Guide for the Structural Design of Oil Tankers

Effective from 1 January 2016

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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.

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1. INTRODUCTION

1.1 General

These Guidelines, jointly developed by Tasneef and RINA, are relevant to the design of tankers and are primarily intended for the technical staff of shipowners or independent consultants, in charge of management and supervision of new ship construction projects, specification development or maintenance of ships in service. The purpose of these Guidelines is to identify the main factors that are likely to be of principal concern regarding the structural design of any newbuilding project. The Guidelines also highlight the relevant class services offered by Tasneef.

The structural design of an oil tanker is a complex process, in which the strength related problems are to be solved taking into account the ship's particular characteristics due to the dangerousness of the cargo. The paramount importance of protecting the safety of the personnel involved in ship operations, as well as the environment, has led regulatory bodies to develop "ad-hoc" rules, which address the various risks in order to reduce their occurrence probability to the minimum.

In addition to SOLAS, the MARPOL requirements that dictate the arrangement, volume and location of cargo and ballast spaces are the most exhaustive set of criteria to be taken into account by the designer at the time the ship's general arrangement is defined. As they impose limits on the double bottom and double side dimensions, they also directly affect the ship's structural arrangement and strength.

The need to adopt permanent means that allow easy access and escape from all the spaces, as well as effective inspection and maintenance, requires manholes of the prescribed dimensions to be made in the ship's primary supporting structures, such as bottom girders and floors, side diaphragms and bulkhead girders. The manhole location is to be adequately assessed, in order to prevent their presence from increasing the load induced stresses above the allowable limits and improved access from weakening the structural strength.

Side longitudinal girders are also to be adequately spaced to allow easy access to the side and inner side structures. Their number and location have a direct influence on the double side behavior, in particular for large ships.

From a pure strength point of view, the oil tanker structural arrangement is, in general, quite regular, with closed type transverse sections and no large differences between the inertia of the various parts (bottom, side, deck and bulkheads). As a consequence, its analysis does not present outstanding problems that deserve specific analyses to be carried out, such as, for example, the warping behavior of container ships or the interactions between double bottom, deck and bulkhead structures of bulk carriers. However, the imperative need to prevent the risk of external oil spill and internal space contamination requires the adoption of the most effective structural solutions in terms of construction, in-service performance and maintenance.

These aspects affect the design of all structural items, from hull girder longitudinal strength to the connections between the structural elements and the detailed analysis of their fatigue behavior.

These Guidelines contain the results of structural design studies, concerning the steel grades, spacing of primary supporting members and ordinary stiffeners and design of transverse bulkheads, carried out for some typical oil tanker designs. The governing factors are reviewed, in the light of the considerations expressed in the above paragraphs: selection of design loading conditions, ultimate strength of the hull girder, fatigue of structural details and strength of the crossing arrangement between different structures such as longitudinal and transverse bulkheads. Advice to owners when drawing up the specification of new building orders is also given.

In addition, the Guidelines review the main characteristics of corrosion in oil cargo tanks and examine the most efficient means to prevent it, giving advice on the actions to be taken at the design and construction stages and while the ship is in service. As far as ballast tank corrosion is concerned, it is recalled that its main features and the relevant protection means are dealt with in the Tasneef "Guide for the selection, application and maintenance of corrosion prevention systems of ships' ballast tanks", which can be consulted for more specific information.
All the examples or case studies developed in these Guidelines meet the requirements of the Tasneef Rules for Classification of Steel Ships and the applicable requirements of the SOLAS and MARPOL Conventions. However, the Guidelines are not to be interpreted as guidance for design or construction, as there are existing class requirements, industry standards or international codes covering these aspects. It is intended to serve as a collection of points to be taken into account when establishing a specification for a newbuilding or an inspection and maintenance plan for an existing ship.

1.2 Class Service Notations

According to the Rules, the service notation **oil tanker** is assigned to a ship of the type defined in 2.1, when she fulfils the Rule general requirements in Parts B, C and D, applicable to all ship types, and the specific requirements in Part E, Chapter 7. The service notation **oil tanker** is always integrated by the additional service feature **ESP** (i.e. **oil tanker ESP**), which means that these ships are subject to the Enhanced Survey Program. Depending on the type of products she is entitled to carry, a ship with the service notation **oil tanker** may be assigned the additional service features **flash point > 60°C** or **asphalt carrier**, where the ship is intended to carry only this type of product. The specific additional requirements for these ships are detailed in Part E, Chapter 7.

Ships complying with the requirements of the IBC Code, as well as with the other applicable Rule requirements, are assigned the service notation **chemical tanker**. The Rule specific requirements for these ships are contained in Part E, Chapter 8. As for oil tankers, the service notation is integrated by the additional service feature **ESP** (i.e. **chemical tanker ESP**) for chemical tankers.

When a ship is entitled to carry both oil products and chemical products, as specified above, she is granted both service notations **oil tanker ESP** and **chemical tanker ESP**. For the sake of simplicity, this type of ship is identified as **“product tanker”** in these Guidelines.

1.3 Additional Class Notations related to the structural arrangement

1.3.1 General

Additional class notations identify those ships that are fitted with certain equipment or arrangements, indicated in the Rules and specifically requested by the owner. These notations may be granted by Tasneef to any individual ship to testify that her characteristics or structural arrangements allow specific services to be carried out, which are not compulsory as far as classification is concerned.

The assignment of an additional class notation is subject to compliance with the relevant Rule requirements, which are detailed in Part F of the Rules.

The following paragraphs illustrate the additional class notations that may be assigned to oil tankers or product tankers, related to their structural arrangement.

1.3.2 Additional Class Notations STAR-HULL and STAR-HULL NB

❒ ***Star-Hull***

The additional class notation **STAR-HULL** is assigned to ships for which a suitable Inspection and Maintenance Plan of hull structures and equipment, hereinafter defined as “IMP”, is prepared in co-operation by the owner and Tasneef.

The purpose of the IMP is to establish the procedures for periodical and occasional inspections of hull structures and equipment, to be carried out on board by the crew, and to check the relevant inspection results.

The IMP is to specify the list of areas, spaces and hull equipment to be inspected, the periodicity and extent of inspections and maintenance planned for each area, space or equipment and the information to be given in the inspection reports, to be submitted to Tasneef upon completion of the inspection. The specific Rule criteria, the results of structural analyses and the owner’s experience are taken into account in preparing the IMP.

The IMP is to contain the “hot spot map”, i.e. the list of hull structural elements for which the structural analyses have shown significant stress levels or fatigue life of structural details close to the design one. The “hot spot items” are to be monitored with particular attention during the inspections carried out on board by the crew.

For this reason, the assignment of this notation implies that all the detailed structural analyses required to assign the notation **STAR-HULL NB**, described below, have been performed for the "new building state" and their results have been used to identify the "hot spot items".

The surveys for the renewal of the **STAR-HULL** notation are carried out concurrently with the class renewal surveys. On the occasion of this survey, the "as-inspected state" of the ship is established, which reflects the actual state resulting from the measured thicknesses of the structural elements. A structural reassessment of the "as-inspected state" is thus performed, by carrying out the same structural analyses applied to the "new building state" and adopting specific acceptance criteria defined by the Rules.

In this way, when deciding possible corrective actions, such as steel renewal or repairs, the behavior and the interactions between the structural elements are examined taking their actual state explicitly into account. Furthermore, a new "hot spot map" is defined on the basis of the analysis results, if necessary, and the IMP is modified accordingly.

The acceptance criteria for the structural element thickness diminution, due to corrosion, are those adopted for the assignment of Rating 2 according to the Tasneef "Guide for the Ship Condition Assessment Program" (CAP).

It is to be noted that the IMP outcome and the results of the structural assessments carried out for the "new building" and for the "as-inspected" states can be used to plan the surveys and address the close-up inspections called for by the Enhanced Survey Program (ESP) requirements.

❒ *Star-Hull NB*

The notation **STAR-HULL NB** is the most significant with respect to the strength analyses that are carried out at the design stage. As a matter of fact, a ship may be assigned this additional class notation when her structures are analyzed by means of the most advanced tools, implying that the following checks are fulfilled.

- The hull girder has a global strength that is capable of sustaining the design still water and wave loads (bending moments and shear forces) acting in each ship's transverse section. The analysis investigates also the behavior of the hull girder if the loads are such as to induce stresses above the yielding limit and takes the buckling behavior of compressed elements into account. This means that the hull girder ultimate strength is evaluated and compared with the extreme loads the ship is subjected to during her life.

- The local structural elements (plating, ordinary stiffeners and primary supporting members) are checked against the most severe combination of stresses due to the hull girder loads, the internal pressures induced by the cargo or ballast carried and the external sea pressures. In calculating the internal pressures, the inertia effects due to the ship motions are explicitly taken into account. Ship motions are also taken into account in calculating the wave induced sea pressures, by means of Rule formulae in which the ship parameters that govern her behavior at sea are introduced.

- The structural strength is checked against the relevant limit states: yielding, buckling and ultimate strength. Primary supporting members are analyzed by means of Finite Element calculations, which allow the load repartition and structural interactions between the different elements to be correctly taken into account. Different structural models are adopted, depending on the type of structures under investigation.

- The fatigue life of the most significant 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 Rule criteria and checked against the design values. For the connections between primary supporting members, the fatigue analyses utilize the results of the Finite Element calculations, thus improving the precision and reliability of the results obtained.

- The renewal thicknesses, to be used on the occasion of a Class Survey involving thickness measurements, are calculated on the basis of the results of the strength analyses. In this way, any extra margin provided by the owner may be taken into account and the areas most susceptible to corrosion, as a consequence of the anticipated stress level, are highlighted. These results are used to address the close-up surveys and thickness measurements.

The structural analyses required by this notation are subdivided into three phases, which are carried out by software programs developed for these purposes.

a) Phase 1

   During this phase, the structural analysis of ship plating and ordinary stiffeners is carried out on the basis of the Rule formulae.

   The structural analysis is carried out according to the Rule criteria, considering the still water and wave loads induced by the sea and cargoes carried. The above criteria include the hull girder and local strength checks of structural elements versus yielding, buckling and ultimate strength criteria.

   Moreover, Phase 1 includes the evaluation of the fatigue life of the structural details relevant to 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 taken into account.

b) Phase 2

   Phase 2 corresponds to the structural analysis of a ship's primary supporting members carried out by means of Finite Element calculations on the basis of the Rule criteria.

   Finite Element calculations are performed on:

- global three dimensional models of the ship's cargo tanks,
- 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,
- localized areas to evaluate the fatigue life of the structural details representing the connections between the various structural elements.

c) Phase 3

This phase concerns the evaluation of the renewal thicknesses based on the results of the strength analyses carried out during Phase 1 and Phase 2.

1.3.3 Other Additional Class Notations

❐ ***Sea pollution prevention (CLEAN-SEA)***

The additional class notation **CLEAN-SEA** is assigned to ships provided with construction and procedural means to prevent sea pollution. This is achieved by compliance with the applicable requirements of Annex I, Annex II, Annex III, Annex IV and Annex V of the MARPOL Convention, relevant to a ship's liquid and solid releases, as well as with the additional Tasneef requirements related to prevention of sea pollution, as illustrated below:

- prevention of accidental pollution by means of protected location of fuel and lubricating oil tanks above the double bottom and away from the ship's sides,
- prevention of operational pollution by means of bilge water separation and filtering, holding tanks for treated sewage and grey water,
- prevention of transfer of harmful organisms and pathogens in the ballast water,
- prevention of pollution caused by tributyltin by means of TBT antifouling paints,
- prevention of pollution caused by solid garbage (resulting from the compacting device and incinerators) by means of proper storage of such waste, for disposal to reception harbor facilities.

❐ ***Air pollution prevention (CLEAN-AIR)***

The additional class notation **CLEAN-AIR** is assigned to ships provided with construction and procedural means to prevent air pollution. This is achieved by compliance with the applicable requirements of Annex VI of the MARPOL Convention, as well as with additional requirements related to low emissions to the air as indicated below:

- prevention of air pollution caused by exhaust gas (particles, COx, NOx, SOx) by means of low emission engines, use of low sulfur content fuels and incinerators,
- use of refrigerants and fixed fire-fighting means with zero ozone depleting potential and low global warming potential,
- control of release of refrigerants to the atmosphere by means of leak detection and evacuation systems,
- recovery of vapors emitted from cargo systems of ships carrying dangerous liquid cargoes in bulk.

❒ *Navigation in ice*

Additional class notations may be granted to ships strengthened for navigation in ice in accordance with the Ice Class Rules published by the Finnish and Swedish authorities.

The following additional class notations are applicable:

- **ICE CLASS IA SUPER**, for navigation in extreme ice conditions,
- **ICE CLASS IA**, for navigation in severe ice conditions,
- **ICE CLASS IB**, for navigation in medium ice conditions,
- **ICE CLASS IC**, for navigation in light ice conditions.

Furthermore, the additional class notation **ICE CLASS ID** is assigned to ships whose reinforcements for navigation in light ice conditions do not cover the whole ship's length, as required for the assignment of the notations defined above, but which comply with the specific requirements of the Rules.

Finally, the additional class notation **ICE** is assigned to ships whose reinforcements for navigation in ice are different from those required by the above notations and are specially considered by Tasneef.

❒ *In-water survey*

The additional class notation **INWATERSURVEY** may be assigned to ships provided with suitable arrangements to facilitate in-water surveys as described in Pt A of the Rules.

❒ *Single point mooring*

The additional class notation **SPM** (Single Point Mooring) may be assigned to ships fitted with a specific mooring installation complying with the provisions of "Recommendations for

Equipment Employed in the Mooring of Ships at Single Point Mooring" (3rd edition 1993), issued by OCIMF (Oil Companies International Marine Forum).

1.4 Double hull tanker characteristics

1.4.1 General

For the purpose of these Guidelines, oil tankers are ships intended to carry crude oil in bulk, other oil products or oil-like substances having any flashpoint or being liquid at atmospheric pressure and ambient temperature (or so maintained by heating). The products carried by oil tankers are listed in Annex 1 of the MARPOL 73/78 Convention and are also reported in Pt E, Ch 7, App 3 of the Rules[1].

Frequently, oil tankers below 45000 dwt are also entitled to carry chemical products, normally of IMO Type 3 or, less frequently, Type 2, where these types of products are defined in the International Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk (IBC Code), which chemical tankers are to comply with.

Six types of tankers can be identified, depending on their size, as shown in Table 1.

Table 1: Tanker types.

Tanker type	Deadweight range, in t	Typical deadweight value, in t	Characteristics
Handy	30.000 – 45.000		Product tankers, in general, entitled to carry also IMO Type 2 or 3 chemical products. They include recent designs of medium size, shallow water tankers for oil and chemical products.
Panamax	55.000 – 70.000	60.000	70.000 dwt is the maximum size tanker able to transit the Panama Canal. The need to pass through a series of Canal locks dictates a maximum length of 274,3 m and a maximum breadth of 32,3 m.
Aframax	75.000 – 120.000	110.000	"AFRA" stands for "Average Freight Rate Assessment". At one time the term Aframax was used to refer to ships up to 79999 dwt, the upper limit of one of six deadweight groups for which the AFRA rate is assessed. Aframax has since become a general term for ships in this overall size range.
Suezmax	120.000 – 200.000	150.000	Tankers generally identified as those capable of transporting one million barrel cargoes.
Very large crude carriers (VLCCs)	200.000 – 320.000	280.000	Tankers able to transport large volumes of oil, including two million barrel cargoes, over relatively long distances.
Ultra large crude carriers (ULCCs)	above 320.000	400.000	Tankers able to transport very large volumes of oil, up to three million barrel cargoes.

[1] Naphtha solvent, which is included in the above list of MARPOL products, is to be considered as a chemical product.

1.4.2 Cargo tank arrangement

In double hull oil tankers, the cargo area is separated from the sea by double side and double bottom spaces dedicated to the carriage of ballast water. For oil tankers, the requirements relevant to cargo area protection, which in large part dictate the cargo, slop and ballast tank arrangements, are detailed in Pt E, Ch 7, Sec 2 of the Rules, which replicate and integrate the requirements of MARPOL Annex I Regulation 13F.

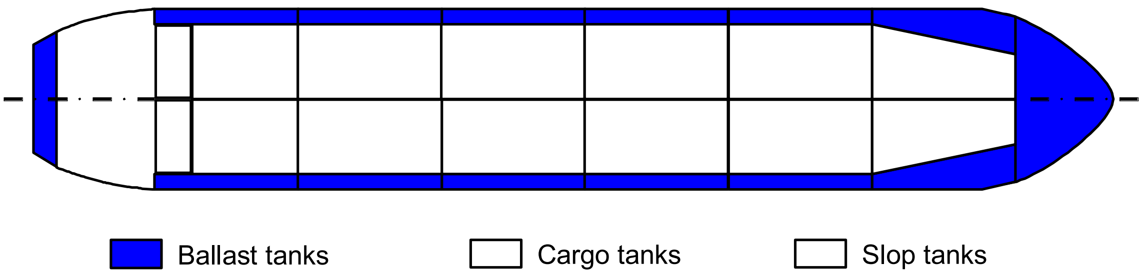
As the MARPOL requirements depend on the ship's size and deadweight, the cargo area arrangement is not uniform:

- for ships up to 5000 dwt, the double side is not necessarily required. Indeed, it depends on the cargo tank capacity, while the double bottom is required and has to have a height neither less than the ship's breadth divided by 15 nor 760 mm,

- for ships over 5000 dwt, the double side is compulsory. Indeed, it is required that its width ranges between 1,0 m and 2,0 m for ships below 20000 dwt and remains constant and equal to 2,0 m for ships above this deadweight. The double bottom height is not to be less than the lesser of B/15 (B is the ship's breadth) and 2,0 m, but in any case not less than 1,0 m.

Typical cargo and ballast tank arrangements for the various oil tanker types are shown in Figures 1 and 2.

Figure 1: Cargo and ballast tank arrangement for tankers up to Suezmax size.



For tankers up to the Suezmax size, the number of tanks normally ranges between 5 and 9, depending on the owner's wishes regarding cargo segregation.

For larger ships (i.e. the VLCCs or the ULCCs), the above strength and stability considerations generally lead to the adoption of two longitudinal bulkheads, which subdivide the cargo areas into centre cargo tanks, portside and starboard wing cargo tanks. This solution also allows longer tanks to be adopted, according to the MARPOL requirements regarding the maximum permissible tank lengths, summarised in Table 2. As a consequence, ships of this type normally have 5 to 6 centre and wing cargo tanks, which are enough for the limited necessity of cargo segregation associated with this type of ship. Some designs have also been developed with one centreline bulkhead and shorter cargo tanks.

Figure 2: Cargo and ballast tank arrangement for VLCCs and ULCCs.

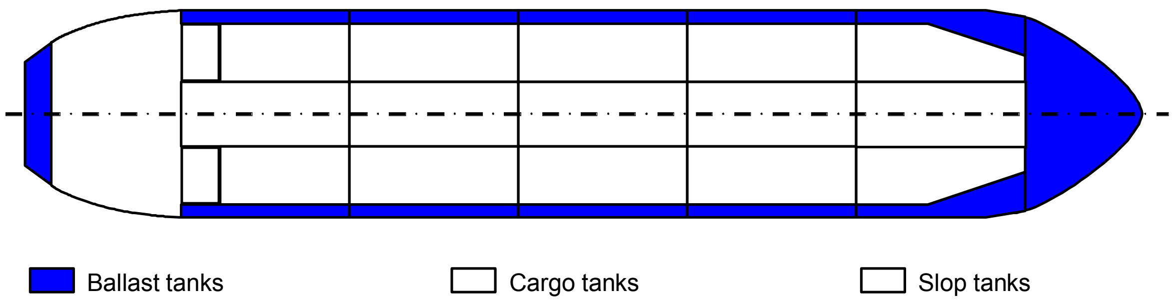


Table 2: Length of cargo tanks.

Longitudinal bulkhead arrangement	Cargo tank	Condition (1)	Centreline bulkhead arrangement	Length of cargo tanks, in m
Centreline bulkhead	---	---	---	$(0,25\ b_i / B + 0,15)\ L$
Two or more bulkheads	Wing cargo tanks	---	---	0,2 L
	Centre cargo tanks	$b_i / B \geq 1/5$	---	0,2 L
		bi / B < 1/5	No	$(0,5\ b_i / B + 0,1)\ L$
			Yes	$(0,25\ b_i / B + 0,15)\ L$

(1) b_i is the minimum distance from the ship side to the outer longitudinal bulkhead of the i-th tank, measured inboard at right angles to the centreline at the level corresponding to the assigned summer freeboard, B is the ship's breadth.
(2) Not to exceed 0,2 L

1.4.3 Structural arrangement

The structural arrangements generally adopted for tankers have the characteristics shown in Table 3.

As far as material selection is concerned, it is to be noted that the use of higher strength steel should be limited to no more than 30% of the total ship's steel weight. However, a greater amount may be accepted provided that advanced structural analyses are carried out, such as those in accordance with the Tasneef Rules, which include a fatigue assessment of the most significant structural details.

The results of the structural analyses, in particular those relevant to buckling and fatigue strength, are used to identify the most appropriate locations for the structural elements made of higher strength steels.

Table 3: Structural arrangement for tankers of different sizes

	DWT < 45000 t	*45000 t ≤ DWT < 150000 t*	*DWT≥ 150000 t*
Framing	Longitudinal (1).	Longitudinal.	Longitudinal.
Hull arrangement	Double bottom, single deck and, for ships above 5000 dwt, double side.	Double bottom, single deck and double side.	Double bottom, single deck and double side.
Longitudinal bulkhead arrangement	Single centreline bulkhead.	Single centreline bulkhead.	Two longitudinal bulkheads (centre and wing cargo tanks), more rarely a single centreline bulkhead.
Double bottom and double side connection	Through a hopper structure in the bilge area (2).	Through a hopper structure in the bilge area.	Through a hopper structure in the bilge area.
Transverse bulkhead arrangement	Corrugated, with or without lower and upper stools. More rarely, plane with vertical ordinary stiffeners and horizontal stringers.	Corrugated, with lower and upper stools. Plane with vertical ordinary stiffeners and horizontal stringers, supported in some cases by vertical girders.	Plane with vertical ordinary stiffeners supported by horizontal stringers aligned with side girders. More rarely, ordinary stiffeners are horizontal and supported by vertical girders.
Topside structure	Generally fitted, may be omitted for smaller ships.		
Reinforced structure	Rings formed by floors, double side diaphragms and deck beams, in some cases fitted every second double side diaphragm. Deck stiffeners and beams are generally fitted above the deck to facilitate tank cleaning operations.	Rings formed by floors, double side diaphragms and deck beams. When plane bulkheads are adopted, the transverse rings also include the longitudinal bulkhead vertical girders.	Rings formed by floors, double side diaphragms, vertical girders of longitudinal bulkheads and deck beams. Cross-ties between bulkhead girders fitted in the centre tanks or in the wing tanks, in all cases in the same tanks as the bulkhead girders. When plane bulkheads are adopted, the transverse rings also include the longitudinal bulkhead vertical girders.
Double bottom and double side girder arrangement	Fitted to form part of the hopper and topside structures' boundaries and to adequately connect the transverse rings. The inner bottom may be inclined towards the centreline, where suction wells are fitted, to facilitate tank cleaning by reducing the amount of cargo that remains trapped within the corrugation.	Fitted to form part of the hopper and topside structures' boundaries and to adequately connect the transverse rings.	Double bottom girders fitted at the centreline and at the side boundary of the hopper structure. Double side girders fitted at the upper boundary of the hopper structure and vertically spaced, so as to enable an adequate connection of the double side vertical diaphragms and to facilitate inspection of the double side compartments.
(1) Transverse framing may be adopted at side and longitudinal bulkheads for small tankers. (2) The hopper structure improves the structural transition between the double bottom and the double side structures. In smaller ships, direct connection between double bottom and double side is normally adopted.			

1.5 Ships considered in these Guidelines

The case studies in these Guidelines are analyzed with reference to the design of three oil tankers of different sizes and dimensions:

- a product tanker of 35000 dwt,
- an Aframax tanker of 105000 dwt,
- a VLCC of 300000 dwt,

whose characteristics are described below. The main dimensions and structural characteristics of each ship are derived from typical designs of ships of the same type, without referring to a specific existing design.

It is considered that this sample of ships (shown in Table 4) provides an overview of the possible design features, which is sufficiently ample to reach conclusions applicable also to the design of tankers of different sizes or arrangements.

Furthermore, each ship's arrangement may be characterized by the following properties:

❒ ***Tank arrangement:***

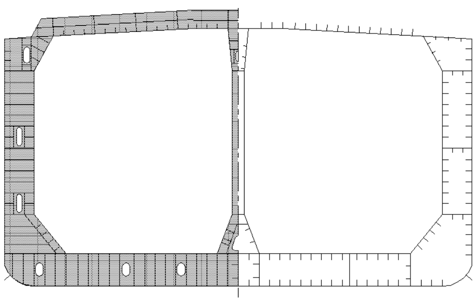
- the product tanker has six couples of cargo tanks and two slop tanks, considered as being transversely and longitudinally separated by corrugated or plane bulkheads, with or without lower and upper stools,
- the Aframax has six couples of cargo tanks and two slop tanks, considered as being transversely and longitudinally separated by plane or corrugated bulkheads,
- the VLCC has six cargo tanks over the cargo area. The cargo area is transversely subdivided in one centre and wing cargo tanks by means of two plane longitudinal bulkheads. The cargo area also includes two slop tanks.

❒ ***Density of transported cargoes:***

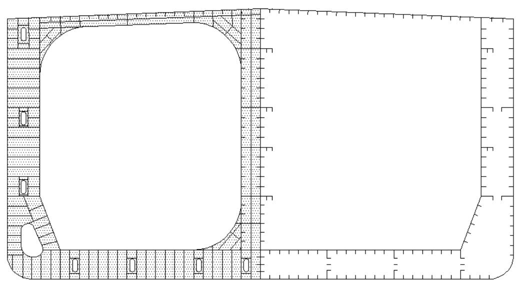
- for the product tanker, the maximum density of cargoes considered in full cargo tanks, slop tanks and recovery tanks is 1,025 t/m3. Cargoes whose density is up to 1,5 t/m3 may be transported in partially filled tanks, provided that the total amount of cargo in each tank does not exceed the value corresponding to the tank completely filled with 1,025 t/m3 density cargo,
- for the Aframax and the VLCC, the density of cargoes transported is 0,9 t/m^3.

Table 4: Main characteristics of the ships considered in these Guidelines

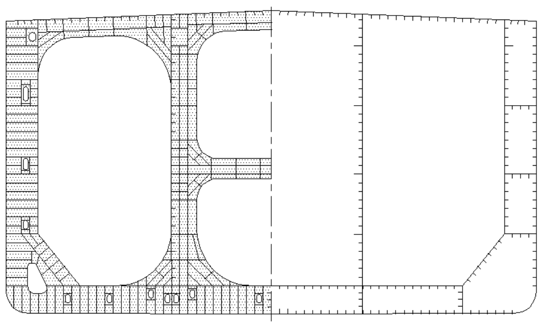
		Product tanker	Aframax	VLCC
Length in m		169,49	229,4	315,82
Breadth in m		32,0	42,0	58,0
Depth in m		16,2	21,2	31,0
Draught (design) in m		9,0	14,9	20,8
Draught (scantling) in m		9,5	14,9	22,0
Block coefficient		0,83	0,83	0,82
Design SWBM, in kN.m	Hogging	1 030 000	2 500 000	7 553 700
	Sagging	784 800	2 300 000	6 160 700



Product tanker design



Aframax tanker design



VLCC design

2. LOADING CONDITIONS

2.1 General

A sound design requires that the ship's structures be checked in all aspects against the local and hull girder loads they are subjected to in the most severe ballast and cargo loading conditions. This does not apply only for the determination of the still water components of loads, but also for the calculations of the wave induced inertial forces and sea pressures.

In order that the design allows the ship her necessary operational flexibility, the loading conditions taken as the basis for the design load calculations are to be appropriately selected. This is valid, in particular, for the determination of the hull girder still water bending moments and shear forces, as well as for the loading distributions to be considered in the structural analysis of primary supporting members, when this is carried out on the basis of three dimensional Finite Element calculations.

Based on that, some aspects are highlighted in 2.2 that should be appropriately taken into account when defining or evaluating the design loading conditions for a new project.

The casualty statistics show that collisions and grounding, in most cases linked with navigation errors and loss of propulsion or manoeuvrability, are the main causes of hull damages and consequent oil spills. To avoid catastrophic effects on the environment, it is therefore extremely important that a possible breach caused by collision or grounding does not result in the overall hull failure, due to the progressive collapse of the elements that constitute the resisting longitudinal structures. From a design point of view, this means that the ultimate strength of the hull girder is to be such as to resist to the loads acting on it, taking into account the possible increase in the still water hull girder bending moment due to the ingressed water.

The appropriate damaged scenarios and the effects of ballast tank flooding when the ship is in different loading conditions are discussed in 2.3.

2.2 Intact conditions

2.2.1 Loading conditions for the scantling of ship structures

Among the key parameters of the structural design, the values of the design still water bending moments and, to a lesser extent, shear forces have great consequences on the ship's in service operation. For these reasons, the loading conditions envisaged at the design stage should be adequately defined so that the possible future conditions in which the ships will operate are reproduced. In this way, one is guaranteed that the structures are designed to sustain the still water hull girder loads in all the rational cargo and ballast distributions, combined with the wave induced loads that originate during the navigation at sea.

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

- homogeneous loading conditions, with all the cargo tanks full, at the ship's scantling draught,
- any specified non-homogeneous loading condition, including partial loading conditions,
- light and heavy ballast conditions,
- mid-voyage conditions relating to tank cleaning or other operations where these latter significantly differ from the ballast conditions,
- for product tankers, conditions for high density or segregated cargo,
- chess loading conditions.

It is to be highlighted that, for the purpose of identifying the most severe design loading conditions, various ship's displacements are to be considered in addition to the full loading conditions at the scantling draught.

❐ ***Design draft***

The design draught is a contractual parameter stipulated between the Owner and the Shipyard, which corresponds to the contractual ship's deadweight for a certain cargo density. At the displacement corresponding to the design draught, the Owner requires that the ship reaches the contractual speed, at the engine continuous rating and accounting for a certain sea margin, normally about 15%.

❐ ***Scantling draft***

The scantling draught, greater than the design draught, but complying with all the Load Line and stability requirements, is that at which the ship reaches its maximum deadweight, agreed between the Owner and the Shipyard.

2.2.2 Amount of consumables

When loading conditions in which the ship is sagged are studied, the amount of consumables should be carefully considered. As consumables are normally carried at the aft end of the ship, any increase of them generally entails a reduction of the sagging bending moment. Furthermore, due to their large lever arm, even a small variation in their quantity has a significant effect on the bending moment value. For these reasons, in the design sagging conditions with homogenous loading the arrival conditions with a minimum of consumables are generally the governing conditions.

At the design stage, when the ship's weight distribution is not detailed, an amount of consumables as low as zero should be assumed for the purpose of obtaining a preliminary value of the still water bending moment for the initial assessment of the longitudinal strength. Indeed, it is to be reminded that the IMO requirements for stability verifications state that a minimum amount of consumables equal to 10% of the total values is to be assumed. It is therefore appropriate that two loading conditions, which differentiate for the amount of consumables, are considered: one, with 0% of consumables, for longitudinal strength calculations, another, with 10% of the total values of consumables, for stability calculations.

2.2.3 Fore peak tank

Due to its large lever arm, the ballast water in the forepeak tank could be used, at the design stage, to control the values of the still water hull girder bending moments and to keep them within certain values. This design practice, however, might reduce the ship's operation flexibility. In addition, 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, in November 2001, a variation in UR S11, applicable to all types of ships, requiring that:

"Ballast conditions involving partially filled peak and other ballast tanks are not permitted to be used as design conditions where alternative filling levels would result in design stress limits being exceeded. The partial filling of such tanks is, however, permitted in service to satisfy operational requirements providing design stress limits are satisfied for all conditions intermediate between 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.

If partial filling of the forepeak tank was used as a mean to keep the design sagging bending moment below a certain design value, any under-filling could entail that this limit value is exceeded.

In order to satisfy the IACS UR S11 requirements, and to avoid operational restrictions, it results that:

1) the loading conditions in which the ship is sagged are to be assessed considering the forepeak as being empty (in general these are the homogeneous loading conditions and some partial loading conditions),
2) those in which the ship is hogged (in general ballast conditions) are to be assessed considering the forepeak tank as being completely full.

It is 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 prohibited 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.

2.2.4 Partial and non homogeneous loading conditions

These loading conditions should be carefully assessed during the ship's design, taking into account her anticipated service and type of cargo transportation.

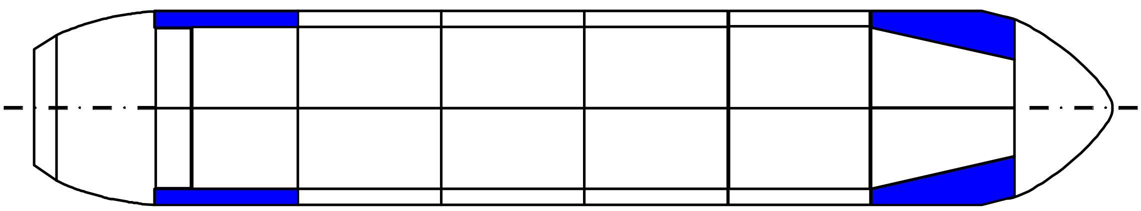
Partial and non homogeneous loading conditions are generally the most demanding for the hull primary supporting members, as they could result in high stresses originated by the unbalance between internal and external local pressures or between the pressures in two adjacent compartments. In particular, double bottom floors and girders, double side diaphragms and girders and bulkhead girders are to be carefully checked in these loading conditions. Under the effects of highly unbalanced loads, the ends of these elements tend to rotate in opposite directions, with the consequence that the interactions between the various structural elements are generally extremely demanding for the element connecting structures. To avoid stress concentrations, additional strengthening may be necessary, including fatigue resistant details. According to the Rules, the fatigue analyses are to be carried out on the basis of the stresses originated in these loading conditions.

Specific considerations on these aspects are reported in [3.1.2] and, more in detail, in Table 9, where the loading distributions to be adopted in the structural analyses of primary supporting members based on three-dimensional Finite Element models are specified. Table 9 also specifies the still water draught and hull girder loads to be associated with each loading distribution.

Partial loading conditions may also be the most severe ones for some plating and ordinary stiffeners, in particular for product tankers, as high density cargoes may be carried non homogeneously distributed.

As far as the hull girder loads are concerned, partial loading conditions induce the highest hull girder shear forces in way of the transverse bulkheads between full and empty tanks. They can also cause high sagging bending moment values. This is the case, in particular, of segregated cargo conditions of product tankers, such as the ones indicated in Figure 3 for the carriage of three different products.

Figure 3: Segregated cargo loading conditions of a product tanker.



2.2.5 Summary of loading conditions

A summary of the main loading conditions that are considered in the product tanker and in the VLCC studies is illustrated in Table 3 and Table 4, respectively. The loading conditions reported in these Tables are selected among those envisaged in the ship's Loading Manual as those that induce the highest still water bending moments.

Table 3: Product tanker – Intact loading condition.

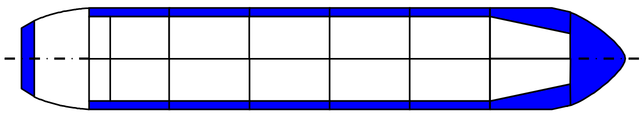
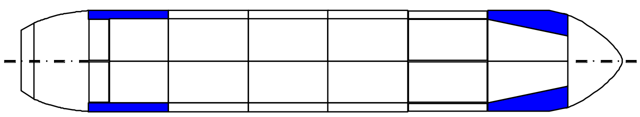
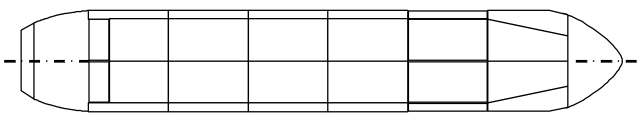
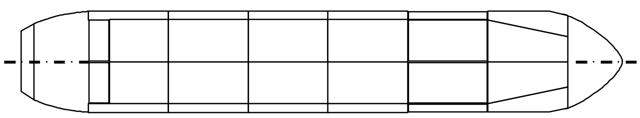
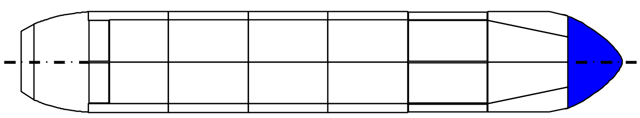
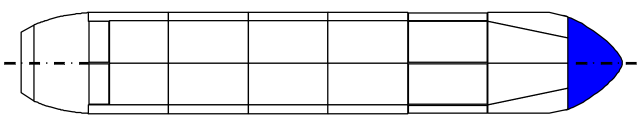
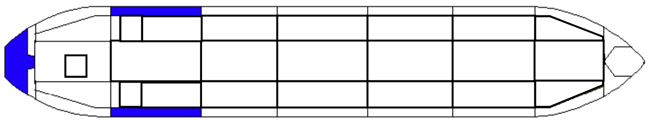
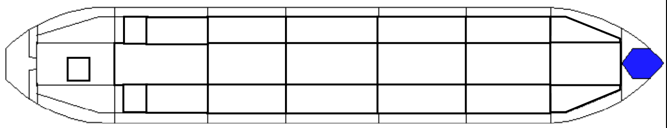
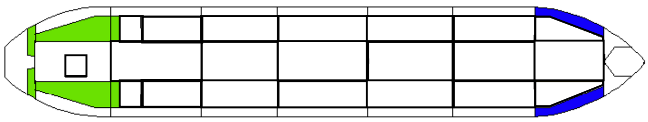
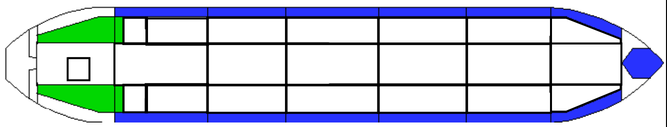
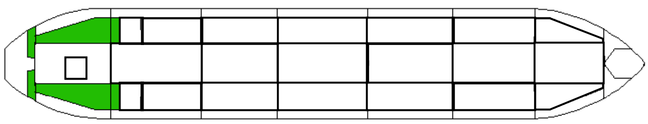
Loading condition	**Displace-ment, in t**	**Draught, in m**	**Max still water bending moment, in kN.m**
Ballast condition – Departure 	31 923	Mean:7,147 Aft: 7,649 Fwd: 6,645	961 090
Segregated cargoes – Arrival 	43 810	Mean:9,506 Aft: 9,923 Fwd: 9,090	-775 471
Homogeneous loading – Arrival 	42 043	Mean:9,180 Aft: 9,212 Fwd: 9,148	-340 721
Typical group loading – Arrival 	42 043	Mean:9,179 Aft: 9,232 Fwd: 9,127	-361 116
Alternate loading – Departure 	35 109	Mean:7,790 Aft: 7,902 Fwd: 7,678	578 476
Homogeneous partial loading – Departure 	32 783	Mean:7,321 Aft: 7,876 Fwd: 6,767	602 471

Table 4: VLCC – Intact loading condition.

Loading condition	Displace-ment, in t	Draught, in m	Max still water bending moment, in kN.m
Homogeneous loading – Arrival 	345 512	Mean:22.16 Aft: 22.10 Fwd: 22.22	-2 685 783
Partial loading – Arrival 	326 177	Mean:21.02 Aft: 21.57 Fwd: 20.46	-6 156 801
Segregated loading N°1 – Departure 	168 501	Mean:11.39 Aft: 11.93 Fwd: 10.85	4 869 388
Ballast condition – Departure 	163 744	Mean:11.24 Aft: 13.86 Fwd: 8.62	7 366 300
Segregated loading N° 1+2 – Departure 	246 955	Mean:16.30 Aft: 16.90 Fwd: 15.70	3 618 891

2.2.6 Hull girder design still water bending moments

As far as the hull girder loads are concerned, an important parameter, which governs most of the ship's structural characteristics, is the design still water bending moment. Its value, which in any case has to cover the envelope of the maximum still water bending moments calculated for the various ship's loading conditions, is to be appropriately selected in order not to limit the ship's flexibility.

At this purpose, and based on the considerations reported in the above paragraphs, it is considered that the absolute values (1) of design still water bending moments, within 0,4 L amidships, should be taken, in kN.m, not less than:

- hogging conditions: $M_{SW\,min,H} = 15CL^2B(8 - C_B)10^{-3}$
- sagging conditions: $M_{SW\,min,S} = 60CL^2B(C_B + 0{,}7)10^{-3}$

where:

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 : Rule length and moulded breadth, in m,

C_B : block coefficient.

At the first design stages, when the still water bending moments are preliminary established, it is recommended that they are defined in excess, by a suitable margin, of the largest still water bending moments calculated for the various loading conditions. 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.

By way of example, Table 5 reports, for the product tanker and the VLCC, the values of the maximum still water bending moments for the considered loading conditions, the minimum values according to the above formulae and the design values.

Table 5: Still water hull girder bending moments.

	Product tanker		VLCC	
	Hogging	**Sagging**	**Hogging**	**Sagging**
Maximum still water bending moment for the considered loading conditions, M_{SW}, in kN.m	961 090	-775 471	7 366 300	-6 156 800
Minimum values according to the formulae in 2.2.6, M_{SWmin}, in kN.m	915 425	-781 370	6 701 520	-5 656 740
Design still water bending moment, M_{SWdes}, in kN.m	1 030 000	-784 800	7 553 700	-6 160 700

(1) It is reminded that, based on the sign convention adopted by IACS and also specified in the Rules, the hull girder bending moment is positive when it induces tension stresses in the strength deck (hogging bending moment); it is negative in the opposite case (sagging bending moment).

2.3 Damaged conditions

2.3.1 Damage scenario and calculation of still water bending moments in flooded conditions

Based on the casualty statistics, the assumed scenario to evaluate the effects of the ingressed water is a breach in the outer shell that causes the flooding of any individual ballast space of the ship.

To quantify the effects of the ingressed water on the hull girder still water bending moments, specific calculations are to be carried out. The loading conditions that induce the highest values of still water bending moments in intact conditions are to be considered and, for each one of them, the ballast tanks are to be considered as being individually flooded up to the equilibrium waterline. The still water bending moments are therefore to be calculated for any combination of loading conditions and flooded ballast tanks.

The calculations of still water hull girder bending moments in flooded conditions for the product tanker and the VLCC are summarised in 2.3.2.

However, the still water bending moment calculations in flooded conditions may be waived, provided that, in the hull girder ultimate strength check, an appropriate reduction factor is introduced, as discussed in 3.2.

2.3.2 Calculation of still water bending moments in flooded conditions

For any loading conditions in 2.2.5, the flooding of any ballast compartment is considered as specified in Table 6 for the product tanker and in Table 7 for the VLCC. These Tables also indicate, for each flooding scenario considered, the value of the maximum still water bending moment along the hull and its percentage difference with respect to the corresponding value in the same intact loading condition. Hogging bending moments are indicated in the Tables with positive values, whereas negative values are used for sagging bending moments.

From the results of the calculations in flooded conditions, some conclusions can be derived as detailed below:

- the highest increases (and decreases) are found when flooding is considered to occur when the ship is in the loading conditions that induce low values of still water bending moments. This is a consequence of the fact that, in these loading conditions, the weight and the buoyancy are more equilibrated and a possible flooding of a ballast tank entails a relatively greater unbalance,

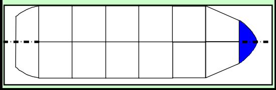
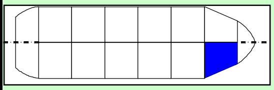
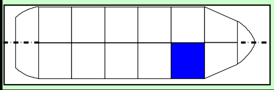
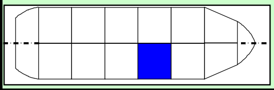
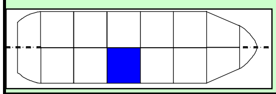
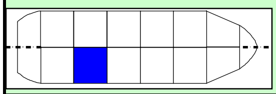
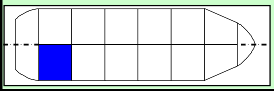
- for the loading conditions that induce high values of still water bending moment (both in hogging and in sagging conditions), the effects of ballast tank flooding is relatively less important, but, in absolute terms, the highest values of the still water bending moment in flooded conditions occur in these loading conditions,

- the maximum values of the still water bending moment in flooded conditions are reported in Table 8, for the hogging and sagging conditions, together with the corresponding maximum values in intact conditions and the relevant percentages of increase,

- if the still water bending moments in flooding conditions are compared with the design still water bending moments, the percentages of increase for the product tanker are of 0,7% and 21%, for the hogging and sagging conditions, respectively. For the VLCC, the hogging still water bending moment increases, in flooded conditions, by 7% also with respect to the design hogging still water bending moment, while the sagging still water bending moment exceeds the corresponding design value by 30%,

- it is to be noted that the design still water bending moments of the two considered ships comply with the criteria reported in 2.2 and, in particular, in 2.2.6.

Table 6: Product tanker - Flooded conditions and corresponding still water bending moments.

		LOADING CONDITIONS					
		Ballast loading Departure	Segregated cargoes loading Arrival	Homogeneous loading Arrival	Typical group loading Arrival	Alternate loading Departure [1]	Homogeneous partial loading Departure [1]
INTACT CONDITION	Bend. Mom. kNm	961 090	-775 471	-340 721	-361 116	578 476	602 471
FLOODING 1 	Bend. Mom. kNm	748 346	-570 785	-147 562	-147 631	N.C.	N.C.
	% Variation	-22%	-26%	-57%	-59%		
FLOODING 2 	Bend. Mom. kNm	854 775	-684 816	-160 482	-180 063	724 331	729 835
	% Variation	-11%	-12%	-53%	-50%	25%	21%
FLOODING 3 	Bend. Mom. kNm	948 745	-742 980	-309 770	-358 762	610 525	631 803
	% Variation	-1%	-4%	-9%	-1%	6%	5%
FLOODING 4 	Bend. Mom. kNm	1 001 562	-905 002	-476 020	-512 955	493 335	539 138
	% Variation	4%	17%	40%	42%	-15%	-11%
FLOODING 5 	Bend. Mom. kNm	1 037 388	-948 627	-522 225	-505 676	433 680 [2]	468 182
	% Variation	8%	22%	53%	40%	-25%	-22%
FLOODING 6 	Bend. Mom. kNm	1 004 701	-876 121	-480 141	-433 680	470 291	504 410
	% Variation	5%	13%	41%	20%	-19%	-16%
FLOODING 7 	Bend. Mom. kNm	944 752	-773 626	-333 599	-343 860	600 630	622 994
	% Variation	-2%	0%	-2%	-5%	4%	3%

"N.C." indicates a flooding condition that is not considered as it is not significant for the scope of this work.

Table 7: VLCC - Flooded conditions and corresponding still water bending moments.

