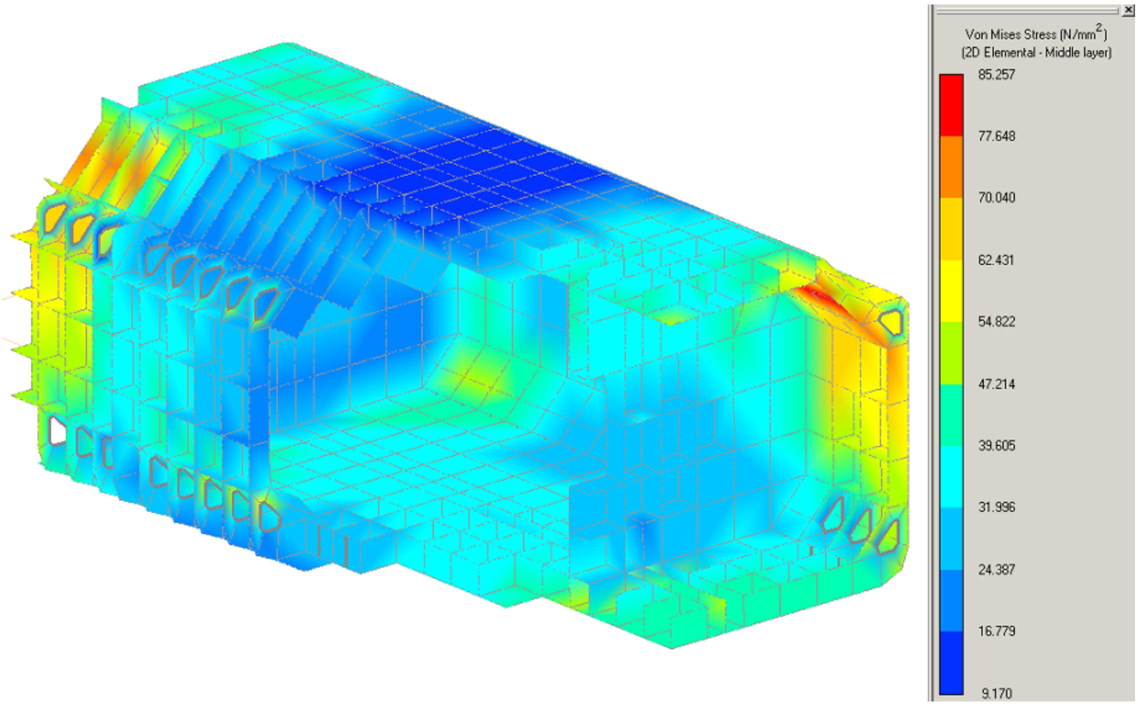


The results of the FE analysis are defined in terms of:

- deformations,
- stresses acting in each element,
- work ratios, i.e. the ratios between the stresses acting in each element and the corresponding allowable ones as defined by the Rules.

An example of the results is reported in Figure 6.7 in terms of calculated stresses.

Figure 6.7: Example of Von Mises stresses calculated with coarse mesh FEM model



According to the Rules, the results are adequate when the stress ratio relevant to the structural element under consideration is less than or equal to 1.0. For buckling checks of plating, values up to 1.15 may be accepted provided that the adjacent stiffeners have adequate buckling and ultimate strength, as specified in the Rules.

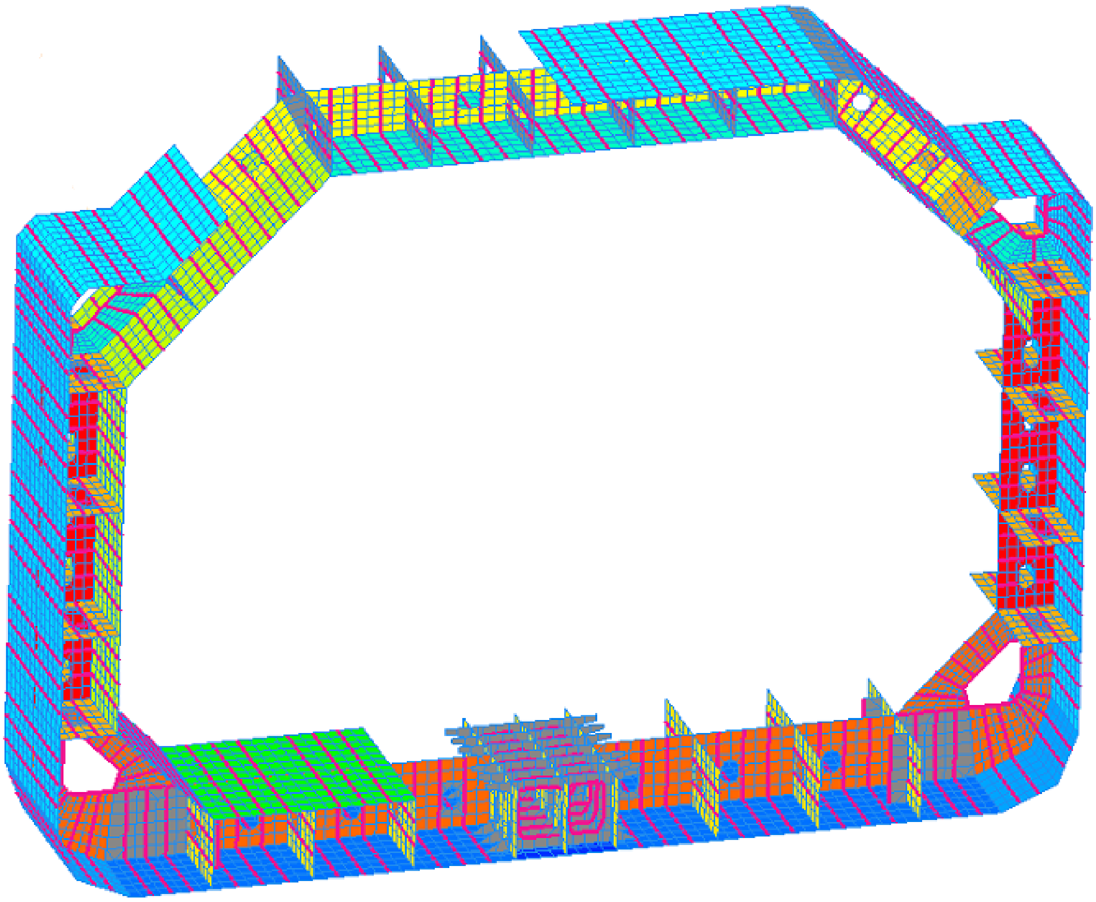
6.5 Fine mesh analysis of a transverse ring

The transverse ring resulting from the global three-dimensional analysis to be the one subjected to the highest stress level was further analysed through a more finely meshed three-dimensional model (Figure 6.8).

The analysis has been carried out considering the same loading conditions and load cases as in the global three-dimensional analysis.

The boundary conditions for the transverse ring analysis are constituted by the nodal displacements obtained from the global three-dimensional analysis.

Figure 6.8: Finely meshed transverse reinforced ring



A summary of the main results is graphically shown in Figure 6.9 to Figure 6.12.

These results confirm those obtained from the global three-dimensional analysis, i.e. the adequacy of the proposed scantlings.

Figure 6.9: Finely meshed transverse reinforced ring - Detail on the double side space structures, example of calculated stresses