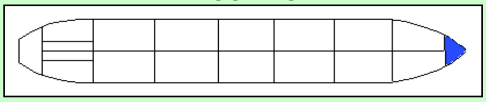
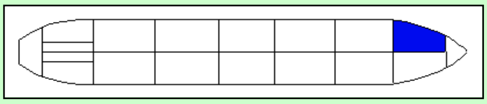
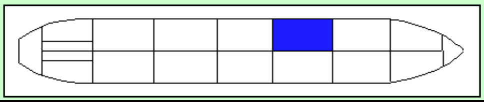
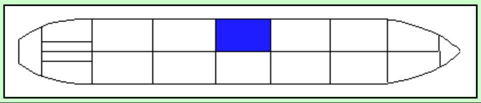
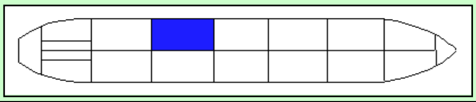
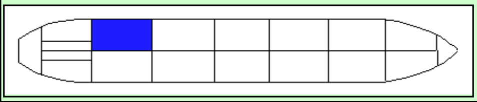
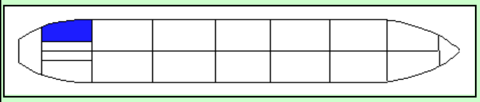
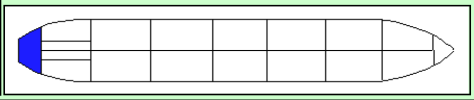
		LOADING CONDITIONS			
		Homogeneous loading Arrival	*Partial loading Arrival*	*Ballast loading Departure*	*Segregated loading 1+ 2 Departure*
INTACT CONDITION	Bend. Mom. kNm	***-2 685 783***	***-6 156 800***	***7 366 300***	***3 618 891***
FLOODING 1 	Bend. Mom. kNm	***-1 457 640***	***-6 156 374***	***6 906 098***	***4 286 184***
	% Variation	***-46%***	***0%***	***-6%***	***18%***
FLOODING 2 	Bend. Mom. kNm	***-1 701 122***	***-4 922 420***	***6 937 831***	***4 020 995***
	% Variation	***-37%***	***-20%***	***-6%***	***11%***
FLOODING 3 	Bend. Mom. kNm	***-2 576 295***	***-5 753 416***	***7 223 192***	***3 872 875***
	% Variation	***-4%***	***-7%***	***-2%***	***7%***
FLOODING 4 	Bend. Mom. kNm	***-4 137 901***	***-7 642 468***	***7 666 537***	***3 446 471***
	% Variation	***54%***	***24%***	***4%***	***-5%***
FLOODING 5 	Bend. Mom. kNm	***-4 635 851***	***-8 019 552***	***8 099 965***	***2 990 205***
	% Variation	***73%***	***30%***	***10%***	***-17%***
FLOODING 6 	Bend. Mom. kNm	***-4 309 101***	***-7 568 995***	***7 833 829***	***3 114 965***
	% Variation	***60%***	***22%***	***6%***	***-14%***
FLOODING 7 	Bend. Mom. kNm	***-2 588 490***	***-5 823 418***	***6 899 094***	***3 570 244***
	% Variation	***-4%***	***-5%***	***-6%***	***-1%***
FLOODING 8 	Bend. Mom. kNm	***-2 579 914***	***-6 089 649***	***6 337 371***	***2 823 775***
	% Variation	***-4%***	***-1%***	***-13%***	***-22%***
FLOODING 9 	Bend. Mom. kNm	***-2 892 032***	***-5 514 085***	***7 384 890***	***3 751 596***
	% Variation	***8%***	***-10%***	***0%***	***4%***

Table 8: Still water hull girder bending moments in intact and flooded conditions.

	Product tanker		VLCC	
	Hogging	**Sagging**	**Hogging**	**Sagging**
Maximum still water bending moment in intact conditions, M_{SW}, in kN.m	961 090	-775 471	7 366 300	-6 156 800
Maximum still water bending moment in flooded conditions, M_{SWF}, in kN.m	1 037 388	-948 627	8 099 915	-8 019 552
% of increase = $100\frac{M_{SWF} - M_{SW}}{M_{SW}}\%$	8%	22%	10%	30%

3. Design parameters affecting fabrication costs (Materials and scantlings)

3.1 Rule strength check criteria

3.1.1 Strength check procedure

The Rule strength check criteria require that the structural elements are assessed by means of the Rule formulae, which represent the equations of the various limit states considered 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 (e.g. the bottom and inner bottom structures or the plating of corrugated bulkheads). Globally, the scantlings of plating, ordinary stiffeners and primary supporting members are to be such as to fulfil the Rule requirements concerning the hull girder strength.

With the exception of the hull girder yielding checks, whose criteria are defined by the International Association of Classification Societies (IACS) to be uniformly applied by all the Member Societies, the structural analysis of each element is carried out considering their net strength characteristics. This means that the strength checks consider the structural scantlings without any implicit margin for corrosion, which are then to be added to the net scantlings to obtain the required as-built scantlings. This approach is detailed in Art.4 of these Guidelines.

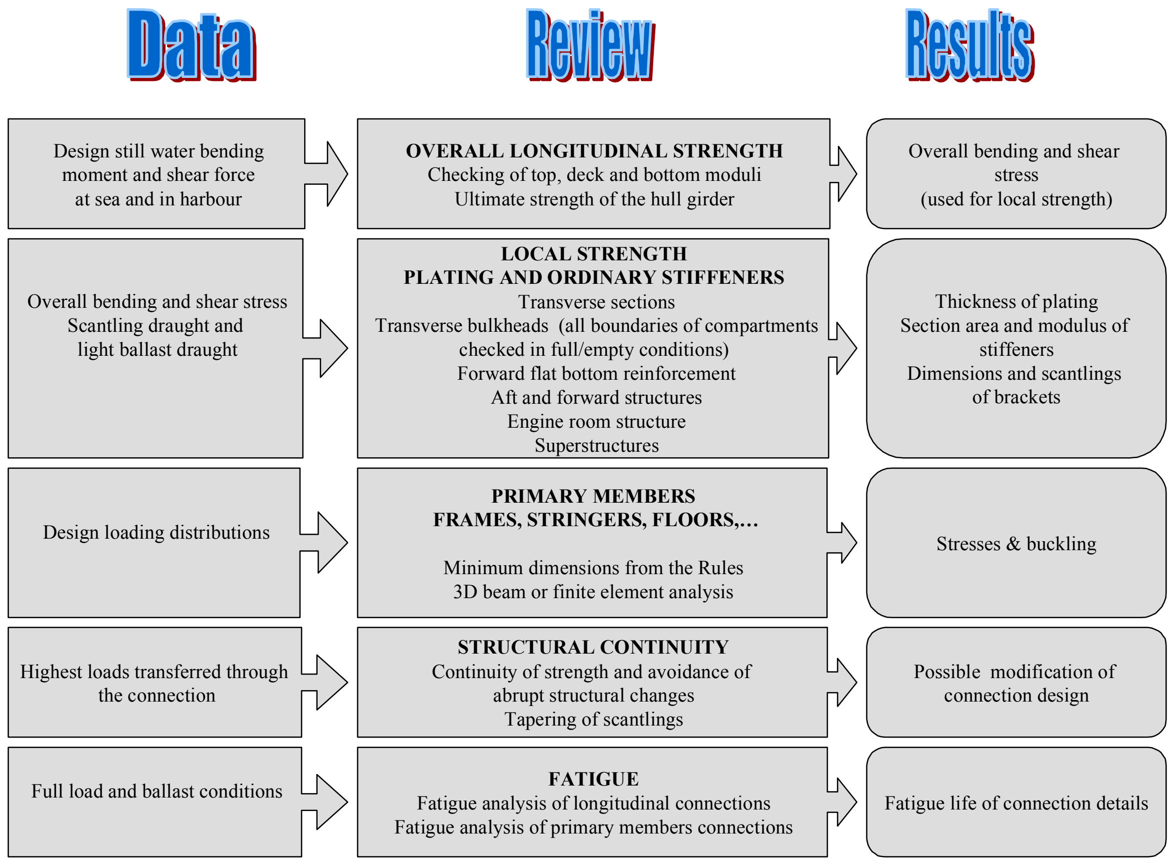
The strength check procedure is subdivided in various steps, as shown in Figure 4, each one corresponding to the structural analysis of a type of structural element. The input needed for each analysis and the results it provides are also shown in the figure.

Once the ship's general characteristics (general arrangement, dimensions, weight distribution, preliminary loading conditions) are defined, the process starts with the checks of the hull girder transverse sections subjected to the hull girder bending moments and shear forces.

The analysis of the hull girder transverse sections also allows the normal and shear stresses, induced by the hull girder loads, to be calculated and assigned as an input in the analysis of the elements which constitute the hull structures, i.e. plating, ordinary stiffeners and primary supporting members. Although these elements are basically dimensioned as to be able to sustain the local external and internal loads, the stresses induced by such loads are to be combined with those originated by the hull girder loads to represent the load situation of each element.

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. To investigate in a comprehensive way the behaviour of slender compressed elements, such as, for instance, the deck longitudinal ordinary stiffeners, the Rules require that they are checked under the combined effects of compression stresses and local loads, by verifying that these effects do not exceed their ultimate strength.

Figure 4: Strength check procedure.



While for plating and ordinary stiffeners the required scantlings can be calculated through the Rules formulae, primary supporting members can be analysed through them only at a preliminary design stage, as, in general, their precise assessment requires investigations of a different type to be carried out.

The analysis of primary supporting members can be exhaustively carried out on the basis of the Rule formulae where their arrangement is not of a grillage type, i.e. where they are predominantly fitted in one direction. Such an arrangement is typically adopted for smaller ships and, at this purpose, the Rules establish a length limit of 120 m, above which more accurate investigations are to be carried out. However, when the structural arrangements of primary supporting members is different, more accurate analyses, as described below, are to be carried out also for smaller ships.

In larger ships, primary supporting members are arranged in rather complex three-dimensional structures in which the interactions between the various elements play a substantial role in the whole system performance. These interactions can not be properly evaluated through simple "hand" calculations, as they depend on the relative rigidity and the load conditions of the various structural elements.

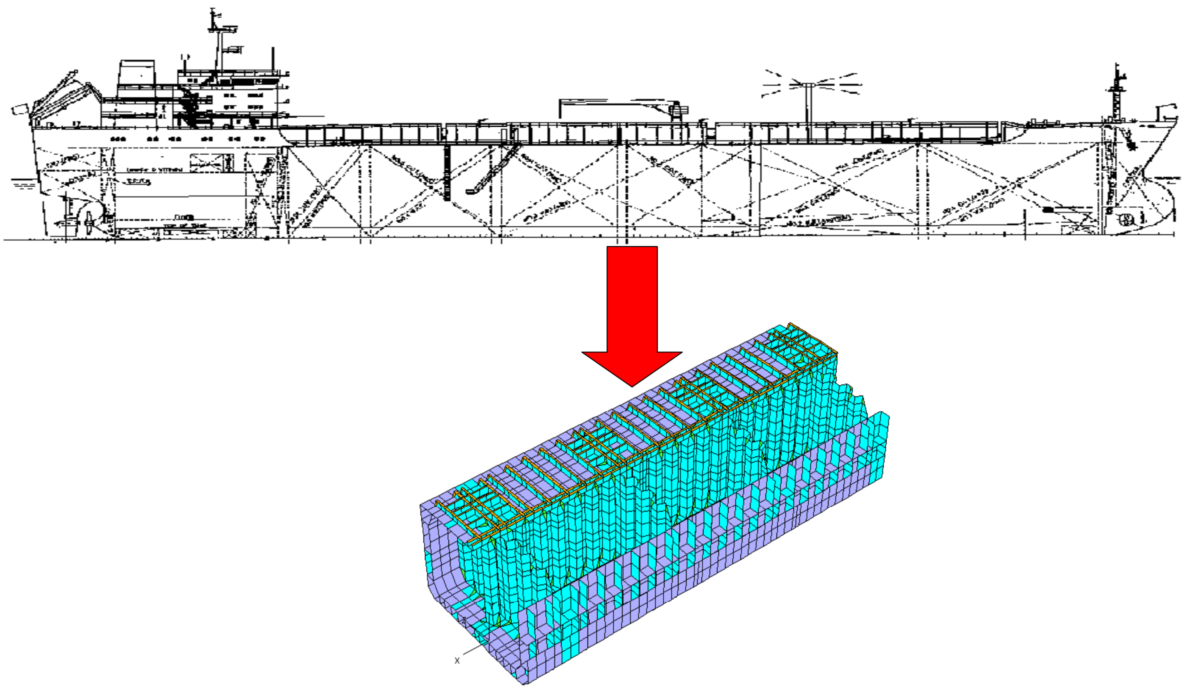
Up to a certain length limit, these effects can be taken into account through three-dimensional beam models, in which primary supporting members are represented as beams of equivalent strength characteristics. However, due to their limited length/height ratio, the variations in their geometry and the presence of brackets, in general the behaviour of primary structures can be properly investigated only on the basis of three-dimensional Finite Element Analyses (see Figure 5). Their most peculiar aspects are discussed in [3.1.2] with particular reference to:

- the model extension and their levels of refinement,

- the design loading distributions from which the loads to be applied to the model are to be derived.

Finite Element Models are to be loaded by the hull bending moments and shear forces, in addition to the local external and internal pressures, to properly combine the stresses they induce with those due to the bending of primary structures, for the purpose of carrying out the strength checks.

Figure 5: Primary supporting members analysed through Finite Element Analyses.



Another structural aspect, which require detailed investigations to be carried out through the use of Finite Element models, is the analysis of the stress concentrations in way of structural discontinuities, such as openings, connections between different elements, geometry changes. The structural models used for these analyses are to be quite accurate in order to correct reproduce the structural behaviour in way of the discontinuity examined and, at this purpose, fine mesh models are to be adopted, as discussed in [3.1.2].

The stress migration from one element to another at their connections is a complex phenomenon, which is to be well evaluated in order to identify the geometry and the local scantlings that are adequate for a good performance, also with respect to the fatigue strength. A good construction practice is a prerequisite for every structural details, which is also established by the Rules for the most significant cases, and, in addition, the results of Finite Element Analyses can provide many detailed information for identifying an efficient solution. 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.

The efficiency of the structural connections subjected to high cyclic stresses is to be check with respect to possible fatigue related problems. For oil tankers, the connection details that deserve particular attention in the design, construction and inspection and whose fatigue strength is to be investigated are the following:

- connections of the longitudinal ordinary stiffeners of side and inner side with transverse primary supporting members (transverse bulkheads and web frames),
- connections of inner bottom plating with transverse bulkheads or lower stools, as the case may be,
- connections of inner bottom plating with inner side or hopper tank sloping plate, as the case may be.

The fatigue capacity of the above connection details, represented by their S-N curves, is to be checked against the load demand, characterised by 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.

Sub-articles [4.3] and [4.4] of these Guidelines provide detailed considerations on the criteria to be followed in designing, building and inspecting these connection details, as well as on the relevant fatigue analyses that are to be carried out.

3.1.2 Finite Element analyses of primary supporting members

According to the basic principles specified in the Rules, the Finite Element Models used for the strength checks of primary supporting members are generally to extend in the longitudinal direction over at least three adjacent cargo tanks, the structures to be analysed belonging to the central one. To account for the non modelled parts of the hull, appropriate loads and constraints are applied at the model boundaries and the Rules state the criteria for their application, in such a way that the hull girder loads are correctly reproduced in the area under investigation. In particular, the bending moment values are to be reproduced at the middle of the model and the shear force values in way of the aft bulkhead of the central tank. This is done in order to avoid that the inevitable inaccuracy in the modelling of boundary conditions affects the results in the areas under investigation.

The analysis is to address all the possible tank structural arrangements in the cargo tank central area. This means that, if the design contemplates different structural arrangements in this area, several Finite Element Models are to be built in such a way that each arrangement is represented in the central part of a model extended over at least three cargo tanks.

For normal typologies, no specific Finite Element Models are to be created for the aft and fore cargo tanks, as the hull shapes are generally such that 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 tanks are significantly different from that of the central ones, which makes the above assumption not to be valid, specific models are to be created for these tanks.

The geometric accuracy of the model and the level of mesh refinement depend on the strength check that is to be carried out on the basis of the calculation results. For yielding and buckling checks, the finite element model is to 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.

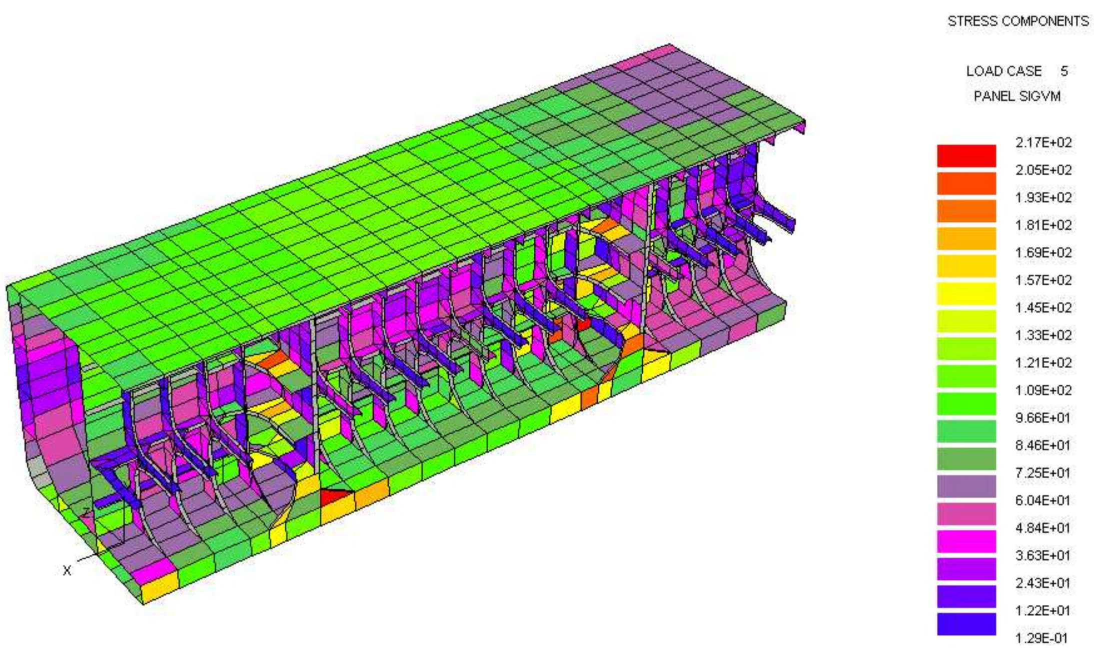
For fatigue strength checks, different levels of accuracy are to be adopted, depending on whether the hot spot stresses are directly obtained from the Finite Element analysis or they are calculated by multiplying the nominal stresses, obtained through the analysis, by appropriate stress concentration factors. In this latter case, the same "fine mesh" level of refinement as for the buckling and yielding checks is to be adopted, while in the other case much more refined models are to be created for the detail under examination. More specific considerations on these aspects are provided in Art. 4 of these Guidelines.

In order to carry out the strength checks, it is not necessary that the whole three cargo tank model is "finely" meshed. A procedure that is generally adopted consists in creating the three cargo tank 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 Finite Element 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 tank 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 Rule 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.

By way of example, Figure 6 shows a typical result obtained from the analysis of the "coarse mesh" three cargo tank models used for the VLCC that is examined in these Guidelines.

Figure 6: "Coarse mesh" Finite Element Analysis of a three cargo tank model (VLCC).



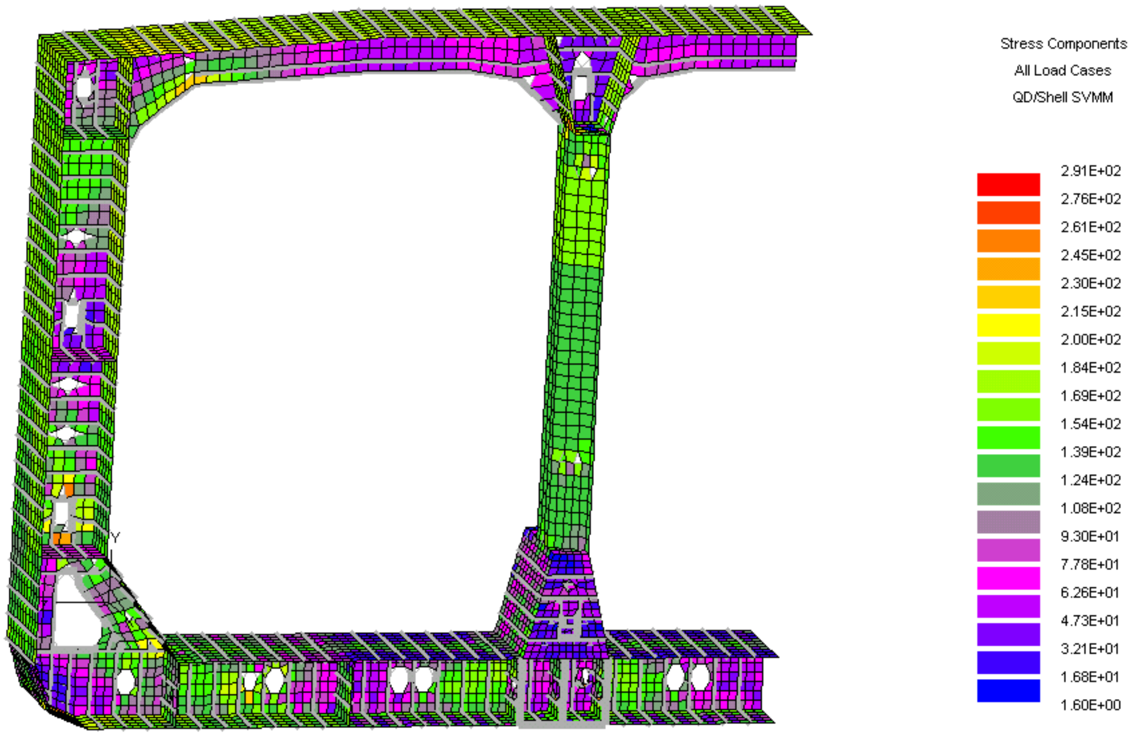
Typical areas of oil and product tankers that need to be analysed on the basis of "fine mesh" models are:

- the transverse web frame ring (see an example in Figure 7), whose model is to reproduce manholes and other major 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.

More detailed information on these analyses are reported in 3.3 to 3.5, with reference to the specific studies carried out for the product tanker, the Aframax tanker and the VLCC.

To calculate the still water and wave induced loads acting on the Finite Element models, various cargo and ballast distributions are to be considered. These distributions are to be defined in such a way that each one of them is the most critical for one or more structural areas. The result envelope obtained for all the distributions considered allows to examine the behaviour of the hull structures under the expected loads.

Figure 7: "Fine mesh" Finite Element Analysis of a transverse web frame ring (product tanker).



As Finite Element analyses are normally carried out at a design stage in which the design loading conditions of the ship are defined and included in the Loading Manual, these are to be used for the selection of the cargo and ballast distributions with which the Finite Element Model is to be loaded.

The Loading Manual also provides the ship's draught and the still water hull girder loads in each loading condition. The ship's draught and the hull girder loads (bending moments and shear forces) to be associated with each loading distribution of the Finite Element analysis could, in principle, be taken from the information contained in the Loading Manual. The process is not so straightforward, due to the fact that the loading manual does not contain all the allowable cargo and ballast distributions, but the typical ones on which the design of the ship is based. During the ship's operation, indeed, loading conditions other than those reported in the Loading Manual may be adopted, provided that the limits therein indicated on hull girder and local loads are not exceeded.

The cargo and ballast distributions to be considered in the structural analysis have also to account for these loading conditions, which are not specifically reported in the Loading Manual.

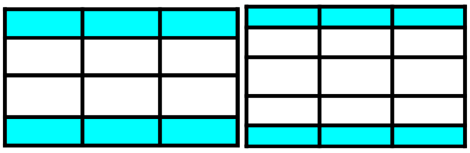
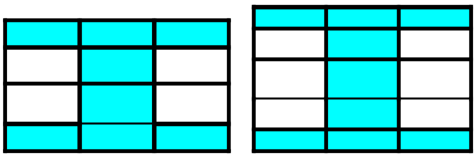
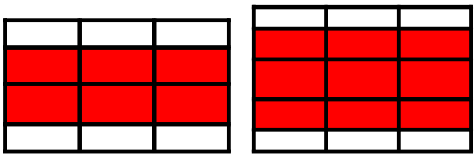
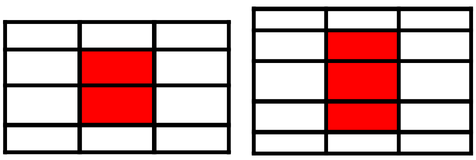
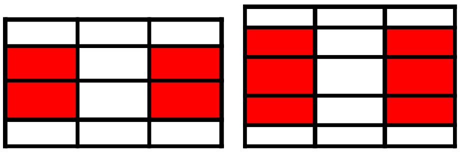
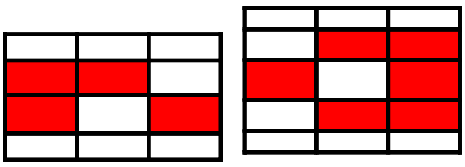
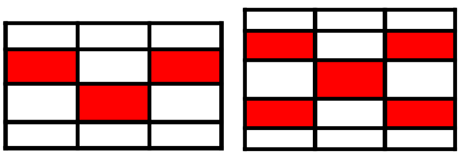
At this purpose, Table 9 lists some typical loading distributions to be considered in the structural analyses; for each distribution, the ship's draught and the still water hull girder loads are indicated, together with the structural areas for which that distribution is critical. This list is not exhaustive, as the consideration of other loading distributions could result to be necessary for any specific ship, depending on her structural and loading arrangement characteristics. On the other hand, some of the distributions reported in Table 9 could result to be superfluous.

For each one of these loading distributions, the still water and wave induced loads acting on the hull structures are to be calculated. Wave induced loads are the sea pressures and the inertial loads that originate when the ships is considered to encounter head sea waves (load cases “a” and “b”, as defined in the Rules) and beam sea waves (load cases “c” and “d”).

In general, it is not required to consider all the load cases for all the loading distributions. It is shown above that the loading distributions are selected and applied to the Finite Element model for the purpose of examining the behaviour of the hull structures, each loading distribution being expected to be the most critical for one or more particular areas. The load cases to be combined with a certain loading distribution are therefore to be selected in order to maximise the stresses in the structural area for which that distribution is significant.

Examples of combinations between loading distributions and load cases are reported in Appendices 1 to 3 of this Chapter, with reference to the case studies carried out for the product tanker, for the Aframax tanker and for the VLCC.

Table 9: Typical loading distributions.

Loading distribution	Draught	Still water bending moment	Shear Force	Critical areas
Light ballast loading 	Light ballast draught	Design hogging bending moment	Not to be considered	Bottom structures (buckling) Side structures
Heavy ballast loading 	Heavy ballast draught	Of the correspon-ding loading condition	Of the correspon-ding loading condition	Bottom structures Transverse bulkhead structures
Homogeneous loading 	Scantling draught	Of the correspon-ding loading condition	Not to be considered	Bottom structures (connections between cargo and ballast tanks)
Non homogeneous loading - central tanks full 	0,4 D	Max. in non-homog. loading conditions	Max. in non-homog. loading condition	Bottom structures Side structures Bulkhead structures
Non homogeneous loading - central tanks empty 	– 0,5D, for oil tankers, – Scantling draught, for product tankers	Max. in non-homog. loading condition	Max. in non-homog. loading condition	Bottom structures Side structures Bulkhead structures
Partial loadings that maximise the still water sagging bending moment  (Example figures)	Of the correspon-ding loading conditions	Design sagging bending moment	Of the correspon-ding loading conditions	Deck structures (buckling) Bulkheads structures Bottom structures
Chess loading 	– 0,4D, for oil tankers, – 0,55D, for product tankers	Max. in non-homog. loading condition	Of the correspon-ding loading condition	Bulkhead and stool structures

3.1.3 Application to the case studies

All the structural analyses described in these Guidelines are carried out applying the Rule strength check criteria. In the course of the case studies, extensive analyses of plating and ordinary stiffeners for all the considered solutions are conducted. The scantlings of primary supporting members for some typical arrangements are checked by means of Finite Element analysis and the results of these latter, supplemented with the results of simplified calculations, are used to define the modifications required when other solutions are considered.

The scantlings provided in these Guidelines are thus fully exploitable for comparison purposes between the considered solutions. For the purpose of identifying the Rule required scantlings for any considered solution, the proposed scantlings are to be confirmed by means of Finite Element analysis, which take into account the specific features of the considered case.

3.2 Longitudinal strength considerations (ultimate strength of the hull girder)

3.2.1 Check criteria

In order the hull girder be capable to sustain the loads it is subjected to in normal operating conditions and, even in damaged conditions, to resist the still water and wave hull girder loads induced by flooding of any ballast tank, 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 Rule defined allowable stresses), which account for the longitudinal strength in normal operations and intact conditions,

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

$$\frac{M_{UD}}{\gamma_R \gamma_m} \geq M_{SWF} + \gamma_{W1} M_{WV}$$

In this formula, M_{UD} is the damaged hull girder ultimate strength, calculated according to the procedure in Pt B, Ch 6, Sec 3 of the Rules for the parts of the damaged section remained intact after the assumed collision or grounding. M_{SWF} is the still water bending moment in flooded conditions, calculated as specified in 2.2.2. 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 for the checks in intact conditions, whose values are:

γ_{W1} = 1,10

γ_m = 1,02

γ_R = 1,03

As far as the ultimate strength check is concerned, a simplified equivalent approach may be adopted, consisting in carrying out the calculations in intact conditions and introducing an appropriate reduction coefficient. Thus, the limiting criterion is:

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

where the hull girder ultimate strength M_U and the still water bending moment M_{SW} are calculated for the ship in intact conditions. The damage effects are taken into account through the coefficient C_D, as discussed in the following paragraph 3.2.2.

3.2.2 Damage effects – Coefficient C_D

The coefficient C_D accounts for two effects related to longitudinal strength calculations in damaged conditions:

a) the increase in the total hull girder bending moment (still water + wave) due to the ballast tank flooding,

b) the reduction in the hull girder strength as a consequence of the damages caused in the outer shell by the hypothetical collision or grounding,

and can be mathematically obtained from the formulae in 3.2.1:

$$C_D = \frac{M_{UD} / M_U}{(M_{SWF} + \gamma_{W1} M_{WV}) / (M_{SWdes} + \gamma_{W1} M_{WV})}$$

The term $R_{MTOT} = (M_{SWF} + \gamma_{W1} M_{WV}) / (M_{SWdes} + \gamma_{W1} M_{WV})$ represents the first effects, whereas the second effects are accounted for by the term $R_U = M_{UD} / M_U$.

The term R_{MTOT} may be evaluated by using the results obtained in 2.3.2 and considering the values of the design wave bending moments for the considered ships, as presented in Table 10.

Table 10: Ultimate strength – Increase of still water plus wave hull girder bending moments in flooded conditions.

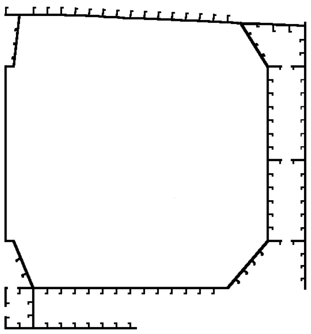
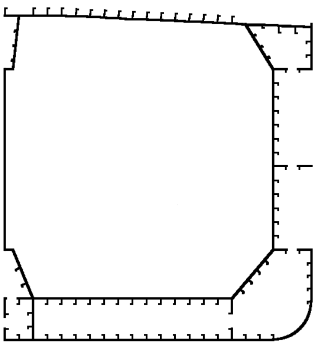
	Product tanker		VLCC	
	Hogging	**Sagging**	**Hogging**	**Sagging**
Vertical wave bending moment, M_{WV}, in kN.m	1 342 294	-1 432 518	9 641 831	-10 370 690
Total bending moments in intact conditions, $M_{SWdes} + \gamma_{W1}M_{WV}$, in kN.m	2 506 523	-2 360 570	18 159 714	–17 568 459
Total bending moments in flooded conditions, $M_{SWF} + \gamma_{W1}M_{WV}$, in kN.m	2 513 911	-2 524 397	18 705 929	–19 427 311
$R_{MTOT} = (M_{SWF} + \gamma_{W1}M_{WV}) / (M_{SWdes} + \gamma_{W1}M_{WV})$	1,003	1,070	1,030	1,106

To evaluate the term R_U, specific analyses are carried out on the reduction in the hull girder ultimate strength that occurs as a consequence of bottom and side damages. The values of the ultimate strength of the undamaged and damaged sections are presented in Table 11. The R_U values reported in the Table 11 are the greatest between those calculated for bottom and side damages.

These results show that bottom damages have significant impact on the hogging ultimate strength, which is largely governed by the buckling failure of bottom structures. The sagging conditions, however, remain the most critical ones for the hull girder ultimate strength also in damaged conditions and, in these situations, the strength reduction due to bottom or side damages ranges between about 6% for smaller tankers to up to about 8% for larger VLCC.

From these results, it is deduced that the effects listed above in a) and b) may be taken into account by assuming a coefficient C_D equal to 0,85. It is reminded that this is valid if the values of the design still water bending moments are assumed so as to be in accordance with the criteria in 2.2 and, in particular, in 2.2.6.

Table 11: Ultimate strength – Effects of bottom and side damages on the ultimate bending moment capacity.

	Product tanker		VLCC	
	Hogging	**Sagging**	**Hogging**	**Sagging**
Undamaged M_U, in kN.m	3 210 134	2 496 641	26 133 620	21 635 460
Bottom damage M_{UD}, in kN.m 	2 774 140	2 351 216	21 884 226	19 865 650
Side damage M_{UD}, in kN.m 	3 200 519	2 372 547	25 289 620	19 858 516
$R_U = M_{UD} / M_U$	0,864	0,942	0,838	0,917

3.2.3 Ultimate strength criteria adopted in the Guidelines

In the Guidelines, various design solutions are analysed through different designs of the midship section, as presented in 3.3, 3.4 and 3.5 for the product tanker, for the Aframax tanker and for the VLCC, respectively.

The ultimate strength criteria adopted for the design of these sections are expressed in terms of ratios between the applied bending moments and the ultimate bending moment capacity of the transverse sections. According to the conclusions in [3.2.2], these ratios are limited to 0,85, approximately.

3.3 Structural analysis of a product tanker

3.3.1 General considerations

The structural analysis of the product tanker, the properties of which is described in 1.3.2, takes into account the specific characteristics of this type of ship. In details, the following most typical design aspects that may impact on the fabrication costs of product tankers are considered:

- the choice of the steel type. For product tankers, either mild steel or high strength steel (HTS) may be used for deck, inner bottom and bottom structures. The aim of using HTS for deck structures is to increase both the hull girder and the buckling strengths, whereas the aim of using HTS for bottom and inner bottom structures is to increase the strength of the plating and of the ordinary stiffeners according to the effects of local pressures due to the sea and to the carried liquids. Therefore, three steel type distributions are investigated:
  - all structures in mild steel,
  - inner bottom and deck structures in HTS,
  - bottom and deck structures in HTS,
- the choice of the transverse bulkhead type. In general, for product tankers, transverse corrugated bulkheads are adopted, as they allow easier tank cleaning operations. Therefore, extensive investigations are carried out on corrugated bulkhead designs. However, for comparison purposes, plane bulkhead designs are also investigated,
- the choice of the ordinary stiffener types. In general, for product tankers, either angle profiles or bulb profiles may be adopted. Therefore, the influence of both these two ordinary stiffener types is investigated.

Moreover, the structural analysis of the product tanker is carried out by considering that:

- the ship trades with tanks completely filled with liquid cargoes having density up to 1,025 t/m^3. However, loading conditions with tanks partially filled with liquid cargoes having density up to 1,5 t/m^3 are considered. In this case, the maximum tank filling level is determined according to the ratio between the considered cargo density and cargo density equal to 1,025 t/m^3,
- in general, for product tankers, the deck structures, namely ordinary stiffeners and deck transverse beams, are fitted on the external side of the deck plating, as this arrangement allows easier tank cleaning operations. Therefore, in this study, deck structures are considered as being fitted in such a manner.

In order to evaluate the effects of the design choices presented above, various design solutions, both for the midship sections and for the transverse bulkheads are compared and the following outputs can be analysed:

- steel weight,
- coating surfaces,
- minimum thickness of longitudinal ordinary stiffener webs,
- length of ordinary stiffener welds,
- length of ordinary stiffener free edges.

3.3.2 Tank structure arrangement

The structural analysis of a product tanker is tailored to investigate the aspects deemed critical for the typical tank structural arrangement of this kind of ship. In details, the structural analysis of the ship presented in this study takes into account the following main aspects:

- as loading condition with partially filled tanks are allowed (see also 3.3.1), the scantlings of the plating and of the ordinary stiffeners of the tank boundaries (top, bottom, bulkheads) are calculated by also taking into account the effects of the sloshing and of the impact pressures. An extensive analysis of the results is presented in 3.3.3 for the plating and the ordinary stiffeners of the midship section and in 3.3.4 for the plating and the ordinary stiffeners of transverse bulkheads,

- the scantlings of the primary supporting members of the tank boundaries (transverse web rings and longitudinal girders) are calculated through finite element analysis performed according to the calculation procedure presented in 3.1.1, with reference to the structural models there specified. Particular attention is paid to details such as the most stressed transverse web frame ring and as the connection between transverse bulkhead and stools. The finite element analysis results are presented in Appendix 1,

- the adequacy of the type of the cross connection between transverse and longitudinal corrugated bulkheads is checked through fine mesh finite element analysis. In order to maximise the stresses in way of this connection, the analysis take into account both static and wave loads induced by the liquids carried in the tanks for chess loading conditions.

With reference to the latter point, a comparison among the fine mesh finite element analysis results obtained for the three types of cross connections shown in Table 12 is performed.

The results of the comparison show that corrugation plates fitted in way of type a) connections are subject to a local stress increase of about 25% with respect to the stresses acting in way of the corrugation plates fitted in corresponding bulkhead location outside the connection area, whose maximum value is normally used for calculating the scantlings of the corrugation plates (see Figure 8).

The local stress increase is caused by the combination of the stresses due to the global deflection of the corrugation considered as a vertical girder with those due to the local deflection of the corrugation plate fitted in way of the bulkheads crossing. However, the results show that no significant local stress increase takes place in way of type b) and c) connections.

Therefore, this means that, in general, when type a) connections are selected for corrugated bulkheads crossing, the thickness needed for all the corrugation plates in way of the connections is obtained by increasing of about 25% the thickness required for the corrugation plates fitted in the corresponding bulkhead location outside the connection area. However, this thickness increment may be lessened or waived provided that a fine mesh finite element analysis of the considered bulkhead connection demonstrates the adequacy of the corrugation scantlings.

Table 12 : Types of cross connection between transverse and longitudinal corrugated bulkheads

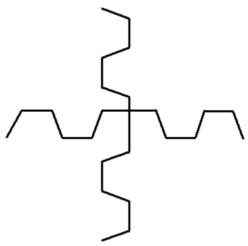
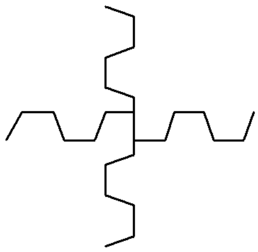
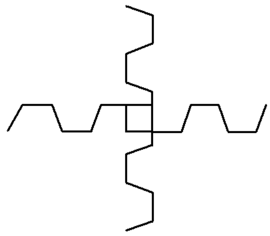
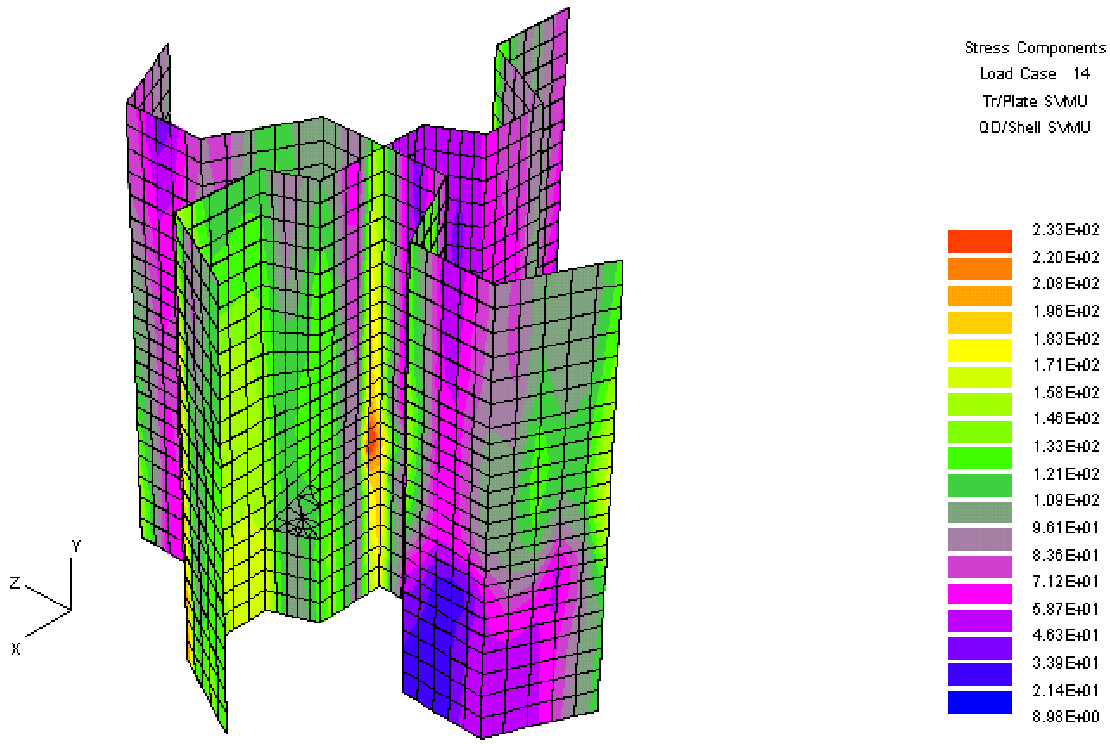
Type a)	Type b)	Type c)
		

Figure 8 : Results of a detailed finite element analysis of the type a) connection between transverse and longitudinal corrugated bulkheads.



3.3.3 Midship section arrangement

In order to investigate the possible design options and their effects in terms of structural strength and weight, the influence of the following design parameters is considered:

- steel yield stress (235 MPa yield stress for a mild steel and 315 MPa yield stress for a HTS),
- longitudinal ordinary stiffener spacing,
- longitudinal ordinary stiffener span,
- ordinary stiffener type.

Various designs of midship sections are analysed, each one coming out from the combination of the different parameters presented above. The obtained midship section data and their associated detailed results are presented in Appendix 1. The main results are also presented in the Figures 9 to 15

❒ ***Steel weight***

The weight of the different midship sections, the results of which are presented in Figures 9 to 11, are obtained by taking into account the weight of the plating and of the ordinary stiffeners of the midship sections as well as the one of the transverse web frames. However, it has to be noted that the weight of the transverse bulkheads is not taken into account at this stage of the present study.

Figure 9 : Influence of the stiffener spacings on the midship section weight (for angles and at constant span = 2,610 m)

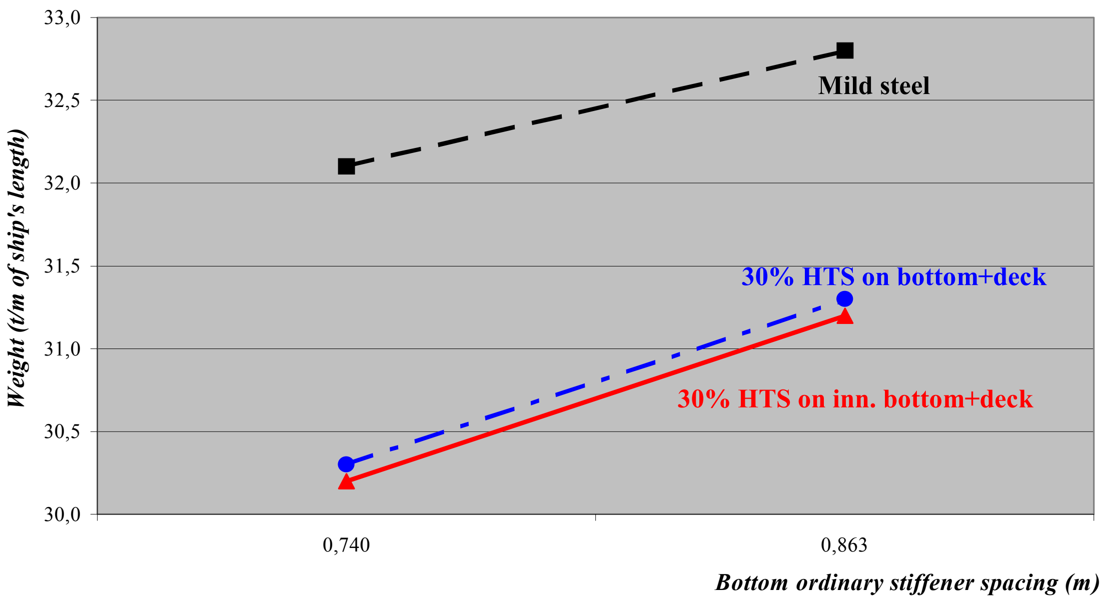


Figure 10 : Influence of the stiffener spans on the midship section weight (for angles and at constant spacing = 0,740 m).

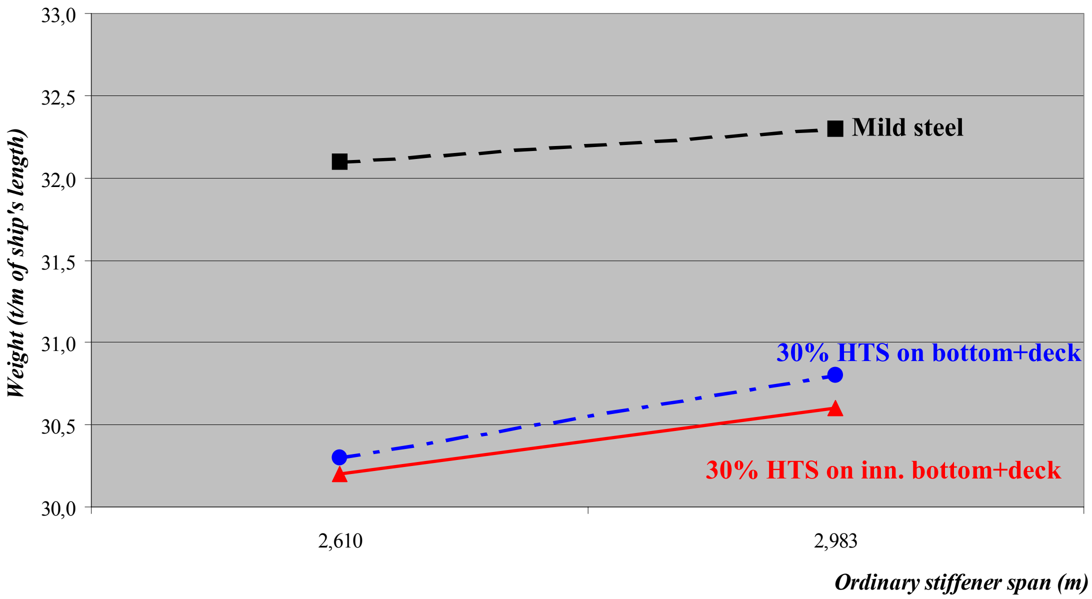
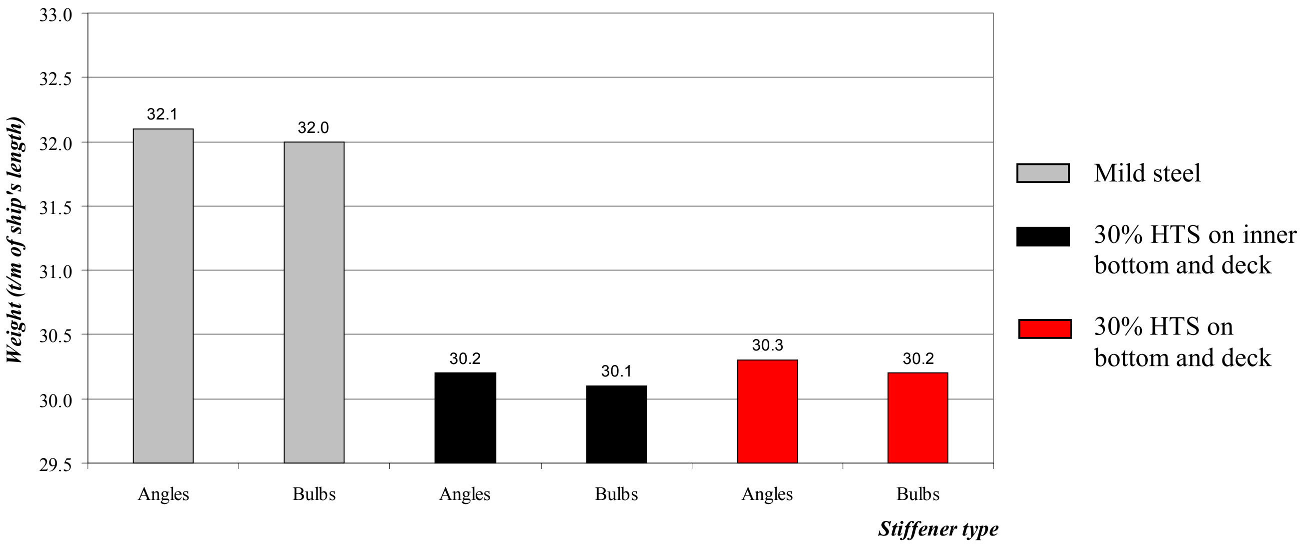


Figure 11 : Influence of the stiffener types on the midship section weight (at constant spacing = 0,740 m and at constant span = 2,610 m)

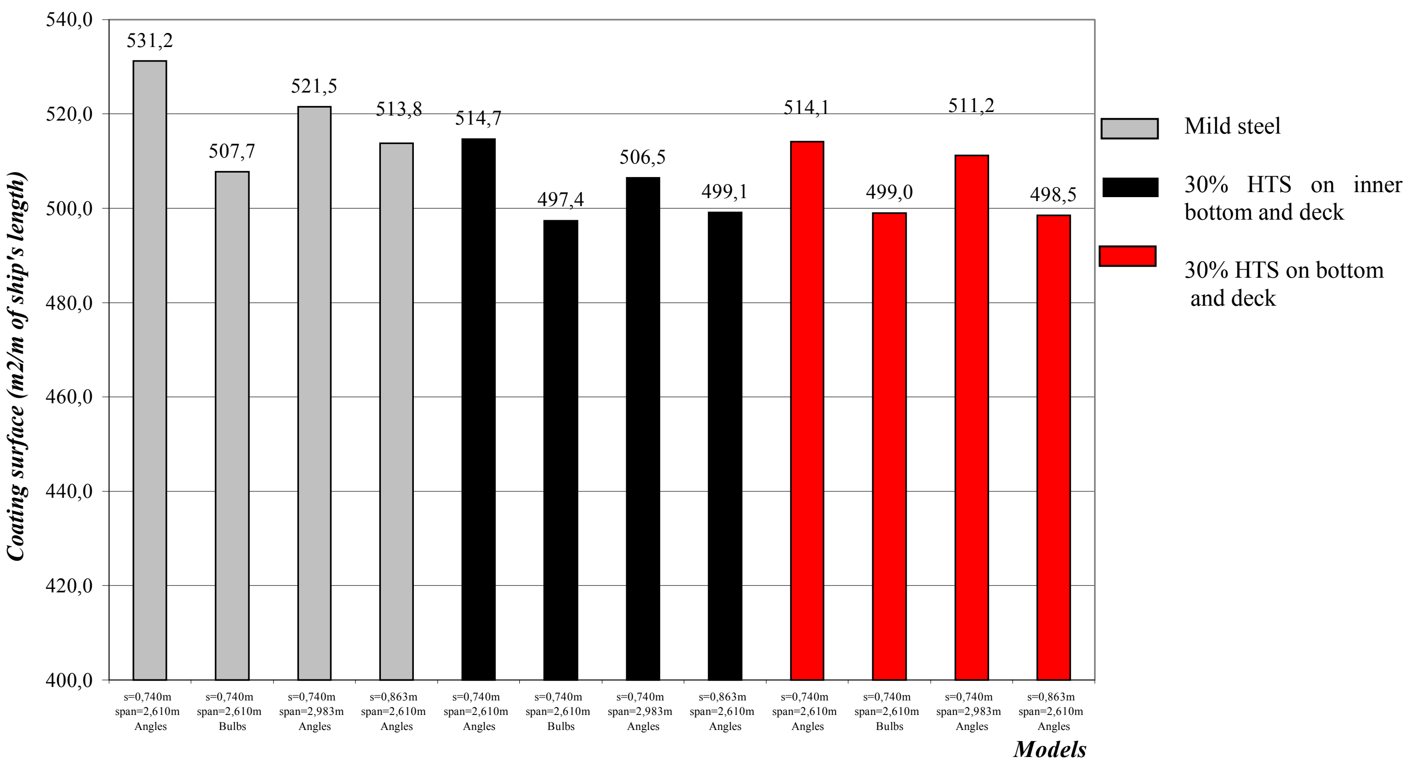


❒ *Coating surfaces*

The coating surface calculations, the results of which are presented in Figure 12, are realised by considering:

- midship section ballast tank surfaces (all plating and ordinary stiffeners), including lower stools (if there are any),
- transverse web frame ballast tank surfaces (all plating and ordinary stiffeners),
- bottom (horizontal inner bottom plating) and top (deck plating) of cargo tanks,
- surfaces of deck plating, ordinary stiffeners and primary supporting members fitted above the deck.