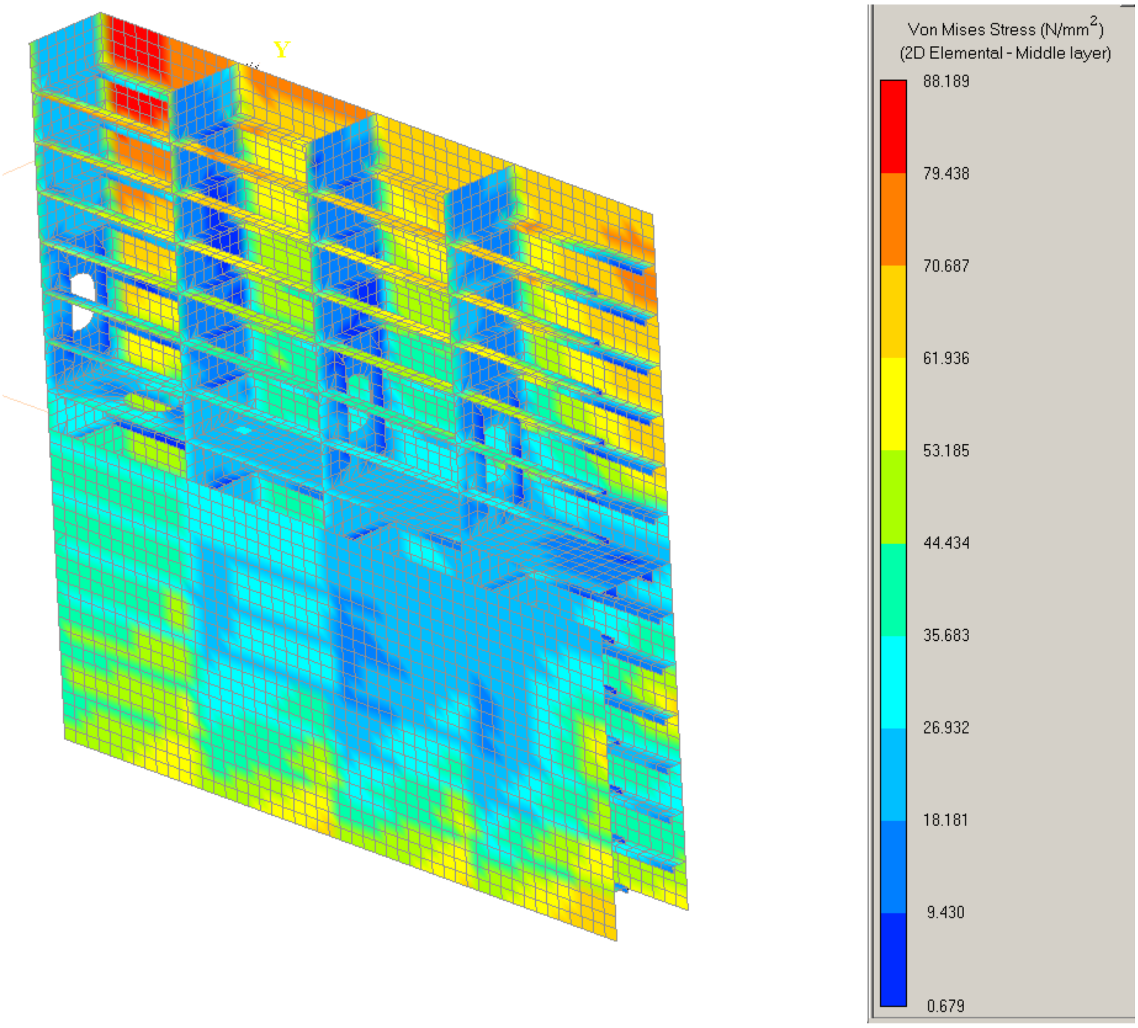


Figure 6.10: Fine mesh results - Transverse web frame

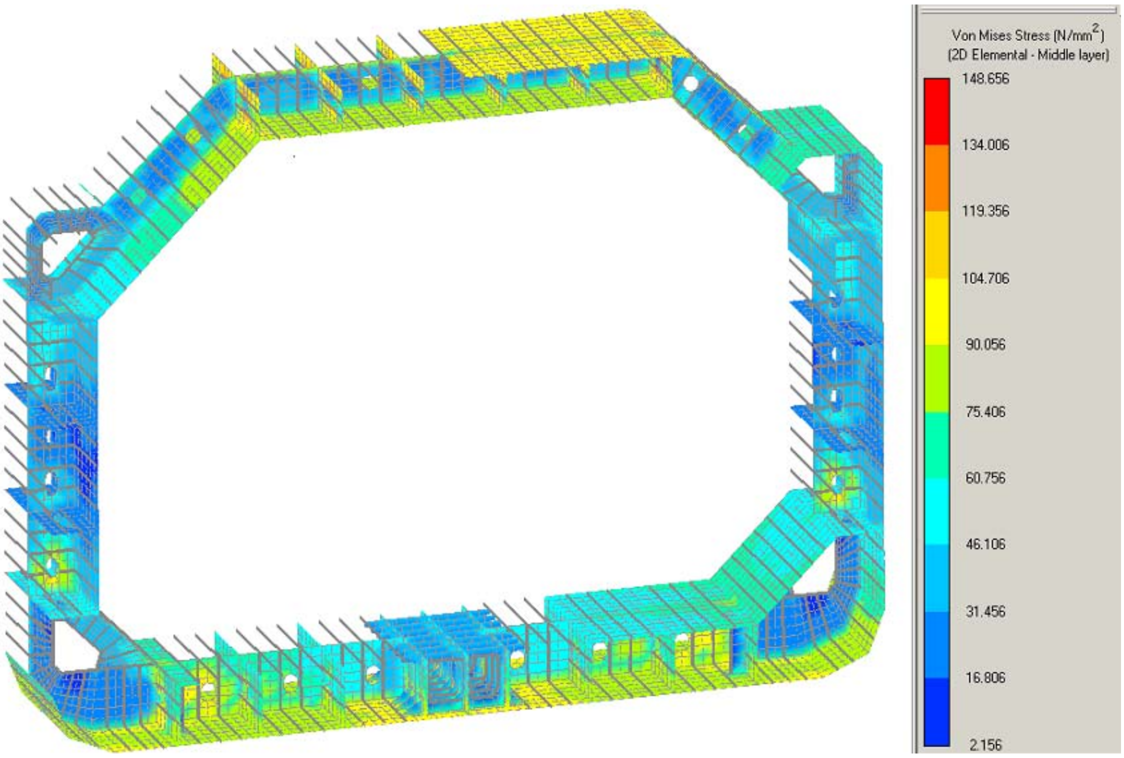


Figure 6.11: Fine mesh results - Detail on web frame manholes

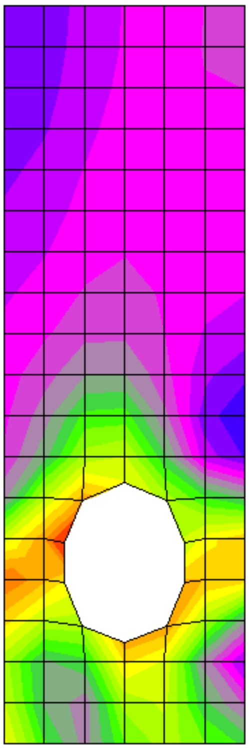
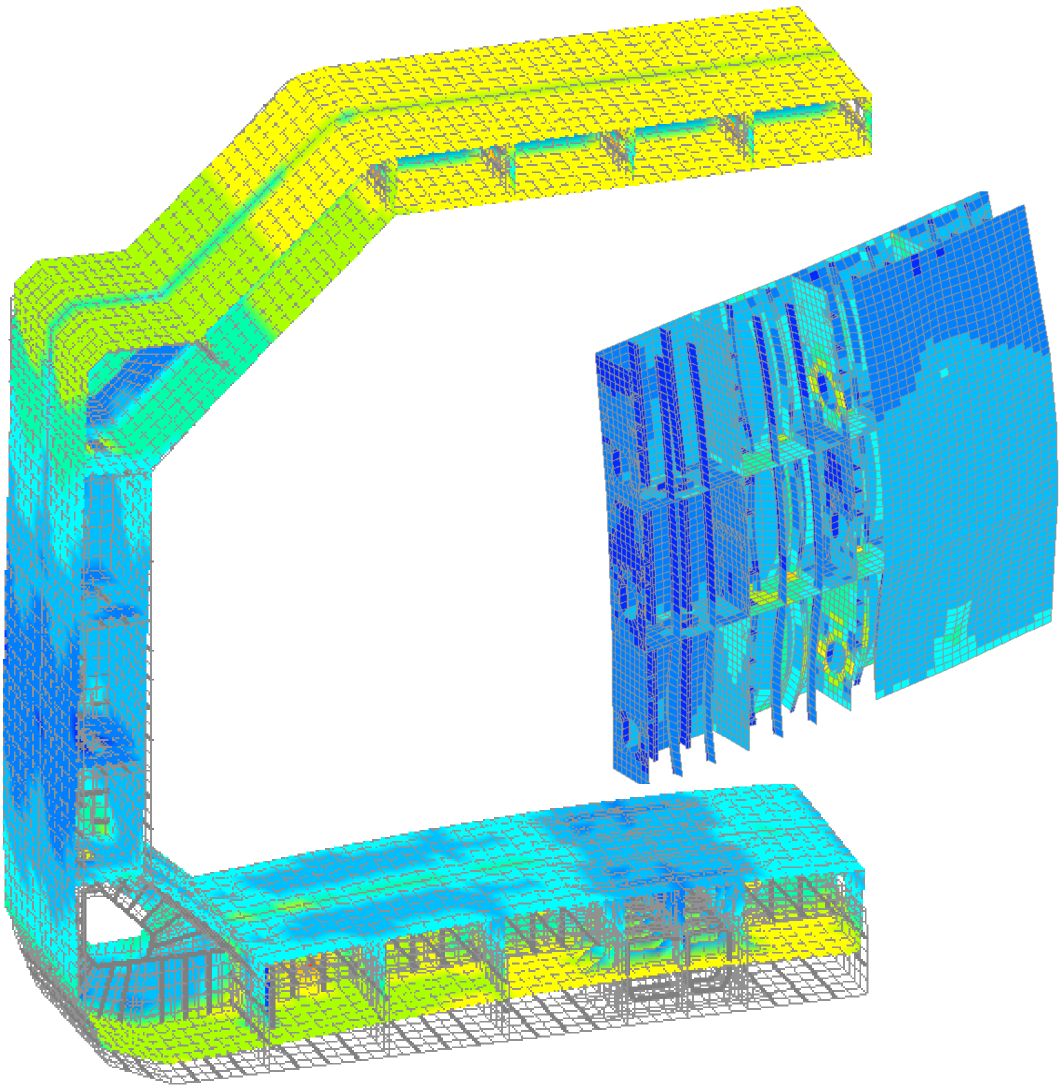