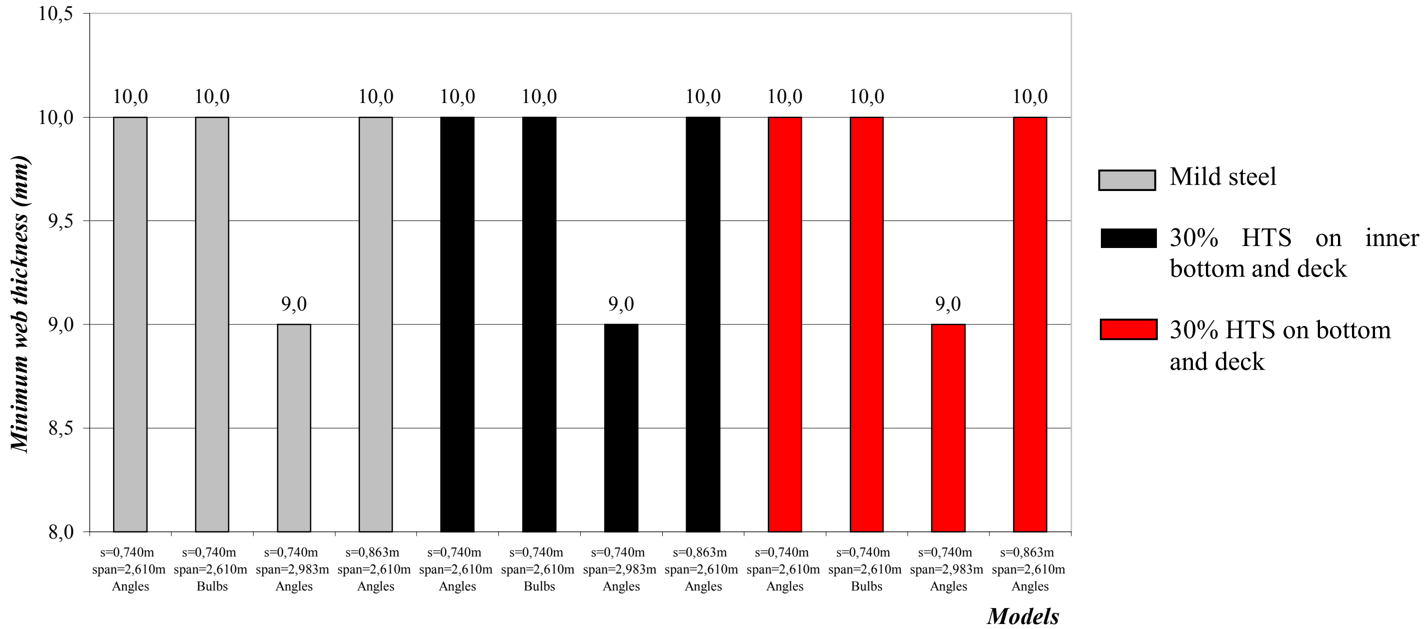
Figure 12 : Midship section coating surfaces.



❒ *Minimum thickness of ordinary stiffener webs*

The minimum thickness of ordinary stiffener webs, the results of which are presented in Figure 13, is calculated for the as-built thickness of the longitudinal ordinary stiffeners of the midship sections.

Figure 13 : Minimum thickness of ordinary stiffener webs.

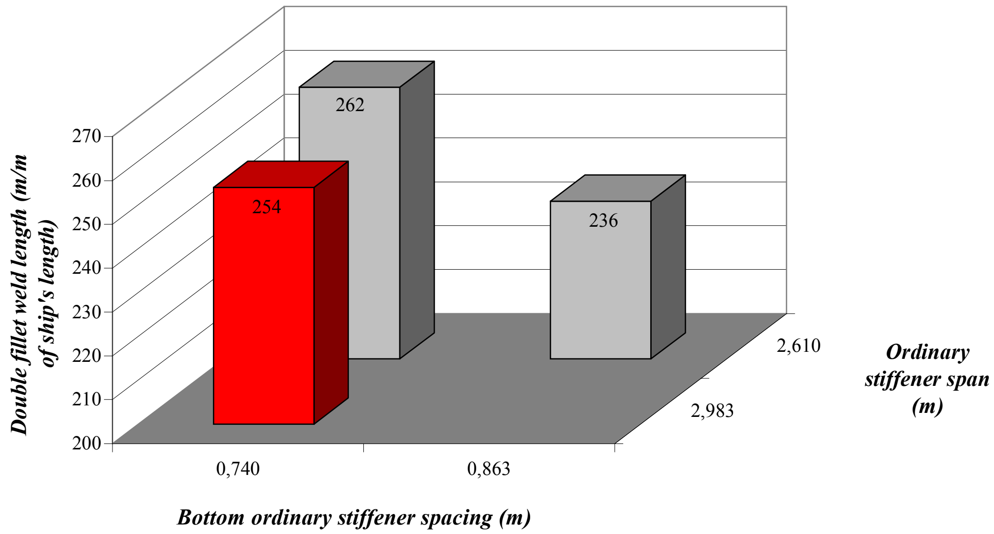


❒ *Midship section double fillet weld lengths*

The midship section double fillet weld lengths are calculated by only considering the welds between the stiffeners and the platings, which means that the welds between the stiffener web and the stiffener face plate are not considered.

Furthermore, it has to be noticed that the calculated midship section double fillet weld lengths do only depend on the ordinary stiffener spacings and spans. Indeed, they do neither depend on the material type nor on the type of ordinary stiffener profile. This is therefore, the reason why the results presented in Figure 14 do only take the ordinary stiffener spacings and spans into account and can thus be affected to midship sections made of any desired material and of any desired type of ordinary stiffeners.

Figure 14 : Influence of the longitudinal ordinary stiffener spacings and spans on the midship section double fillet weld lengths.



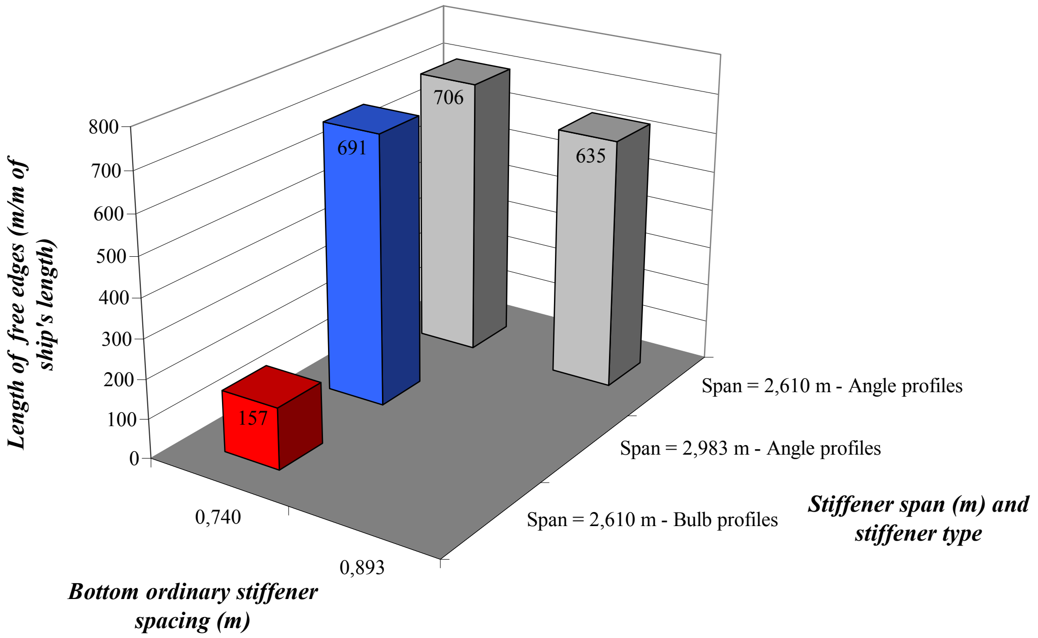
❒ *Midship section free edge lengths*

The free edge lengths of ordinary stiffeners are calculated by considering:

- no free edge for bulb profiles and laminated angle profiles,
- 2 free edges for flat bar profiles,
- 3 free edges for built-up angle profiles,
- 4 free edges for built-up T profiles.

Furthermore, those free edge lengths do only depend on the ordinary stiffener types, on their spacings and on the ordinary stiffener spans. Indeed, they do not depend on the material type. This is therefore the reason why the results presented in Figure 15 do only take the ordinary stiffener types, spacings and spans into account and can thus be affected to midship sections made of any desired material.

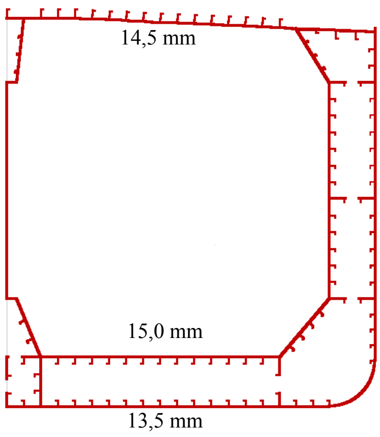
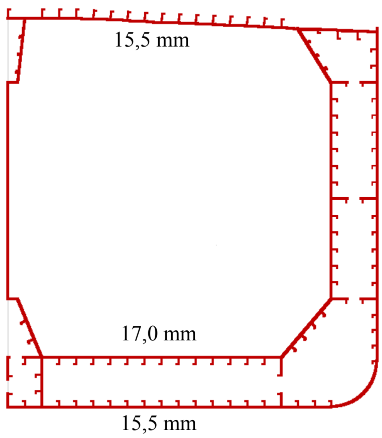
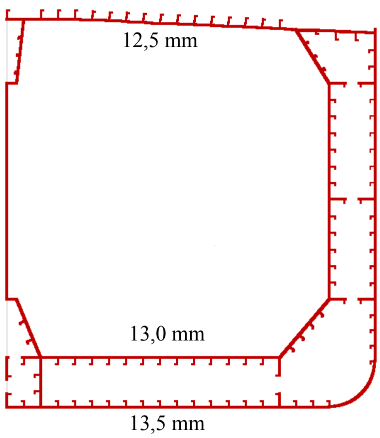
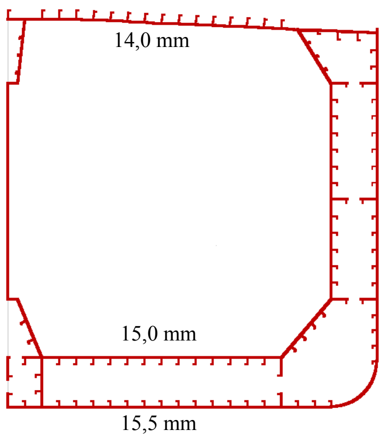
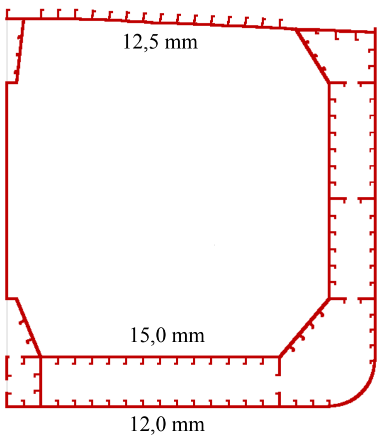
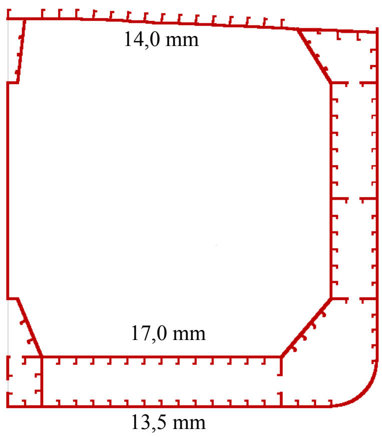
Figure 15 : Influence of the longitudinal ordinary stiffener types, spacings and spans on the midship section free edge lengths.



❐ *Conclusions*

In order to sum up the different results presented in the Appendix 1, Table 13 presents the thickness that guarantee that the ratios between the applied bending moments in sagging or hogging conditions and the corresponding ultimate bending moment capacity of the section, calculated according to the Rules criteria, do not exceed about 85%, according to the different possible design options.

Table 13 : Plating thickness of deck, inner bottom and bottom that verify the maximum ultimate strength limit of 85%

Material	Bottom ordinary stiffener spacing	
	0,740 m	0,863 m
Mild steel		
HTS 30% Deck + inner bottom		
HTS 30% Deck + bottom		

From the results of midship sections presented in the Figures 9 to 15, it can be noticed that:

3) midship sections obtained by considering all structures in mild steel are about 5-6%, depending on the design solution, heavier than those obtained by considering either HTS on deck and inner bottom structures or on deck and bottom structures at equivalent

structural characteristics (number of transverse web frames and longitudinal ordinary stiffener spacing). Moreover, the surfaces to be coated for all structures in mild steel are about 2-3%, depending on the design solution, greater than the ones for either deck and inner bottom structures or on deck and bottom structures in HTS,

4) the weight and the coating surfaces of midship sections obtained by considering deck and inner bottom structures in HTS are approximately the same as the ones obtained by considering HTS on deck and bottom structures,

5) midship sections obtained by considering a 17% increased ordinary stiffener spacing, equal to 0,863 m, are heavier than those obtained by considering an ordinary stiffener spacing equal to 0,740 m of about:

- 2,2% for mild steel midship section,
- 3,3% for HTS either on deck and inner bottom structures or on deck and bottom structures.
- However, the surfaces to be coated for a 17% increased ordinary stiffener spacing model are about 3% less than the ones obtained for an ordinary stiffener spacing equal to 0,740 m. For the coating surfaces, the influence of the steel grade is negligible.
- Moreover, the lengths of stiffener welds and the lengths of stiffener free edges calculated for a 17% increased ordinary stiffener spacing model are about 10% less than the ones obtained for an ordinary stiffener spacing equal to 0,740 m,

6) midship sections obtained by considering a 14% increased ordinary stiffener span, equal to 2,983 m, are heavier than those obtained by considering an ordinary stiffener span of 2,610 m of about:

- 0,5% for mild steel midship section,
- 1,5% for sections with HTS either on deck and inner bottom structures or on deck and bottom structures.

However, the surfaces to be coated for a 14% increased stiffener span model are less than the ones obtained for a 2,610 m ordinary stiffener span model of about:

- 1,5% for mild steel sections and sections with HTS on deck and inner bottom structures,
- 0,5% for sections with HTS on deck and bottom structures.

- Moreover, the lengths of stiffener welds and the lengths of stiffener free edges calculated for a 14% increased ordinary stiffener span model are about 3% and 2%, respectively, less than the ones obtained for an ordinary stiffener span equal to 2,610 m,

7) considering points 3) and 4), it can be noticed that the weight increments for HTS midship sections due to either increased stiffener spacing or increased stiffener span, equal to about 3,3% and 1,5%, respectively, are greater than the ones obtained for mild steel midship sections, equal to about 2,2% and 0,5%, respectively,

8) considering points 3) and 4), it can be noticed that an increase of 17% of the stiffener spacing induces a weight increment greater than the one induced by an increase of 14% of the stiffener span of about:

- 4 times for mild steel midship section,
- 2 times for sections with HTS either on deck and inner bottom structures or on deck and bottom structures.

9) the weight of bulb profile midship sections is approximately the same as the one of angle profile midship sections. However, the surfaces to be coated for bulb profile models are less than the ones for angle profile models of about:

- 4% for mild steel midship section,
- 3% for sections with HTS either on deck and inner bottom structures or on deck and bottom structures.

   Moreover, the number of free edges for bulb profile midship sections is much less than the one for angle profile midship sections.

3.3.4 Bulkhead arrangement

In order to investigate the possible design options and their effects in terms of structural strength and weight, the influence of the following design parameters is considered:

- bulkhead type: corrugated or plane,
- corrugated bulkhead parameters:
  - bulkhead with or without stools,
  - corrugation geometry: angle, flange width and height,
- plane bulkhead parameters:

- number of stringers,
- ordinary stiffener spacing,
- ordinary stiffener type.

More precisely, the analysis of the corrugation parameter influence is carried out by considering:

- the variation of the flange width for a given angle value,
- the variation of the angle value for a given corrugation height.

Moreover, the designs of corrugated bulkheads are obtained by imposing that flanges and webs have approximately the same width, which is beneficial for the plate strength behaviour.

Various designs of the bulkhead are analysed, each one coming out from the combination of the different parameters presented above and by considering a HTS with a 315 MPa yield stress. The obtained bulkhead data and their associated detailed results are presented in Appendix 1. The main results are also presented in the Figures 16 to 24.

❒ *Corrugated bulkheads*

➢ *Steel weight of corrugated bulkhead designed with stools*

The steel weight of the different corrugated bulkheads designed with stools, the results of which are presented in the Figures 16 and 17, is obtained by taking into account the weight of:

- the corrugated bulkhead in cargo tank,
- the plating, the ordinary stiffeners and the webs of upper and lower stools,
- the plating, the ordinary stiffeners and the brackets of the watertight web frame fitted in the j-ballast tank.

Figure 16 : Influence of the corrugation flange width (at given corrugation angle) on the weight of HTS corrugated bulkheads designed with stools.

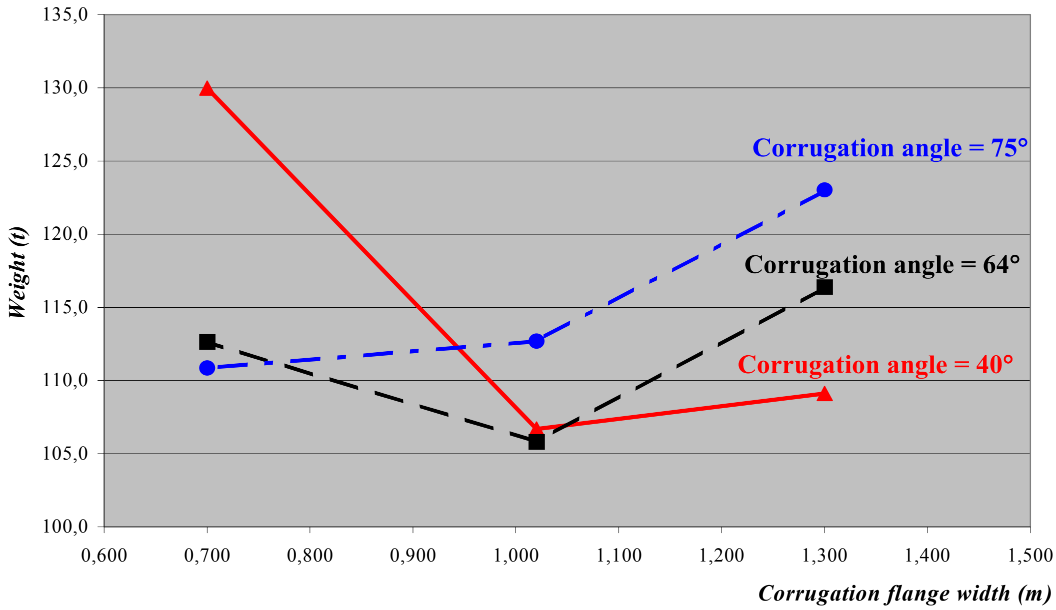
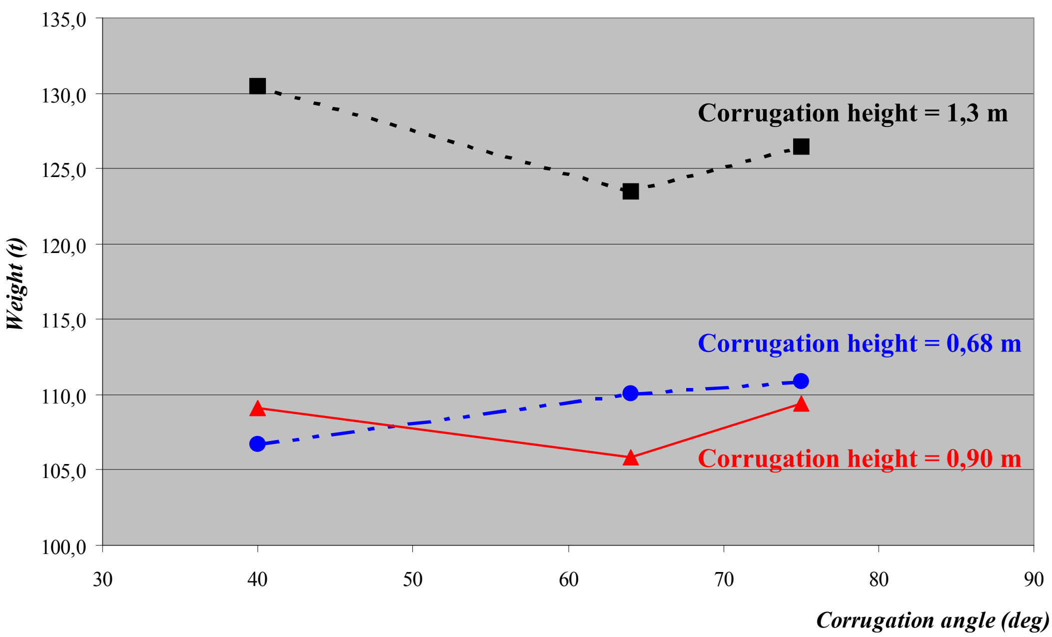


Figure 17 : Influence of the corrugation flange angle (at given corrugation height) on the weight of HTS corrugated bulkheads designed with stools.



From the results presented in the Figures 16 to 17, it can be noticed that:

1) the flange width that provides the lightest bulkhead is lower for greater corrugation angles,

2) the corrugation height that provides the lightest bulkhead is equal to about 0,9 m. It can be noticed that the greater the bulkhead span is, the greater the corrugation height is,

3) for corrugation angles ranging between 40° and 65°, approximately (the most commonly used in this type of ships for bulkhead designed with stools), the lightest design is the one that adopts flange and web of about 1,0 m width. For greater angles, weight reduction can be obtained with smaller width,

4) considering points 2) and 3), the corrugation parameters that provide the lightest bulkhead are:

- corrugation height equal to about 0,9 m,
- corrugation flange and web widths equal to about 1,0 m,
- corrugation angle equal to about 65°.

➢ ***Steel weight of corrugated bulkhead designed without stools***

The steel weight of the different corrugated bulkheads designed without stools, the results of which are presented in the Figures 18 and 19, is obtained by taking into account the weight of:

- the corrugated bulkhead in cargo tank,
- the plating and of the ordinary stiffeners of the watertight web frame fitted in the j-ballast tank.

Figure 18 : Influence of the corrugation flange width (at given corrugation angle) on the weight of HTS corrugated bulkheads designed without stools.

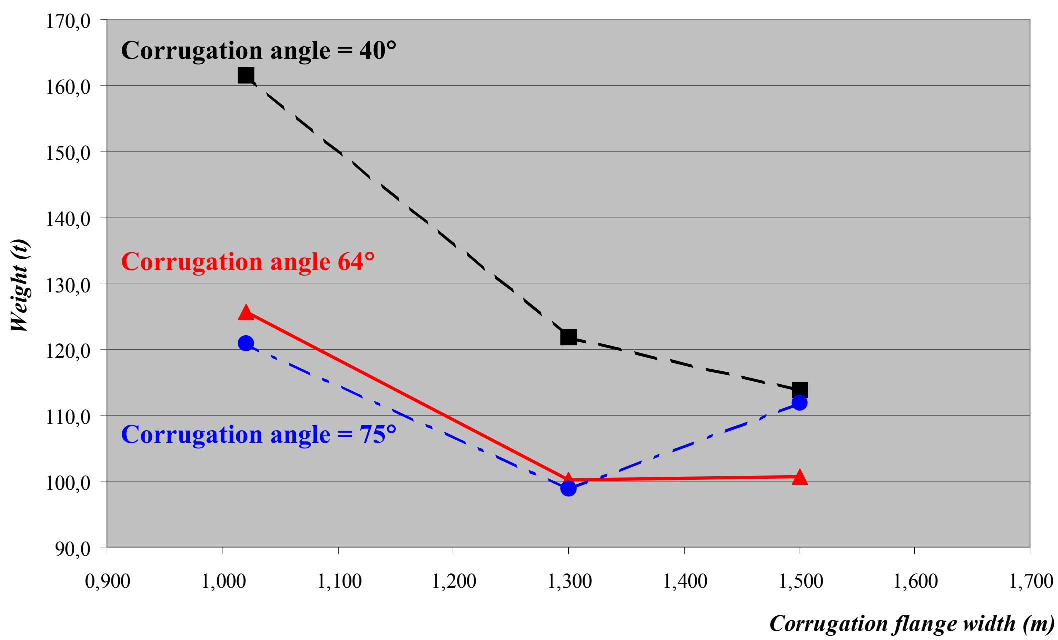
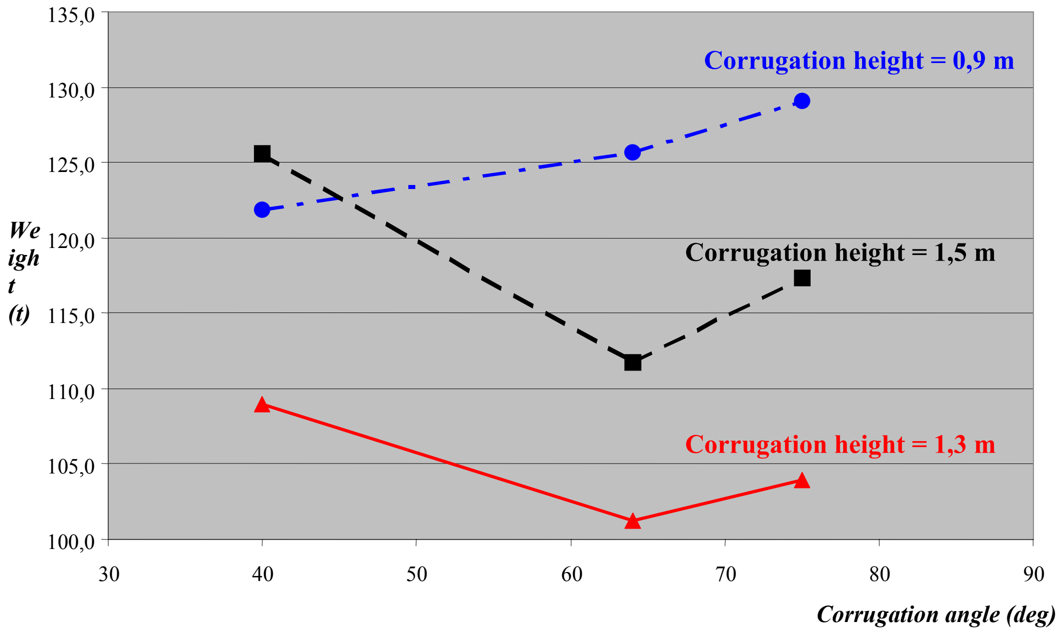


Figure 19 : Influence of the corrugation flange angle (at given corrugation height) on the weight of HTS corrugated bulkheads designed without stools.



From the results presented in the Figures 18 to 19, it can be noticed that:

1) the flange width that provides the lightest bulkhead is lower for greater corrugation angles,

2) the corrugation height that provides the lightest bulkhead is equal to about 1,3 m. It can be noticed that the greater the bulkhead span is, the greater the corrugation height is,

3) the corrugation height that provides the lightest corrugated bulkhead designed without stools (h = 1,3 m) is greater than the corresponding one for corrugated bulkhead designed with stools (h = 0,9 m),

4) for corrugation angles ranging between 60° and 75°, approximately (the most commonly used in this type of ships for bulkheads designed without stools), the lightest design is the one that adopts flange and web having width equal to about 1,3 m. For greater angles, weight reduction can be obtained with smaller width,

5) considering points 2) and 4), the corrugation parameters that provide the lightest bulkhead are:

– corrugation height equal to about 1,3 m,

– corrugation flange and web widths equal to about 1,3 m,

– corrugation angle equal to about 75°.

➢ ***Coating surfaces***

The bulkhead coating surface calculations, the results of which are presented in Table 14, are realised by only considering ballast tank surfaces (plating, ordinary stiffeners and primary supporting members), including lower stools.

➢ ***Bulkhead double fillet weld length***

The bulkhead double fillet weld lengths are calculated by only considering the welds between the stiffeners and the platings, which means that the welds between the stiffener web and the stiffener face plate are not considered.

Furthermore, it has to be noticed that no ordinary stiffeners are considered as being fitted on the corrugated bulkheads. Therefore, the calculated bulkhead double fillet weld lengths do only depend on the length of ordinary stiffeners fitted in the stools and in the watertight web frame fitted in the j-ballast tank. Indeed, they do neither depend on the ordinary stiffener profile nor on the corrugation geometry.

As, in the case of this study for corrugated bulkheads, the bottom ordinary stiffener spacing is taken as a constant equal to 0,740 m, the results presented in Table 14 do only take the type of corrugated bulkhead (with or without stool) into account.

➢ ***Bulkhead free edge length***

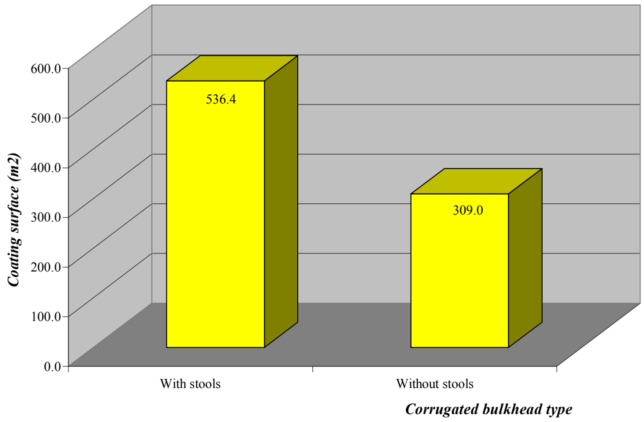
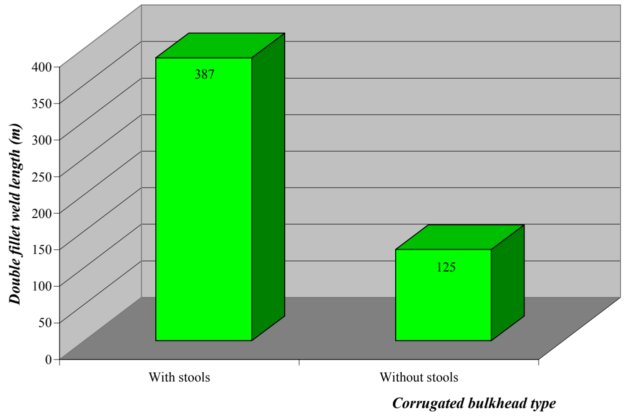
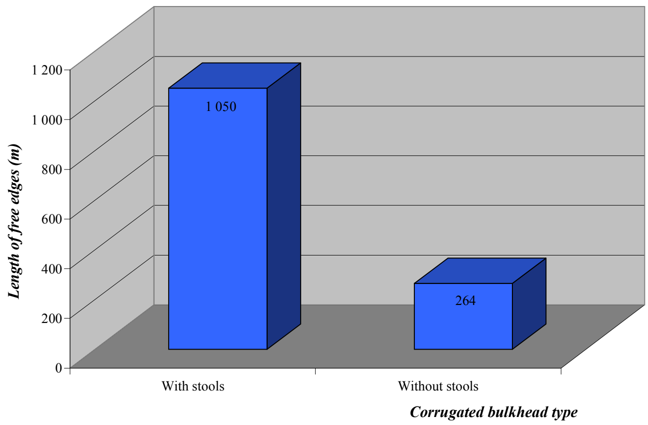
The free edge lengths of the ordinary stiffeners are calculated by considering:

- no free edge for bulb profiles and laminated angle profiles,
- 2 free edges for flat bar profiles,
- 3 free edges for built-up angle profiles,
- 4 free edges for built-up T profiles.

Furthermore, it has to be noticed that no ordinary stiffeners are considered as being fitted on the corrugated bulkheads. Therefore, the calculated bulkhead free edge lengths do only depend on the types and length of the ordinary stiffeners fitted in the stools and in the watertight web frame fitted in the j-ballast tank. Indeed, they do not depend on the corrugation geometry.

As, in the case of this study for corrugated bulkheads, the bottom ordinary stiffener spacing is taken as a constant equal to 0,740 m and the ordinary stiffener profile is not changed (angles in stools and flat bars in the watertight web frame), the results presented in Table 14 do only take the type of corrugated bulkhead (with or without stool) into account.

Table 14 : Coating surface, double fillet weld length and free edge length of HTS corrugated bulkheads

Coating surfaces	
Length of stiffener double fillet welds	
Length of stiffener free edges	

➢ ***Conclusions***

By comparing the results relevant to corrugated bulkheads designed without stools with the ones relevant to corrugated bulkheads designed with stools, it can be noticed that corrugated bulkheads designed with stools are about 6% heavier than corrugated bulkheads designed without stools. Moreover, the number of stiffeners, the lengths of stiffener welds, the lengths of stiffener free edges and the coating surfaces for corrugated bulkheads designed with stools are much greater than those for corrugated bulkheads designed without stools.

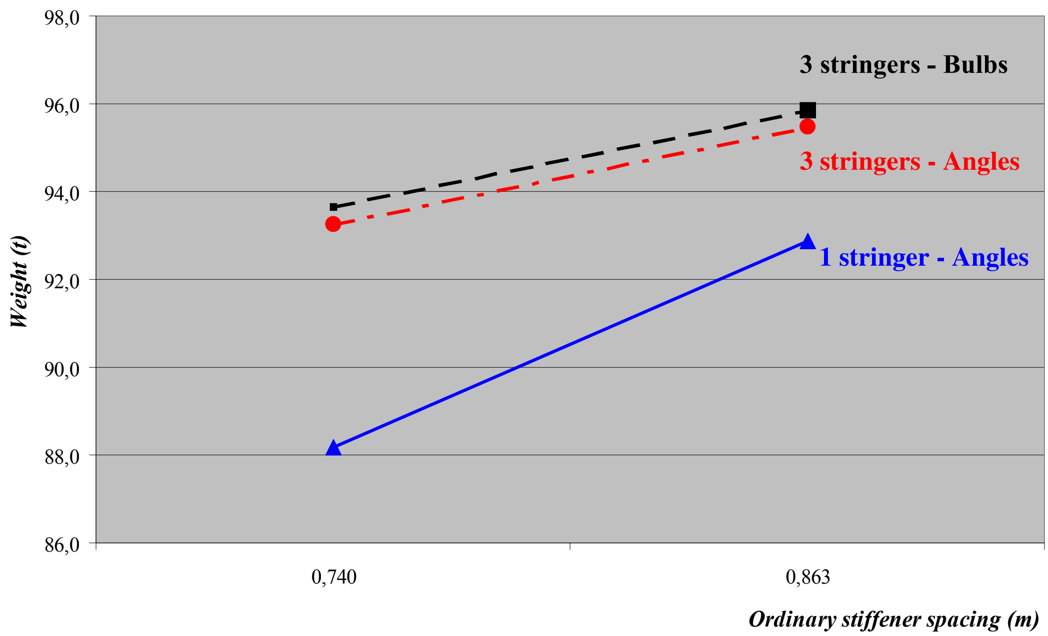
❒ *Plane bulkheads*

➢ *Steel weight*

The steel weight of the different plane bulkheads, the results of which are presented in Figure 20, is obtained by taking into account the weight of:

- the plating, the ordinary stiffeners, the brackets and of the stringers of the plane bulkhead in cargo tank,
- the plating, the ordinary stiffeners and the brackets of the watertight web frame fitted in the j-ballast tank.

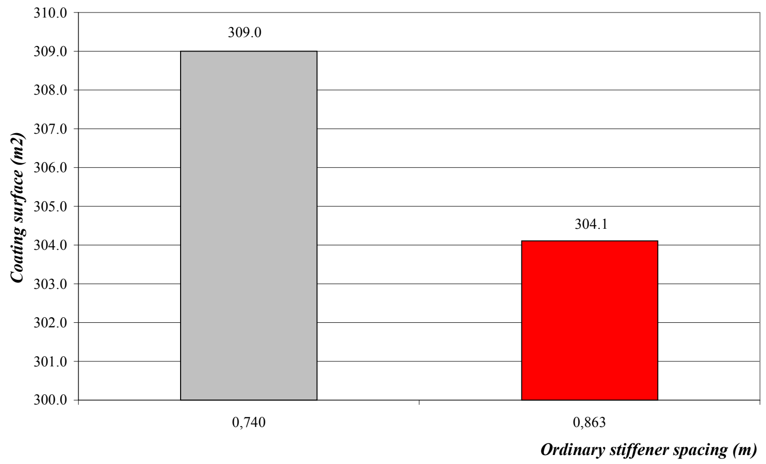
Figure 20 : Influence of the stiffener spacing on the HTS plane bulkhead weight.



➢ *Coating surfaces*

The bulkhead coating surface calculations, the results of which are presented in Figure 21, are realised by considering only ballast tank surfaces (plating, ordinary stiffeners and primary supporting members).

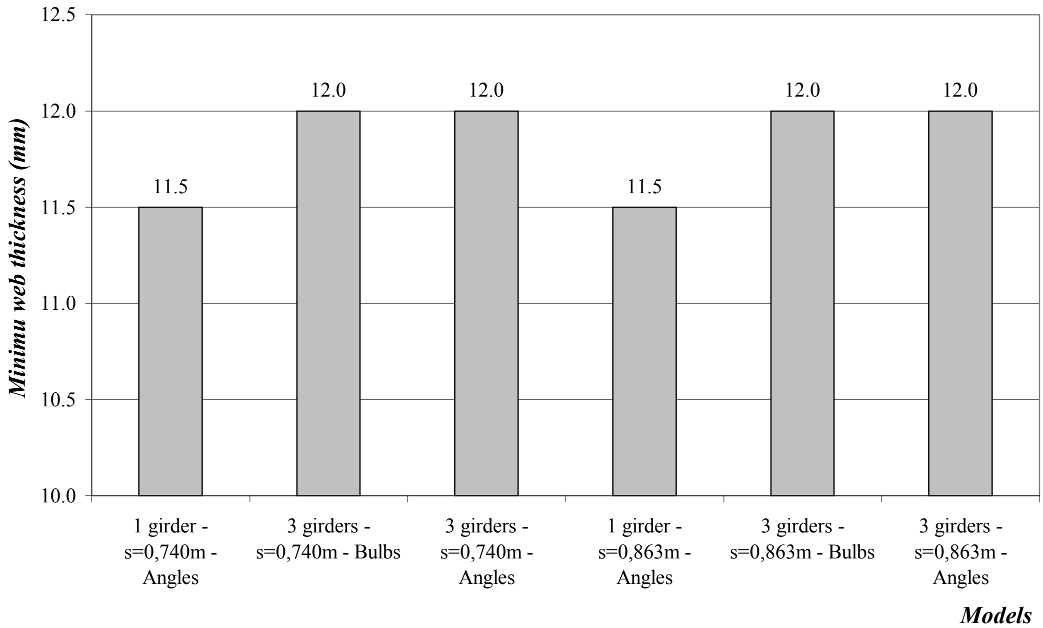
Figure 21 : Influence of the stiffener spacing on the coating surface of HTS plane bulkheads



- ***Minimum thickness of ordinary stiffener web***

The minimum thickness of ordinary stiffener webs, the results of which are presented in Figure 22, is calculated for the as-built thickness of the plane bulkhead ordinary stiffeners.

Figure 22 : Minimum thickness of ordinary stiffener webs

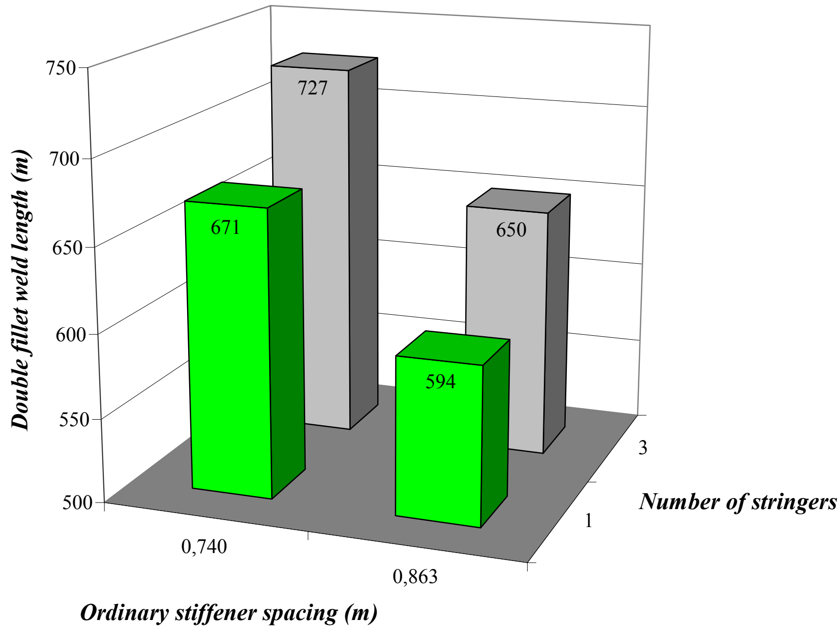


- ***Bulkhead double fillet weld length***

The bulkhead double fillet weld lengths are calculated by only considering the welds between the stiffeners and the platings, which means that the welds between the stiffener web and the stiffener face plate are not considered.

Furthermore, it has to be noticed that the calculated bulkhead double fillet weld lengths do only depend on the ordinary stiffener spacing and on the number of stringers. Indeed, they do not depend on the ordinary stiffener profile. This is therefore, the reason why the results presented in Figure 23 do only take the ordinary stiffener spacing and the number of stringers into account and can thus be affected to plane bulkheads made of any desired type of ordinary stiffeners.

Figure 23 : Influence of the stiffener spacing and of the number of stringers on the HTS plane bulkhead of stiffener double fillet weld lengths.



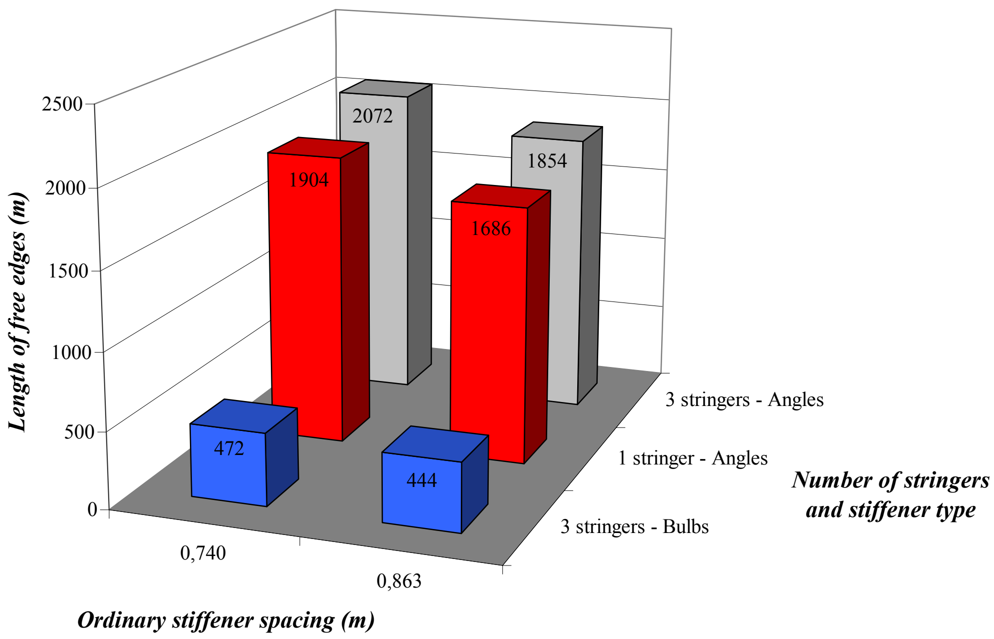
- ***Bulkhead free edge length***

The free edge lengths of ordinary stiffeners are calculated by considering:

- no free edge for bulb profiles and laminated angle profiles,
- 2 free edges for flat bar profiles,
- 3 free edges for built-up angle profiles,
- 4 free edges for built-up T profiles.

Furthermore, the free edge lengths calculated for the bulkheads do only depend on the ordinary stiffeners types, on their spacings and on the number of stringers. This is therefore the reason why the results presented in Figure 24 do only take the ordinary stiffener types and spacings and the number of stringers type into account.

Figure 24 : Influence of the stiffener types and spacings and of the number of stringers on the HTS plane bulkhead length of stiffener free edges.



➢ ***Conclusions***

From the results of plane bulkheads presented in the Figures 20 to 24, it can be noticed that:

1) plane bulkheads with an ordinary stiffener spacing equal to 0,740 m are lighter than those with a spacing equal to 0,863 m of about:

   - 5% for single stringer bulkheads,
   - 2% for bulkheads fitted with three stringers.