Figure 6.12: Fine mesh results - Examples of deformed structure



6.6 Fatigue analysis

6.6.1 Connections of longitudinal ordinary stiffeners with transverse primary supporting structures

The fatigue behaviour of the connections between longitudinal ordinary stiffeners has been analysed by considering the following loads:

- hull girder vertical and horizontal bending moment;
- external wave pressures;
- internal pressures due to the inertial forces originated by the ship's longitudinal, transverse and vertical accelerations.

The nominal stress ranges take into account the following stress contributions:

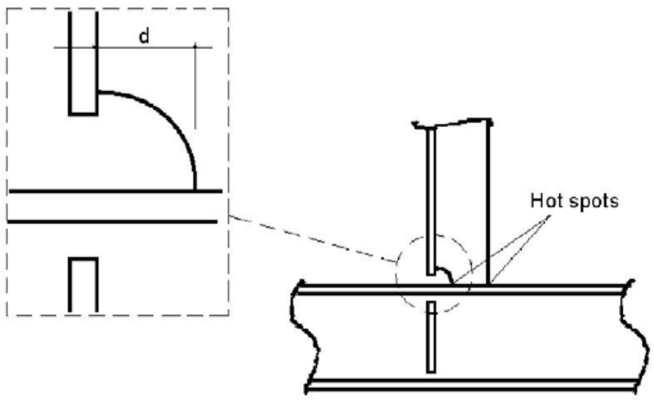
- axial stresses due to the hull girder bending moments, both vertical and horizontal,
- bending stresses induced by the local wave loads supported by the stiffener.

The hot spot stress ranges have been calculated by multiplying the nominal stress ranges induced in the considered connections by the hull girder and local wave loads by the SCF's defined by the Rules for this specific type of connections. They are indicated in Table 6.4, which is an extract from the Rules, together with the other relevant Rules requirements.

Table 6.4: Connection of ordinary stiffeners with transverse primary supporting structures

ALL LONGITUDINALLY FRAMED SIDE SHIPS

AREA 1: Side between $0{,}7T_B$ and 1,15T from the baseline	**Connection of side longitudinal ordinary stiffeners with stiffeners of transverse primary supporting members - No bracket**	**Sheet 1.7** *(1/1/2001)*



t = minimum thickness between those of:
- web of side longitudinal,
- stiffener of transverse primary supporting member.

SCANTLINGS:	**FATIGUE:**
d to be as small as possible, maximum 35 mm recommended.	Fatigue check to be carried out for L ≥ 150 m: $K_h = 1{,}3$ $K_f = 1{,}65$

CONSTRUCTION:	**NDE:**
Misalignment (measured between the outer edges) between longitudinal and web stiffener to be in general equal to or less than 0,7 t. For bulbs, a misalignment equal to 0,8 t may generally be accepted.	Visual examination 100%.

WELDING AND MATERIALS:

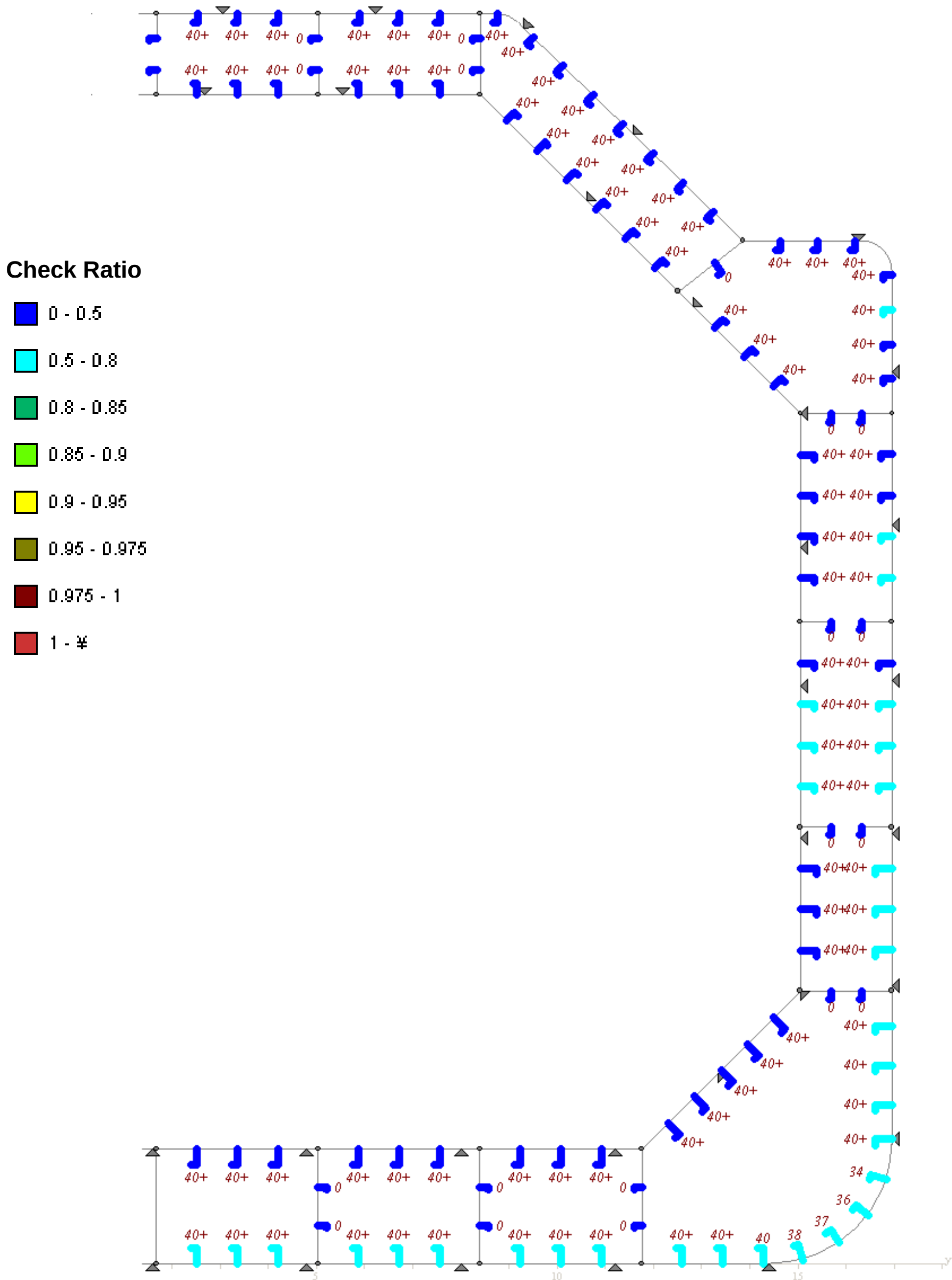
Welding requirements:
- continuous fillet welding,
- throat thickness = 0,45 t_W , where t_W is the web stiffener thickness,
- weld around the stiffener's toes,
- fair shape of fillet at toes in longitudinal direction.

For the connections between longitudinal ordinary stiffeners and transverse primary supporting structures, the Rules fatigue check criteria may be expressed in terms of required net section modulus for the ordinary stiffeners.

A summary of the main results is shown in Figure 6.13, where, for each ordinary stiffener, are indicated both the fatigue usage factor, i.e. the ratio between the required and the offered net section modulus of the stiffener, and the fatigue life of the connection detail.

The results presented indicate that the connections between longitudinal ordinary stiffener and transverse primary supporting structures (both reinforced rings and transverse bulkheads) have fatigue life greater than 40 years, which satisfies the Rules requirements.

Figure 6.13: Fatigue analysis results – Usage factors and fatigue life of connections of longitudinal ordinary stiffeners with transverse primary supporting structures



6.6.2 Connections between primary supporting members

The procedure has been applied to investigate the fatigue behaviour of the connections between primary supporting members. The global three dimensional model subject to the cyclic fatigue loads, has allowed to identify the areas characterised by the highest cyclic stresses. These areas resulted to be:

- the connection of the inner bottom with the inner side sloping plate, see Figure 6.14, Hot spot 1,
- the connection of the inner side sloping plate with the inner side, see Figure 6.14, Hot spot 2.