   However, the coating surfaces and the lengths of stiffener welds for bulkheads with a spacing of 0,740 m are about 2% and 12%, respectively, greater than those for bulkheads with a spacing of 0,863 m.

   Moreover, the lengths of stiffener free edges for bulkheads with a spacing of 0,740 m are greater than those for bulkheads with a spacing of 0,863 m of about:

   - 6% for bulkheads fitted with bulb profiles,
   - 12% for bulkheads fitted with angle profiles,

2) the weight of bulb profile bulkheads is approximately the same as the one of angle profile bulkheads. However, the number of free edges for bulb profile models is much less than the one for angle profile models,

3) single stringer plane bulkheads are lighter than those fitted with three stringers of about:

   - 6% for ordinary stiffener spacing equal to 0,740 m
   - 3% for ordinary stiffener spacing equal to 0,863 m.

   Moreover, the lengths of stiffener welds and the lengths of stiffener free edges for single stringer plane bulkhead are both about 9% less than those for bulkheads fitted with three stringers.

❐ *Comparison between corrugated and plane bulkheads*

By comparing the results relevant to plane bulkheads, presented in the Figures 20 to 24, with the ones relevant to corrugated bulkheads designed with or without stools, presented in the Figures 16 to 19 and in Table 14, it can be noticed that:

1) corrugated bulkheads designed with stools are heavier than plane bulkheads of about 10-20%, depending on the considered plane bulkhead design. The highest value (20%) is relevant to single stringer plane bulkhead fitted with angle profiles spaced of 0,740 m; the lowest value (10%) is relevant to plane bulkhead fitted with three stringers and with bulb profiles spaced of 0,863 m.

   Moreover, the coating surfaces and the number of stiffeners for corrugated bulkheads designed with stools are much greater than those for plane bulkheads.

   However, the lengths of stiffener welds and the lengths of stiffener free edges for corrugated bulkheads designed with stools are less than those for plane bulkheads (only when angle profiles are adopted) and the differences vary in the ranges of about 50-90% and 60-100%, respectively. These values depend on the considered plane bulkhead design: the lowest differences are relevant to the single stringer plane bulkhead fitted with angle profiles spaced of 0,863 m; the greatest differences are relevant to plane bulkheads fitted with three stringers and with angle profiles spaced of 0,740 m,

2) corrugated bulkheads designed without stools are heavier than plane bulkheads of about 5-14%, depending on the considered plane bulkhead design. The highest value (14%) is relevant to single stringer plane bulkhead fitted with angle profiles spaced of 0,740 m; the lowest value (5%) is relevant to plane bulkhead fitted with three stringers and bulb profiles spaced of 0,863 m.

   However, the number of stiffeners, the lengths of stiffener welds and the lengths of stiffener free edges for corrugated bulkheads designed without stools are much less than those for plane bulkheads (only when angle profiles are adopted).

Moreover, the coating surfaces of corrugated bulkheads designed without stools are approximately the same as the ones of plane bulkheads.

3.4 Structural analysis of an Aframax

3.4.1 General considerations

The structural analysis of the Aframax, the properties of which are described in 1.3.3, takes into account the specific characteristics of this type of ship. In details, the following most typical design aspects that may impact on its fabrication costs are considered:

- the choice of the steel type. For Aframax tankers, either mild steel or high strength steel (HTS) may be used for deck, inner bottom and bottom structures. The aim of using HTS for deck structures is to increase both the hull girder and the buckling strengths, whereas the aim of using HTS for bottom and inner bottom structures is to increase the strength of the plating and of the ordinary stiffeners according to the effects of local pressures due to the sea and to the carried liquids. Therefore, three steel type distributions are investigated:
    - all structures in mild steel,
    - bottom, inner bottom and deck structures in HTS,
    - bottom and deck structures in HTS.
- the choice of the transverse bulkhead type. In general, for Aframax tankers, transverse plane bulkheads are adopted. Therefore, extensive investigations are carried out on plane bulkhead designs. However, for comparison purposes, corrugated bulkhead designs are also investigated.

In order to evaluate the effects of the design choices presented above, various design solutions, both for the midship sections and for the transverse bulkheads are compared and the following outputs can be analysed:

- steel weight,
- coating surfaces,
- length of ordinary stiffener welds,
- length of ordinary stiffener free edges.

3.4.2 Tank structure arrangement

The structural analysis of an Aframax tanker is tailored to investigate the aspects deemed critical for the typical tank structural arrangement of this kind of ship. In details, the structural analysis of the ship presented in this study takes into account the following main aspects:

- the scantlings of the plating and of the ordinary stiffeners of the tank boundaries (top, bottom, bulkheads) are calculated by taking into account the effects of global and local loads. An extensive analysis of the results is presented in 3.4.3 for the plating and for the ordinary stiffeners of the midship sections and in 3.4.4 for the plating and for the ordinary stiffeners of the transverse bulkheads,

- the scantlings of the primary supporting members of the tank boundaries (transverse web frames and transverse bulkhead stringer) are calculated through finite element analysis performed according to the calculation procedure presented in 3.1.1, with reference to the structural models there specified. Particular attention is paid to details such as the most stressed transverse web frame and as the transverse bulkhead upper stringer. The finite element analysis results are presented in Appendix 2.

3.4.3 Midship section arrangement

In order to investigate the possible design options and their effects in terms of structural strength and weight, the influence of the following design parameters is considered:

- steel yield stress (235 MPa yield stress for a mild steel and 355 MPa yield stress for a HTS),

- longitudinal ordinary stiffener (angle profile) spacing,

- longitudinal ordinary stiffener span.

Various designs of midship sections are analysed, each one coming out from the combination of the different parameters presented above. The obtained midship section data and their associated detailed results are presented in Appendix 2. The main results are also presented in the Figures 25 to 29.

❐ ***Steel weight***

The weight of the different midship sections, the results of which are presented in Figures 25 and 26, is obtained by taking into account the weight of the plating and of the ordinary stiffeners of the midship sections as well as the one of the transverse web frames. However, it has to be noted that the weight of the transverse bulkheads is not taken into account at this stage of the present study.

Figure 25: Influence of the ordinary stiffener spacing on the midship section weight (at constant span=3,75m).

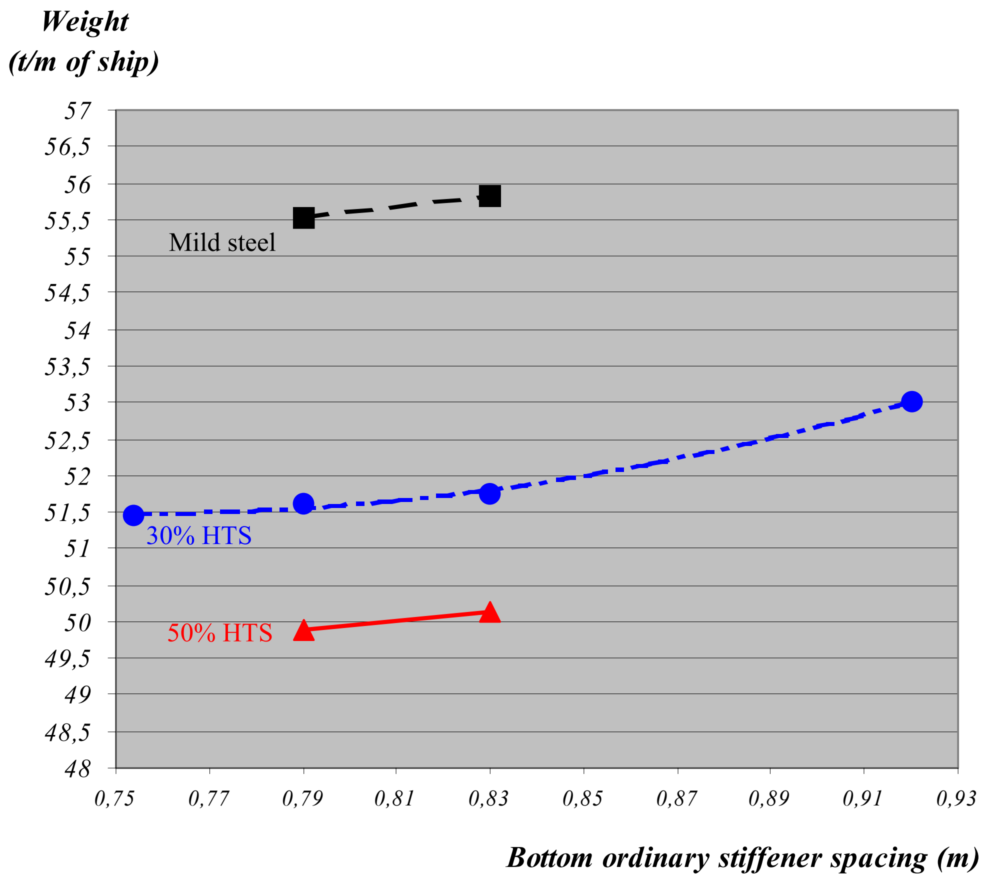
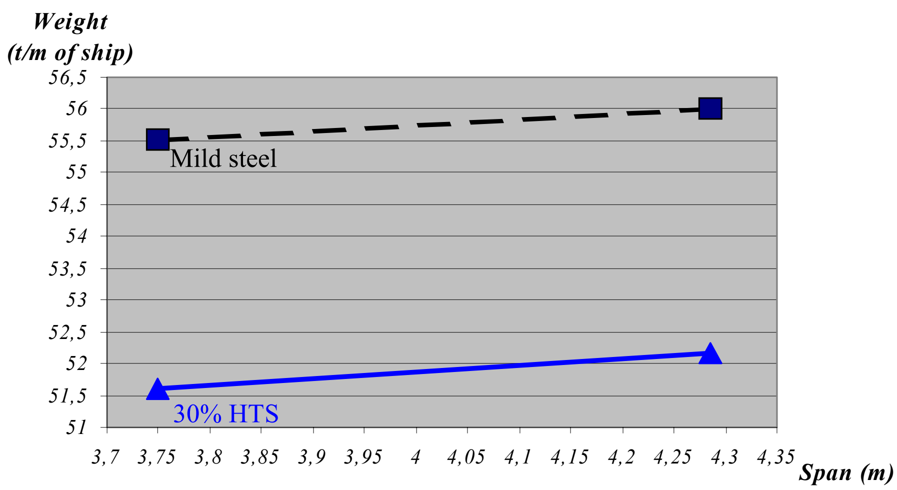


Figure 26: Influence of the longitudinal ordinary stiffener span on the midship section weight (at constant spacing=0,790m).

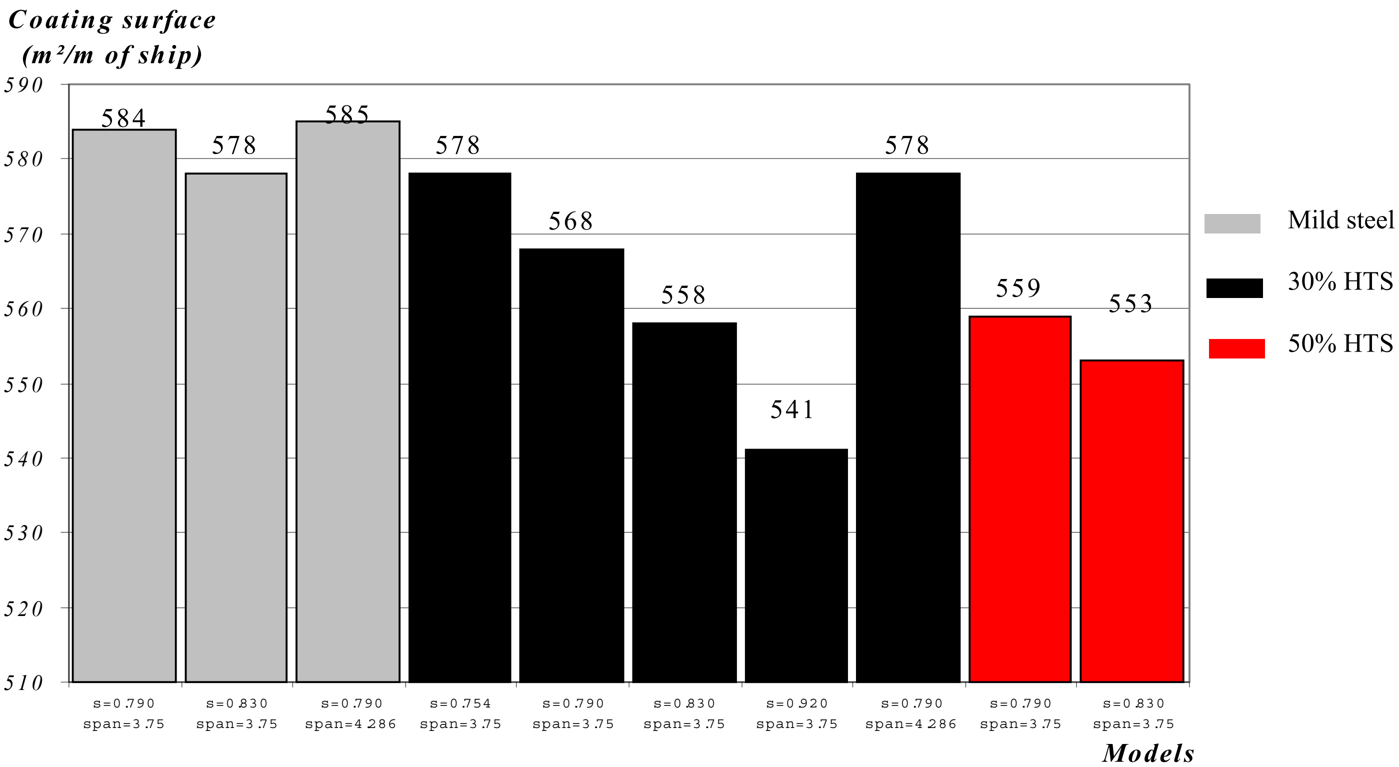


❒ *Coating surfaces*

The coating surface calculations, the results of which are presented in Figure 27, are realised by considering:

- midship section ballast tank surfaces (all plating and ordinary stiffeners),
- transverse web frame ballast tank surfaces (all plating and ordinary stiffeners),
- cargo tank surfaces (plating of horizontal inner bottom to which is added plating and ordinary stiffeners of deck).

Figure 27: Midship section coating surfaces.

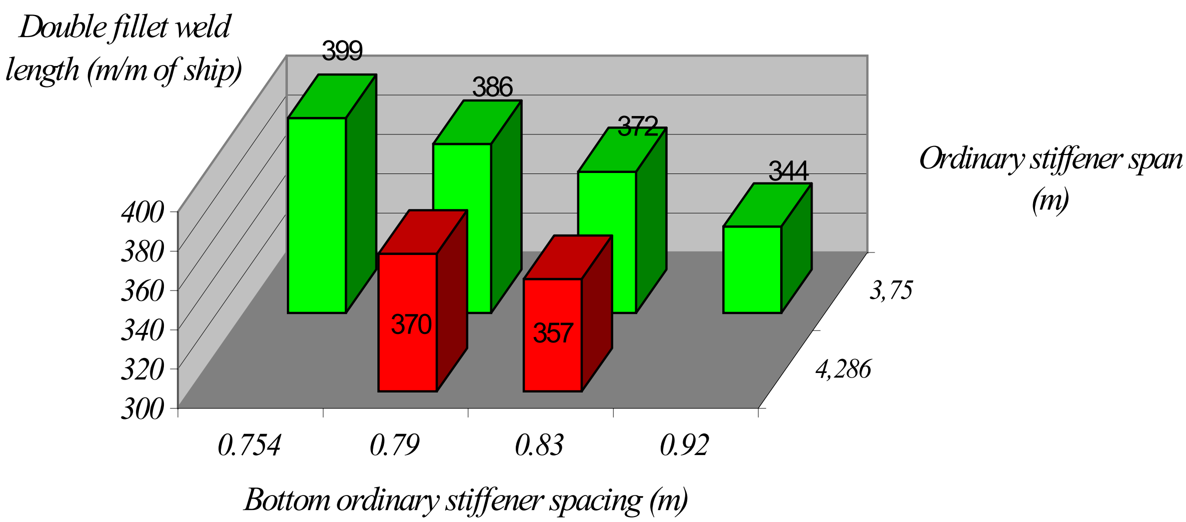


❒ *Midship section double fillet weld lengths*

The midship section double fillet weld lengths are calculated by considering the welds between the stiffeners and the platings, which means that the welds between the stiffener web and the stiffener face plate are not considered.

Furthermore, it has to be noticed that the calculated midship section double fillet weld lengths do only depend on the ordinary stiffener spacing and on the ordinary stiffener span. Indeed, they do neither depend on the material type nor on the type of ordinary stiffener profile. This is therefore, the reason why the results presented in Figure 28 do only take the ordinary stiffener spacings and the ordinary stiffener spans into account and can thus be affected to midship sections made of any desired material and of any desired type of ordinary stiffeners.

Figure 28: Influence of the longitudinal ordinary stiffener spacing and of the ordinary



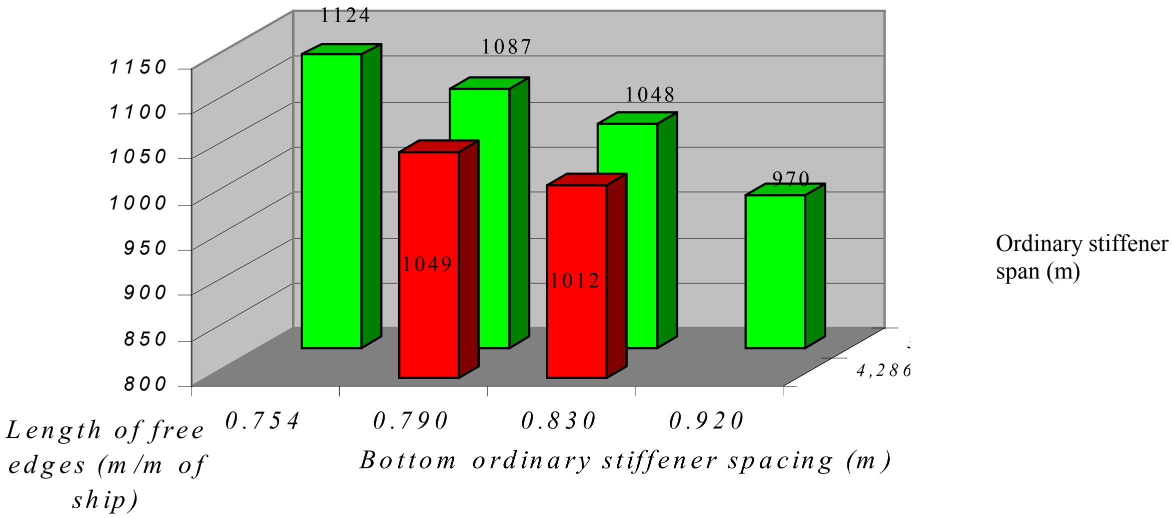
❒ *Midship section free edge lengths*

The free edge lengths of the ordinary stiffeners are calculated by considering:

- no free edge for bulb profiles and laminated angle profiles,
- 2 free edges for flat bar profiles,
- 3 free edges for built-up angle profiles,
- 4 free edges for built-up T profiles.

Furthermore, those free edge lengths do only depend on the ordinary stiffener types, on their spacings and on the ordinary stiffener spans. Indeed, they do not depend on the material type. As, in the case of this study, only angle profile ordinary stiffeners are considered, the results presented in Figure 29 do only take the ordinary stiffener spacings and the ordinary stiffener spans into account and can thus be affected to midship sections made of any desired material, as long as only angle profile ordinary stiffeners are considered.

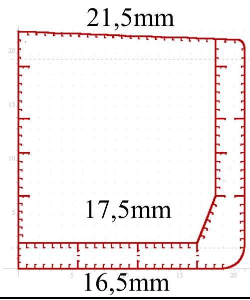
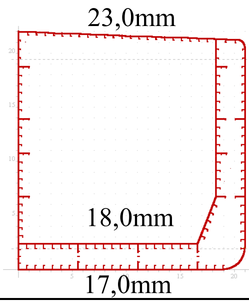
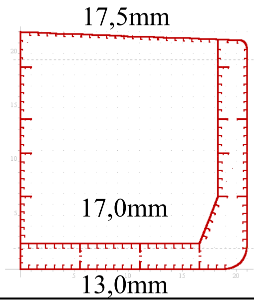
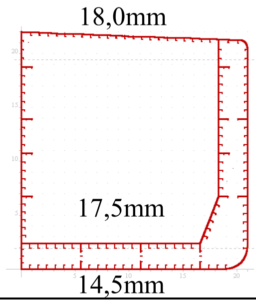
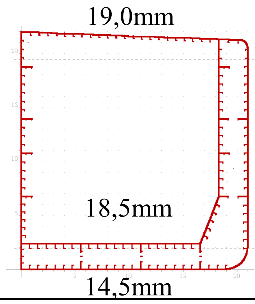
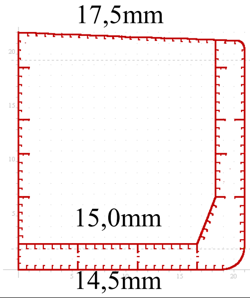
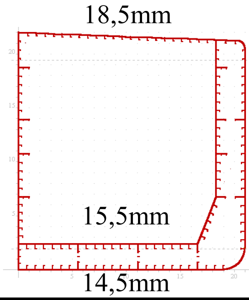
Figure 29: Influence of the longitudinal ordinary stiffener spacing and of the ordinary stiffener span on the midship section free edge lengths.



❐ *Conclusions*

In order to sum up the different results presented in the Appendix 2, Table 15 presents the thickness that guarantee that the ratios between the applied bending moments in sagging or hogging conditions and the corresponding ultimate bending moment capacity of the section, calculated according to the Rule criteria, do not exceed 85%, according to the different possible design options.

Table 15: Plating thickness of deck, inner bottom and bottom that verify the maximum ultimate strength limit of 85%.

	Bottom ordinary stiffener spacing		
Material	0,754 m	0,790 m	0,830 m
Mild steel	Design solution not considered in this study		
HTS 30%			
HTS 50%	Design solution not considered in this study		

From the results of midship sections presented in the Figures 25 to 29, it can be noticed that:

1) for an ordinary stiffener spacing varying between 0,754m and 0,920m, the less the ordinary stiffener spacing is, the lighter the midship section is. Indeed, for instance, for the 30% HTS midship sections, a decrease of 22,0% of the ordinary stiffener spacing results in a 3,03% decrease of the steel weight. However, it has to be specified that if an ordinary stiffener spacing lower than 0,754m is chosen, which does not correspond to any studied case of the present study, the steel weight can not be evaluated by extrapolating the steel weight values presented in Figure 25. Indeed, the steel weight value considered for a 0,754m ordinary stiffener spacing might correspond to a curve minimum (in which case, if an ordinary stiffener spacing midship section lower than 0,754m is considered, the steel weight for this latter might increase) or might be an asymptotic value. Thus, the

presented values have to be carefully considered and can not be extrapolated for any further conclusions that the ones that can only be drawn from the values of the figures,

2) from a general point of view, midship sections made of mild steel are about 7,5% heavier than 30% HTS midship sections at equivalent structural characteristics (number of transverse web frames and longitudinal ordinary stiffener spacing),

3) from a general point of view, midship sections made of mild steel are around 11,3% heavier than 50% HTS midship sections at equivalent structural characteristics (number of transverse web frames and longitudinal ordinary stiffener spacing),

4) for any given material, a 14,3% decrease of the number of transverse web frames results in an about 1,1% increase of the weight, but in an about 4,3% decrease of the double fillet weld lengths and in an about 3,6% decrease of the lengths of free edges,

5) for any given material and primary structure span, the more the ordinary stiffener spacing is, the less the coating surfaces, the lengths of free edges and the lengths of welds are. Indeed, for instance, for the 30% HTS midship sections with a 3,75m ordinary stiffener span, an increase of 22,0% of the ordinary stiffener spacing results in a 6,8% decrease of the surfaces to be coated and in a 16,0% decrease of the lengths of double fillet welds and of the lengths of free edges,

6) from a general point of view, midship sections made of mild steel are about 3,2% more coated than 30% HTS midship sections and 4,5% more coated than 50% HTS midship sections at equivalent longitudinal ordinary stiffener spacing and for a 3,75m ordinary stiffener span,

7) for a 4,286m ordinary stiffener span, midship sections made of mild steel are about 1,2% more coated than 30% HTS midship sections at equivalent longitudinal ordinary stiffener spacing.

3.4.4 Bulkhead arrangement

In order to investigate the possible design options and their effects in terms of structural strength and weight, the influence of the following design parameters is considered:

- steel yield stress (235 MPa yield stress for a mild steel and 355 MPa yield stress for a HTS),

- bulkhead type: plane or corrugated,

- plane bulkhead parameters:
  - number of stringers,
  - ordinary stiffener spacing,
- corrugated bulkhead parameters: number of corrugations.

Various designs of bulkheads are analysed, each one coming out from the combination of the different parameters presented above. The obtained bulkhead data and their associated detailed results are presented in Appendix 2. The main results are also presented in the Figures 30 to 35.

❒ *Steel weight*

For the steel weight calculations, the results of which are presented in Figures 30 and 31, the steel weight of the stringers and of the corresponding watertight web frame fitted in the J-ballast tanks are also included.

Figure 30: Influence of the ordinary stiffener spacings on the plane bulkhead steel weight.

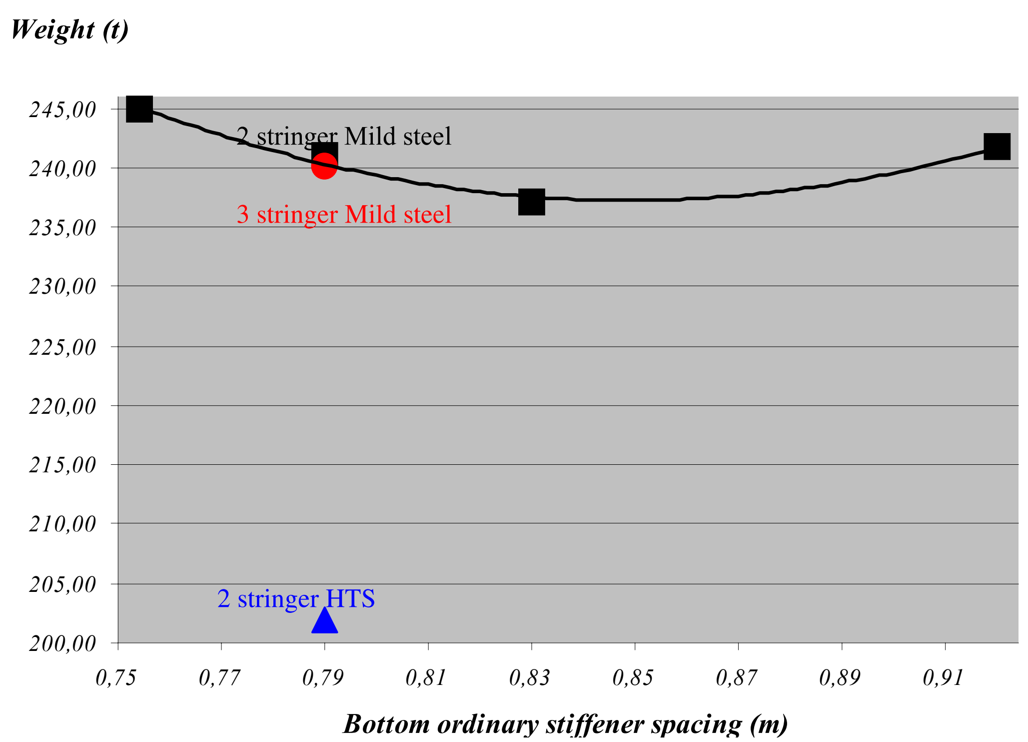
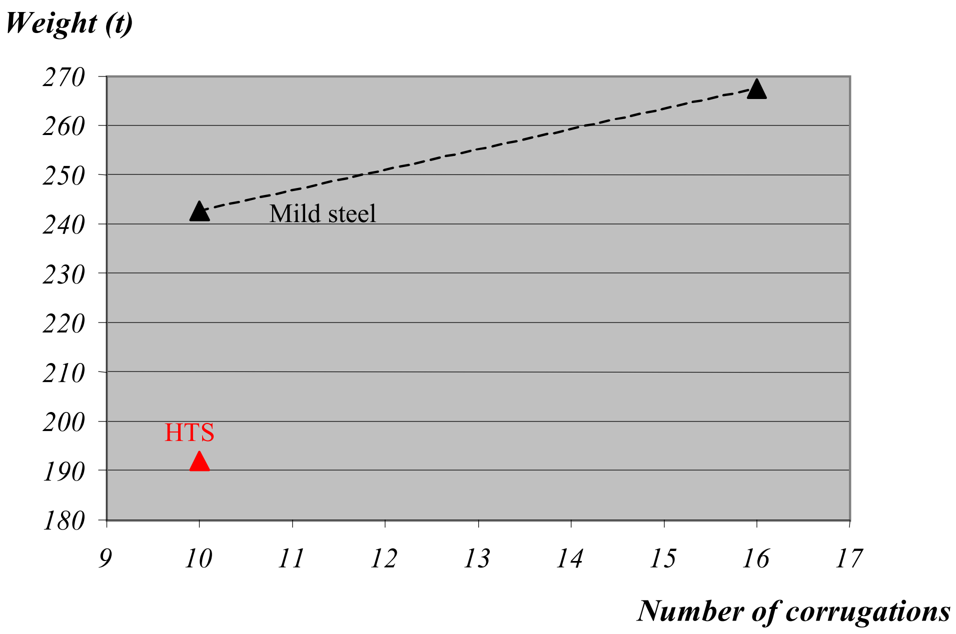


Figure 31: Influence of the number of corrugations on the corrugated bulkhead steel weight.



❒ *Coating surfaces*

The bulkhead coating surface calculations, the results of which are presented in the Figures 32 and 33, are realised by only considering ballast tank surfaces (plating, ordinary stiffeners and primary supporting members).

Figure 32: Influence of the ordinary stiffener spacings, of the number of stringers and of the material on the coating surface of plane bulkheads.

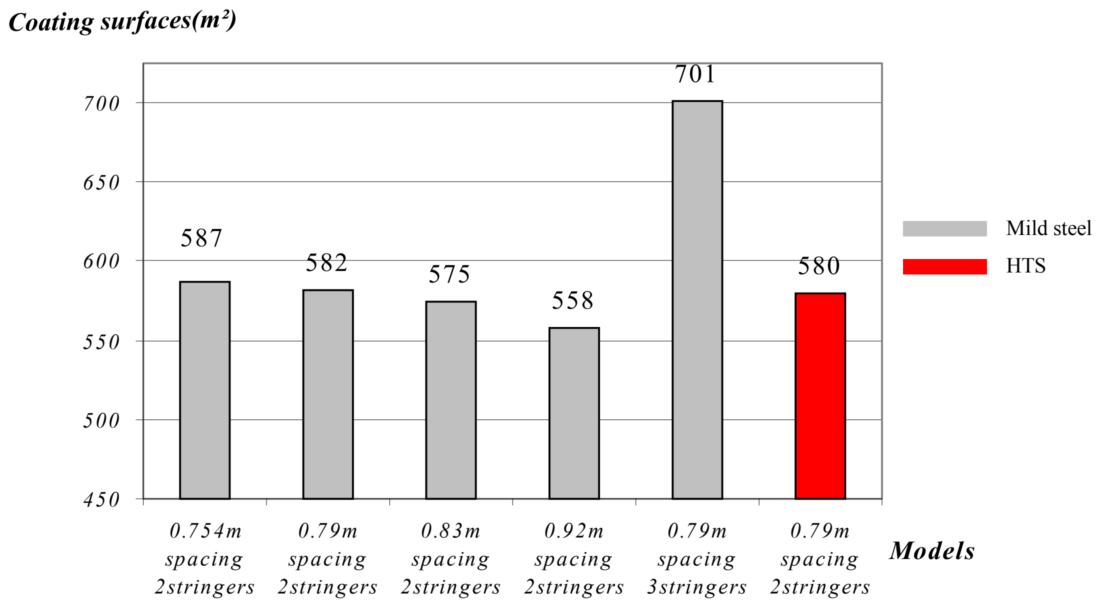
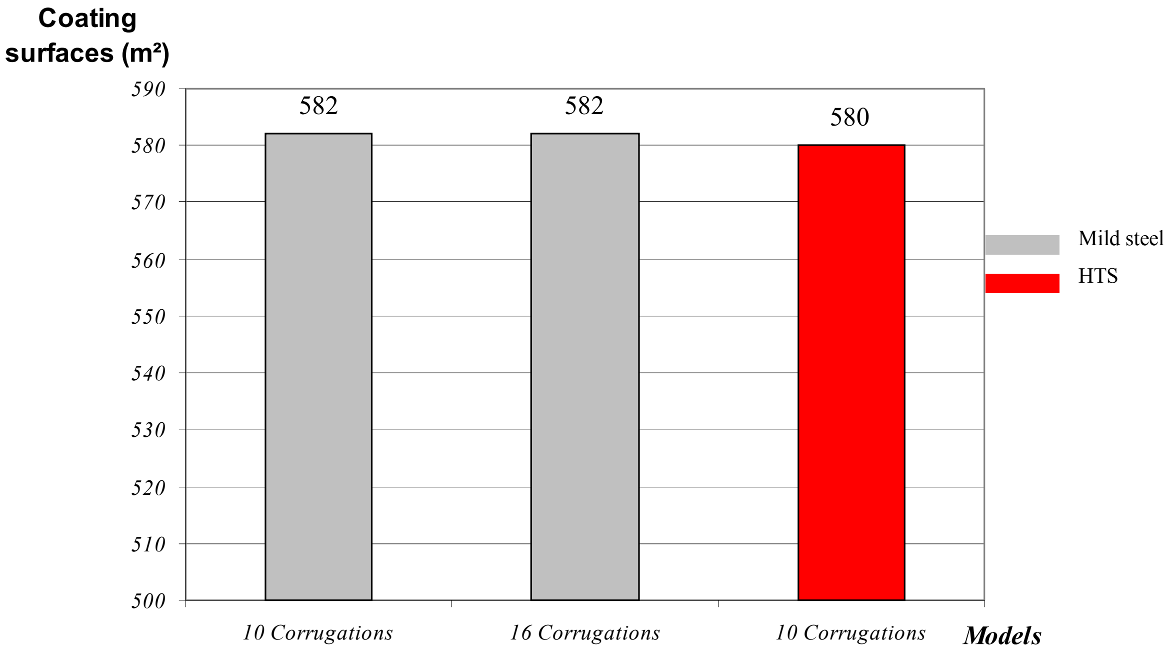


Figure 33: Influence of the number of corrugations and of the material on the coating surface of corrugated bulkheads.

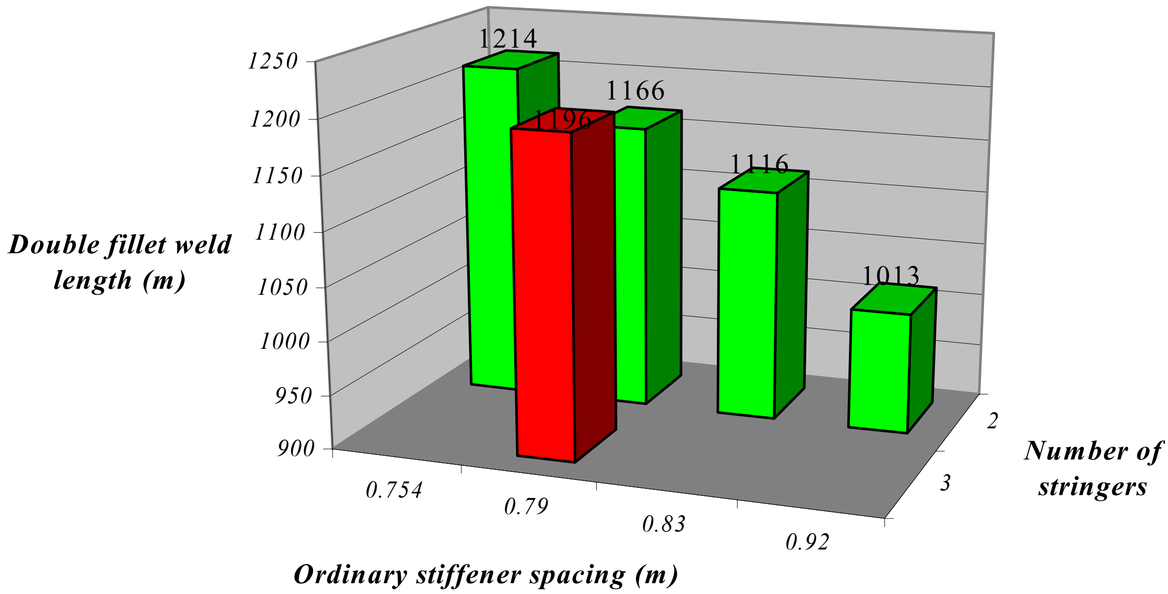


❒ *Bulkhead double fillet weld lengths*

The bulkhead double fillet weld lengths are calculated by considering the welds between the stiffeners and the platings, which means that the welds between the stiffener web and the stiffener face plate are not considered.

The double fillet weld lengths calculated for the plane bulkheads do only depend on the ordinary stiffener spacing and on the number of stringers. Indeed, they do neither depend on the material type nor on the type of ordinary stiffener profile. This is therefore, the reason why the results presented in Figure 34 do only take the ordinary stiffener spacings and the number of stringers into account and can thus be affected to plane bulkheads made of any desired material and made of any type of ordinary stiffeners.

Figure 34: Influence of the ordinary stiffener spacing and of the number of stringers on the plane bulkhead double fillet weld lengths.



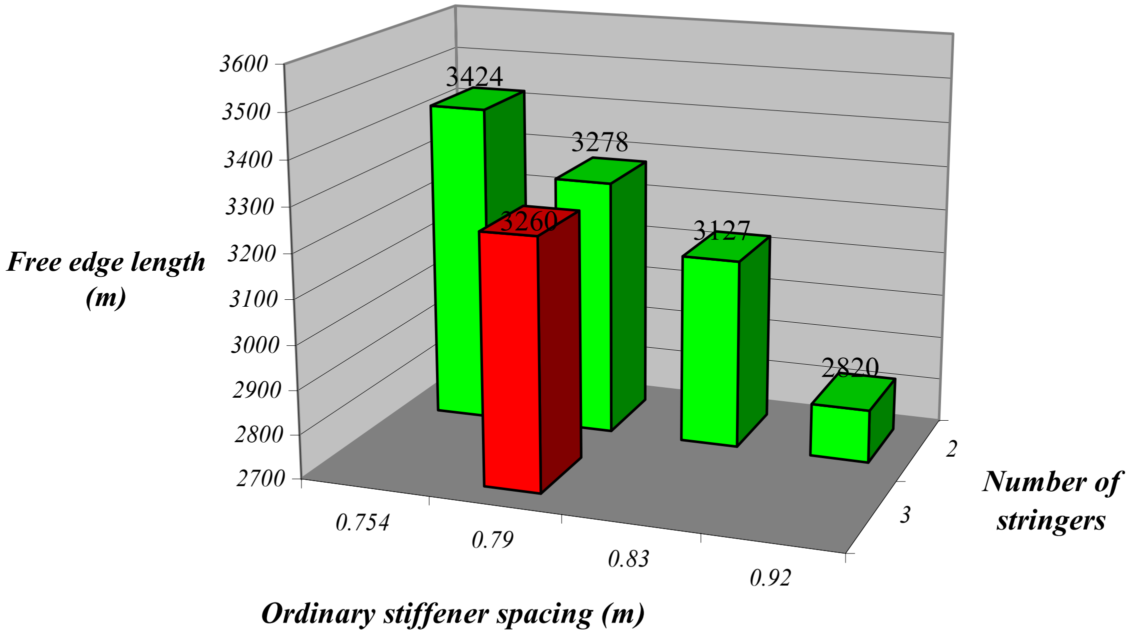
❐ *Bulkhead free edge lengths*

The free edge lengths of the ordinary stiffeners are calculated by considering:

- no free edge for bulb profiles and laminated angle profiles,
- 2 free edges for flat bar profiles,
- 3 free edges for built-up angle profiles,
- 4 free edges for built-up T profiles.

The free edge lengths calculated for the plane bulkheads do only depend on the ordinary stiffener types, on their spacings and on the number of stringers (they do not depend on the material type). As, in the case of this study, only angle profile ordinary stiffeners are considered, the results presented in Figure 35 do only take the ordinary stiffener spacings and the number of stringers into account and can thus be affected to plane bulkheads made of any desired material, as long as only angle profile ordinary stiffeners are considered.

Figure 35: Influence of the ordinary stiffener spacing and of the number of stringers on the plane bulkhead free edge lengths.



The fillet weld lengths of ballast tanks (double fillet welds are considered) calculated for the corrugated bulkhead models, do only depend on the bottom ordinary stiffener spacing. Indeed, they do neither depend on the material type nor on the type of ordinary stiffener profile. As, in the case of this study, the bottom ordinary stiffener spacing is taken as a constant equal to 0,790m for the corrugated models, the fillet weld lengths for all the studied corrugated bulkhead models (mild steel 10 corrugations, mild steel 16 corrugations and HTS 10 corrugations) are constant and equal to 652m.

The free edge lengths in ballast tanks calculated for the corrugated bulkhead models do only depend on the ordinary stiffener types and on their spacings (they do not depend on the material type). As, in the case of this study, only angle profile ordinary stiffeners are considered with a constant spacing in the bottom equal to 0,790m, the lengths of free edges for all the corrugated bulkhead models (mild steel 10 corrugations, mild steel 16 corrugations and HTS 10 corrugations) are constant and equal to 2089m.

❒ *Conclusions*

From the results of bulkheads presented in the Figures 30 to 35, it can be noticed that:

1) for mild steel bulkhead models, plane bulkheads are between 0,7% and 11,0% lighter than corrugated ones (according to the number of corrugations),

2) for HTS bulkhead models, the plane bulkhead is heavier than the corrugated one by about 5,3%,

3) at equivalent structural properties (number of stringers, ordinary stiffener spacing), the mild steel plane bulkhead is 19,3% heavier than the HTS one and does have 0,4% more surface to be coated,

4) at equivalent structural properties (number of corrugations), the mild steel corrugated bulkhead is 26,4% heavier than the HTS one,

5) at constant ordinary stiffener spacing, the 2 stringer plane bulkhead model and the 3 stringer one nearly do have the same weight, but the 3 stringer plane bulkhead model is 20,5% more coated than the 2 stringer one and the 3 stringer plane bulkhead model does have 2,6% more lengths of welds,

6) for the plane bulkheads, for a given number of stringers and for a given material, the bigger the ordinary stiffener spacing is, the less the coating surface, the lengths of welds and the lengths of free edges are. Indeed, for instance, for the 2 stringer mild steel bulkhead models, a increase of 22,0% of the ordinary stiffener spacing results in a 5,20% decrease of the surfaces to be coated, in a 19,8% decrease of the lengths of double fillet welds and in a 21,4% decrease of the lengths of free edges.

3.5 Structural analysis of a VLCC

3.5.1 General considerations

The structural analysis of the VLCC, the properties of which are described in 1.3.4 takes into account the specific characteristics of this type of ship. In details the following most typical design aspects that may impact on the fabrication costs are investigated:

- the choice of the steel type. For a VLCC, high strength steel (HTS) is usually used for deck and bottom structures. Indeed the use of HTS for deck structures allows to increase both the hull girder and the buckling strengths; moreover the use of HTS for bottom structures allows to increase the strength of the plating and of the ordinary stiffeners according to the effects of local pressures due to the sea and to the carried liquids. However, as the hull girder stresses in the inner bottom are not as high as on the bottom either mild steel or high strength steel may be used for inner bottom. Therefore, two steel grade distributions are investigated:
  - one distribution with HTS on deck, inner and bottom of the structure,
  - a second distribution with HTS only on deck and bottom of the structure,

Moreover, the structural analysis of the VLCC is carried out by considering that:

- in general, this kind of ship has long cargo tank which may induce risks of resonance. In order to avoid those problems a swash bulkhead is considered as being fitted in the middle of each tank,

- in general, for a VLCC, plane bulkheads are adopted as the Crude Oil Washing procedure is adopted to clean up this kind of ship. Therefore, investigations are carried out only on plane bulkhead design,

In order to evaluate the effects of the design choices presented above, various design solutions, both for the midship sections and for the transverse bulkheads are considered and the following outputs can be evaluated:

- steel weight,

- coating surfaces,

- lengths of ordinary stiffener welds,

- lengths of ordinary stiffener free edges.

3.5.2 Tank structure arrangement

The structural analysis of a VLCC is tailored to investigate the aspects deemed critical for the typical tank structural arrangement of this kind of ship. In details, the structural analysis of the ship presented in this study takes into account the following main aspects:

- the scantlings of the plating and of the ordinary stiffeners of the tank boundaries (top, bottom, bulkheads) are calculated by taking into account the effects of global and local loads. An extensive analysis of the results is presented in 3.5.3 for the plating and the ordinary stiffeners of the midship sections and in 3.5.4 for the plating and the ordinary stiffeners of the transverse bulkheads,

- the scantlings of the primary supporting members of the tank boundaries (transverse web rings and longitudinal girders) are calculated through finite element analysis performed according to the calculation procedure presented in 3.1.1, with reference to the specified structural models. Particular attention is paid to details such as the most stressed transverse web frame ring among those considered in the model, the swash bulkhead and the watertight bulkhead. The finite element analysis are presented in Appendix 3.

3.5.3 Midship section arrangement

In order to investigate the possible design options and their effects in terms of structural strength and weight, the influence of the following parameters is considered:

– steel yield stress (235 N/mm^2 yield stress for a mild steel and 315 N/mm^2 yield stress for a HTS),

– longitudinal ordinary stiffener spacing,

– longitudinal ordinary stiffener span.

Various designs of the midship section are analysed, each one coming out from the combination of the different parameters presented above. The obtained midship section data and their associated detailed results are presented in Appendix 3. The main results are also presented in the Figures 36 to 40.

❐ *Steel weight*

The weight of the different midship sections, the result of which are presented in Figures 36 and 37, is obtained by taking into account the weight of the plating and of the ordinary stiffeners of the midship sections as well as the one of the transverse web frames. However, it has to be noted that the weight of the transverse bulkheads is not taken into account at this stage of the present study.

Figure 36: Influence of the stiffener spacings on the midship section weight.

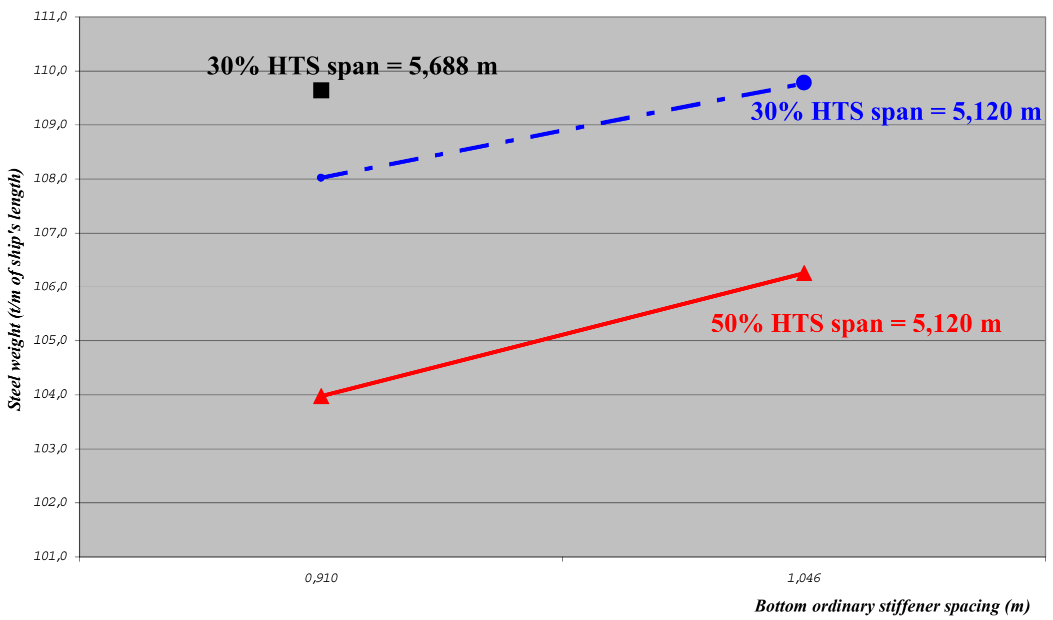
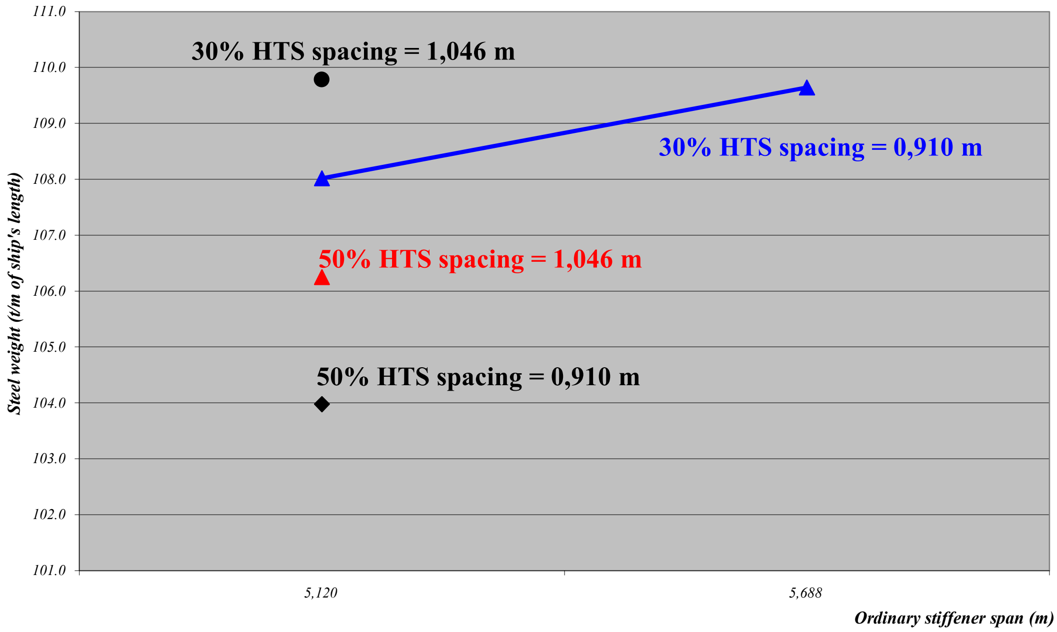


Figure 37: Influence of the stiffener spans on the midship section weight.

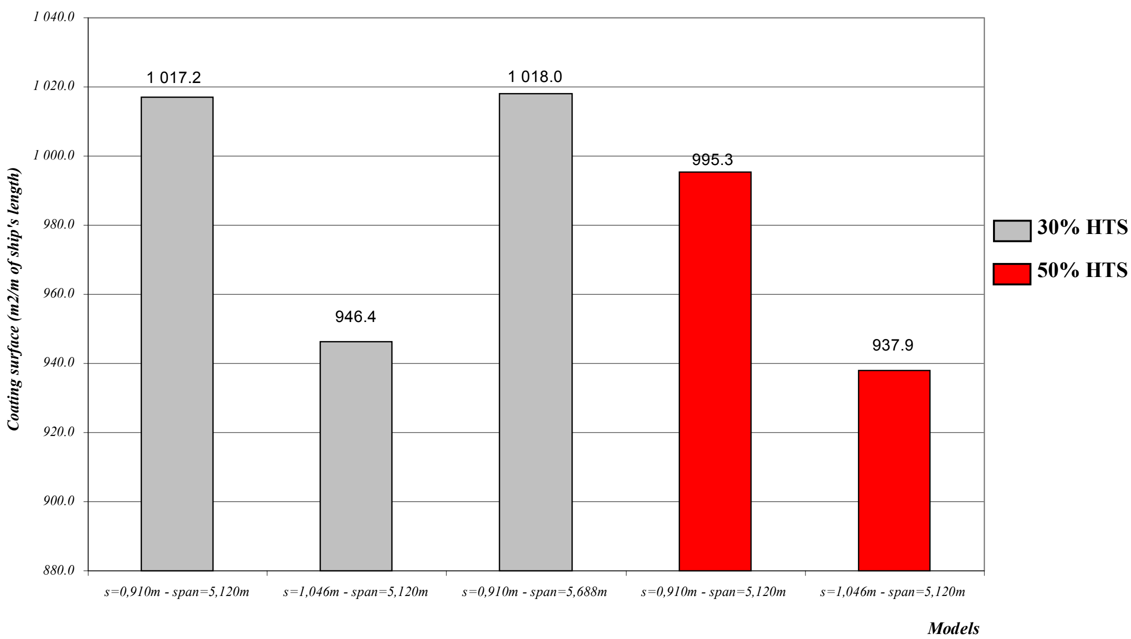


❒ *Coating surfaces*

The coating surface calculations, the results of which are presented in Figure 38, are realised by considering:

- midship section ballast tank surfaces (all plating and ordinary stiffeners),
- transverse web frame ballast tank surfaces (all plating and ordinary stiffeners),
- cargo tank surfaces (plating of horizontal inner bottom to which is added plating and ordinary stiffeners of deck).

Figure 38: Midship section coating surfaces.

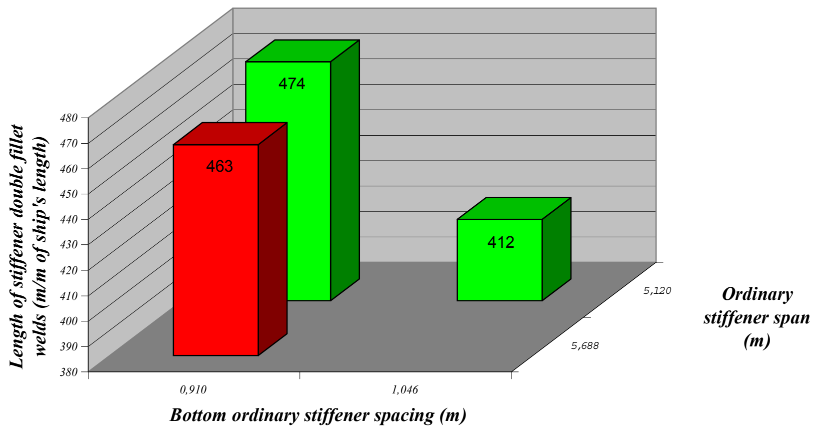


❒ *Midship section double fillet weld lengths*

The midship section double fillet weld lengths are calculated by only considering the welds between the stiffeners and the platings, which means that the welds between the stiffener web and the stiffener face plate are not considered.

Moreover, it has to be noticed that the calculated midship section double fillet weld lengths do only depend on the ordinary stiffener spacing and on the ordinary stiffener span. Indeed they do neither depend on the material type nor on the type of ordinary stiffener profile. This is therefore the reason why the results presented in Figure 39 do only take the ordinary stiffener spacings and the ordinary stiffeners spans into account and can thus be affected to midship sections made of any desired material and of any desired type of ordinary stiffeners.

Figure 39: Influence of the longitudinal ordinary stiffener spacing and of the ordinary stiffener span on the midship section double fillet weld lengths.



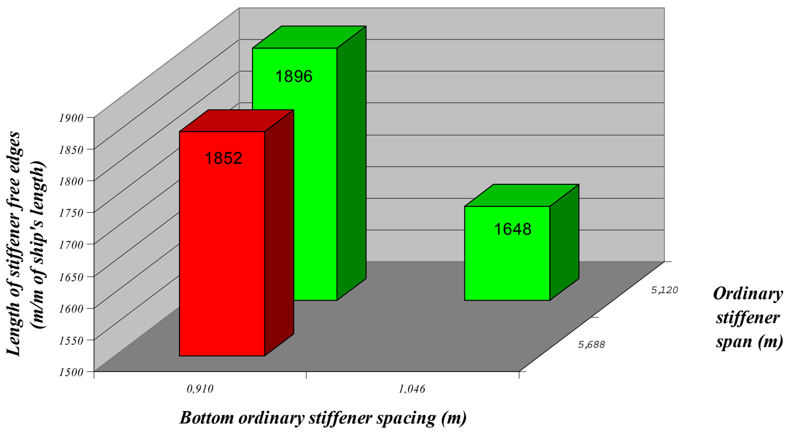
❒ *Midship section free edge lengths*

The free edge lengths of the ordinary stiffeners are calculated by considering:

- no free edge for laminated angle profiles,
- 2 free edges for flat bar profiles,
- 3 free edges for built-up angle profiles,
- 4 free edges for built-up T profiles.

Furthermore, those free edges lengths do only depend on the ordinary stiffener types, on their spacings and on the ordinary stiffeners span. Indeed, they do not depend on the material type. Moreover the influence of ordinary stiffener type is not considered in this study. Therefore the results presented in Figure 40 do only take the ordinary stiffener spacings and the ordinary stiffener spans into account and can thus be affected to midship sections made of any desired material.

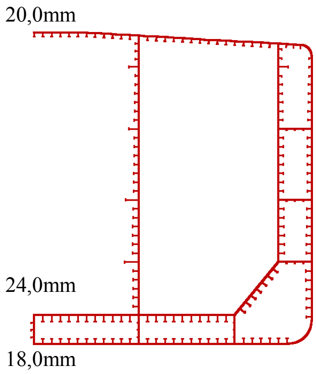
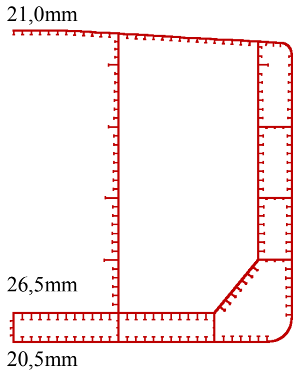
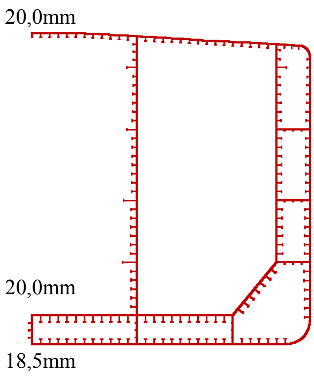
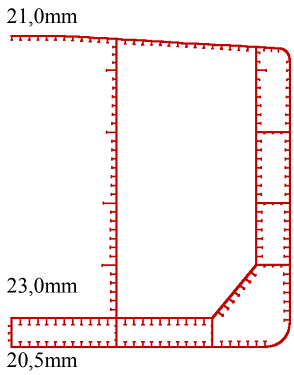
Figure 40: Influence of the longitudinal ordinary stiffener spacings and span on the midship section free edge lengths.



❒ *Conclusions*

In order to sum up the different results presented in the Appendix 3, Table 16 presents the thicknesses that guarantee that the ratios between the applied bending moments in sagging or hogging conditions and the corresponding ultimate bending moment capacity of the section, calculated according to the Rules criteria, do not exceed about 85%, according to the different possible design options.

Table 16: Plating thickness of deck, inner bottom and bottom that verify the maximum ultimate strength limit of 85%

<table>
<tr><th rowspan="2">Material</th><th colspan="2">Bottom ordinary stiffener spacing, in m</th></tr>
<tr><th>0,910 m</th><th>1,046 m</th></tr>
<tr><td>30% HTS</td><td>
</td><td>
</td></tr>
<tr><td>50% HTS</td><td>
</td><td>
</td></tr>
</table>

From the results of midship sections presented in Figures 36 to 40, it can be noticed that:

1) midship sections obtained by considering HTS fitted on the inner double bottom are lighter than those obtained by considering a mild steel inner double bottom, deck and bottom plating being made of HTS, at equivalent structural characteristics (number of transverse web frames and longitudinal ordinary stiffener spacing) about:

   - 3,8% for an ordinary stiffener spacing of 0,910 m,
   - 3,3% for an ordinary stiffener spacing of 1,046 m.

   Moreover the surface to be coated for structures obtained by considering HTS fitted on the inner double bottom is about 1-2 % less than the one for structures obtained by considering a mild steel inner double bottom.

2) midship sections obtained by considering a 15% increased ordinary stiffener spacing, equal to 1,046 m, are heavier than those obtained by considering an ordinary stiffener spacing of 0,910 m, of about:

   - 1,6% for 30% HTS midship section,
   - 2,2% for 50% HTS midship section

   However the surface to be coated for a 15% increased ordinary stiffener spacing model is about 5-7 % less than the one obtained for an ordinary stiffener spacing of 0,910.

   Moreover the lengths of double fillet welds and the number of free edges for a 15% increased ordinary stiffener spacing model are about 15% less than the ones obtained for an ordinary stiffener spacing of 0,910,

3) midship section obtained by considering an 11% increase of ordinary stiffener span, equal to 5,688 m, is about 1,5% heavier than the one obtained by considering an ordinary stiffener span of 5,120 m. However the lengths of double fillet welds and the number of free edges for an 11% increase of ordinary stiffener span model are about 2% less than the ones obtained for an ordinary stiffener span of 5,120 m.

   Moreover the surface to be coated for a stiffener span of 5,688 m is approximately the same as the one obtained for a stiffener span equal to 5,120 m,

4) considering points 2) and 3), it can be noticed, for a 30% midship section, that an increase of 15% of the stiffener spacing induces a weight increment equal, approximately, to the one induced by an increase of 11% of the stiffener span.

3.5.4 Bulkhead arrangement

In order to investigate the possible design options and their effects in terms of structural strength and weight, the influence of the following design parameters is considered:

- steel yield stress (a mild steel and a HTS with a yield stress of 315 N/mm^2),
- number of stringers,
- longitudinal ordinary stiffener spacing.

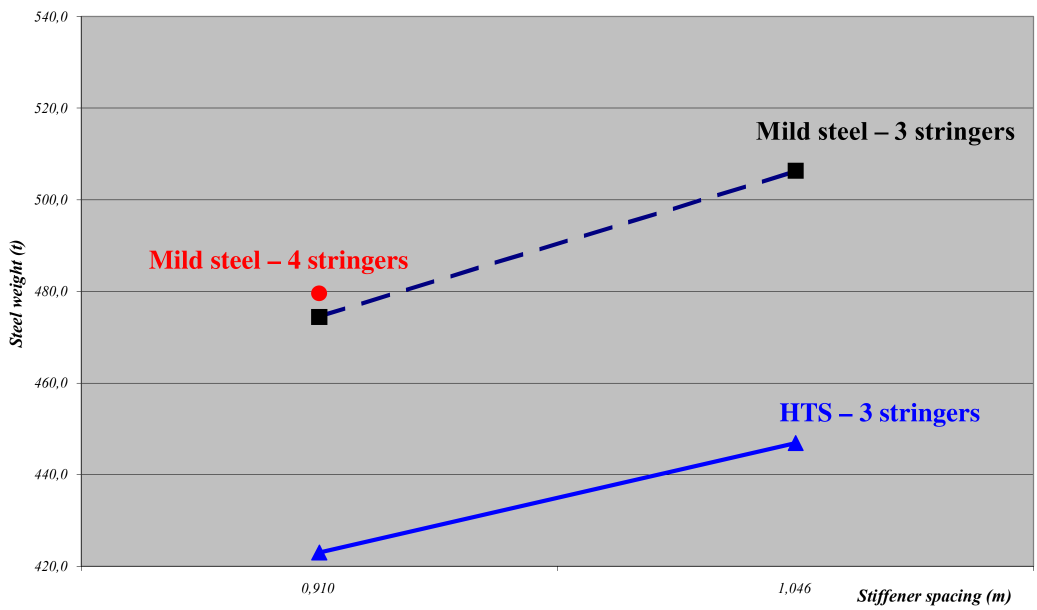
Various designs of the bulkhead are analysed, each one coming out from the combination of the different parameters presented above. The obtained bulkhead data and their associated detailed results are presented in Appendix 3. The main results are also presented in the Figures 41 to 44.

❒ *Steel weight*

The weight of the different plane bulkheads, the results of which are presented in Figure 41, is obtained by taking into account the weight of:

- the plating, the ordinary stiffeners, the brackets and of the stringers of the plane bulkhead in cargo tank,
- the plating, the ordinary stiffeners and the brackets of the watertight web frame fitted in the j-ballast tank.

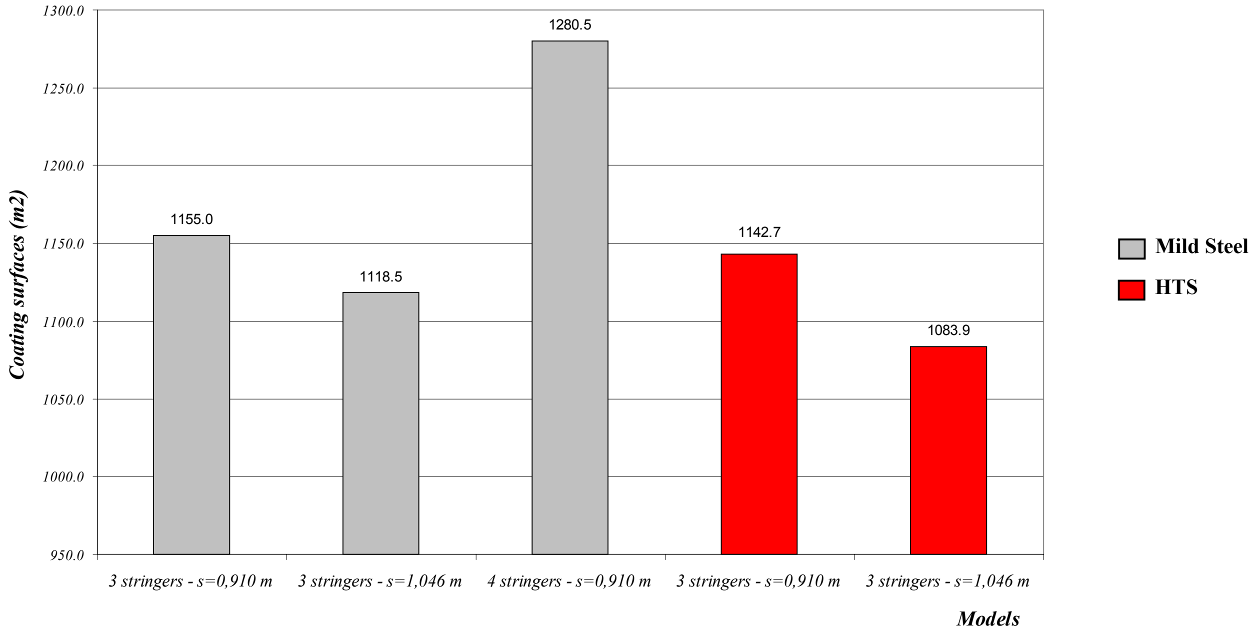
Figure 41: Influence of the stiffener spacings on the plane bulkhead steel weight.



❒ *Coating surfaces*

The bulkhead coating surface calculations, the results of which are presented in figure 42, are realised by only considering only ballast tank surfaces (plating, ordinary stiffeners and primary supporting members).

Figure 42: Influence of the stiffener spacing on the coating surface of plane bulkhead.

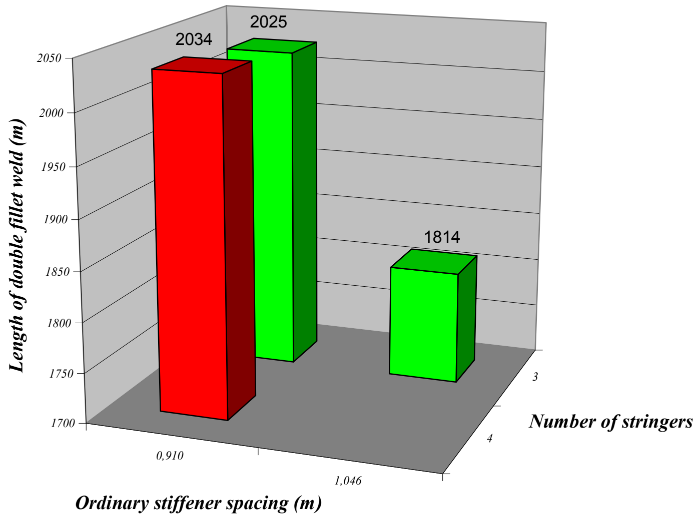


❒ *Bulkhead double fillet weld length*

The bulkhead double fillet weld lengths are calculated by only considering the welds between the stiffener and the plating, which means that the welds between the stiffener web and the stiffener face plate are not considered.

Furthermore, it has to be noticed that the calculated bulkhead double fillet weld lengths do only depend on the ordinary stiffener spacing and on the number of stringers. Indeed, they do not depend on the material type. This is therefore the reason why the results presented in Figure 43 do only take the ordinary stiffener spacing and the number of stringers into account and can thus be affected to plane bulkheads made of any desired type of ordinary stiffeners.

Figure 43: Influence of the stiffener spacing and of the number of stringers on the plane bulkhead lengths of stiffener double fillet weld.



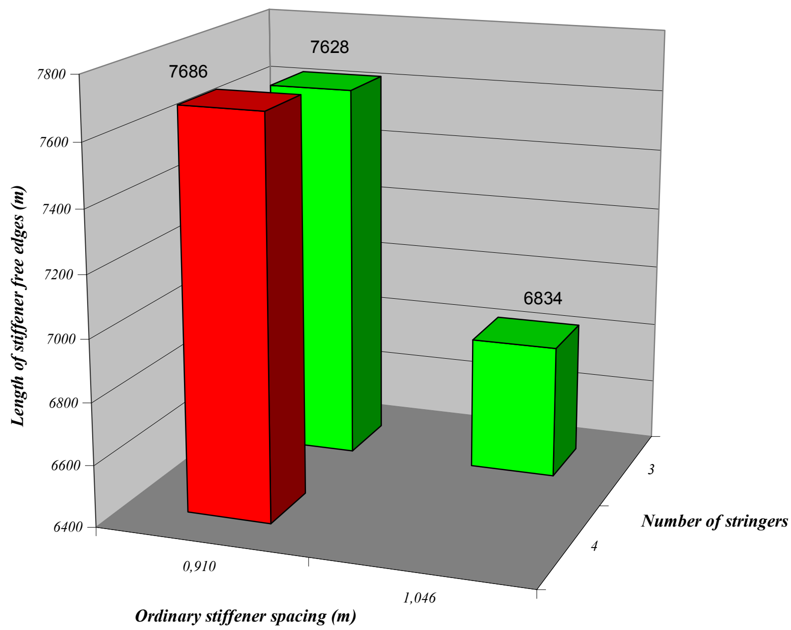
❒ *Free edges length*

The free edge lengths of ordinary stiffeners are calculated by considering:

- no free edge for laminated angle profiles,
- 2 free edges for flat bar profiles,
- 3 free edges for built-up angle profiles,
- 4 free edges for built-up T profiles.

Furthermore, the free edge lengths calculated for the bulkheads do only depend on the type of ordinary stiffeners, on the lengths of ordinary stiffeners and on the number of stringers. Indeed, they do not depend on the material type. Moreover the influence of ordinary stiffener type is not considered in this study. This is therefore the reason why the results presented in Figure 44 only take the ordinary stiffener spacing and the number of stringers into account.

Figure 44: Influence of the stiffener spacings and of the number of stringers on the plane bulkhead length of stiffener free edges.



From the results of plane bulkheads presented in Figures 41 to 44, it can be noticed that:

1) HTS bulkheads are lighter than mild steel bulkheads of about:

   - 12,2% for an ordinary stiffener spacing of 0,910 m,
   - 13,3% for an ordinary stiffener spacing of 1,046 m.

   It may be noted that the decrease of weight between a HTS bulkhead and a mild steel bulkhead is more important in the case of an ordinary stiffener spacing of 1,046 m,

2) plane bulkheads with an ordinary stiffener spacing of 0,910 m are lighter than those with a spacing of 1,046 m, of about:

   - 6,7% for mild steel bulkheads,
   - 5,6% for HTS bulkheads.

   However the lengths of stiffener double fillet weld and the lengths of stiffener free edges for bulkheads with a spacing of 0,910 m are both about 11% greater than those with a spacing of 1,046 m.

   Moreover the coating surface for the bulkhead with a spacing of 0,910 m is about 3% greater than the one for the bulkhead with a spacing of 1,046 m,

3) the three stringer plane bulkhead is about 1% lighter than the one fitted with four stringers.

Moreover the double fillet weld lengths and the lengths of free edges of the three stringer bulkhead are approximately the same as those for the four stringer bulkhead.

4. Design criteria affecting lifetime performance

4.1 Corrosion and corrosion protection

4.1.1 Corrosion and its causes

Corrosion is one of main causes of structural steel deterioration of a ship, which considerably affects its life. Since ships are exposed to a severe environment and service, in general all surfaces, but ballast tanks, cargo tanks, deck and hull are the areas that are the most subject to corrosion. The corrosive process is influenced and developed by many factors, such as the ship type, the project, the structural design, the trading, the use and many others. This article of the Guideline briefly describes the corrosion mechanisms and the methods to prevent them.

On the last years, the coming into force of new rules has significantly modified the structural arrangement of oil tankers, causing a considerable increase of ballast tank surfaces to be coated. For a double hull tanker, this increase can be evaluated in the order of 250-400% (in consideration of the type and of the size of the ship) more than a single hull tanker.

As corrosion is a natural phenomenon, it is possible to prevent it or to slow it down, but not to totally eliminate it.

Corrosion is an electrochemical process by which materials deteriorate as a consequence of the reaction between the material itself and the environment. The corrosion mechanism is very complex. A detailed study would be beyond the scope of this Guideline. Therefore, basic elements will be provided to understand the phenomenon, the causes and different typologies connected with steel corrosion, only.

The main cause of steel corrosion is its chemical instability. Steel becomes stable by oxidation and has the tendency of returning to the natural condition of ore from which it was produced. For corrosion to occur, the following four components must be present:

- an anode,
- a cathode,
- an electrolyte,
- an electric path (circuit) connecting the anode and the cathode.

During the corrosive process, electricity passes from a negative area (called *anode*) of a piece of steel to a positive area (called *cathode*) through an external conductive vehicle (called *electrolyte*). The electric path is completed when electricity returns to the anode.

Metal loss (corrosion) occurs in the anodic area while the cathodic area is protected. Chemical reactions occurring in the anodic area are acid and those that occur at the cathode are alkaline with development of hydrogen gas. These reactions can be basically illustrated as follows:

Anode:	Fe	$\Rightarrow$	Fe^{2+}	+	$2e^-$
			Ferrous Ions		Electrons

The two free electrons cause the following two reactions:

Cathode:	$2H^+$	$+ 2e^-$	$\Rightarrow$	2H	$\Rightarrow H_2$
	Hydrogen Ion			Hydrogen atom	Hydrogen gas
Or					
	$2H_2O$	$+ O_2$	+	$4e^-$	$\Rightarrow 4OH^-$
					Hydroxyl Ions

The hydroxyl ions, extensively produced by water ionisation, react with ferrous ions producing various forms of rust: brown rust (Fe_2O_3), black magnetite (Fe_3O_4) and green hydrated magnetite (Fe_3O_4 + H_2O). An important factor affecting the corrosion rate is the cathode or anode electrical potential.

There are several tables listing the potential of metals (also named electro-negativity, namely their tendency to go in solution) in a particular environment. In Table 17 these potentials referred to seawater are listed.

If two metals of Table 17 are in contact in an electrolyte, the corrosion rate of the higher one in the table will increase, while that of the lower one will decrease. Similarly, a single piece of steel has a slight difference of chemical composition or physical proprieties in different areas. These differences act as anodes and cathodes and initiate a corrosion process. As occurs for metals of different composition, the greater the electronegative potentials are in anode and cathode areas on the same piece of metal, the greater the corrosion rate is.

Table 17: Galvanic series in sea water.

	Metal	Potential mV
More anodic - Less Noble - Higher Corrosiveness ↑	Sodium (Na)	- 2,300
	Magnesium (Mg)	- 1,400
	Zinc (Zn)	- 760
	Aluminium (Al)	- 530
	Steel-Iron (Fe)	- 400
	Nickel (not passivated) (Ni)	- 30
	Copper (Cu)	+ 40
	Mill scale	+ 45
	Nickel passivated (Ni)	+ 50
	Stainless steel (active)	+ 70
	Silver (Ag)	+ 300
↓	Stainless steel (passive)	+ 310
More cathodic - More noble - Lower Corrosiveness	Titanium (passive) (Ti)	+ 370
	Platinum (Pt)	+ 470
	Gold (Au)	+ 690

4.1.2 Common forms of corrosion

There are many forms of corrosion. In the following items, the common forms of corrosion usually observed in ballast tanks are briefly described.

❒ ***Uniform corrosion***

The anodic and cathodic areas on the same piece of steel can change with time, so those areas that were once anodes become cathodes and vice versa. This process allows the formation of a relatively uniform corrosion of steel in similar environments.

❒ ***Galvanic corrosion***

Galvanic corrosion occurs when two dissimilar metals are in contact in an electrolyte. The less noble metal (anode) will corrode at a higher rate compared to the more noble metal that will be protected or will corrode at a lower rate.

Potential difference can exist on a piece of similar metal and cause galvanic corrosion. The following factors can cause these differences:

– new steel is anodic to old steel,

– steel is anodic to mill scale,

– brightly cut surfaces are anodic to uncut surfaces,

– cold worked areas are anodic to less stressed areas.

❒ *Localised corrosion (pitting)*

Pitting corrosion is one of the most common forms that can be noted in ballast and cargo tanks. It is caused by the action of a localised corrosion cell on a steel surface due to the breaking of the coating (if present), to the presence of contaminants or impurities on the steel (e.g. mill scale) or to impurities present in the steel composition.

Pitting occurs every time an electric current leaves the steel going into the electrolyte. Furthermore, the defective areas of a coating or any other damages can become anodic to the surrounding intact coated surface and cause a corrosion process.

Pitting is a very dangerous form of corrosion, which can have tremendous consequences, causing steel perforation in a short time.

❒ *Crevice corrosion*

Crevice corrosion is also localised corrosion that appears as pitting. The most common case occurs in cracks and generally on steel surfaces covered by scales and deposits. Typical examples are skip welding seams, pipe supports and bolts.

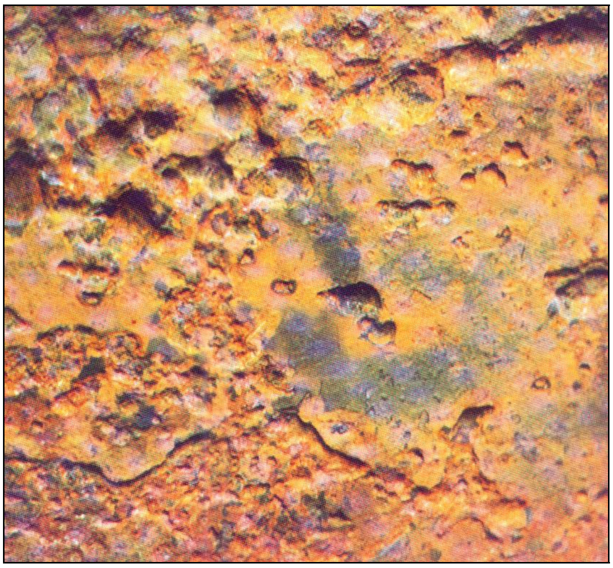
The phenomenon is due to the fact that a small area of steel (i.e. the crevice, the crack or the area covered by debris) lacks oxygen and becomes the anode of a corrosion cell, while the remaining free surface, abundantly oxygenated, becomes the cathode. Since the anodic area is very small compared to the cathodic one, the corrosion process is extremely fast.

❒ *Bacterial corrosion*

Over the last two decades, the shipping industry has become conscious of the seriousness of this form of corrosion, which does not only affect steel surfaces of ballast tanks and bilges, but also, very often, cargo tank surfaces.

Bacterial corrosion, called Microbiologically Influenced Corrosion (MIC) appears as scattered and/or localised pitting (see Figure 45).

Figure 45: Corrosion of steel surface caused by MIC.



MIC is a form of corrosion originated by the presence of microscopic one-celled living organism including bacteria, fungi and algae. The corrosive bacteria live in water layer on the bottom of cargo oil tanks as well as in the sediment of water ballast tank bottom.

Wide ranges of bacterial species have been detected in all the areas of ships. Sulphate Reducing Bacteria (SRB) and Acid Producing Bacteria (APB) are the two most important and well known groups of micro-organisms, which cause corrosion. SRB and APB live together with other species of bacteria in colonies on the steel surfaces helping each other to grow.

SRB's are anaerobic in nature and obtain their needs of sulphur by a complex chemical reaction. During this reaction, the organism assimilates a small amount of sulphur, while the majority is released into the immediate environment as sulphide ions, which are hydrolysed as free H_2S. In this way, SRB give rise to a corrosive process that supports the anodic dissolution of the steel. When bacteria have started to produce sulphide, the environmental condition becomes more favourable for growth, resulting in a population explosion.

APB's use the small quantity of oxygen of the water to metabolise hydrocarbons and produce organic acids such as propionic acid, acetic acid and other higher molecular acids. Since the APB's "consume" the residual oxygen present in the sediment, they produce, under the colonies, a suitable and ideal environment for the SRB's.

When active, the corrosion process originated by these bacteria can be extremely fast and can cause corrosion pits with a rate up to 1,5 – 3 mm per year, which is about five times higher than normally expected. Colonies of bacteria appear like slimy black deposits on the steel surfaces.

❒ *Erosion corrosion*

Corrosion due to erosion occurs when sand or other abrasives held in the water or in the cargo or a liquid flow impinges, with a certain velocity, an existing corrosion cell. The sand or the liquid flows remove the accumulation of corrosion products keeping the metal clean and the corrosion active. There are three forms of corrosion that can be connected to velocity:

- impact caused by air bubbles,
- cavitation due to void formation or cavities in the water due to turbulence,
- erosion caused by the slime and mud present in the water or in the liquid cargo.

Crude oil washing or hot and cold seawater washing can be considered as a particular erosion corrosion form. The greasy or waxy layer that, covering the steel surfaces, act as a corrosion inhibitor is removed, together with corrosion product, by the washing process keeping the steel clean and the corrosion active.

❒ ***Stress corrosion***

Steel subject to stress or fatigue can be affected by fractures, even small. These areas act as a crevice and, due to low aeration, will corrode as already described. Furthermore, a fracture can also cause micro cracking on the protective coating, giving rise to a very active corrosion cell.

4.1.3 Corrosion rate

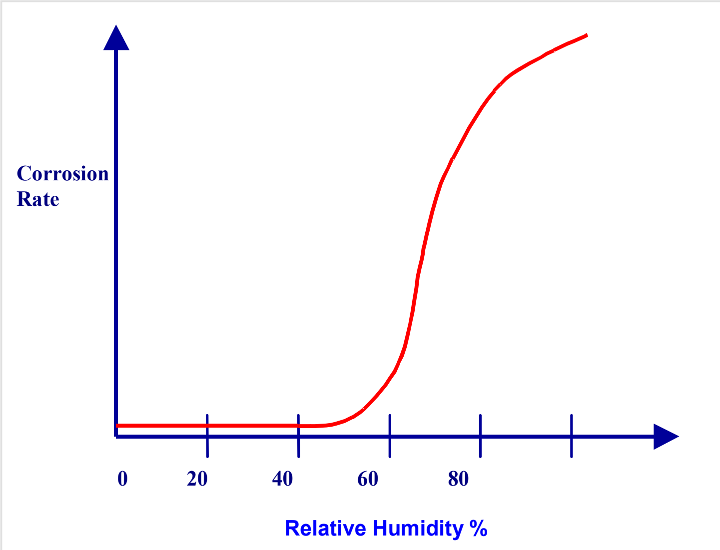
The development of the corrosion process of steel in immersion is affected by many factors. A detailed analysis would be beyond the scope of this Guideline. Seawater and cargoes are a complex mixture containing several salts, suspended mud, gases, bacteria, various species of micro-organisms, etc. All of them together or simply one of them may considerably affect the corrosion process making a situation already complicated at its origin even more complex.

In any cases, the following factors considerably influence corrosion rate: humidity, oxygen, temperature and salinity.

❒ ***Humidity***

The corrosion rate is almost null when the relative humidity is below the 40%, but it considerably increases in the range of 60 and 80% (see Figure 46).

Figure 46: Variation of corrosion rate with relative humidity.



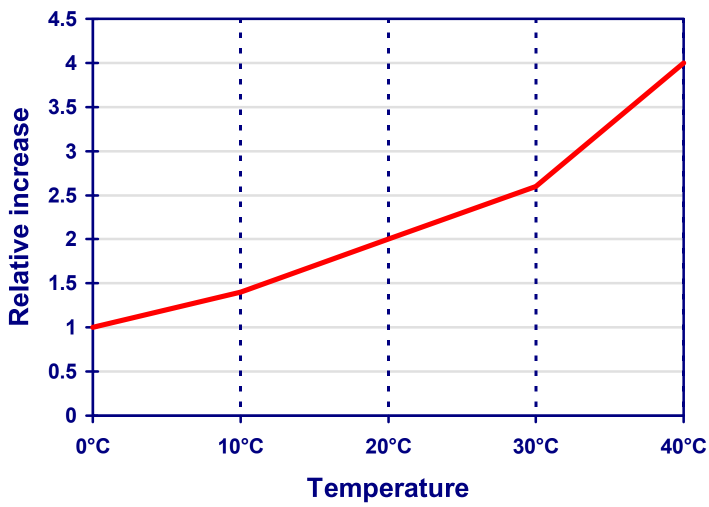
❒ ***Oxygen***

High oxygen content significantly affects the chemical reaction that occurs at the cathode (as shown in the equation of item 4.1.1 above) and consequently a more rapid metal loss at the anode (namely an increase of the corrosion rate).

❒ ***Temperature***

Like any other chemical reaction, the corrosion process rate increases when the temperature increases. The relative corrosion rates at various temperatures are shown in Figure 47, where a value of 1 is assigned to the temperature of 0°C.

Figure 47: Increase of corrosion rate with temperature.



❒ ***Salinity***

Seawater is an excellent electrolyte since, containing a certain amount of salts, it is very conductive. In oceans, the average salt content is 3,2-3,7% for surface water. This concentration significantly changes in some specific areas, ranging for example from 8.000 PPM of the Baltic Sea to 41.000 PPM of the Mediterranean Sea.

The changes of total content of dissolved salts in various seas affect water conductivity. A higher amount of salts means greater conductivity, which is quite sufficient to cause an increase of the corrosion process.

Chloride ions, present in salts, tend to accelerate the corrosion rate due to the formation of permeable corrosion product layers.

4.1.4 Factors affecting the corrosion process in cargo and ballast tanks of oil tankers

The corrosion process in cargo and ballast tank surfaces has the characteristics previously discussed and, in addition, is considerably influenced by a long serie of other variables, which are listed below.

❒ ***Cargo tanks:***

- type of cargo,
- sulphur content of cargo oil,
- frequency of sediment removal,
- presence of surface coating,
- presence of water,
- type of steel used for construction,
- design and structural arrangement of the tank,
- inert gas quality,
- Crude Oil Washing.

❒ ***Ballast tanks:***

- ballasting frequency,
- full or partial filling of the tank,
- cleanliness of ballast water,
- frequency of sediment removal,

- cargo temperature of adjacent tanks,
- design and structural arrangement of the tank,
- coating type, application and related maintenance,
- presence of sacrificial anodes.

4.1.5 Corrosion control methods

There are several methods to control the corrosion process. Each method has its advantages and limitations. In the next items, each method is briefly described, but it is necessary to underline that the best solution in a total corrosion program is a suitable combination of all the methods.

❒ ***Design***

Corrosion prevention starts during the design stage of the ship. A suitable structural design may control the corrosion by eliminating one or more components necessary for the corrosion reaction or by permitting an easier application of other methods of corrosion control and prevention. A good design must avoid:

- contact of dissimilar metals,
- stagnation and water traps,
- crevices (e.g. skip welds or irregular welding seams), that apart from the already described reasons, are difficult to protect with coating,
- irregular and sharp surfaces, because they are difficult to coat with the correct film thickness,
- difficult-to-reach-areas, since they can prevent the correct application of the coating.

❒ ***Cathodic protection***

Cathodic protection is a system of corrosion control by means of which a sufficient amount of direct current passing onto a metallic surface converts the entire anodic surface to a cathodic area. Cathodic protection is effective only when the metallic surface is immersed.

A cathodic protection system can be carried out by means of impressed current equipment or by sacrificial anodes.

In cargo and ballast tanks, the impressed current system is not permitted, due to the large amount of hydrogen gas produced by the process. Therefore, only a system of sacrificial anodes is used. Anodes generate the necessary direct current so that they are corroded by their natural potential difference, protecting the surrounding steel.

Since the cathodic protection by sacrificial anodes is effective only when the tank is full of water and no empty spaces are left, and furthermore since sacrificial anodes need a certain time (1 or more days) to become effective and active (polarisation time), it is advisable to install a cathodic protection system by sacrificial anodes in cargo and ballast tanks only in conjunction with a protective coating. The scope of this additional corrosion protection is to prevent or reduce the corrosion rate of the steel if coating defects and/or damages occur.

When a cathodic protection system by sacrificial anodes is adopted, zinc anodes are to be installed.

❒ *Protective coating (paints)*

The application of a protective coating on metal surface can be considered as the most suitable method for corrosion prevention on the ship. Coatings can protect metals from corrosion by providing a barrier between the metal and the electrolyte, preventing or inhibiting the corrosion process or, in some cases, by a particular form of cathodic protection.

The selection of the coating system, as well as the selection of its application procedure is extremely important since it affects the performance of the coating itself and consequently the life of the steel structure.

The photos in Figures 48 and 49 show the ballast tanks of two ships with the same age of 13 years. During the construction, both ships were coated with an epoxy system, but the application procedure of the ship of photo in Fig 48 was correctly done, while that one of the ship shown in photo in Fig 49 was clearly poor. The photos are a clear example of the importance of the implementation of correct application procedure (surface preparation and paint system application) and coating selection.

Figure 48: Coating condition after 13 years – Correct application.

Figure 49: Coating condition after 13 years – Poor application.

If the protective coating is properly applied and a suitable maintenance program is performed, it can control the corrosion process of cargo and ballast tank surfaces for the complete life of the ship (see the photos in Figures 50 and 51).

Figure 50: Ballast tank after 28 years.

Figure 51: Ballast tank after 16 years.

4.1.6 Ballast tanks

Ballast tanks are probably the area of the ship where the rate of the corrosion process and steel deterioration is the most significant.

On June 4, 1996, IMO approved Resolution MSC.47(66), adopting the amendment to Chapter II-1 of SOLAS Convention 1974. In particular, item 2 of Regulation 3-2 Part A-1 requires: "*All dedicated seawater ballast tanks shall have an efficient corrosion prevention system, such as hard protective coatings or equivalent. The coating should preferably be of a light colour. The scheme for the selection, application and maintenance of the system shall be approved by the Administration, based on the guidelines adopted by the Organisation. Where appropriate, sacrificial anodes shall also be used*"

On 23 November 1995 with Resolution A.798(19), IMO adopts the "Guidelines for the selection, application and maintenance of corrosion prevention systems of dedicated seawater ballast tanks", further detailed by IACS with Recommendation SC 122.

As for the corrosion process, the life of protective coating in ballast tanks is also affected by several factors: frequency of ballasting operation, partial or complete filling of each tank, ballasting duration, temperature of cargo transported in adjacent cargo tanks, surface preparation and selected paint system. All these factors, separately or combined, can considerably affect the coating life.

The selection of a paint system must take into consideration, firstly, the expected and intended life of the coating, then the surface preparation; the paint system is to be selected accordingly. As any choice can considerably affect the cost of construction, it is advisable that the Owner makes the right evaluations on the investment, according to his requirements and on the basis of a suitable Life Cycle Cost.

Detailed information and recommendation concerning the corrosion prevention systems of ballast tank surfaces can be found in the relevant Guide published by the Society.

There are numerous paint systems for ballast tanks available on the market. The majority of them are epoxies, pure and modified.

In the past, bituminous and tar products, mainly coal tar epoxy and bleached tar epoxy, were extensively used for ballast tank coating with satisfactory results. Due to the presence of tar, which could induce cancer, the use of paint containing tar or bitumen has been restricted or forbidden in several countries and shipyards. Furthermore, the Amendment to SOLAS 1974 Convention (Reg. II-1/3.2), requiring that coating applied on ballast tanks is to be preferably in a light colour, reduced in practice the possibility of applying epoxy-tar systems or bituminous emulsions, which are usually black or brown.

In the last years, paint manufacturers have developed new products and paint systems both to meet the new rules and specific requirements of ship-builders and solvent free or solvent less epoxies have become more and more used.

Nevertheless, these new products have required some changes in the application procedures. For instance, solvent free epoxies have a limited pot life compared with traditional epoxies. They are applied in a single coat and consequently require special equipment and airless spray. Furthermore, ventilation during the film formation and curing and max dry film thickness are two important factors for the solvent free epoxies, that if not carefully followed can cause premature coating failures.

It is advisable that the Owner makes its coating selection after a careful evaluation of the product characteristics, case history, references, as well as shipbuilder facilities and related capabilities to apply these "new systems".

4.1.7 Cargo tanks

The selection of a corrosion prevention system of cargo tanks depends on the cargo type the ship is intended to transport. Ships carrying liquid cargoes can be divided into four categories: crude oil tankers, product tankers, chemical tankers and edible liquid tankers. For the purpose of this Guideline, a distinction is therefore made between product tankers and crude oil tankers.

The design and structure of these ships are similar, with double hull, dedicated ballast tanks and minimal reinforcing structures in cargo tanks, since they are placed in ballast wing tanks and double bottoms and, in some cases, on the upper side of the deck. This system certainly facilitates the tank coating work and the cleaning operation of the tanks during the service of the ship, but in the meantime complicates the paintworks in ballast tanks and on deck.

❒ ***Product Carriers***

The cargo tank surfaces of the Product Carriers are to be completely coated, not only for corrosion prevention purpose, but mainly to avoid cargo contamination and to facilitate the cleaning of the surfaces.

Today, the paint systems usually applied are phenolic epoxy, pure epoxy and isocyanate epoxy, formed by two or three coats of paint. In any case, the selection of the paint system is governed by the fact that it is to be suitable for the range of products intended to be transported.

The epoxy phenolics have a good chemical resistance to a wide range of products, including pre-refined petroleum products, lube oils, unleaded gasoline, strong solvents and fatty acids. The application procedure is not very easy, requiring skilled and qualified operators. If, from one hand, a long overcoating time makes the recoating time less critical compared to other systems, the tendency of epoxy phenolics to create more dry-spray and their poor tolerance to over-thickness require a lot of care during the application of the various coats.

The chemical resistance and mechanical properties of pure epoxy can considerably vary in relation to the formulation of each paint. The molecular weight of the resins, hardener type, pigment and solvent mixture are factors affecting the characteristics of the paint. Pure epoxies, like polyamine epoxy, have a good resistance to the majority of refined petroleum products, excluded some unleaded gasoline, lube oils but a limited resistance to strong solvents and fatty acids.

The application procedure is quite easy. Pure epoxies have a good tolerance to high thickness without sagging, limited dry-spray formation, cracking and pinholing. On the other hand, the short overcoating interval (from three to five days depends from the product) requires a tight working sequence, making the application very difficult in large tanks.

❒ *Crude Oil Tankers*

In the past, cargo tanks of oil tankers were left completely uncoated, since the operators did not consider the cleaning of the surfaces and cargo contamination as major issues. As a matter of fact, it is not yet unusual today to find uncoated cargo tanks.

Fortunately, due to serious corrosion problems faced during the ship service on the last 5-10 years, a large number of operators started to coat the bottom and the ceiling of crude oil tanks. Although the factors affecting corrosion have already been mentioned, some of them, specific for cargo tanks of oil tankers, are analysed in details.

1) ***Crude oil composition:*** Sulphur and water content can widely vary in the chemical composition of the crude oil. High concentrations of sulphur reacting with residual seawater form acid compounds, which can considerably increase the general corrosion rate and accelerate pitting. Furthermore, it must be pointed out that sulphur is cathodic and then very active when a corrosion cell is formed.

2) ***Crude oil and water washing***: As already mentioned, the greasy or waxy layer left by the cargo on the steel surfaces, act as a corrosion inhibitor. During the washing operation, this protective layer is removed, together with corrosion product and rust scales, keeping the steel clean and the corrosion active.

3) ***Inert gas***: Soot in the flue gas and sulphur compounds can be introduced in the tanks and properly removed during the cleaning and washing operations. In addition, the oxygen concentration has to be maintained below the 8% in order to reduce the corrosion rate. In case the inert gas system does not work properly and the above-mentioned factors are not suitably monitored, the impact on the corrosion process will be serious, mainly on ceiling surfaces and vapour spaces of the tanks where moisture tends to condensate and to react with sulphur.