Figure 6.14: Fine mesh analysis - Hot spots

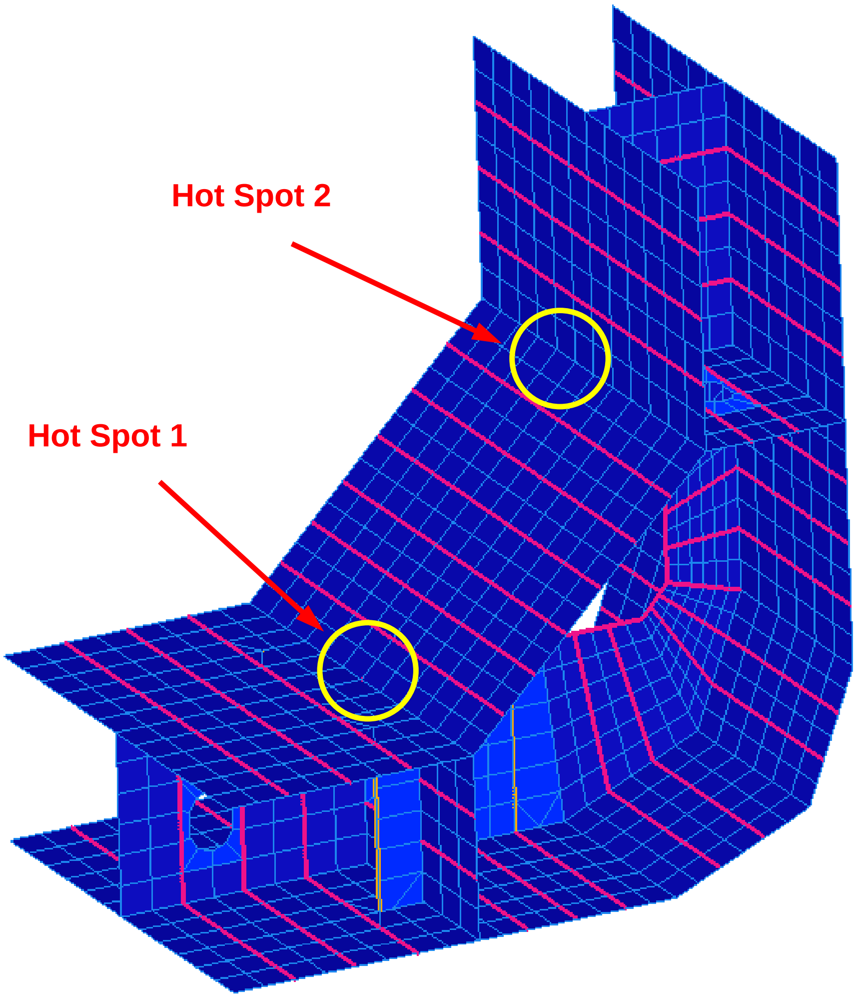


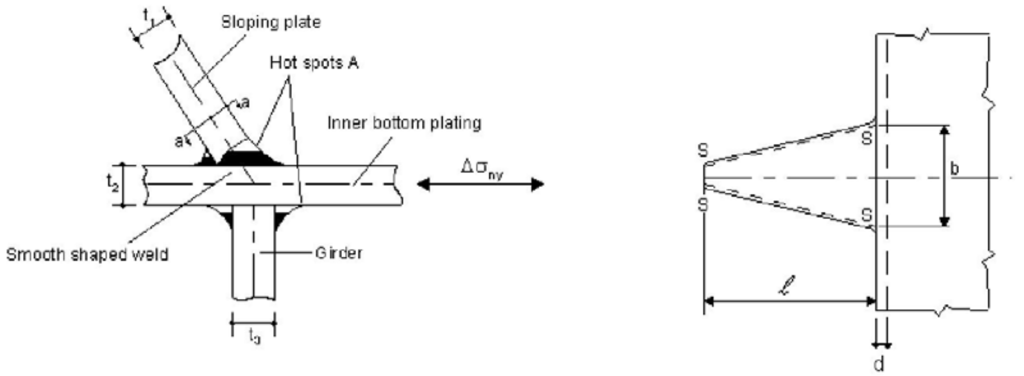
Table 6.5 is an extract of Rules indicating parameters and requirements relevant to calculation of the hot spots in way of the connection between inner bottom and hopper tank sloping plates.

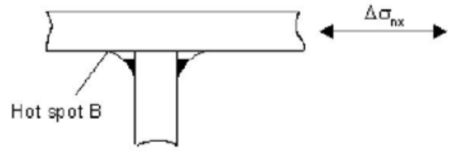
The fatigue analysis has pointed out that the fatigue life of the connection between the primary supporting members is greater than 40 years, which satisfies the Rules requirements.