4) ***Bacterial Corrosion***: This subject has already been described in previous item; however, in this case, it must be underlined that crude oil can be a serious source of SRB infection. Furthermore, bacteria are great "survivors" and can therefore stay in a dormant status long time under sludge and/or scales many often present on the bottom and on horizontal surfaces of the tanks; but they are ready to thrive as soon as the conditions become favourable.

In consideration of the above-mentioned factors, it seems obvious that a corrosion prevention system has to be implemented in the cargo tanks of oil tankers, as well.

Since cathodic protection is not effective against MIC (in reality, it seems that bacteria can co-exist with cathodic protection system and live on cathodically protected surfaces) and is not neither effective on the overhead surface, also in this case, the most effective system is the application of a protective coating.

The selection of the coating material, as well as the application procedure, is easier in this particular case compared to that necessary for the cargo tanks of product carriers. The main scope of the coating is to provide good corrosion prevention; it is therefore sufficient that the coating has a good chemical resistance to crude oil and anti-bacterial characteristic.

For this purpose, a wide range of epoxy systems is available, which include other group of epoxy like the epoxy mastics. While the epoxy phenolics and pure epoxies require abrasive blasting to be applied, epoxy mastics can be applied on intact and sound shop-primer, provided that welding seams are cleaned and surfaces free of dust, grease, oil and any other foreign contaminants. This, of course, makes the application process considerably less complicated during the construction of oil tanker, although the surfaces to coat are, in many cases, larger.

4.1.8 Structures located above the deck plating

In order to reduce the amount of structural elements in the cargo tanks, in several cases product carriers, but not only, are fitted with reinforcing structures on upper side of the deck.

This system certainly facilitates the tank coating works as well as the cleaning operations of the tanks, but, on the other hand, the accessibility to the areas to be coated above the deck and, mainly, the painting maintenance during the ship service are more difficult and complicated.

The presence of many pipelines, supports, walkways, valves, edges of structures, holes, bolts, etc. makes the correct application of the paint system difficult. If it is also considered that the deck surfaces are subject to severe environmental conditions, to mechanical damages, to working traffics, etc. it is easy to conclude that particular attention has to be paid to this ship area to assure a suitable corrosion protection.

On deck of ships built in this way it is not unusual to note rusted spots, some months after the delivery and heavy rust scale and pitting corrosion few years after the delivery.

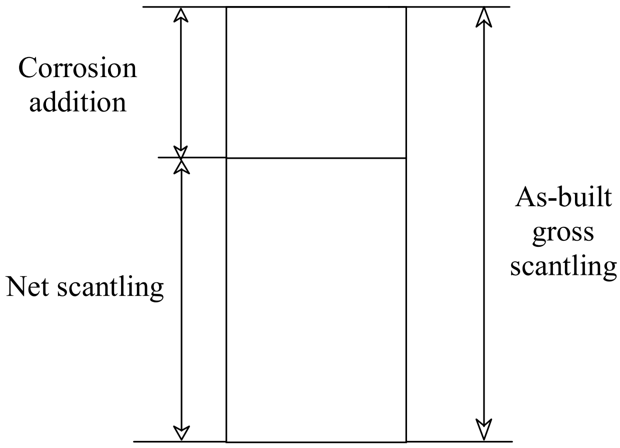
Therefore, in order to ensure a proper corrosion protection, it is advisable that these surfaces are correctly coated at the time of the ship construction. The application of a zinc rich primer followed by two coats of epoxy paint with a dry film thickness not less than 125 µm per coat can be considered as a good system. It is necessary to underline that just the selection of a good paint system can not ensure a satisfactory result. Surface preparation and application procedures have an important, if not greater, role to assure the good performance of the corrosion prevention system.

4.2 Corrosion additions

In order to rationally and efficiently cope with the corrosion aspects of ship structures, the Rule strength checks of plating, ordinary stiffeners and primary supporting members are carried out on the basis of their "net scantlings". This means that the Rule strength criteria aim at evaluating the scantlings that are necessary to sustain the loads acting on the structural elements, without any implicit margin for corrosion. The thickness additions intended to provide the required margin for the corrosion expected during the ship's service, thus called "corrosion additions", are then to be added to the net scantlings to obtain the minimum scantlings with which the ship is to be built (see Figure 52).

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

Figure 52: Net scantling concept.



The Rule corrosion additions are derived from the service experience and the data available in the literature. However, greater values than those defined by the Rule may be adopted, when agreed between the Owner and the Shipyard.

Table 18 reports the values of the one-side corrosion additions defined by the Rules for the types and destinations of compartments in oil and product tankers. 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. To give an example, for the plating of the inner sides, which divide the cargo tanks from the double side ballast tanks, the total corrosion addition is the sum of the corrosion addition relevant to "cargo tanks" and that relevant to "ballast tank". For the elements within a compartment (e.g. the inner side longitudinal stiffeners located in the ballast tanks), the total corrosion addition is twice the value relevant to the compartment destination ("ballast tank" for the example case).

In this way, all the possible locations of structural elements are covered, not only in the cargo area, but also in the service and accommodation spaces.

The "net scantling approach" has several advantages with respect to an approach that implicitly includes the corrosion additions in the strength criteria. First of all, the possibility, already mentioned, to commensurate the corrosion additions with the environment severity, with the consequence of a more rational distribution of the corrosion additions.

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 18: Rule corrosion additions, in mm.

Compartment type	General (1)	Particular cases
Ballast tank (2)	1,00	1,25 in upper zone (4)
Cargo tank and fuel oil tank (3)		
– Plating of horizontal surfaces	0,75	1,00 in upper zone (4)
– Plating of non-horizontal surfaces	0,50	1,00 in upper zone (4)
– Ordinary stiffeners	0,75	1,00 in upper zone (4)
Accommodation space	0,00	
Compartments other than those mentioned above Outside sea and air	0,50	

(1) General: the corrosion additions are applicable to all members of the considered item with possible exceptions given for upper and lower zones.

(2) Ballast tank: does not include cargo oil tanks which may carry ballast according to Regulation 13 of MARPOL 73/78.

(3) For ships with service notation chemical tanker, the corrosion additions may be taken equal to 0 for cargo tanks covered with a protective lining or coating

(4) 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.

4.3 Structural detail design

4.3.1 Structural details specific to Oil Tankers

Critical areas within the tank structure of double hull tankers can be defined as locations that, by reason of stress concentration, alignment or discontinuity, need particular attention for what regards the construction, the design and the survey.

The ordinary stiffener connections and the double bottom structure are subjected to high stress concentration and their construction must be carried out with particular care in order not to jeopardize the intended structural strength. These are therefore the special structural details examined in this Guide.

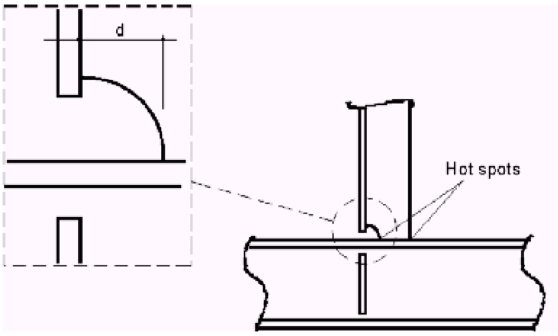
The ordinary stiffener connections are presented in details in 4.3.2 and the bottom structure is presented in 4.3.3.

The oil tanker special structural details are described with particular attention in the Rules, in Part B, Chapter 12, Appendix 1. In the Rules, a sheet is dedicated to each detail where requirements are given about the scantlings and the construction of the details as well as the input data to be used for assessing the fatigue strength of the detail. Requirements are also given about the material to be chosen for the structural elements of the specific detail and how they are to be welded. Finally requirements are given about the survey.

An example of sheet that describes the special structural details is presented in Figure 53.

Figure 53: Example of structural detail as presented in the Rules

Cell 1 **Cell 2**

<table>
<tr><td>AREA 1: Side between 0,7T_B and 1,15T from the baseline</td><td colspan="2">Connection of side longitudinal ordinary stiffeners with stiffeners of transverse primary supporting members – No bracket</td><td>Sheet 1.7</td></tr>
<tr><td colspan="4">
t = minimum thickness between those of:
- web of side longitudinal,
- stiffener of transverse primary supporting member.</td></tr>
<tr><td colspan="3">SCANTLINGS:</td><td>FATIGUE:</td></tr>
<tr><td colspan="3">d to be as small as possible, maximum 35 mm recommended.</td><td>Fatigue check to be carried out for L ≥ 150 m:
$K_h = 1,3$
$K_l = 1,65$</td></tr>
<tr><td colspan="3">CONSTRUCTION:</td><td>NDE:</td></tr>
<tr><td colspan="3">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.</td><td>Visual examination 100 %</td></tr>
<tr><td colspan="4">WELDING AND MATERIALS:</td></tr>
<tr><td colspan="4">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.</td></tr>
</table>

Cell 3 **Cell 4** **Cell 5** **Cell 6** **Cell 7**

Each sheet is presented as a table where each cell aims at describing a characteristic of the detail:

- Cells 1 and 2: Location of the detail and type of connection.

For oil tankers, 6 areas where the details are located are studied. These are:

a) the part of side extended (longitudinally, between the after peak bulkhead and the collision bulkhead and vertically, between $0,7T_B$ and 1,15T from the baseline). For this area, the connection of the side longitudinal ordinary stiffeners with the transverse primary supporting members is studied,

b) the part of inner side and longitudinal bulkheads in the cargo area extended vertically above half tank height, where the tank breadth exceeds 0,55B. For this area, the connection of the inner side or the bulkhead longitudinal ordinary stiffeners with the transverse primary supporting members is studied,

c) the double bottom in way of transverse bulkheads. For this area, the connection of the inner bottom with transverse bulkheads or lower stools is studied,

d) the double bottom in way of hopper tanks. For this area, the connection of inner bottom with hopper tank sloping plates is studied,

e) the lower part of transverse bulkheads with lower stools. For this area, the connection of lower stools with plane or corrugated bulkheads is studied,

f) the lower part of inner side. For this area, the connection of hopper tank sloping plates with inner side is studied.

- Cell 3: Scantlings requirements.

In this cell, requirements are given about the local geometry, dimensions and scantlings of the structural elements that constitute the detail.

- Cell 4: Construction requirements.

In this cell, requirements are given about the allowable misalignment and tolerances that are to be respected during the construction, depending on the detail arrangement and any local strengthening.

- Cell 5: Welding and material requirements.

The material quality is here specified. It depends on the manufacturing procedure of the detail and on the type of stresses the detail is submitted to. Welding requirements specify the type of weld that is to be adopted for the detail. For instance, it specifies where partial or full T penetration welding or any particular welding type or sequence is needed. Scantlings of fillet welds are specified where in addition to the general requirements given in the Rules.

- Cell 6: Survey requirements.

In this cell, is specified where non-destructive examinations of welds are to be carried out and, where this is the case, which type of examination is to be adopted.

- Cell 7: Fatigue requirements.

Fatigue is one of the factors that contribute to the structural failures observed on ships in service that involve much costly ship repair work. The fatigue strength of a structural detail is characterized by the stress concentration factor. This factor is the factor of proportionality between the nominal and the hot spot stresses. In this cell, the stress concentration factor to be adopted for each detail is specified.

4.3.2 Ordinary stiffener connection with transverse supporting structures

The ordinary stiffener connections with transverse structures studied are those described in points a) and b) in 4.3.1.

These details are subjected to high cyclic loading through the ship's life and they constitute one of the most subjected to fatigue potential problem areas.

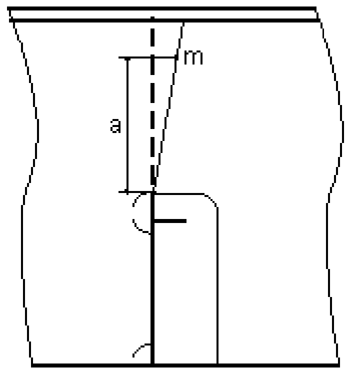
The different types of ordinary stiffener connections with the transverse web stiffeners and how a change of type of connection may increase the fatigue strength of the detail by reducing the stress concentration factor can be seen in Appendix 4.

Improvements are obtained by adopting soft toe connection (see details 4/5, 8/9, 12/13 in Appendix 4) that may be obtained with suitable shaped web stiffener.

By adding a second bracket (see details 2/3 and 10/11 in Appendix 4), the stress concentration factor decreases and thus the fatigue strength increases.

Moreover, requirements exist for the misalignment of the webs of longitudinal ordinary stiffeners connected to transverse primary supporting members. This type of connection is presented in Figure 54.

Figure 54: Allowed misalignment between longitudinal and transverse ordinary stiffeners.



The Rules recommend that, for a given "a" (see Figure 54), the deviation "m" from the axis of the transverse ordinary stiffener web is to be less than a/50. This requirement is in complete accordance with the IACS criteria.

4.3.3 Double bottom hull structural details – Standards' comparison

The most critical types of joint are the welded angle and cruciform joints that are subjected to high magnitudes of tensile stresses. It is reminded that these connections are those described in points c) to f) in 4.3.1.

The fatigue stress range is calculated by taking into account three stress components: the stress due to the hull girder effect, the stress due to the local bending stress and the stress due to the bending double bottom structure. In order to be sure that the stresses induced by the misalignment of the plates can be neglected, some criteria concerning the misalignment of the plates are adopted. The society rule criteria are presented in this Guide and are compared with the IACS criteria and with shipyard standards.

In order to compare the different criteria, numerical examples are given. The thickness are taken from the designs of the different ships that are studied in this Guideline.

The different standards used in this Guide are:

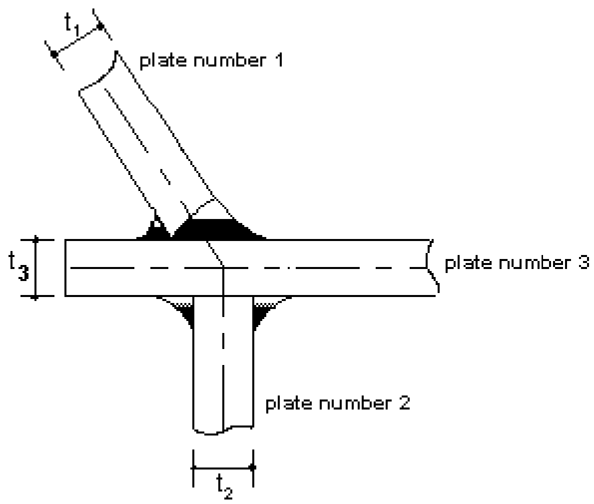
- society rule standards according to the Rules, Part B, Ch12,
- IACS criteria according to recommendation 47,
- typical shipyard standards.

The most general type of welded joint is the angle connection. A typical one is presented in Figure 55.

The angle connections may be found in:

- the double bottom in way of transverse bulkheads with lower stool,
- the double bottom in way of hopper tanks,
- the lower part of transverse bulkheads in way of the lower stool (if any),
- the lower part of inner side in way of hopper tanks.

Figure 55: Angle connection



As example, comparisons between IACS and shipyard standards and Rule requirements are given in Table 19. The misalignment "m" is taken between the median lines of the plates 1 and 2 (see Figure 55).

Table 19: Requirements for angle connections

Geometric properties	IACS criteria	Shipyard standards	Rule criteria
t_1 = 19 mm t_2 = 15 mm t_3 = 19,5 mm	m = t_2/3 = 5 mm	m = min(t_1, t_3)/3 = 6,3 mm	m = min(t_1, t_2, t_3)/3 = 5 mm
t_1 = 16,5 mm t_2 = 14 mm t_3 = 13 mm	m = t_2/3 = 4,6 mm	m = min(t_1, t_3)/3 = 4,3 mm	m = min(t_1, t_2, t_3)/3 = 4,3 mm
t_1 = 16,5 mm t_2 = 18 mm t_3 = 15 mm	m = t_2/3 = 6 mm	m = min(t_1, t_3)/3 = 5 mm	m = min(t_1, t_2, t_3)/3 = 5 mm
t_1 = 18 mm t_2 = 13 mm t_3 = 18 mm	m = t_2/3 = 4,3 mm	m = min(t_1, t_3)/3 = 6 mm	m = min(t_1, t_2, t_3)/3 = 4,3 mm

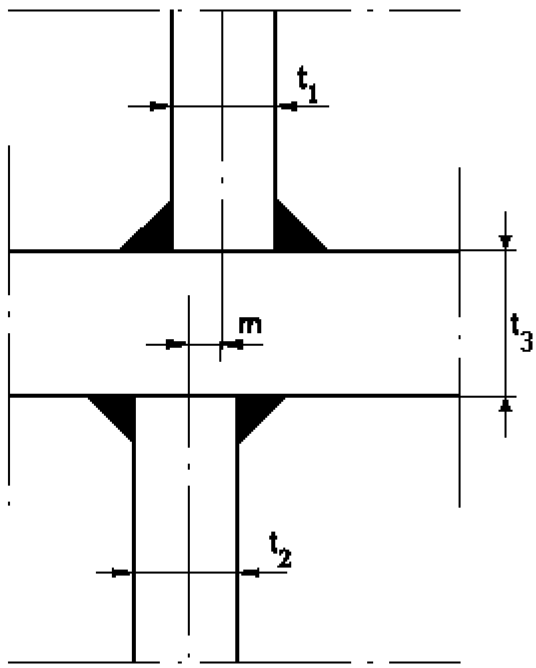
From the results presented above it can be seen that rule criteria are equivalent to IACS criteria, or more stringent. In comparison to shipyard standards, rule criteria are generally more stringent.

The cruciform connection is a particular case of angle connection. Indeed, the angle between the plates is now a right angle. A typical cruciform connection is presented in Figure 56.

The cruciform connections may be found in:

- the double bottom in way of transverse bulkheads without lower stool,
- the double bottom in way of the inner side when there are no hopper tanks,
- the double bottom in way of longitudinal bulkheads.

Figure 56: Cruciform connection



In this particular case rule criteria, IACS criteria and shipyard standards require the same following misalignment:

$$m = \min(t_1, t_2, t_3)/3$$

Thus the three criteria are in perfect accordance.

4.4 Fatigue of structural details

4.4.1 General

Fatigue is one of the factors that 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.

Fatigue may be defined as a process of cycle by cycle accumulation of damage in a structure subjected to fluctuating stresses, going through several stages from the initial ″crack-free″ state to a ″failure″ state. For welded structures, the fatigue process, which includes three main phases:

- initiation,
- propagation or crack growth, and
- final failure,

is mainly governed by the crack growth.

There are two different types of fatigue:

- oligo-cyclic fatigue occurring for a low number of cycles, less than 5.10^3, in the range of plastic deformations,

- high-cyclic fatigue occurring for a large number of cycles in the range of elastic deformations.

Fatigue observed on ship structures is generally of the second type.

4.4.2 Structural elements subjected to fatigue problems

Experience gathered for many years on oil tankers enables to define the structural details for which it may be necessary to assess the fatigue strength, taking into account the consequences of failures on the ship's structural integrity.

The details, identified from experience, which are covered by fatigue analysis are the following ones:

1. The connections between the longitudinal ordinary stiffeners and the transverse primary members:

   - connection of side longitudinal ordinary stiffeners with stiffeners of transverse primary supporting members, at side between $0{,}7T_B$ and 1,15T from the baseline,

   - connection of inner side or bulkhead longitudinal ordinary stiffeners with stiffeners of transverse primary supporting members, at inner side and longitudinal bulkheads above 0,5H,

   - connection of bottom and inner bottom longitudinal ordinary stiffeners with floors, in double bottom in way of transverse bulkheads.

2. The angle connections between bulkheads and lower stools – inner bottom:

   - connection of inner bottom with lower stools,

   - connection of lower stools with lower part of plane transverse bulkheads,

   - connection of lower stools with lower part of corrugated transverse bulkheads.

3. The angle connections between hopper tank sloping plates and inner bottom – inner side.

4.4.3 Fatigue analysis

❒ ***Procedure for fatigue analysis***

Analysis of the fatigue strength of welded ship structures necessitates:

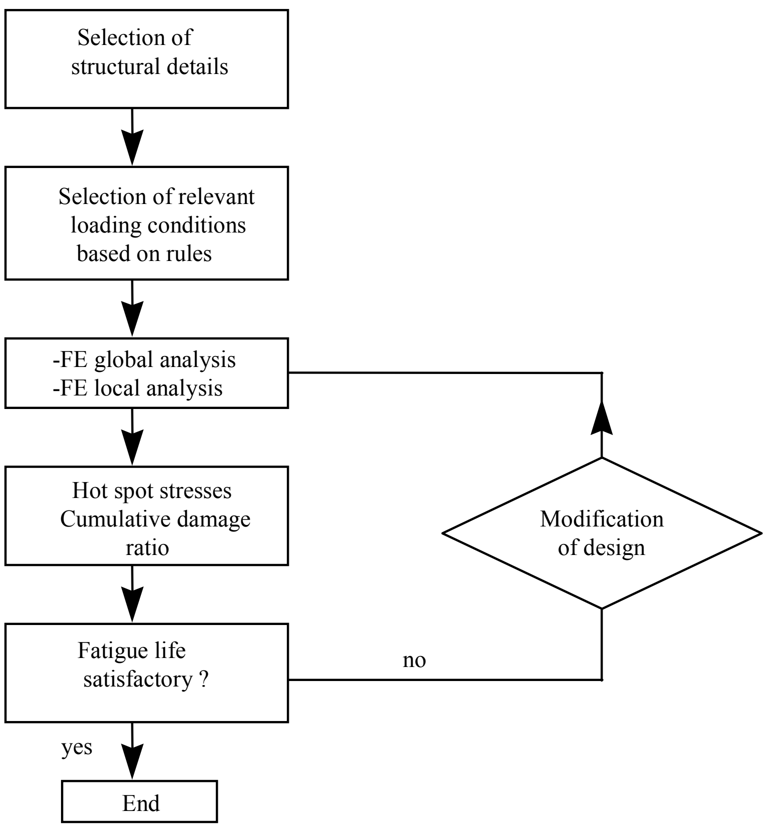
- to determine the demand characterized by the long term distribution of stresses resulting from the action of the various cyclic loads applied on the structure,
- to determine the fatigue capacity of the structure, characterized either by S-N curves or by the fatigue crack growth rate of the material,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

Consequently, the procedure for fatigue analysis includes the following steps:

- the determination of loads and stresses,
- the selection of the design S-N curve for the considered structural detail,
- the assessment of the fatigue strength and calculation of the fatigue life according to the Miner cumulative damage rule.

This procedure is described in Figure 57.

Figure 57: Procedure for fatigue analysis.



There are many factors that affect the fatigue behaviour of ship structures subjected to cyclic loads. They are:

- geometry of the members or configuration of the weld details producing stress concentrations,
- materials and welding procedures,
- workmanship,
- loading conditions,
- sea conditions,
- environmental conditions.

Influence on the fatigue life of most of these factors is considered in the analysis. However, it is assumed that the welding procedures and workmanship are carried out according to the Rule standards and state-of-the-art in such a way that, with the exception of particular designs, their influence on the fatigue life need not to be considered since it is implicitly imbedded in the experimental S-N curves.

The fatigue analysis presented in the paragraphs b) and c) and in 4.3.4 are based on the following assumptions:

- the operational frequency is considered to be evenly distributed between full load condition and ballast condition,
- the sea conditions are evenly distributed between head seas and beam seas,
- the sea state corresponds to the North Atlantic conditions.

❒ *Fatigue analysis based on a nominal stress procedure*

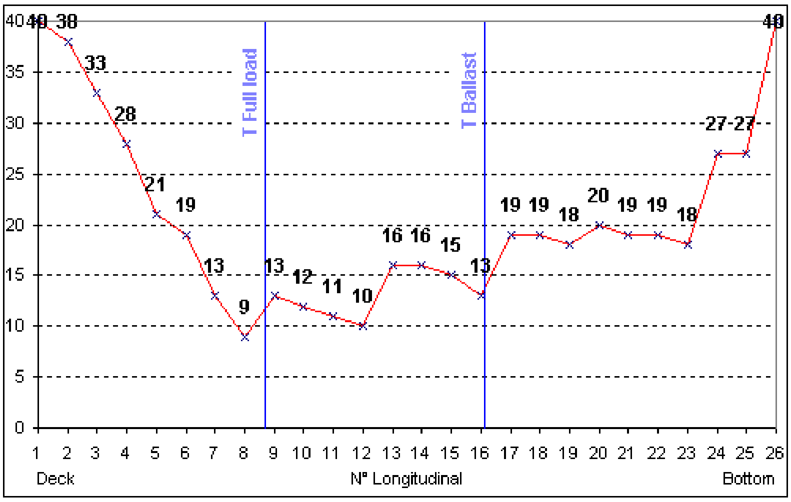
The connection of longitudinal ordinary stiffeners with transverse primary members (web frames or transverse bulkheads) may be analysed by using a bi-dimensional model. In such a case, the calculation is based on a nominal stress procedure. It means that details of a standard library are used, and that 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.

As a first example, such an analysis is carried out for a single hull oil tanker (referenced in this document as SH#01) and compared to the data acquired from experience.

This analysis is carried out within the midship area, for the connections between longitudinal stiffeners and transverse primary members on side shell, at mid-distance between transverse bulkheads. In this location, far from the transverse bulkheads, the relative displacement between the ends of the longitudinal stiffener considered can be disregarded.

The distribution of the calculated fatigue life of connection details of longitudinal stiffeners along the side shell is shown in Figure 58, in years.

Figure 58: Fatigue life, in years, of connection details of side shell longitudinal stiffeners (ship SH#01).



These results show that the minimum fatigue life occurs for longitudinal stiffeners located in the area extending approximately between the ballast draught and the draught in full load condition ("splash zone").

Data acquired from experience for this oil tanker (ship SH#01) are given by survey reports. From these reports, it can be noted that fatigue cracks have been detected mainly on longitudinal stiffeners numbers 11 to 16. This area approximately corresponds to the one obtained from the calculation.

A statistical evaluation, carried out for connection details of longitudinal stiffeners located in the "splash zone" (stiffeners 11 to 16), gives the following statistical values on the fatigue life:

- mean value: 10,5 years,
- standard deviation: 4 years.

These values are to be compared to the ones obtained from the calculation:

- mean value: 13,5 years,
- standard deviation: 2,5 years.

This comparison show that values calculated by using a nominal stress procedure are in a good agreement with the data acquired from experience.

An other example can be taken from an other single hull oil tanker (referenced in this document as SH#02), on which fatigue damages have been detected on some longitudinal stiffeners after 19 years in service, meaning that the fatigue life is less than 19 years. These damages have been noticed for the connection between a side shell stiffener and the first transverse web frame, i.e. the nearest of the transverse bulkhead. According to survey reports, cracks were identified on the web and on the flange of such stiffener, close to the first web frame and between this web frame and the second one.

In such a case, a calculation indicates a fatigue life greater than 40 years, if the relative displacements between the ends of the longitudinal stiffener are not taken into account.

However, by taking into account such relative displacements, obtained from a finite element calculation, the fatigue life decreases to 15 years, value that is in agreement with the fatigue life deduced from experience, i.e. less than 19 years.

This example shows that, in areas in which relative displacements are large (i.e. in areas close to transverse bulkheads), the nominal stress procedure also gives quite good results, compared to experience, but only if the relative displacements are taken into account in the fatigue analysis.

❒ *Fatigue analysis based on a 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.

Two examples of such an analysis are given below.

The first example concerns the connection of the inner bottom plating with the hopper tank sloping plates in a VLCC. Two different configurations are studied: one with horizontal brackets located in hopper tanks and in line with the inner bottom, and the other one without such brackets.

Figure 59 shows the fine mesh model used for the fatigue analysis and the table 20 gives results on both configurations.

Figure 59: Lower hopper angle in a VLCC – Fine mesh model for fatigue analysis.

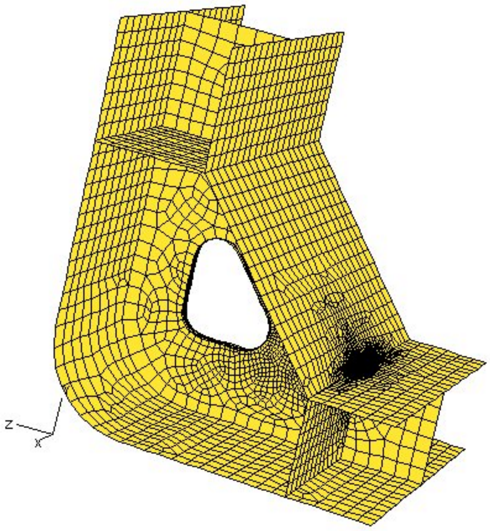
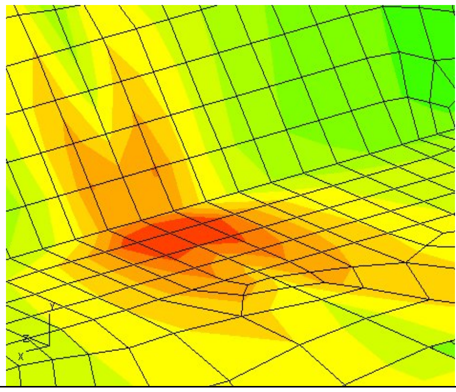
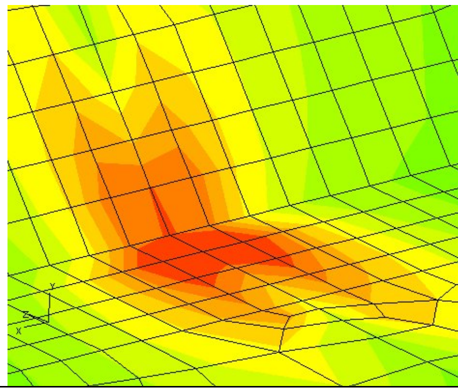


Table 20: Lower hopper angle in a VLCC – Results of fatigue analysis.

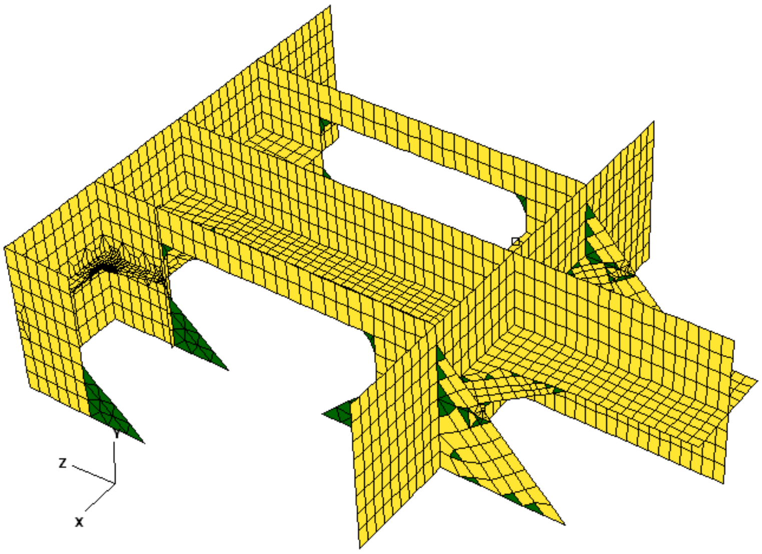
Brackets prolonging inner bottom inside hopper tank	YES	NO
Hot spot damage ratio	1,0	2,4
Fatigue life	20 years	8 years
Distribution of stresses		
Maximum equivalent stress at hot spot	349 Mpa	471 MPa

This analysis shows that, in that specific case, the fitting of prolonging brackets significantly improves the fatigue life of the lower angle.

The second example of fatigue analysis by using a hot spot stress procedure is carried out on the connection detail presented in b) above for ship SH#02.

A general view of the fine mesh model used for the fatigue analysis is given in figure 60.

Figure 60: Connection longitudinal stiffener / stringer on side shell - Fine mesh model for fatigue analysis (ship SH#02).



As shown in figures 61 and 62, this procedure allows to identify the location in which the stress concentration occurs (hot spot). The fatigue damages on the web of the longitudinal stiffener and in the rounded area of the bracket are respectively found equal to 2 and 1,17, which corresponds to fatigue lives of about 10 and 17 years.

This result is in a quite good agreement with the fatigue life of 15 years obtained by using a nominal stress procedure (see b) above).

Figure 61: Stress concentration and damage ratio on the web (ship SH#02).

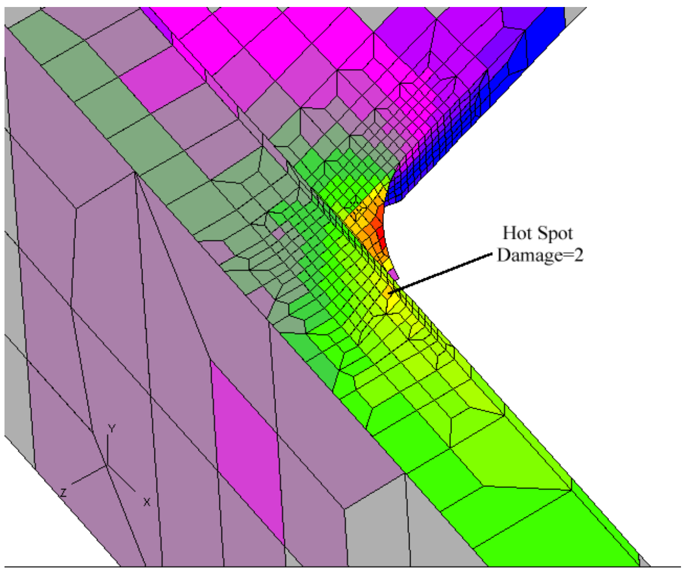
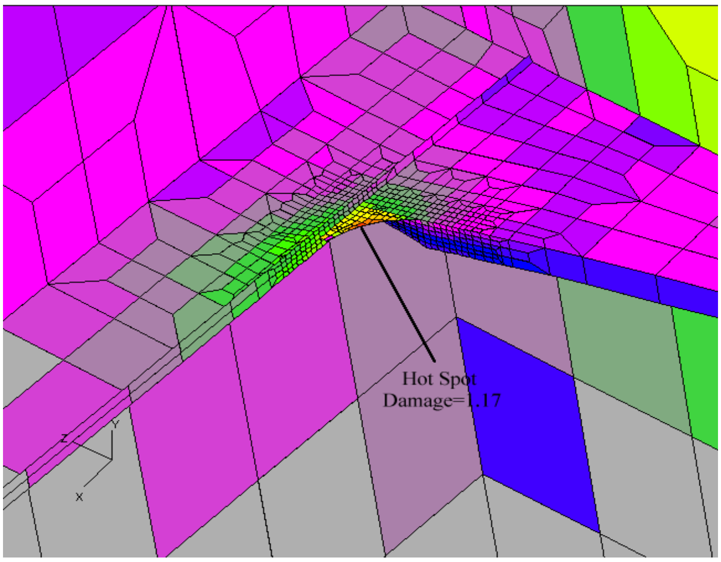


Figure 62: Stress concentration and damage ratio on the bracket (ship SH#02).



4.4.4 Improvement of the fatigue life

When the theoretical fatigue life is significantly less than the expected one, some measures may be envisaged to improve the fatigue strength, generally by reducing the stress concentration factors. The improvement may be obtained by using improvement methods during building and/or by improving the design of structural details.

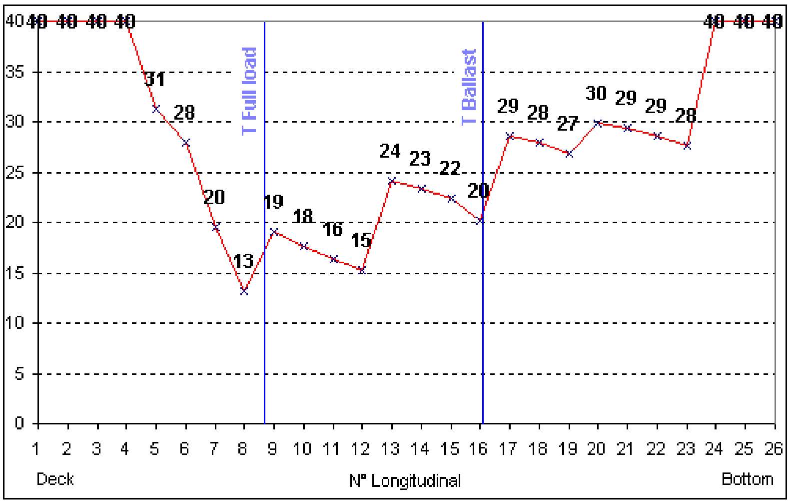
At the building stage, the following improvement methods can be used:

- improvement of the welding procedures and workmanship,
- modification of the weld geometry by grinding,
- introduction of compressive stresses, for example by hammer or shot peening,
- post weld heat treatment.

Such methods, with the exception of improvement of welding procedures and workmanship, are difficult to envisage on a current basis on board ship and are considered only as exceptional measures or for very particular welded joints.

However, the rounding and softening of the weld geometry by grinding is an efficient method: it increases the fatigue life by about 45%. For example, the fatigue life, calculated by considering grinding of welds, is indicated in figure 63 for the same connection details as the ones considered in figure 58.

Figure 63: Fatigue life, in years, of connection details of side shell longitudinal stiffeners, with grinding of welds (ship SH#01).

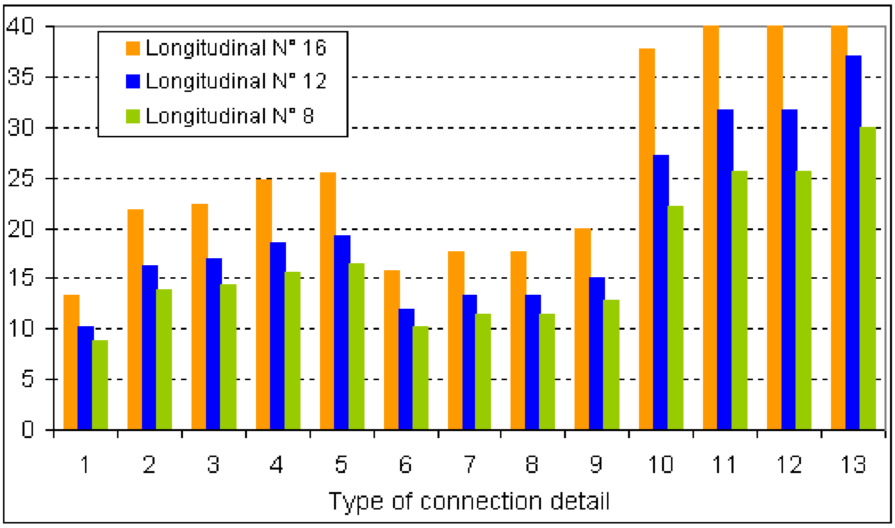


The most efficient way to improve the fatigue strength consists in improving the design of the detail. For example, in the case of the connections between longitudinal stiffeners and transverse primary members the parameters that more effectively control the fatigue strength are:

- 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).

The influence of the bracket number, their location, their shape and their size may be illustrated by a calculation of the fatigue life for three side shell longitudinal stiffeners of ship SH#01. Figure 64 shows the fatigue life for different connection details (types 1 to 13 as referenced in Table of Appendix 4).

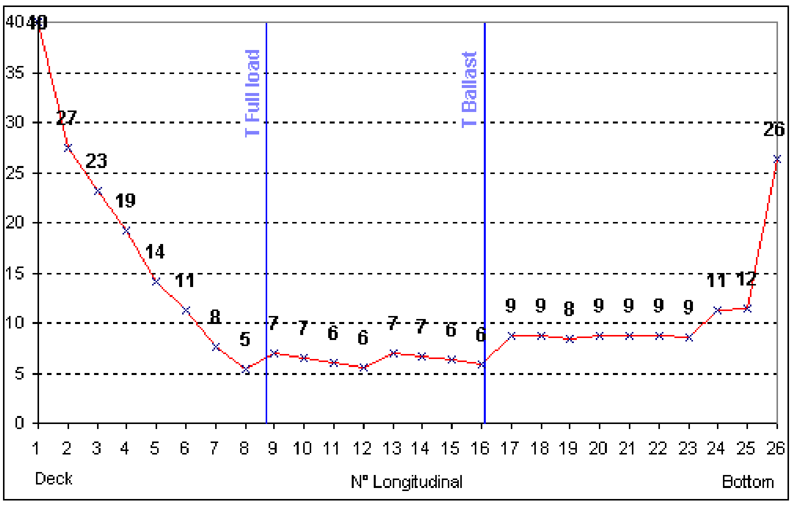
Figure 64: Fatigue life, in years, for different connection details – Side shell longitudinal stiffeners (ship SH#01).



The influence of the type of profile (symmetrical or not) may be illustrated by a calculation of the fatigue life on connection details of side shell longitudinal stiffeners on ship SH#01. Figure 65 shows the fatigue life for the same connection details (i.e. type 1) as in figure 66, the only difference being that T profiles are replaced by angles profiles of same dimensions.

It may be noted that the fatigue life is divided by about 2 when angle profiles are selected instead of T profiles.

Figure 65: Fatigue life, in years, of connection details of side shell longitudinal stiffeners, with angles instead of T profiles (ship SH#01).



4.4.5 Recommendations

Owners generally ask for ships designed for a life time of 25-30 years. It is recommended to design the structural details for a fatigue life of 30 years in North Atlantic conditions, which are the most severe ones. However, in case of worldwide trading, i.e. in less severe conditions than for North Atlantic, a design for a fatigue life of 30 years will conduct to a lesser strength of the structural details, regarding the fatigue behaviour.

To have an equivalent fatigue behaviour, a fatigue life of about 40 years in worldwide conditions may be specified.

As fatigue analysis is now a part of plan approval procedure, the following recommendations may be applied:

- systematic analysis of the fatigue life of structural details, by using as much as possible a “simplified” nominal stress procedure. For this analysis, the expected fatigue life is to be specified in combination with the sea state conditions relevant to the navigation zone,

- identification of hot spots, and increase of surveys, and particularly non-destructive examinations in way of these hot spots,

- improvement of quality control of welding and preparation (permissible misalignments) within the shipyards.

4.5 Accessibility

4.5.1 IMO regulations

Means of access are needed for:

- inspections and maintenance carried out by the ship’s personnel,

- overall and close-up surveys carried out by the Classification Society,

- thickness measurements.

The International Maritime Organisation (IMO) has developed requirements for the access to spaces in the cargo area of oil tankers, which concern their location, arrangement and dimensions. These requirements are presently contained in SOLAS regulation II-1/12-2.

However, a new SOLAS regulation II-1/3.6 has been recently adopted by IMO, which will enter into force on 1 July 2004 for application to oil tankers of 500 gross tonnage and over (and to bulk carriers of 20.000 gross tonnage and over) constructed on or after 1 January 2005. This new regulation, which will replace regulation II-1/12-2, makes compulsory reference to the

"Technical provisions for means of access for inspections", adopted by the Maritime Safety Committee by resolution MSC.133(76).

The text of the SOLAS regulation II-1/3.6 and of the text of the "Technical provisions for means of access for inspections" applicable to oil tankers are reported in Appendix.

By comparison to the present regulation II-1/12-2, the following main changes can be noticed:

- each space within the cargo area shall be provided with permanent means of access to enable, throughout the life of a ship, overall and close-up inspections and thickness measurements of the ship's structures,

- where a permanent mean of access may be susceptible to damage during normal cargo loading and unloading operations or where it is impracticable to fit permanent means of access, movable or portable means of access, as specified in the "*Technical provisions*", may be allowed, provided the means of attaching, rigging, suspending or supporting the portable means of access forms a permanent part of the ship's structure,

- the number of accesses to tanks becomes compulsory,

- a ship structure access manual, indicating the means of access and instructions for using and maintaining them, is to be established. Records of periodical inspections and maintenance of the means of access should be included in this manual,

- such manual should be approved by the Administration, and an updated copy of it has to be kept on board.

4.5.2 IMO "Technical provisions for means of access for inspections"

The purpose of these provisions is to clarify the location and dimensions, if any, of permanent means of access, such as elevated passageways and ladders. The conditions under which permanent means of access may be replaced by movable ones are also indicated.

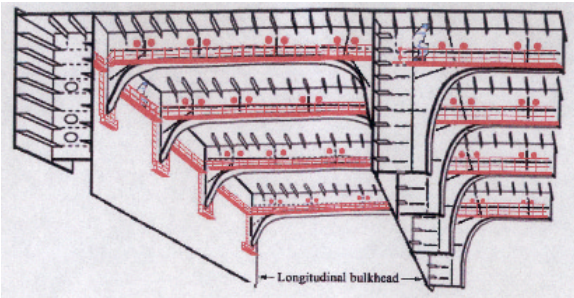
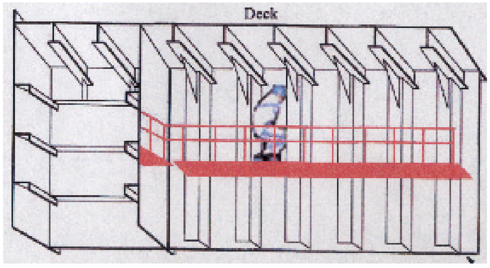
The text of these provisions applicable to oil tankers is reported in Appendix 5. The following points, which have an influence on the structural arrangement and design, are highlighted.

❐ ***Access to the overhead structures of cargo oil tanks***

- For tanks the height of which is 6 m and over, permanent means of access are to be provided. Such means of access should consists of a continuous athwartship access arranged at the transverse bulkheads and at every deck transverse, at least one longitudinal means of access on a longitudinal bulkhead, and access between these arrangements and from the main deck. These permanent means of access are to be located at a minimum of 1,8 m and a maximum of 2,5 m below the overhead structure (see Fig 1).

– For tanks the height of which is less than 6 m, raft or portable means may be used.

Figure 66: Permanent access to the overhead structures of cargo oil tanks of more than 6 m in height

On transverse deck webs and longitudinal bulkhead	On tranverse bulkhead
	

❒ *Access to the vertical structures of cargo oil tanks*

– For tanks the height of which is 6 m and over, containing internal structures, permanent mean of access are to be provided at each transverse web.

– For tanks the height of which is less than 6 m, raft or portable means may be used.

❒ *Access to the overhead structures of wing ballast tanks less than 5 m in width*

– Where the vertical distance between horizontal upper stringer and deck head exceeds 6 m then one continuous permanent mean of access is to be provided for the full length of the tank with a mean to allow passing through transverse swash bulkheads, with a vertical access ladder at each end and mid-span of tank. This mean of access is to be located at a minimum of 1,8 m and a maximum of 2,5 m from the overhead structure.

– For bilge hopper sections the vertical distance of which from baseline to the upper knuckle point is 6 m and over, one longitudinal permanent mean of access is to be provided for the full length of the tank. It is to be accessible by vertical permanent means of access at both ends of the tank. Where this vertical distance is less than 6 m, portable means of access may be used.

– Whenever practicable, distance between the overhead structure and the uppermost longitudinal stringer and between longitudinal stringers should not exceed 6 m.

❒ ***Access to the vertical structures of wing ballast tanks less than 5 m in width***

- Where the vertical distancesfrom baseline to the upper knuckle point of the bilge hopper section, or from the upper knuckle point of the bilge hopper section to main deck where no horizontal stringers are provided, or between horizontal stringers are 6 m and over, vertical permanent means of access are to be provided to each transverse web. When these vertical distances are less than 6 m, portable means of access may be used.

- Access holes within 600 mm of the stringer are to be provided in each transverse web/swash bulkhead above each stringer and tank base.

Appendix 1
Structural arrangement of a product tanker

1. Midship section arrangement

1.1 Mild steel section

In order to investigate the possible mild steel design options and their effects in terms of structural strength and weight, several design criteria are considered:

❐ ***strength check criteria - 2 cases:***

- all global and local strength check criteria results are within the Rule allowable limits,
- the previous case to which is added the condition that the ultimate strength work ratios (i.e. the ratios between the applied bending moments in sagging or hogging conditions and the corresponding ultimate bending moment capacity of the section, calculated according to the Rule criteria) do not exceed approximately 85%,

❐ ***number of longitudinal ordinary stiffeners - 2 stiffener spacings:***

- bottom and deck stiffener spacing = 0,760 m, side and inner side stiffener spacing = 0,720 m,
- bottom and deck stiffener spacing = 0,863 m, side and inner side stiffener spacing = 0,851 m,

❐ ***span of longitudinal ordinary stiffeners – 2 cases:***

- ordinary stiffener span = 2,610 m,
- ordinary stiffener span = 2,983 m. This span value is relevant to a solution where the number of transverse web frames is reduced by one within each cargo tank, with respect to the previous solution,

❐ ***type of ordinary stiffeners - 2 cases:***

- angle profiles,
- bulb profiles.