Table 6.5: Connection of inner bottom with hopper tank sloping plates

LIQUEFIED GAS CARRIERS

AREA 4: Double bottom in way of hopper tanks	Connection of inner bottom with hopper tank sloping plates - Prolonging brackets	Sheet 4.6





Section a - a

Hot spot stresses:

- At hot spot A: $\Delta\sigma_{SY} = K_{SY} \cdot \Delta\sigma_{nY}$
- At hot spot B: $\Delta\sigma_{SX} = K_{SX} \cdot \Delta\sigma_{nX} + K_{SYX} \cdot \Delta\sigma_{nY}$

$t_A = \min (t_1, t_2, t_3)$,

t_B = minimum among:

- floor thickness,
- hopper transverse web thickness,
- t_3.

SCANTLINGS:

- Inner bottom plating to be prolonged within the hopper tank structure by brackets as shown in the sketch.
- $d \geq 50$ mm.
- Guidance values, to be confirmed by calculations carried out according to Ch 7, Sec 3:
  - thickness of the above brackets $\geq t_2$,
  - $b \geq 0,4$ times the floor spacing,
  - $\ell \geq 1,5b$.

FATIGUE:

Fatigue check to be carried out for $L \geq 150$ m:

- $K_{SY} =$ 2,4 where closed scallops
  3,4 where open scallops
- $K_{SX} =$ 1,3
- $K_{SYX} =$ 1,5

CONSTRUCTION:

- Misalignment (median lines) between girder and sloping plate $\leq t_A / 3$, max 6 mm.
- Misalignment (median lines) between floor and hopper transverse web $\leq t_B / 3$, max 6 mm.

NDE:

The following NDE are required:

- VE 100%,
- UE 35% of full penetration weld for absence of cracks, lack of penetration and lamellar tears.

WELDING AND MATERIALS:

- Welding requirements:
  - sloping plate to be connected with full penetration welding to inner bottom plating, except in way of void spaces where partial penetration may be accepted,
  - prolonging brackets to be connected with full penetration welding to inner bottom plating
  - approval of the procedure on a sample representative of the actual conditions foreseen in production,
  - welding sequence against the risk of lamellar tearing,
  - weld finishing well faired to the inner bottom plating on tank side.
- Material requirements:
  - the strake of inner bottom plating in way of the connection is to be of Z25/ZH25 or of a steel of the same mechanical performances. In particular cases, grade E/EH low temperature steel may be accepted by the Society provided that the results of 100% UE of the plate in way of the weld, carried out prior to and after welding, are submitted for review,
  - material properties of prolonging brackets to be not less than those of the inner bottom plating.

7 GLOSSARY

Boil off – Liquid vaporisation due to heat transfer into a cargo which is transported near its boiling point

Bunkers – Crude based Fuel oil for ships, loaded from Jetty or Barge

Cooling Down – The operation of cooling down cargo tanks after gassing up, by spraying LNG liquid at a predefined and controlled rate, in order to prepare tanks for loading a cargo

Force Vaporisation – The practice of vaporising LNG liquid using a heat exchanger, to provide extra vapour to burn as fuel in addition to NBO

Gas Freeing – The removal of toxic gas (IG) from a tank, followed by the introduction of fresh air

Gassing Up – The operation of replacing an inert atmosphere in a tank with a suitable quantity of warm methane vapour

Heel – An amount of cargo left in the tanks after discharge, quantity calculated to keep tanks cold on ballast passage

INVAR – A metal composed of 63% iron and 36% nickel which has a negligible coefficient of expansion. Used for Gaz Transport tank membranes and the balance wheels in clocks

Inerting – the reduction of flammable vapour content, by the introduction of inert gas, to a level below which combustion cannot be supported if aeration takes place

Inert Gas – A single gas, such as nitrogen, or a mixture of gases containing insufficient oxygen to support combustion

Membrane Tank – A container for LNG comprising a thin metallic liquid-tight lining, completely supported by load-bearing insulation. This, in turn, is supported by the structure of the ship

NBO – Natural Boil-Off

Reliquifaction – Converting cargo boil off vapour back to liquid by refrigeration

Safe Reserve – A quantity of Fuel Oil over and above the amount required to carry out a voyage – usually expressed in days steaming at full charter party speed

Vaporiser – A heat exchanger used to vaporise liquid gases

Warming Up – The operation of replacing cold methane vapour/liquid in a tank with warm methane vapour