Various designs of mild steel midship sections are analysed, each one coming out from the combination of the different parameters presented above and summarised in Table 1.

Table 1: Mild steel midship section - Design solutions.

	Parameter	Initial model	Initial model	Initial model –1 Web frame	Increased spacing model
		stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,740 m – Bulbs	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,863 m – Angles
Deck (global + local strength)	Thickness, in mm	13,0	13,0	13,0	14,0
	Spacing, in m	0,740	0,740	0,740	0,863
	Span, in m	5,220	5,220	5,966	5,220
Deck (global + local strength + 85% ultimate strength)	Thickness, in mm	14,5	13,5	14,0	15,5
	Spacing, in m	0,740	0,740	0,740	0,863
	Span, in m	5,220	5,220	5,966	5,220
Inner bottom	Thickness, in mm	15,0	15,0	15,0	17,0
	Spacing, in m	0,740	0,740	0,740	0, 863
	Span, in m	2,610	2,610	2,983	2,610
Bottom	Thickness, in mm	13,5	13,5	13,5	15,5
	Spacing, in m	0,740	0,740	0,740	0,863
	Span, in m	2,610	2,610	2,983	2,610

The ultimate strength check results are presented in Table 2, for all the considered design solutions, in terms of ultimate strength work ratios.

Table 2: Mild steel midship section - Ultimate strength work ratios.

Ship's condition	Initial model	Initial model	Initial model –1 Web frame	Increased spacing model
	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,740 m – Bulbs	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,863 m – Angles
Sagging (global + local strength)	95%	91%	91%	96%
Hogging (global + local strength)	78%	76%	74%	75%
Sagging (global + local strength + 85% ultimate strength)	85%	86%	86%	85%
Hogging (global + local strength + 85% ultimate strength)	75%	74%	73%	72%

Furthermore, the steel areas provide the possibility to determine the weight variations. The results are presented in Tables 3 and 4, for the two strength check criteria adopted (global and local strength checks and the same with the further limit of 85% of ultimate bending moment capacity).

Table 3: Mild steel midship section - Steel weights – Global and local strength check criteria.

	Initial model	Initial model	Initial model –1 Web frame	Increased spacing model
	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,740 m – Bulbs	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,863 m – Angles
Strakes' weight, in t/m ship's length	19,1	19,1	19,1	20,6
Secondary stiffeners' weight, in t/m ship's length	6,4	6,5	7,3	5,8
Transverse web frames weight, in t/m ship's length	5,9	5,9	5,6	5,9
Total weight, in t/m ship's length	31,4	31,5	32,0	32,3
Steel weight variations (with respect to Mild steel initial model)	0,0%	0,3%	1,9%	2,9%

Table 4: Mild steel midship section - Steel weights – Global and local strength check criteria and 85% of ultimate bending moment capacity.

	Initial model	Initial model	Initial model –1 Web frame	Increased spacing model
	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,740 m – Bulbs	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,863 m – Angles
Strakes' weight, in t/m ship's length	19,4	19,2	19,3	20,9
Secondary stiffeners' weight, in t/m ship's length	6,8	6,9	7,4	6,0
Transverse web frames weight, in t/m ship's length	5,9	5,9	5,6	5,9
Total weight, in t/m ship's length	32,1	32,0	32,3	32,8
Steel weight variations (with respect to Mild steel initial model)	0,0%	-0,3%	0,6%	2,2%

1.2 30% HTS section (HTS at deck and inner bottom structures)

In order to investigate the possible 30% HTS design options and their effects, in terms of structural strength and weight, several design criteria are considered:

❒ ***number of longitudinal ordinary stiffeners - 2 stiffener spacings:***

- bottom and deck stiffener spacing = 0,760 m, side and inner side stiffener spacing = 0,720 m,

- bottom and deck stiffener spacing = 0,863 m, side and inner side stiffener spacing = 0,851 m,

❒ ***span of longitudinal ordinary stiffeners – 2 cases:***

- ordinary stiffener span = 2,610 m,
- ordinary stiffener span = 2,983 m. This span value is relevant to a solution where the number of transverse web frames is reduced by one within each cargo tank, with respect to the previous solution,

❒ ***type of ordinary stiffeners - 2 cases:***

- angle profiles,
- bulb profiles.

Various designs of 30% HTS midship sections are analysed, each one coming out from the combination of the different parameters presented above and summarised in Table 5, considering a HTS with yield stress of 315 MPa.

Table 5: 30% HTS midship section (deck and inner bottom) - Design solutions.

	Parameter	**Initial model**	**Initial model**	**Initial model –1 Web frame**	**Increased spacing model**
		stiffeners spacing 0,740 m – Angles	Stiffeners spacing 0,740 m – Bulbs	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,863 m – Angles
Deck	Thickness, in mm	12,5	12,5	12,5	14,0
	Spacing, in m	0,740	0,740	0,740	0,863
	Span, in m	5,220	5,220	5,966	5,220
Inner bottom	Thickness, in mm	13,0	13,0	13,0	15,0
	Spacing, in m	0,740	0,740	0,740	0,863
	Span, in m	2,610	2,610	2,983	2,610
Bottom	Thickness, in mm	13,5	13,5	13,5	15,5
	Spacing, in m	0,740	0,740	0,740	0,863
	Span, in m	2,610	2,610	2,983	2,610

The ultimate strength check results are presented in Table 6, for all the considered design solutions, in terms of work ratios.

It can be noticed that, for the cases in the last two columns of Table 6, the ultimate strength work ratios are less than 85%. This means that, for these cases, the global and local strength check criteria govern the design of the midship section more than the ultimate strength criteria does.

Table 6: 30% HTS midship section (deck and inner bottom) - Ultimate strength check work ratios.

Ship's condition	Initial model	Initial model	Initial model –1 Web frame	Increased spacing model
	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,740 m – Bulbs	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,863 m – Angles
Sagging	86%	85%	80%	82%
Hogging	74%	73%	70%	69%

Furthermore, the steel areas provide the possibility to determine the weight variations. The results are presented in Table 7.

Table 7: 30% HTS midship section (deck and inner bottom) - Steel weights.

	Initial model	Initial model	Initial model –1 Web frame	Increased spacing model
	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,740 m – Bulbs	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,863 m – Angles
Strakes' weight, in t/m ship's length	18,5	18,5	18,5	20,0
Secondary stiffeners' weight, in t/m ship's length	5,8	5,7	6,5	5,3
Transverse web frames weight, in t/m ship's length	5,9	5,9	5,6	5,9
Total weight, in t/m ship's length	30,2	30,1	30,6	31,2
Steel weight variations (with respect to 30% HTS initial model)	0,0%	-0,3%	1,3%	3,3%

1.3 30% HTS section (HTS at deck and bottom structures)

In order to investigate the possible 30% HTS design options and their effects, in terms of structural strength and weight, several design criteria are considered:

❒ ***number of longitudinal ordinary stiffeners - 2 stiffener spacings:***

- bottom and deck stiffener spacing = 0,760 m, side and inner side stiffener spacing = 0,720 m,
- bottom and deck stiffener spacing = 0,863 m, side and inner side stiffener spacing = 0,851 m,

❒ ***span of longitudinal ordinary stiffeners – 2 cases:***

- ordinary stiffener span = 2,610 mm,

- ordinary stiffener span = 2,983 mm. This span value is relevant to a solution where the number of transverse web frames is reduced by one within each cargo tank, with respect to the previous solution,

❒ ***type of ordinary stiffeners - 2 cases:***

- angle profiles,
- bulb profiles.

Various designs of 30% HTS midship sections are analysed, each one coming out from the combination of the different parameters presented above and summarised in Table 8, considering a HTS with yield stress of 315 MPa.

Table 8: 30% HTS midship section (deck and bottom) - Design solutions.

	Parameter	Initial model	Initial model	Initial model –1 Web frame	Increased spacing model
		stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,740 m – Bulbs	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,863 m – Angles
Deck	Thickness, in mm	12,5	12,5	12,5	14,0
	Spacing, in m	0,740	0,740	0,740	0,863
	Span, in m	5,220	5,220	5,966	5,220
Inner bottom	Thickness, in mm	15,0	15,0	15,0	17,0
	Spacing, in m	0,740	0,740	0,740	0,863
	Span, in m	2,610	2,610	2,983	2,610
Bottom	Thickness, in mm	12,0	12,0	12,0	13,5
	Spacing, in m	0,740	0,740	0,740	0,863
	Span, in m	2,610	2,610	2,983	2,610

The ultimate strength check results are presented in Table 9, for all the considered design solutions, in terms of work ratios.

It can be noticed that, for the cases in the last two columns of Table 9, the ultimate strength work ratios are less than 85%. This means that, for these cases, the global and local strength check criteria govern the design of the midship section more than the ultimate strength criteria does.

Table 9: 30% HTS midship section (deck and bottom) - Ultimate strength check work ratios.

Ship's condition	Initial model	Initial model	Initial model –1 Web frame	Increased spacing model
	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,740 m – Bulbs	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,863 m – Angles
Sagging	87%	86%	81%	83%
Hogging	71%	72%	67%	67%

Furthermore, the steel areas provide the possibility to determine the weight variations. The results are presented in Table 10.

Table 10: 30% HTS midship section (deck and inner bottom) - Steel weights.

	Initial model	Initial model	Initial model –1 Web frame	Increased spacing model
	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,740 m – Bulbs	stiffeners spacing 0,740 m – Angles	stiffeners spacing 0,863 m – Angles
Strakes' weight, in t/m ship's length	18,5	18,5	18,5	20,0
Secondary stiffeners' weight, in t/m ship's length	5,9	5,8	6,7	5,4
Transverse web frames weight, in t/m ship's length	5,9	5,9	5,6	5,9
Total weight, in t/m ship's length	30,3	30,2	30,8	31,3
Steel weight variations (with respect to 30% HTS initial model)	0,0%	-0,3%	1,7%	3,3%

1.4 Influence of parameters

In order to compare the considered design solutions, the following results are evaluated:

– steel weight,

– minimum thickness of longitudinal ordinary stiffener webs,

– length of ordinary stiffener welds (double fillet welding is considered),

– length of ordinary stiffener free edges (no free edge for bulbs and laminated angles, 2 free edges for flat bars, 3 free edges for built-up angles and 4 free edges for built-up T profiles),

– coating surfaces, calculated by considering:

- midship section ballast tank surfaces (all plating and ordinary stiffeners), including lower stools (if there are any),
- transverse web frame ballast tank surfaces (all plating and ordinary stiffeners),
- bottom (horizontal inner bottom plating) and top (deck plating) of cargo tanks,
- surfaces of deck plating, ordinary stiffeners and primary supporting members fitted above the deck.

The different analysis results are presented in Tables 11 and 12.

Table 11: Midship section - Design solutions – Parameter comparison.

Material	Midship section design solution	Section weight, in t/m of ship's length	Transverse web frames weight, in t/m of ship's length	Total weight, in t/m of ship's length	N. of longitudinal ordinary stiffeners	N. of transverse web frame stiffeners	Min thick. of stiffener webs, in mm	Length of stiffener double fillet weld, in m/m of ship's length	Length of stiffener free edges, in m/m of ship's length	Coating surface, in m^2/m of ship's length
Mild steel (1)	Initial model – s=0,740m- Angles	26,2	5,9	32,1	201	84	10,0	262	706	531,2
	Initial model - s=0,740m- Bulbs	26,1	5,9	32,0	201	84	10,0	262	157	507,7
	Initial model –1 Web frame - s=0,740m- Angles	26,7	5,6	32,3	201	84	9,0	254	691	521,5
	Increased spacing model - s=0,863m-Angles	26,9	5,9	32,8	181	76	10,0	236	635	513,8
30% HTS on deck and inner bottom	Initial model – s=0,740m- Angles	24,3	5,9	30,2	201	84	10,0	262	706	514,7
	Initial model - s=0,740m- Bulbs	24,1	5,9	30,1	201	84	10,0	262	157	497,4
	Initial model –1 Web frame - s=0,740m- Angles	25,1	5,6	30,6	201	84	9,0	254	691	506,5
	Increased spacing model - s=0,863m-Angles	25,3	5,9	31,2	181	76	10,0	236	635	499,1
30% HTS on deck and bottom	Initial model – s=0,740m- Angles	24,4	5,9	30,3	201	84	10,0	262	706	514,1
	Initial model - s=0,740m- Bulbs	24,3	5,9	30,2	201	84	10,0	262	157	499,0
	Initial model –1 Web frame - s=0,740m- Angles	25,3	5,6	30,8	201	84	9,0	254	691	511,2
	Increased spacing model - s=0,863m-Angles	25,4	5,9	31,3	181	76	10,0	236	635	498,5

1) The results presented in this Table for design solutions in mild steel refer to the strength check criteria relevant to all global and local strength checks with the further limit of 85% of ultimate bending moment capacity (see also 1.1).

Table 12: Midship section - Design solutions - Detail of coating surface results.

Material	Midship section design solution	Ballast tank, in m^2/m of ship's length				Cargo tanks, in m^2/m of ship's length				Deck, in m^2/m of ship's length			
		Strakes	Ord. stiff.	Trans. web frames	Total	Strakes	Ord. stiff.	Trans. web frames	Total	Strakes	Ord. stiff.	Trans. web frames	Total
Mild steel (1)	Initial model – s=0,740m- Angles	178,9	109,0	121,4	409,3	44,4	0,0	0,0	44,4	23,7	35,3	18,6	77,6
	Initial model - s=0,740m- Bulbs	178,9	92,7	121,4	393,0	44,4	0,0	0,0	44,4	23,7	28,1	18,6	70,4
	Initial model –1 Web frame - s=0,740m- Angles	178,9	116,7	106,2	401,8	44,4	0,0	0,0	44,4	23,7	35,3	16,3	75,3
	Increased spacing model - s=0,863m-Angles	178,9	97,9	119,6	396,4	44,4	0,0	0,0	44,4	23,7	30,7	18,6	73,0
30% HTS on deck and inner bottom	Initial model – s=0,740m- Angles	178,9	103,9	121,4	404,2	44,4	0,0	0,0	44,4	23,7	23,8	18,6	66,1
	Initial model - s=0,740m- Bulbs	178,9	89,3	121,4	389,6	44,4	0,0	0,0	44,4	23,7	21,1	18,6	63,4
	Initial model –1 Web frame - s=0,740m- Angles	178,9	109,5	106,2	394,6	44,4	0,0	0,0	44,4	23,7	27,5	16,3	67,5
	Increased spacing model - s=0,863m-Angles	178,9	93,2	119,6	391,7	44,4	0,0	0,0	44,4	23,7	20,7	18,6	63,0
30% HTS on deck and bottom	Initial model – s=0,740m- Angles	178,9	103,3	121,4	403,6	44,4	0,0	0,0	44,4	23,7	23,8	18,6	66,1
	Initial model - s=0,740m- Bulbs	178,9	90,9	121,4	391,2	44,4	0,0	0,0	44,4	23,7	21,1	18,6	63,4
	Initial model –1 Web frame - s=0,740m- Angles	178,9	114,2	106,2	399,3	44,4	0,0	0,0	44,4	23,7	27,5	16,3	67,5
	Increased spacing model - s=0,863m-Angles	178,9	92,6	119,6	391,1	44,4	0,0	0,0	44,4	23,7	20,7	18,6	63,0

1) The results presented in this Table for design solutions in mild steel refer to the strength check criteria relevant to all global and local strength checks with the further limit of 85% of ultimate bending moment capacity (see also 1.1).

2. Bulkhead arrangement

2.1 HTS corrugated bulkheads with lower and upper stools

In order to investigate the possible HTS bulkhead design options and their effects, in terms of structural strength and weight, several design criteria are considered:

- ***corrugation angle - 3 cases:***
  - angle = 40°,
  - angle = 64°,
  - angle = 75°,
- ***corrugation flange width - 3 cases:***
  - flange width = 1,3 m,
  - flange width = 1,02 m,
  - flange width = 0,7 m,
- ***corrugation height - 3 cases:***
  - height = 0,68 m,
  - height = 0,9 m,
  - height = 1,3 m.

More precisely, the analysis of the influence of corrugation parameters (angle, flange width, etc.) is carried out by considering:

- the variation of flange width vs. given angle values,
- the variation of angle value vs. given corrugation heights.

Moreover, the designs of corrugated bulkheads are obtained by imposing that flanges and webs have approximately the same width, which is beneficial for the plate strength behaviour. Plating thickness is considered as constant all over the bulkhead height.

Various designs of the HTS bulkhead are analysed, each one coming out from the combination of the different parameters presented above and summarised in Tables 13 and 14, considering a HTS with yield stress of 315 MPa.

Table 13: HTS corrugated bulkhead with stools - Design solutions – Influence of width variation vs. given angles.

Corrugation web inclination angle	**40°**			**64°**			**75°**		
Corrugation flange width, in m	1,300	1,020	0,700	1,300	1,020	0,700	1,300	1,020	0,700
Plating thickness, in mm	18,5	17,5	28,0	18,5	14,5	16,5	18,5	14,5	14,5

Table 14: HTS corrugated bulkhead with stools - Design solutions - Influence of angle variation vs. given heights.

Corrugation height, in m	**0,680**			**0,900**			**1,300**		
Corrugation web inclination angle	40°	64°	75°	40°	64°	75°	40°	64°	75°
Plating thickness, in mm	17,5	15,5	14,5	18,5	14,5	13,5	28,0	20,0	19,0

The comparison between the steel weights, calculated for the considered bulkhead designs, is presented in Tables 15 and 16.

For each design, the bulkhead steel weight also includes the weight of brackets, of stringer(s) and of the corresponding watertight web frame fitted in the J-ballast tanks.

Table 15: HTS corrugated bulkhead with stools – Influence of width variation vs. given angles - Steel weights.

Corrugation web inclination angle	**40°**			**64°**			**75°**		
Corrugation flange width, in m	1,300	1,020	0,700	1,300	1,020	0,700	1,300	1,020	0,700
Strake weight, in t	43,6	41,2	64,5	50,9	40,3	47,2	57,5	47,2	45,4
Lower stool weight, in t	31,5	31,5	31,5	31,5	31,5	31,5	31,5	31,5	31,5
Upper stool weight, in t	19,9	19,9	19,9	19,9	19,9	19,9	19,9	19,9	19,9
J-ballast tank WT bulkhead strake weight, in t	12,0	12,0	12,0	12,0	12,0	12,0	12,0	12,0	12,0
J-ballast tank WT bulkhead stiffener weight, in	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1
Total weight, in t	109,1	106,7	130,0	116,4	105,8	112,6	123,0	112,7	110,9
Weight variation	3,1%	0,8%	22,8%	10,0%	0,0%	6,5%	16,3%	6,5%	4,8%

Table 16: HTS corrugated bulkhead with stools – Influence of angle variation vs. given heights - Steel weights.

Corrugation height, in m	**0,680**			**0,900**			**1,300**		
Corrugation web inclination angle	40°	64°	75°	40°	64°	75°	40°	64°	75°
Strake weight, in t	41,2	44,5	45,4	43,6	40,3	43,9	65,0	58,0	61,0
Lower stool weight, in t	31,5	31,5	31,5	31,5	31,5	31,5	31,5	31,5	31,5
Upper stool weight, in t	19,9	19,9	19,9	19,9	19,9	19,9	19,9	19,9	19,9
J-ballast tank WT bulkhead strake weight, in t	12,0	12,0	12,0	12,0	12,0	12,0	12,0	12,0	12,0
J-ballast tank WT bulkhead stiffener weight, in t	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1
Total weight, in t	106,7	110,0	110,9	109,1	105,8	109,4	130,5	123,5	126,4
Weight variation	0,8%	4,0%	4,8%	3,1%	0,0%	3,4%	23,3%	16,7%	19,5%

2.2 HTS corrugated bulkheads without stools

In order to investigate the possible HTS bulkhead design options and their effects in terms of structural strength and weight, several design criteria are considered:

❒ ***corrugation angle - 3 cases:***

- angle = 40°,
- angle = 64°,
- angle = 75°,

❒ ***corrugation flange width - 3 cases:***

- flange width = 1,5 m,
- flange width = 1,3 m,
- flange width = 1,02 m,

❒ ***corrugation height - 3 cases:***

- height = 0,9 m,
- height = 1,3 m,
- height = 1,5 m.

More precisely, the analysis of the influence of corrugation parameters (angle, flange width, etc.) is carried out by considering:

- the variation of flange width vs. given angle values,
- the variation of angle value vs. given corrugation heights.

Moreover, the designs of corrugated bulkheads are obtained by imposing that flanges and webs have approximately the same width, which is beneficial for the plate strength behaviour. Two different plating thickness are considered for the lower and upper parts of the bulkhead, corresponding to 65% and 35% of the bulkhead height, respectively.

Various designs of the HTS bulkhead are analysed, each one coming out from the combination of the different parameters presented above and summarised in Tables 17 to 18, considering a HTS with yield stress of 315 MPa.

Table 17: HTS corrugated bulkhead without stools - Design solutions - Influence of width variation vs. given angles.

Corrugation web inclination angle	**40°**			**64°**			**75°**		
Corrugation flange width, in m	1,500	1,300	1,020	1,500	1,300	1,020	1,500	1,300	1,020
Strake 1 (lower strake) thickness, in mm	32,0	33,5	46,0	23,0	23,0	29,5	22,5	20,0	24,0
Strake 2 (upper strake) thickness, in mm	22,0	23,5	32,0	16,0	16,0	20,5	16,0	14,0	17,0

Table 18: HTS corrugated bulkhead without stools - Design solutions - Influence of angle variation vs. given heights.

Corrugation height, in m	**0,900**			**1,300**			**1,500**		
Corrugation web inclination angle	40°	64°	75°	40°	64°	75°	40°	64°	75°
Strake 1 (lower strake) thickness, in mm	33,5	29,5	26,0	30,0	22,0	20,5	36,0	25,0	23,5
Strake 2 (upper strake) thickness, in mm	23,5	20,5	18,0	21,0	15,5	14,5	25,0	17,5	16,5

The comparison between the steel weights, calculated for the considered bulkhead designs, is reported in Tables 19 and 20.

For each design, the bulkhead steel weight also includes the weight of the corresponding watertight web frame fitted in the J-ballast tanks. For this purpose, the thickness of the watertight floor fitted in way of the corrugated bulkhead is taken equal to about 80% of the thickness of the bulkhead lower strake.

Table 19: HTS corrugated bulkhead without stools – Influence of width variation vs. given angles - Steel weights.

Corrugation web inclination angle	40°			64°			75°		
Corrugation flange width, in m	1,500	1,300	1,020	1,500	1,300	1,020	1,500	1,300	1,020
Strake weight, in t	99,8	107,8	147,4	86,6	86,2	111,6	97,7	84,8	106,9
J-ballast tank WT bulkhead strake weight, in t	18,26	19,08	24,38	14,56	14,56	17,23	14,36	13,33	14,75
J-ballast tank WT bulkhead stiffener weight, in t	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1
Total weight, in t	120,2	128,9	173,8	103,2	102,8	130,9	114,2	100,2	123,7
Weight variation	19,9%	28,7%	73,5%	3,0%	2,6%	30,7%	13,9%	0,0%	23,4%

Table 20: HTS corrugated bulkhead without stools – Influence of angle variation vs. given heights - Steel weights.

Corrugation height, in m	0,900			1,300			1,500		
Corrugation web inclination angle	40°	64°	75°	40°	64°	75°	40°	64°	75°
Strake weight, in t	107,8	111,6	115,1	94,9	87,2	89,9	111,6	97,7	103,3
J-ballast tank WT bulkhead strake weight, in t	19,08	17,23	15,78	17,43	13,93	13,53	20,47	15,15	14,75
J-ballast tank WT bulkhead stiffener weight, in t	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1	2,1
Total weight, in t	128,9	130,9	132,9	114,4	103,2	105,5	134,1	114,9	120,1
Weight variation	25,0%	26,9%	28,9%	10,9%	0,0%	2,3%	30,0%	11,4%	16,5%

2.3 HTS plane bulkheads (single skin)

In order to investigate the possible HTS bulkhead design options and their effects, in terms of structural strength and weight, several design criteria are considered:

- ❒ ***number of stringers – 2 cases:***
  - 1 stringer,

- 3 stringers,

❒ ***number of ordinary stiffeners – 2 stiffener spacings:***

- stiffener spacing = 0,740 m,
- stiffener spacing = 0,863 m,

❒ ***type of ordinary stiffeners - 2 cases:***

- angle profiles,
- bulb profiles.

Various designs of the HTS bulkhead are analysed, each one coming out from the combination of the different parameters presented above and summarised in Table 21, considering a HTS with yield stress of 315 MPa.

Table 21: HTS plane bulkhead - Design solutions.

	1 stringer		**3 stringers**			
Stiffener type	Angle	Angle	Angle	Angle	Bulb	Bulb
Stiffener spacing, in m	0,740	0,863	0,740	0,863	0,740	0,863
Strake 1 (lower strake) thickness, in mm	12,0	14,0	12,0	14,0	12,0	14,0
Strake 2 thickness, in mm	11,0	13,0	11,0	13,0	11,0	13,0
Strake 3 thickness, in mm	10,0	11,0	10,0	11,0	10,0	11,0
Strake 4 (upper strake) thickness, in mm	11,0	11,0	11,0	11,0	11,0	11,0

The comparison between the steel weights, calculated for the considered bulkhead designs, is reported in Table 22.

For each design, the bulkhead steel weight also includes the weight of brackets, of stringer(s) and of the corresponding watertight web frame fitted in the J-ballast tanks.

Table 22: HTS plane bulkhead - Steel weights.

	1 stringer		3 stringers			
Stiffener type	Angle	Angle	Angle	Angle	Bulb	Bulb
Stiffener spacing, in m	0,740	0,863	0,740	0,863	0,740	0,863
Strake weight, in t	32,7	36,6	32,7	36,6	32,7	36,6
Stiffener weight, in t	29,8	29,8	23,5	20,9	23,9	21,3
Stringer weight, in t	8,5	8,5	18,1	18,1	18,1	18,1
Bracket weight, in t	3,2	3,1	4,9	4,9	4,9	4,9
J-ballast tank WT bulkhead strake weight, in t	12,0	12,9	12,0	12,9	12,0	12,9
J-ballast tank WT bulkhead stiffener weight, in t	2.1	2.1	2.1	2.1	2.1	2.1
Total weight, in t	88,2	92,9	93,2	95,5	93,7	95,8
Weight variation	0,0%	5,3%	5,7%	8,3%	6,2%	8,7%

2.4 Influence of parameters

In order to compare the considered design solutions, the following results are evaluated:

- steel weight,
- minimum thickness of longitudinal ordinary stiffener webs,
- length of ordinary stiffener welds (double fillet welding is considered),
- length of ordinary stiffener free edges (no free edge for bulbs and laminated angles, 2 free edges for flat bars, 3 free edges for built-up angles and 4 free edges for built-up T profiles),
- coating surfaces, calculated by considering ballast tank surfaces (plating and ordinary stiffeners), including lower stools (if any).

The different analysis results are presented in Table 23. For each design, the bulkhead results also include brackets, stringer(s) and the corresponding watertight web frame fitted in the J-ballast tanks.

Table 23: Transverse bulkhead - Design solutions – Parameter comparison.

Bulkhead type	**Bulkhead design solution**	**Bulkhead weight, in t**	**N. of stiffeners**	**Min thick. of stiffeners webs, in mm**	**Length of stiffeners double fillet weld, in m**	**Length of stiffeners free edges, in m**	**Coating surface of ballast tank, including lower stool, in m^2**		
							Strakes	Ordinary stiffeners	Total
Corrugated with stools – Flange width variation vs. given angles	40° - s=1,3 m	109,1	140	11,0	387	1050	418,6	117,9	536,4
	40° - s=1,02 m	106,7							
	40° - s=0,7 m	130,0							
	64° - s=1,3 m	116,4							
	64° - s=1,02 m	105,8							
	64° - s=0,7 m	112,6							
	75° - s=1,3 m	123,0							
	75° - s=1,02 m	112,7							
	75° - s=0,7 m	110,9							
Corrugated with stools – Angle variation vs. given heights	40° - h=0,68 m	106,7	140	11,0	387	1050	418,6	117,9	536,4
	64° - h=0,68 m	110,0							
	75° - h=0,68 m	110,9							
	40° - h=0,9 m	109,1							
	64° - h=0,9 m	105,8							
	75° - h=0,9 m	109,4							
	40° - h=1,3 m	130,5							
	64° - h=1,3 m	123,5							
	75° - h=1,3 m	126,4							
Corrugated without stools – Flange width variation vs. given angles	40° - s=1,5 m	120,2	68	11,0	125	264	259,9	49,1	309,0
	40° - s=1,3 m	128,9							
	40° - s=1,02 m	173,8							
	64° - s=1,5 m	103,2							
	64° - s=1,3 m	102,8							
	64° - s=1,02 m	130,9							
	75° - s=1,5 m	114,2							
	75° - s=1,3 m	100,2							
	75° - s=1,02 m	123,7							
Corrugated without stools – Angle variation vs. given heights	40° - h=0,9 m	128,9	68	11,0	125	264	259,9	49,1	309,0
	64° - h=0,9 m	130,9							
	75° - h=0,9 m	132,9							
	40° - h=1,3 m	114,4							
	64° - h=1,3 m	103,2							
	75° - h=1,3 m	105,5							
	40° - h=1,5 m	134,1							
	64° - h=1,5 m	114,9							
	75° - h=1,5 m	120,1							
Plane OS spacing = 0,740 m	1 stringer – angles	88,2	105	11,5	671	1904	259,9	49,1	309,0
	3 stringer – bulbs	93,7	105	12,0	727	472			
	3 stringer – angles	93,2	105	12,0	727	2072			
Plane OS spacing = 0,863 m	1 stringer – angles	92,9	93	11,5	594	1686	259,9	44,2	304,1
	3 stringer – bulbs	95,8	93	12,0	650	444			
	3 stringer – angles	95,5	93	12,0	650	1854			

3. Primary supporting member arrangement

3.1 Structural analysis

The scantlings of primary supporting members are checked through three dimensional finite element analysis. The finite element analysis is performed according to the calculation procedure presented in Ch 2, 3.1.1, summed up as follows:

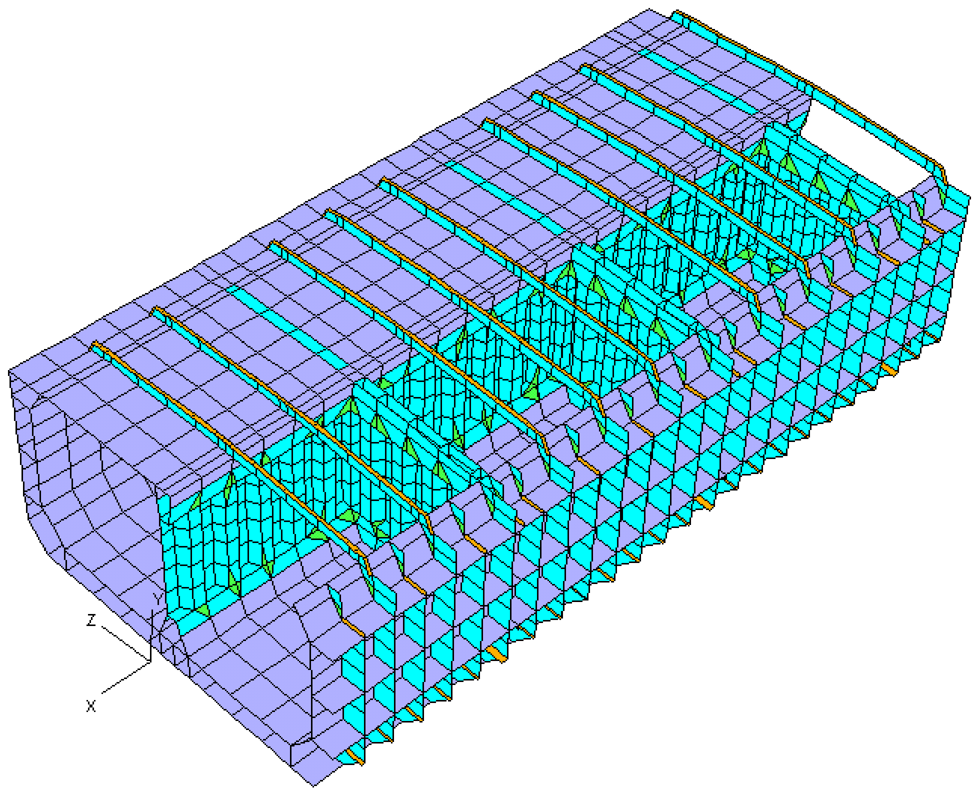
- analysis of a three cargo tank "coarse mesh" model,
- subsequent "fine mesh" analyses of the following localised structural areas:
  - the most stressed transverse web frame ring among those considered in the model,
  - the connections between transverse bulkheads and stools.

3.2 Three cargo tank "coarse mesh" model

3.2.1 Structural model

The three dimensional three cargo tank "coarse mesh" model used for the finite element analysis is presented in Fig 1.

Figure 1: Three cargo tank "coarse mesh" model (port deck plating and port side shell plating are removed for illustration purposes).



3.2.2 Combinations between ship's loading conditions and load cases

The combinations between each one of the considered ship's loading conditions and load cases "a", "b", "c" and "d", which are needed for calculating the still water and wave induced loads acting on the hull structures (see also 3.1.1), are presented in Tab 24. In that Table, columns marked with M or Q refer to associations where either hull girder bending moment M or shear Q are correctly reproduced in the model area under investigation for the relevant loading condition.

Table 24: Combinations between loading conditions and load cases considered in the structural analysis.

Loading condition	Load case							
	"a" crest		"a" trough		"b"		"c"	"d"
	M	Q	M	Q	M	Q		
Homogeneous			✔		✔			
Ballast	✔		✔		✔		✔	
Chess cargo 1,6 t/m^3	✔			✔	✔	✔	✔	✔
Non-homogeneous cargo 1,2 t/m^3		✔	✔		✔			✔

3.2.3 Analysis results

The results of the "coarse mesh" finite element analysis are presented in Figures 2 to 4 in terms of maximum Von Mises stress, calculated for the most severe combination between loading conditions and load cases among those considered.

Figure 2: Maximum Von Mises stresses' results of the "coarse mesh" three cargo tank finite element analysis on the outer shell and deck plating.

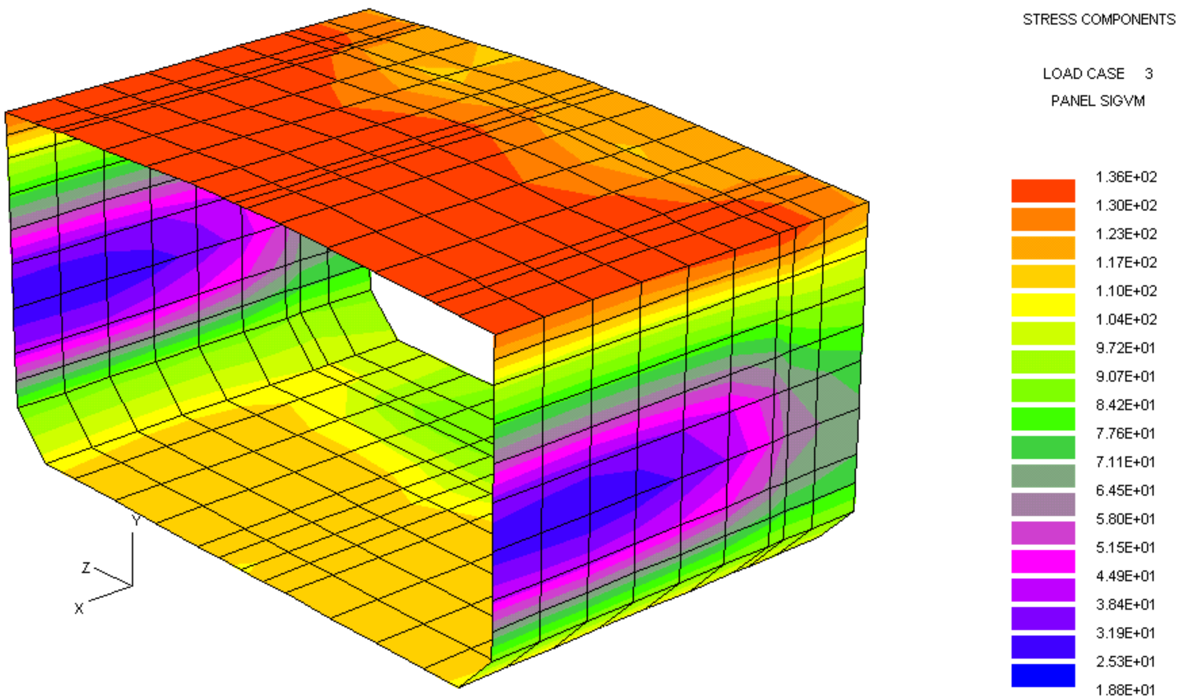


Figure 3: Maximum Von Mises stresses' results of the "coarse mesh" three cargo tank finite element analysis on the primary supporting members.

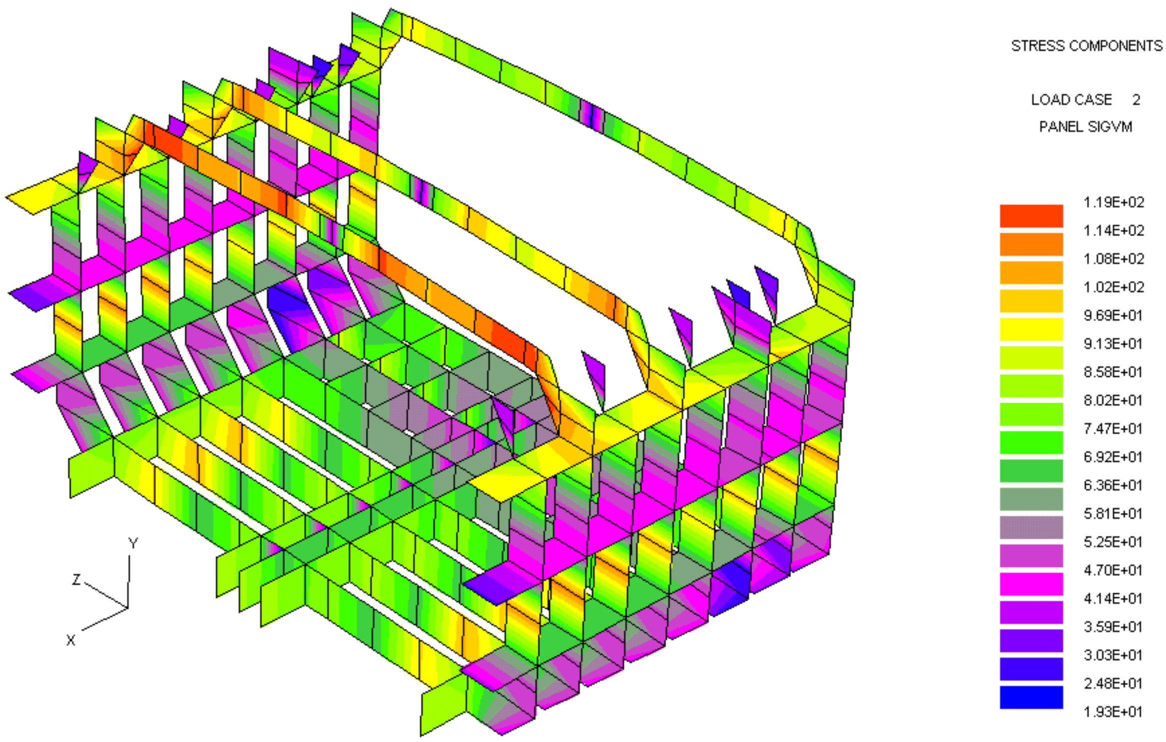
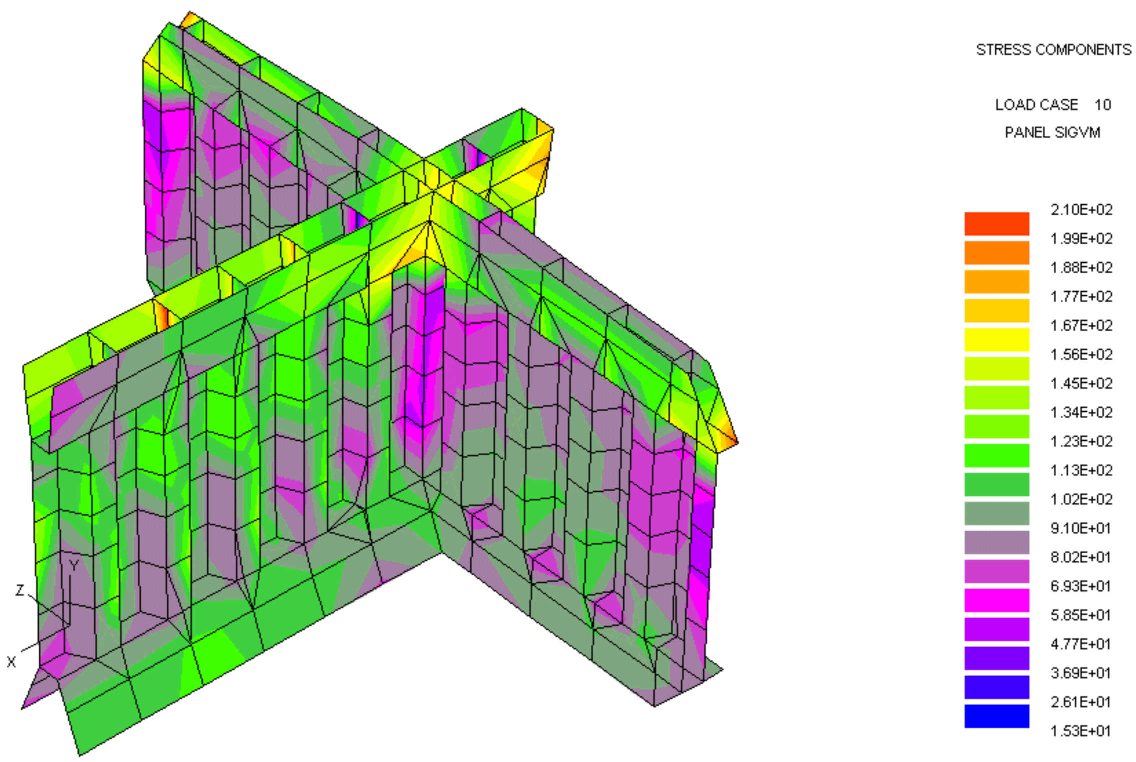


Figure 4: Maximum Von Mises stresses' results of the "coarse mesh" three cargo tank finite element analysis on longitudinal and transverse bulkheads.



3.3 "Fine mesh" analyses

3.3.1 Analyses

The hull parts resulting from the three cargo tank "coarse mesh" model finite element analysis to be the ones subjected to the highest stress level and the hull parts deemed critical for the ship's tank structure arrangement are further analysed through more finely meshed three dimensional models.

In details, "fine mesh" finite element analyses are performed on the following hull parts:

- the most stressed transverse web frame ring among those considered in the model (see Fig 5),
- the connections between transverse bulkhead and stools (see Fig 6).

Figure 5: "Fine mesh" finite element model of the most stressed transverse web frame ring.

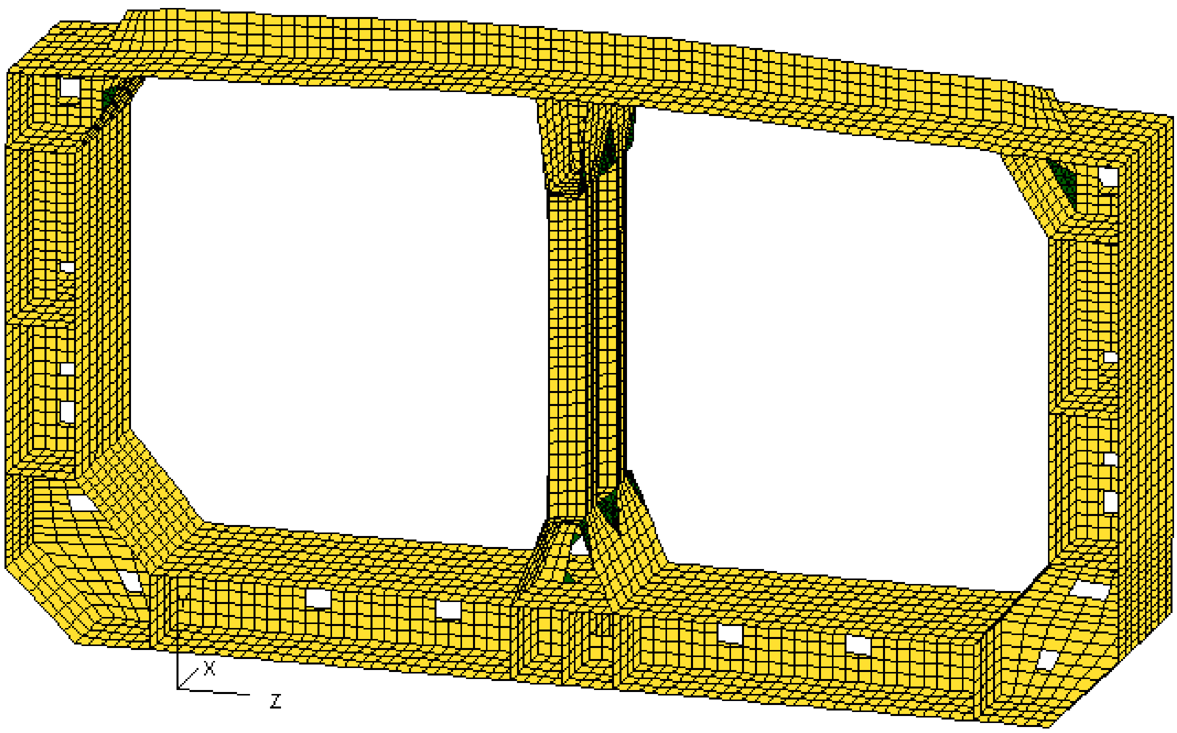
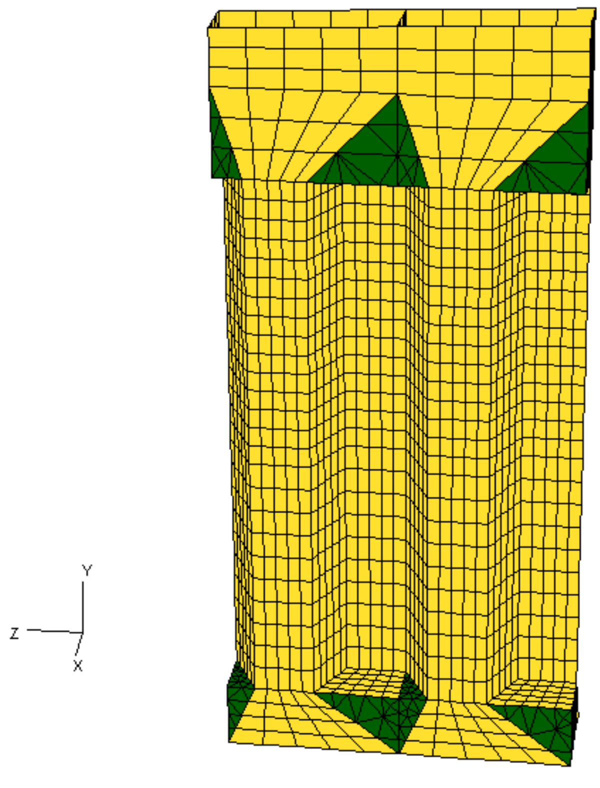


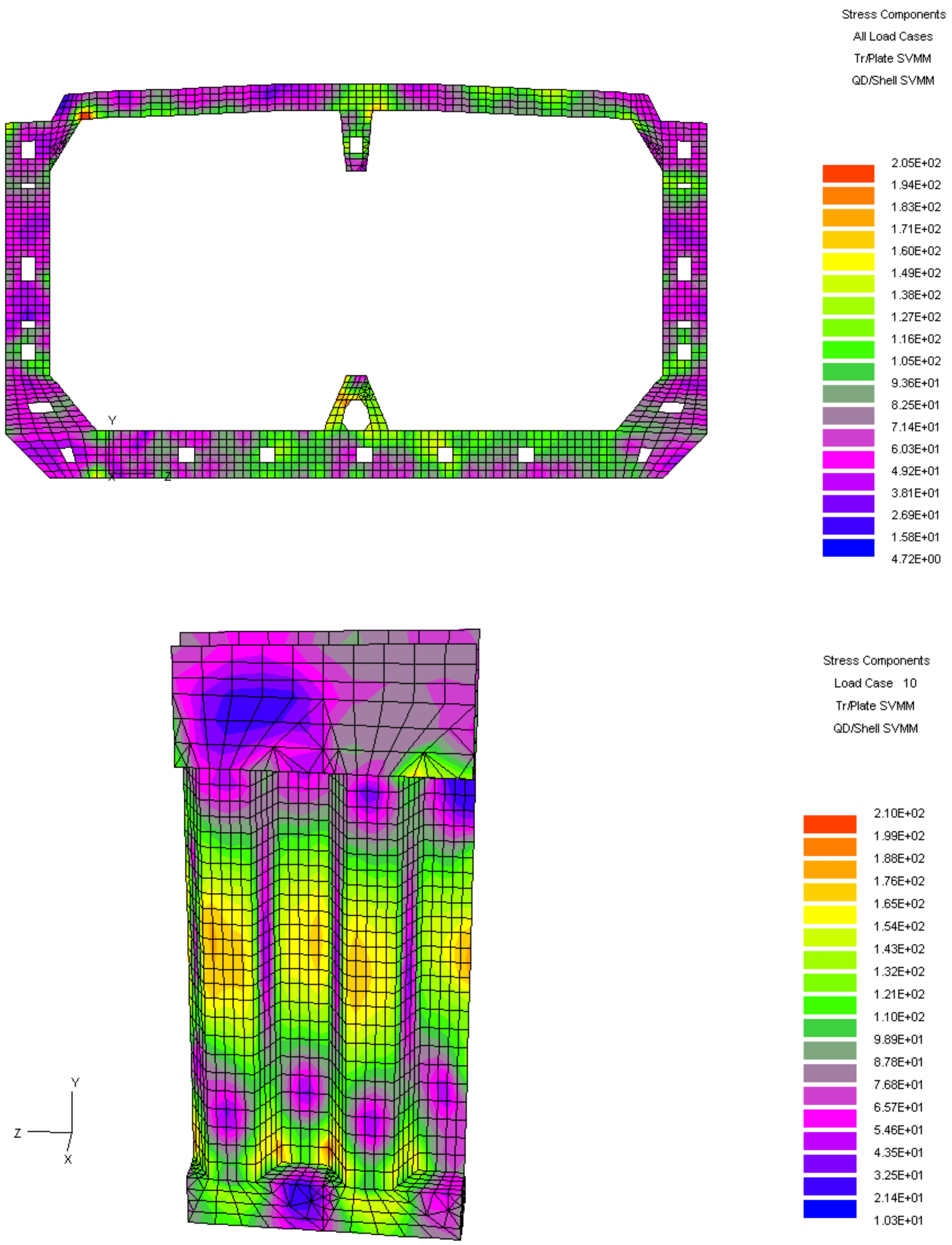
Figure 6: "Fine mesh" finite element model of the connections between transverse bulkhead and stools.



3.3.2 Analysis results

The results of the "fine mesh" finite element analyses are presented in the Figure 7, in terms of maximum Von Mises stresses, calculated for the most severe combination between loading conditions and load cases among those considered.

Figure 7: Maximum Von Mises stresses' results of "fine mesh" finite element analysis for the transverse web frame ring and for the connections between transverse bulkhead and stools.



Appendix 2
Structural arrangement of an Aframax tanker

1. Midship section arrangement

1.1 Mild steel section

In order to investigate the possible mild steel design options and their effects, in terms of structural strength and weight, several design criteria are considered:

- ***strength check criteria - 2 cases:***
  - all global and local strength check criteria results are within the allowable Rule limits,
  - the previous case, to which is added the condition that the ultimate strength work ratios (i.e. the ratios between the applied bending moments in sagging or hogging conditions and the corresponding ultimate bending moment capacity of the section, calculated according to the Rule criteria) do not approximately exceed 85%.
- ***number of longitudinal ordinary stiffeners - 2 stiffener spacings:***
  - bottom, inner bottom and deck stiffener spacing = 0,790m, side and inner side stiffener spacing = 0,800m,
  - bottom, inner bottom and deck stiffener spacing = 0,830m, side and inner side stiffener spacing = 0,850m.
- ***span of longitudinal ordinary stiffener – 2 cases:***
  - ordinary stiffener span = 3,750m,
  - ordinary stiffener span = 4,286m. This span value is relevant to a solution where the number of transverse web frames is reduced by one within each cargo tank.
- ***type of ordinary stiffener cross section: angle profiles.***

Various designs of mild steel midship sections are analysed, each one coming out from the combination of the different parameters presented above and summarised in Table 1.

Table 1: Mild steel midship section – Design solutions.

Midship section part	Parameter	Initial model	Initial model –1 Web frame	Increased spacing model
		Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,830m
Deck	Thickness, in mm	21,5	22,0	23,0
	Spacing, in m	0,790	0,790	0,830
	Span, in m	3,750	4,286	3,750
Inner bottom	Thickness, in mm	17,5	17,5	18,0
	Spacing, in m	0,790	0,790	0,830
	Span, in m	3,750	4,286	3,750
Bottom	Thickness, in mm	16,5	16,5	17,0
	Spacing, in m	0,790	0,790	0,830
	Span, in m	3,750	4,286	3,750

The ultimate strength check results are presented in Table 2 for all the considered design solutions, in terms of ultimate strength work ratios.

Table 2: Mild steel midship section – Ultimate strength work ratios.

Ship's conditions	Initial model	Initial model -1 Web frame	Increased spacing model
	Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,830m
Sagging	85%	85%	86%
Hogging	77%	75%	76%

Furthermore, the steel volumes provide the possibility to determine the weight variations. The results are presented in Table 3.

Table 3: Mild steel midship section – Steel weights.

Design parts	Initial model	Initial model –1 Web frame	Increased spacing model
	Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,830m
Strakes' volume, in m3/m ship's length	4,12	4,14	4,21
Secondary stiffeners' volume, in m3/m ship's length	1,74	1,91	1,69
Total section volume, in m3/m ship's length	5,86	6,05	5,90
Total section weight, in t/m ship's length	45,71	47,19	46,02
Transverse web frame weight, in t/m ship's length	9,8	8,8	9,8
Total weight in t/m ship's length	55,51	56,0	55,82
Steel weight variations (by comparison to the mild steel initial model)	0,0%	+0,9%	+0,6%

1.2 30% HTS section

In order to investigate the possible 30% HTS (1) design options and their effects, in terms of structural strength and weight, several design criteria are considered:

- ***strength check criteria - 2 cases:***
  - all global and local strength check criteria results are within the allowable Rule limits,
  - the previous case, to which is added the condition that the ultimate work ratios (i.e. the ratios between the applied bending moments in sagging or hogging conditions and the corresponding ultimate bending moment capacity of the section, calculated according to the Rule criteria) do not approximately exceed 85%.
- ***number of longitudinal ordinary stiffeners - 4 stiffener spacings:***
  - bottom, inner bottom and deck stiffener spacing = 0,754m, side and inner side stiffener spacing = 0,760m,
  - bottom, inner bottom and deck stiffener spacing = 0,790m, side and inner side stiffener spacing = 0,800m,
  - bottom, inner bottom and deck stiffener spacing = 0,830m, side and inner side stiffener spacing = 0,850m,
  - bottom, inner bottom and deck stiffener spacing = 0,920m, side and inner side stiffener spacing = 0,930m.
- ***span of longitudinal ordinary stiffener – 2 cases:***
  - ordinary stiffener span = 3,750m,
  - ordinary stiffener span = 4,286m. This span value is relevant to a solution where the number of transverse web frames is reduced by one within each cargo tank.
- ***type of ordinary stiffener cross section: angle profiles.***

Various designs of 30% HTS midship sections are analysed, each one coming out from the combination of the different parameters presented above and summarised in Table 4.

Note 1: The HTS considered for the Aframax tanker is a 355 MPa yield stress steel.

Table 4: 30% HTS midship section – Design solutions.

Midship section part	Parameter	Decreased spacing model Bottom stiffener spacing 0,754m	Initial model Bottom stiffener spacing 0,790m	Initial model –1 Web frame Bottom stiffener spacing 0,790m	First increased spacing model Bottom stiffener spacing 0,830m	First increased spacing model –1 Web frame Bottom stiffener spacing 0,830m	Second increased spacing model Bottom stiffener spacing 0,920m
Deck	Thickness, in mm	17,5	18,0	18,0	19,0	19,0	20,0
	Spacing, in m	0,754	0,790	0,790	0,830	0,830	0,920
	Span, in m	3,750	3,750	4,286	3,750	4,286	3,750
Inner bottom	Thickness, in mm	17,0	17,5	17,5	18,5	18,5	20,5
	Spacing, in m	0,754	0,790	0,790	0,830	0,830	0,920
	Span, in m	3,750	3,750	4,286	3,750	4,286	3,750
Bottom	Thickness, in mm	13,0	14,5	14,5	14,5	14,5	15,5
	Spacing, in m	0,754	0,790	0,790	0,830	0,830	0,920
	Span, in m	3,750	3,750	4,286	3,750	4,286	3,750

The ultimate strength check results are presented in Table 5 for all the considered design solutions, in terms of ultimate strength work ratios.

Table 5: 30% HTS midship section – Ultimate strength check work ratios.

Ship's conditions	Decreased spacing model Bottom stiffener spacing 0,754m	Initial model Bottom stiffener spacing 0,790m	Initial model –1 Web frame Bottom stiffener spacing 0,790m	First increased spacing model Bottom stiffener spacing 0,830m	First increased spacing model –1 Web frame Bottom stiffener spacing 0,830m	Second Increased spacing model Bottom stiffener spacing 0,920m
Sagging	84%	85%	84%	84%	84%	85%
Hogging	69%	68%	66%	68%	66%	67%

Furthermore, the steel volumes provide the possibility to determine the weight variations. The results are presented in Table 6.

Table 6: 30% HTS midship section – Steel weights.

Design parts	**Decreased spacing model**	**Initial model**	**Initial model –1 Web frame**	**First increased spacing model**	**First increased spacing model –1 Web frame**	**Second increased spacing model**
	Bottom stiffener spacing 0,754m	Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,830m	Bottom stiffener spacing 0,830m	Bottom stiffener spacing 0,920m
Strakes' volume, in m3/m ship's length	3,74	3,82	3,82	3,91	3,91	4,16
Secondary stiffeners' volume, in m3/m ship's length	1,60	1,54	1,74	1,47	1,69	1,38
Total section volume, in m3/m ship's length	5,34	5,36	5,56	5,38	5,60	5,54
Total section weight, in t/m ship's length	41,65	41,81	43,37	41,96	43,68	43,21
Transverse web frame weight, in t/m ship's length	9,8	9,8	8,8	9,8	8,8	9,8
Total weight in t/m ship's length	51,45	51,61	52,17	51,76	52,48	53,01
Steel weight variations (by comparison to the 30% HTS initial model)	-0,3%	0,0%	+1,1%	+0,3%	+1,7%	+2,7%

1.3 50% HTS section

In order to investigate the possible 50% HTS (2) design options and their effects, in terms of structural strength and weight, several design criteria are considered:

❒ ***strength check criteria - 2 cases:***

- all global and local strength check criteria results are within the allowable Rule limits,
- the previous case, to which is added the condition that the ultimate work ratios (i.e. the ratios between the applied bending moments in sagging or hogging conditions and the corresponding ultimate bending moment capacity of the section, calculated according to the Rule criteria) do not approximately exceed 85%.

❒ ***number of longitudinal ordinary stiffeners - 2 stiffener spacings:***

- bottom, inner bottom and deck stiffener spacing = 0,790m, side and inner side stiffener spacing = 0,800m,
- bottom, inner bottom and deck stiffener spacing = 0,830m, side and inner side stiffener spacing = 0,850m.

❒ ***span of longitudinal ordinary stiffener: 3,750m.***

❒ ***type of ordinary stiffener cross section: angle profiles.***

Various designs of 50% HTS midship sections are analysed, each one coming out from the combination of the different parameters presented above and summarised in Table 7.

Note 2: It has to be noticed that the 50% HTS design actually corresponds to a design that is made of 45,7% of 355 MPa yield stress steel.

Table 7: 50% HTS midship section – Design solutions.

Midship section part	**Parameter**	**Initial model**	**Increased spacing model**
		Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,830m
Deck	Thickness, in mm	17,5	18,5
	Spacing, in m	0,790	0,830
	Span, in m	3,750	3,750
Inner bottom	Thickness, in mm	15,0	15,5
	Spacing, in m	0,790	0,830
	Span, in m	3,750	3,750
Bottom	Thickness, in mm	14,5	14,5
	Spacing, in m	0,790	0,830
	Span, in m	3,750	3,750

The ultimate strength check results are presented in Table 8 for all the considered design solutions, in terms of ultimate strength work ratios.

Table 8: 50% HTS midship section – Ultimate strength check work ratios.

Ship's conditions	**Initial model**	**Increased spacing model**
	Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,830m
Sagging	86%	85%
Hogging	68%	67%

Furthermore, the steel volumes provide the possibility to determine the weight variations. The results are presented in Table 9.

Table 9: 50% HTS midship section – Steel weights.

Design parts	Initial model	Increased spacing model
	Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,830m
Strakes' volume, in m3/m ship's length	3,69	3,76
Secondary stiffeners' volume, in m3/m ship's length	1,45	1,41
Total section volume, in m3/m ship's length	5,14	5,17
Total section weight, in t/m ship's length	40,09	40,33
Transverse web frame weight, in t/m ship's length	9,8	9,8
Total weight in t/m ship's length	49,89	50,13
Steel weight variations (by comparison to the 50% HTS initial model)	0,0%	+0,5%

1.4 Influence of parameters

In order to compare the considered design solutions, the following results are evaluated:

- steel weight,
- length of ordinary stiffener welds (double fillet welding is considered),
- length of ordinary stiffener free edges (no free edge for bulbs and laminated angles, 2 free edges for flat bars, 3 free edges for built-up angles and 4 free edges for built-up T profiles),
- coating surfaces, calculated by considering:
  - midship section cargo tank surfaces (plating of horizontal inner bottom to which is added plating and ordinary stiffeners of the deck),
  - midship section ballast tank surfaces (all plating and ordinary stiffeners),
  - transverse web frame ballast tank surfaces (all plating and ordinary stiffeners).

The different analysis results are presented in tables 10, 11 and 12.

Table 10: Midship section – Design solutions – Weight comparison.

Midship section model	**Decreased spacing model**	**Initial model**	**Initial model –1 Web frame**	**First increased spacing model**	**First increased spacing model –1 Web frame**	**Second increased spacing model**
	Bottom stiffener spacing 0,754m	Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,790m	Bottom stiffener spacing 0,830m	Bottom stiffener spacing 0,830m	Bottom stiffener spacing 0,920m
	3,75m primary structure span	3,75m primary structure span	4,286m primary structure span	3,75m primary structure span	4,286m primary structure span	3,75m primary structure span
Mild steel total weight, in t/m ship's length	-	55,51	56,0	55,82	-	-
30% HTS total weight, in t/m ship's length	51,45	51,61	52,17	51,76	52,48	53,01
50% HTS total weight, in t/m ship's length	-	49,89	-	50,13	-	-

Table 11: Length of double fillet weld and length of free edge results for the different designed midship sections.

	Mild steel section			**30% HTS section**						**50% HTS section**	
	Initial model	Initial model – 1 web frame	Increased spacing model	Decreased spacing model	Initial model	Initial model –1 Web frame	First Increased spacing model	First Increased spacing model –1 Web frame	Second increased Spacing model	Initial model	Increased Spacing model
Bottom secondary stiffener spacing, in m	0,790	0,790	0,830	0,754	0,790	0,790	0,830	0,830	0,920	0,790	0,830
Number of secondary stiffeners	273 angles	273 angles	262 angles	284 angles	273 angles	273 angles	262 angles	262 angles	240 angles	273 angles	262 angles
Number of secondary stiffeners for the transverse web frames	707	606	679	735	707	606	679	582	609	707	679

Table 11 (continued)

	Mild steel section			30% HTS section						50% HTS section	
	Initial model	Initial model – 1 web frame	Increased spacing model	Decreased spacing model	Initial model	Initial model –1 Web frame	First Increased spacing model	First Increased spacing model –1 Web frame	Second increased Spacing model	Initial model	Increased Spacing model
Double fillet length, in m/m ship's length	386	370	372	399	386	370	372	357	344	386	372
Double fillet length for a 30m long hold, in m	11580	11100	11160	11970	11580	11100	11160	10710	10320	11580	11160
Length of free edges, in m/m ship's length	1087	1049	1048	1124	1087	1049	1048	1012	970	1087	1048
Length of free edges for a 30m long hold, in m	32610	31470	31440	33720	32610	31470	31440	30360	29100	32610	31440

Table 12: Coating surface results for the different designed midship sections.

		Initial number of web frames								-1 web frame for each hold		
		Mild steel		30% HTS				50% HTS		Mild steel	30% HTS	
		Initial model	Increased Spacing model	Decreased Spacing model	Initial model	First Increased Spacing model	Second increased Spacing model	Initial model	Increased Spacing model	Initial model	Initial model	First Increased Spacing model
Ballast	Strakes, in m²/m ship's length	175	175	175	175	175	175	175	175	175	175	175
	Stiffeners, in m²/m ship's length	179	176	180	172	165	153	163	160	197	199	190
	Total, in m²/m ship's length	354	351	355	347	340	328	338	335	372	374	365
Cargo tank	Strakes, in m²/m ship's length	70	70	70	70	70	70	70	70	70	70	70
	Stiffeners, in m²/m ship's length	43	41	35	34	32	29	34	32	43	34	32

Table 12 (continued)

		Initial number of web frames								-1 web frame for each hold		
		Mild steel		30% HTS				50% HTS		Mild steel	30% HTS	
		Initial model	Increased Spacing model	Decreased Spacing model	Initial model	First Increased Spacing model	Second increased Spacing model	Initial model	Increased Spacing model	Initial model	Initial model	First Increased Spacing model
Cargo tank	Total, in m²/m ship's length	113	111	105	104	102	99	104	102	113	104	102
Transverse Web frame	Strakes, in m²/m ship's length	97	97	97	97	97	97	97	97	83	83	83
	Stiffeners, in m²/m ship's length	20	19	21	20	19	17	20	19	17	17	16
	Total, in m²/m ship's length	117	116	118	117	116	114	117	116	100	100	99
Total Section	Strakes, in m²/m ship's length	342	342	342	342	342	342	342	342	328	328	328
	Stiffeners, in m²/m ship's length	242	236	236	226	216	199	217	211	257	250	238
	Total, in m²/m ship's length	584	578	578	568	558	541	559	553	585	578	566
Coating surface for a 30m long hold, in m²		17520	17340	17340	17040	16740	16230	16770	16590	17550	17340	16980

2. Bulkhead arrangement

2.1 Mild steel bulkheads

In order to investigate the possible mild steel bulkhead design options and their effects, in terms of structural strength and weight, several design criteria are considered:

- ***types of bulkhead – 2 types:***
  - plane bulkheads,
  - corrugated Bulkheads.

❒ ***number of stringers for a plane bulkhead – 2 cases:***

- 2 stringer plane bulkhead,
- 3 stringer plane bulkhead.

❒ ***plane bulkhead secondary stiffener spacing – 4 cases:***

- stiffener spacing = 0,754m,
- stiffener spacing = 0,790m,
- stiffener spacing = 0,830m,
- stiffener spacing = 0,920m.

❒ ***number of corrugations for a corrugated bulkhead – 2 cases:***

- 10 corrugations,
- 16 corrugations.

Various designs of mild steel bulkheads are analysed, each one coming out from the different parameters presented above and summarised in Tables 13 and 14.

Table 13: Design parameters for the mild steel plane bulkheads.

Models	**2 stringers**				**3 stringers**
Stiffener spacing, in m	0,754	0,790	0,830	0,920	0,790
Cargo strake 1 (lower strake) thickness, in mm	17,0	16,0	16,0	17,5	16,0
Cargo strake 2 thickness, in mm	16,5	15,5	15,0	16,0	15,5
Cargo strake 3 thickness, in mm	14,5	14,0	13,5	14,0	14,0
Cargo strake 4 thickness, in mm	13,0	12,5	12,0	12,5	12,5
Cargo strake 5 (upper strake) thickness, in mm	11,5	11,0	10,5	11,0	11,0
Ballast strake 1 (lower strake) thickness, in mm	13,5	14,0	14,5	16,0	14,0
Ballast strake 2 thickness, in mm	14,5	16,0	14 ,5	17,5	15,0
Ballast strake 3 thickness, in mm	14,5	14,5	16,0	17,5	14,5
Ballast strake 4 thickness, in mm	13,0	13,0	14,0	15,5	13,0
Ballast strake 5 thickness, in mm	10,0	11,0	11,5	11,5	11,5
Ballast strake 6 (upper strake) thickness, in mm	8,5	9,0	9,5	9,5	9,0

Table 14: Design parameters for the mild steel corrugated bulkheads.

Models	10 corrugations	16 corrugations
Lower stool	YES	YES
Cargo strake 1 (lower strake) thickness, in mm	22,0	22,0
Cargo strake 2 thickness, in mm	21,5	21,0
Cargo strake 3 thickness, in mm	20,5	19,5
Cargo strake 4 (upper strake) thickness, in mm	15,0	15,0
Upper stool	NO	NO
Ballast strake 1 (lower strake) thickness, in mm	14,0	14,0
Ballast strake 2 thickness, in mm	16,0	16,0
Ballast strake 3 thickness, in mm	14,5	14,5
Ballast strake 4 thickness, in mm	13,0	13,0
Ballast strake 5 thickness, in mm	11,0	11,0
Ballast strake 6 (upper strake) thickness, in mm	9,0	9,0

The steel volumes provide the possibility to determine the weight variations. The results are presented in Tables 15 and 16.

Table 15: Mild steel plane bulkhead weight results.

Models	2 stringers				3 stringers
Stiffener spacing, in m	0,754	0,790	0,830	0,920	0,790
Cargo strake volume, in m3	10,2	9,7	9,4	10,0	9,7
Cargo stiffener volume, in m3	9,1	9,0	8,7	8,5	6,1
Cargo stringer volume, in m3	8,4	8,4	8,4	8,4	9,9
Total cargo volume, in m3	27,7	27,1	26,5	26,9	25,7
Ballast strake volume, in m3	2,7	2,8	2,9	3,2	2,8
Ballast stiffener volume, in m3	1,0	1,0	1,0	0,9	0,9
Ballast stringer volume, in m3 (1)	-	-	-	-	1,4
Total ballast volume, in m3	3,7	3,8	3,9	4,1	5,1
Total bulkhead volume, in m3	31,4	30,9	30,4	31,0	30,8
Total bulkhead weight, in t	244,9	241,0	237,1	241,8	240,2
(1) Calculations for the 2 stringers are already included in the midship section ones when those latter are 2 stringer ballast midship section models. For the case of a 3 stringer plane bulkhead, an additional volume needs to be considered.					

Table 16: Mild steel corrugated bulkhead weight results.

Models	10 corrugations	16 corrugations
Lower stool volume, in m3	11,4	11,4
Cargo strake volume, in m3	15,9	19,1
Upper stool volume, in m3	0,0	0,0
Total cargo volume, in m3	27,4	30,5
Ballast strake volume, in m3	2,8	2,8
Ballast stiffener volume, in m3	1,0	1,0
Ballast stringer volume, in m3 (1)	-	-
Total ballast volume, in m3	3,8	3,8
Total bulkhead volume, in m3	31,1	34,3
Total bulkhead weight, in t	242,6	267,5
(1) Calculations for the 2 stringers are already included in the midship section ones as those latter are 2 stringer ballast midship section models.		

2.2 HTS bulkheads

In order to investigate the possible HTS (1) bulkhead design options and their effects, in terms of structural strength and weight, several design criteria are considered:

- ***types of bulkhead – 2 types:***
  - plane bulkheads,
  - corrugated Bulkheads.
- ***number of stringers for a plane bulkhead: 2 stringers.***
- ***plane bulkhead secondary stiffener spacing: 0,790m.***
- ***number of corrugations for a corrugated bulkhead: 10 corrugations.***

Note 1: HTS actually corresponds to a 355 MPa yield stress steel

Various designs of HTS bulkheads are analysed, each one coming out from the different parameters presented above and summarised in Table 17.

Table 17: Design parameters of the HTS bulkheads.

Model	2 stringer plane bulkhead		Model	10 Corrugation corrugated bulkhead
Stiffener spacing, in m	0,790		Lower stool	YES
Cargo strake 1 (lower strake) thickness, in mm	14,0		Cargo strake 1 (lower strake) thickness, in mm	18,5
Cargo strake 2 thickness, in mm	13,5		Cargo strake 2 thickness, in mm	16,5
Cargo strake 3 thickness, in mm	12,0		Cargo strake 3 thickness, in mm	15,0
Cargo strake 4 thickness, in mm	11,0		Cargo strake 4 (upper strake) thickness, in mm	13,0
Cargo strake 5 (upper strake) thickness, in mm	9,5		Upper stool	NO
Ballast strake 1 (lower strake) thickness, in mm	12,5		Ballast strake 1 (lower strake) thickness, in mm	12,5
Ballast strake 2 thickness, in mm	13,0		Ballast strake 2 thickness, in mm	13,0
Ballast strake 3 thickness, in mm	12,5		Ballast strake 3 thickness, in mm	12,5
Ballast strake 4 thickness, in mm	11,0		Ballast strake 4 thickness, in mm	11,0
Ballast strake 5 thickness, in mm	9,5		Ballast strake 5 thickness, in mm	9,5
Ballast strake 6 (upper strake) thickness, in mm	8,0		Ballast strake 6 (upper strake) thickness, in mm	8,0

The steel volumes provide the possibility to determine the weight variations. The results are presented in Table 15.

Table 18: HTS bulkhead weight results.

Models	2 stringer plane bulkhead		Models	10 corrugation corrugated bulkhead
Stiffener spacing, in m	0,790		Lower stool volume, in m3	8,5
Cargo strake volume, in m3	8,4		Cargo strake volume, in m3	12,7
Cargo stiffener volume, in m3	7,8		Upper stool volume, in m3	0,0
Cargo stringer volume, in m3	6,3		Total cargo volume, in m3	21,2
Total cargo volume, in m3	22,5		Ballast strake volume, in m3	2,4
Ballast strake volume, in m3	2,4		Ballast stiffener volume, in m3	0,9
Ballast stiffener volume, in m3	0,9		Ballast stringer volume(1), in m3	-
Ballast stringer volume (1),in m3	-		Total ballast volume, in m3	3,4
Total ballast volume, in m3	3,4		Total bulkhead volume, in m3	24,6
Total bulkhead volume, in m3	25,9			
Total bulkhead weight, in t	202,0		Total bulkhead weight, in t	191,9
(1) Calculations for the 2 stringers are already included in the midship section ones as those latter are 2 stringer ballast midship section models.				

2.3 Influence of parameters

In order to compare the considered design solutions, the following results are evaluated:

- steel weight,
- length of ordinary stiffener welds (double fillet welding is considered),
- length of ordinary stiffener free edges (no free edge for bulbs and laminated angles, 2 free edges for flat bars, 3 free edges for built-up angles and 4 free edges for built-up T profiles),
- coating surfaces, calculated by considering ballast tank surfaces (plating and ordinary stiffeners).

The different analysis results are presented in tables 19, 20 and 21. For each design, the bulkhead results also include the brackets, the stringers and the corresponding watertight web frame fitted in the J-ballast tanks.

Table 19: Weight results for the different designed bulkheads.

Material	Bulkhead type	Design parameter	Total weight, in t
Mild steel	Plane	Ordinary stiffener spacing 0,754m, 2 stringers	244,9
		Ordinary stiffener spacing 0,790m, 2 stringers	241,0
		Ordinary stiffener spacing 0,830m, 2 stringers	237,1
		Ordinary stiffener spacing 0,920m, 2 stringers	241,8
		Ordinary stiffener spacing 0,790m, 3 stringers	240,2
	Corrugated	Ordinary stiffener spacing 0,790m, 10 corrugations	242,6
		Ordinary stiffener spacing 0,790m, 16 corrugations	267,5
HTS	Plane	Ordinary stiffener spacing 0,790m, 2 stringers	202,0
	Corrugated	Ordinary stiffener spacing 0,790m, 10 corrugations	191,9

Table 20: Length of double fillet weld and length of free edge results for the different designed bulkheads.

		Mild steel Bulkhead							**HTS Bulkhead**	
		Plane Bulkheads					Corrugated Bulkheads		Plane Bulkhead	Corrugated Bulkhead
		2 Stringers				3 Stringers	10 Corrugations	16 Corrugations	2 Stringers	10 Corrugations
Cargo	Secondary stiffener spacing, in m	0,754	0,790	0,830	0,920	0,790	—	—	0,790	—
	Number of secondary stiffeners	46 angles	44 angles	42 angles	38 angles	44 angles	72T+28 bulbs (in the lower stool)	72T+28 bulbs (in the lower stool)	44 angles	72T+28 bulbs (in the lower stool)
	Double fillet length, in m	960	922	883	806	958	408	408	922	408
	Length of free edges, in m	2661	2546	2430	2198	2546	1357	1357	2546	1357
Ballast	Number of secondary stiffeners	98	94	90	80	92	94	94	94	94
	Double fillet length, in m	254	244	233	207	238	244	244	244	244
	Length of free edges, in m	762	733	698	622	714	733	733	733	733
Bulkhead	Number of secondary stiffeners	144	138	132	118	136	72T+28 bulbs (in the lower stool) +94 angles	72T+28 bulbs (in the lower stool) +94 angles	138	72T+28 bulbs (in the lower stool) +94 angles
	Double fillet length, in m	1214	1166	1116	1013	1196	652	652	1166	652
	Length of free edges, in m	3424	3278	3127	2820	3260	2089	2089	3279	2090

Table 21: Coating surface results for the different designed bulkheads.

		Mild steel							HTS	
		2 stringers				3 stringers	Corrugated	Corrugated	2 stringers	Corrugated
		Secondary stiffener spacing 0.754m	Secondary stiffener spacing 0.790m	Secondary stiffener spacing 0.830m	Secondary stiffener spacing 0.920m	Secondary stiffener spacing 0.790m	10 corrugations	16 corrugations	Secondary stiffener spacing 0.790m	10 corrugations
Cargo	Strake surface, in m²	1397	1397	1397	1397	1397	1936	2291	1397	1936
	Stiffener surface, in m²	1213	1156	1139	1069	875	0,0	0,0	1026	0,0
	Stringer surface, in m²	802	802	802	802	1196	0,0	0,0	802	0,0
	Total cargo surface, in m²	3412	3355	3338	3268	3468	1936	2291	3225	1936
Ballast	Strake surface, in m²	415	415	415	415	415	415	415	415	415
	Stiffener surface, in m²	172	167	160	143	162	167	167	165	165
	Stringer surface (1), in m²	-	-	-	-	124	-	-	-	-
	Total ballast surface, in m²	587	582	575	558	701	582	582	580	580
Bulkhead total surface, in m²		3999	3937	3913	3826	4169	2518	2873	3805	2516

(1) Calculations for the 2 stringers are already included in the midship section ones when those latter are 2 stringer ballast midship section models. For the case of a 3 stringer plane bulkhead, an additional coating surface needs to be considered.

3. Primary supporting member arrangement

3.1 Structural analysis

The scantlings of the primary supporting members are checked through three dimensional finite element analysis. The finite element analysis are performed according to the calculation procedure presented in 3.1.1, as summed up below:

– analysis of a three cargo tank "coarse mesh" model,

– subsequent "fine mesh" analysis of the following localised structural areas:

– the most stressed transverse web frame ring among those considered in the model,

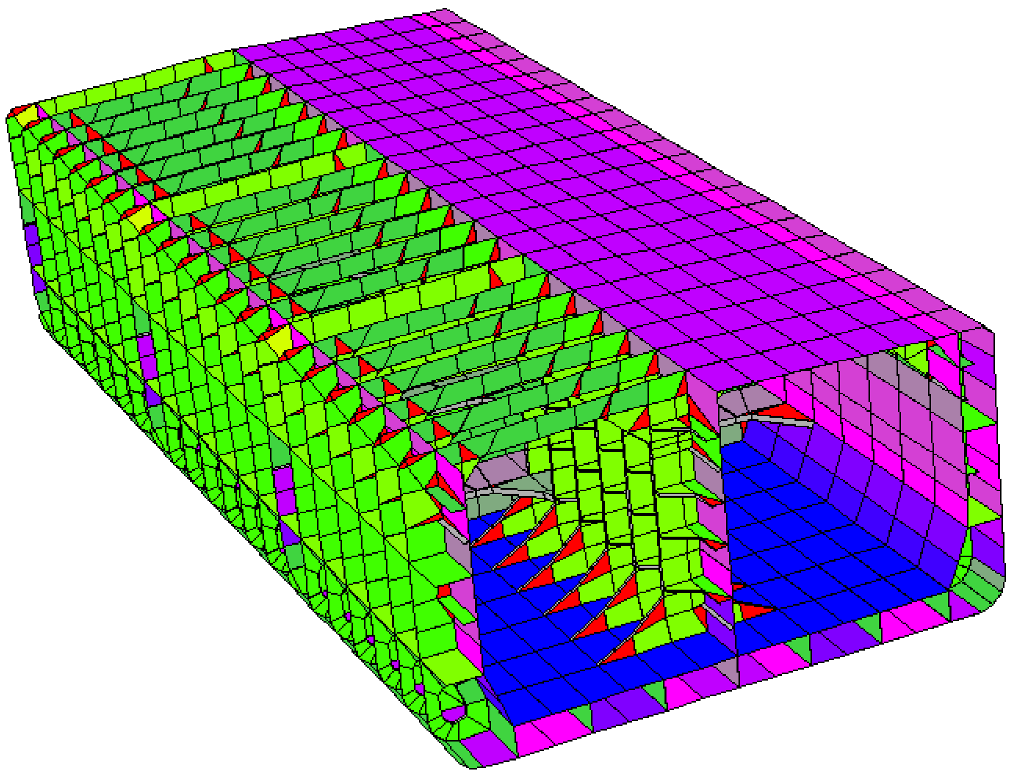
– the most stressed transverse bulkhead stringer.

3.2 Three cargo tank "coarse mesh" model

3.2.1 Structural model

The three dimensional three cargo tank "coarse mesh" model used for the finite element analysis is presented in Figure 1.

Fig. 1: Three cargo tank "coarse mesh" model (starboard deck plating and starboard side shell plating are removed for illustration purposes).



3.2.2 Combination between ship's loading conditions and load cases

The combinations between each one of the considered ship's loading conditions and load cases "a", "b", "c" and "d", which are needed for calculating the still water and wave induced loads acting on the hull structures (also see 3.1.1.), are presented in Tab 22. In that Table, columns marked with M or Q refer to associations where either hull girder bending moment M or shear Q are correctly reproduced in the model area under investigation for the relevant loading condition.

Table 22: Combinations between loading conditions and load cases considered in the structural analysis.

Loading condition	Load case							
	"a" crest		"a" trough		"b"		"c"	"d"
	M	Q	M	Q	M	Q		
Homogeneous			✔		✔			✔
Non homogeneous	✔		✔		✔		✔	
Light ballast	✔						✔	
Partial loading 0.5D			✔		✔			✔
Partial loading 0.4D			✔		✔			✔

3.2.3 Analysis results

The results of the finite element "coarse mesh" analysis are presented in Figures 2 to 4 in terms of maximum Von Mises stresses, calculated for the most severe combination between loading conditions and load cases among those considered.

Fig. 2: Maximum Von Mises stresses' results of the "coarse mesh" three cargo tank finite element analysis on the outer shell and on the deck plating.

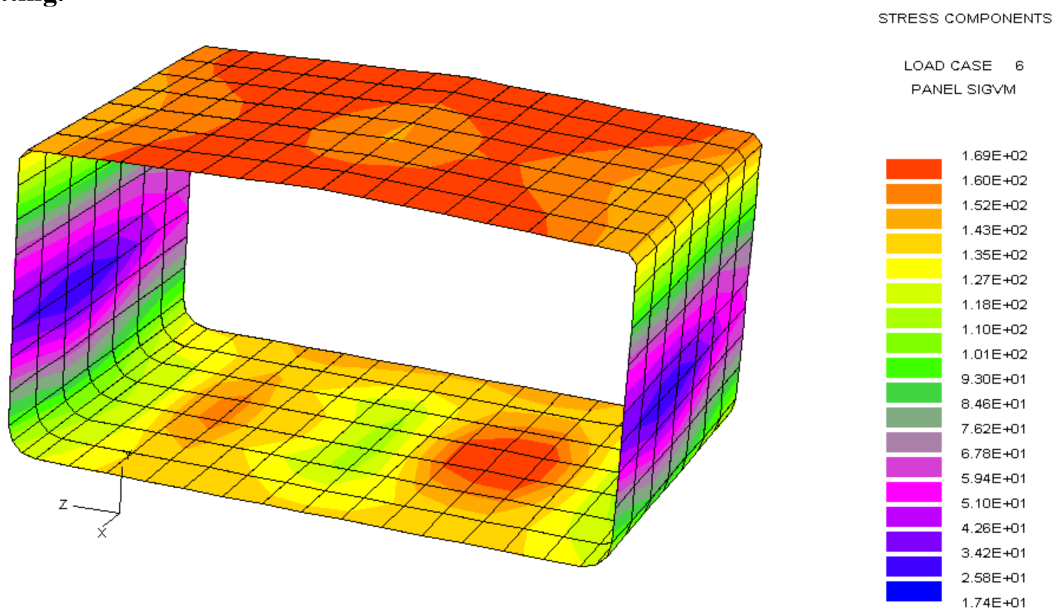


Fig. 3: Maximum Von Mises stresses' results of the "coarse mesh" three cargo tank finite element analysis on the primary supporting members.

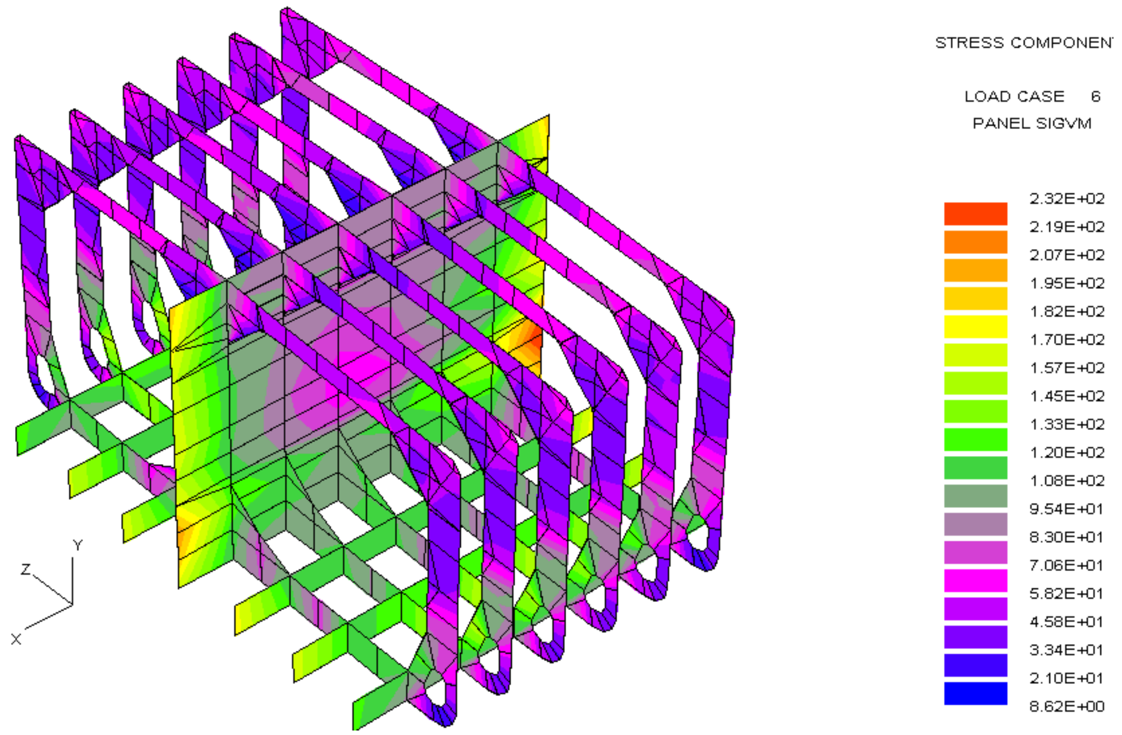
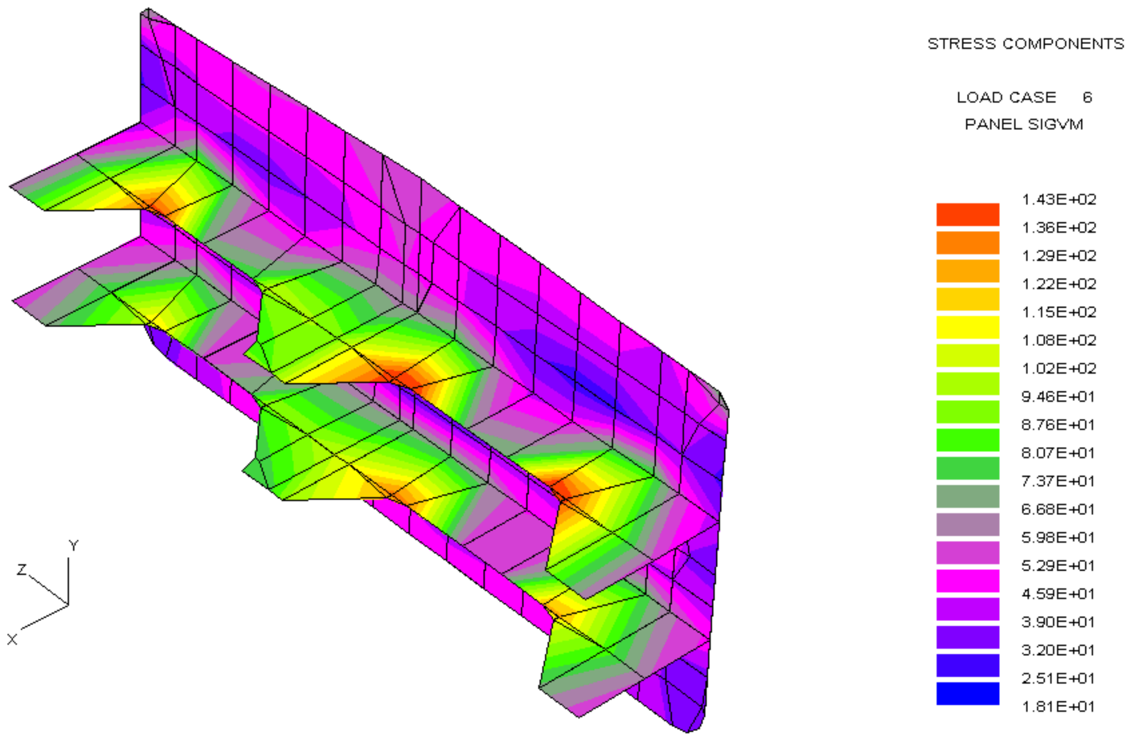


Fig. 4: Maximum Von Mises stresses' results of the "coarse mesh" three cargo tank finite element analysis on the transverse bulkhead.



3.3 "Fine mesh" analysis

3.3.1 Analysis

The hull parts resulting from the three cargo tank "coarse mesh" model finite element analysis to be the ones subjected to the highest stress level and the hull parts deemed critical for the ship's tank structure arrangement are further analysed through more finely meshed three dimensional models.

In details, "fine mesh" finite element analysis are performed on the following hull parts:

- the most stressed transverse web frame ring among those considered in the model (see Figure 5),

- the most stressed transverse bulkhead stringer (see Figure 6).

Fig. 5: "Fine mesh" finite element model of the most stressed transverse web frame ring.

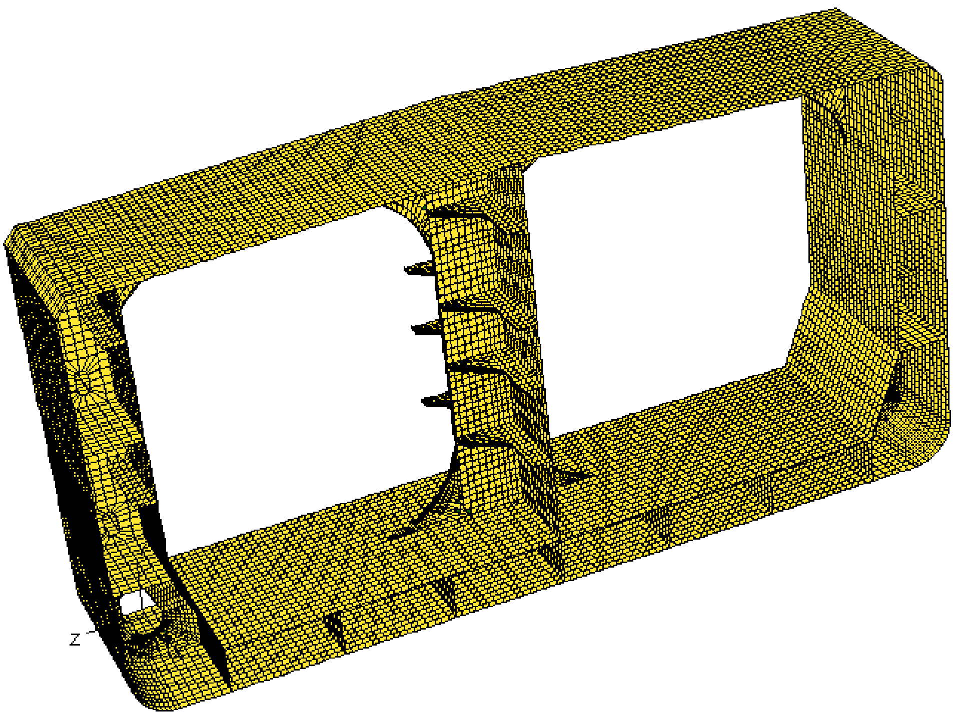
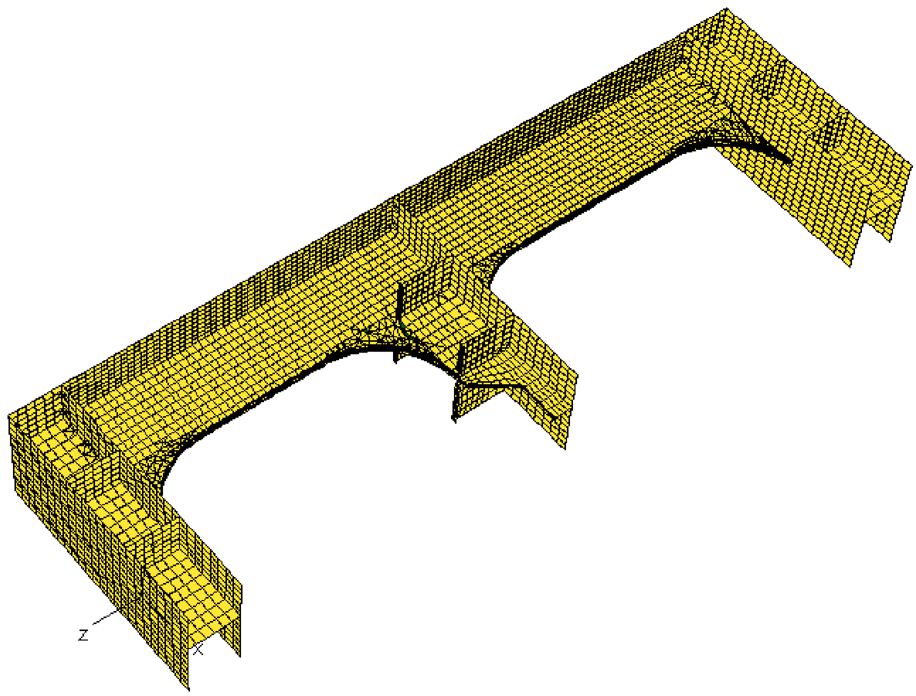


Fig. 6: "Fine mesh" finite element model of the upper transverse bulkhead stringer.



3.3.2 Analysis results

The results of the "fine mesh" finite element analysis are presented in the Figures 7 and 8, in terms of maximum Von Mises stresses, calculated for the most severe combination between loading conditions and load cases among those considered.

Fig. 7: Maximum Von Mises stresses' results of the "fine mesh" finite element analysis for the transverse web frame ring.

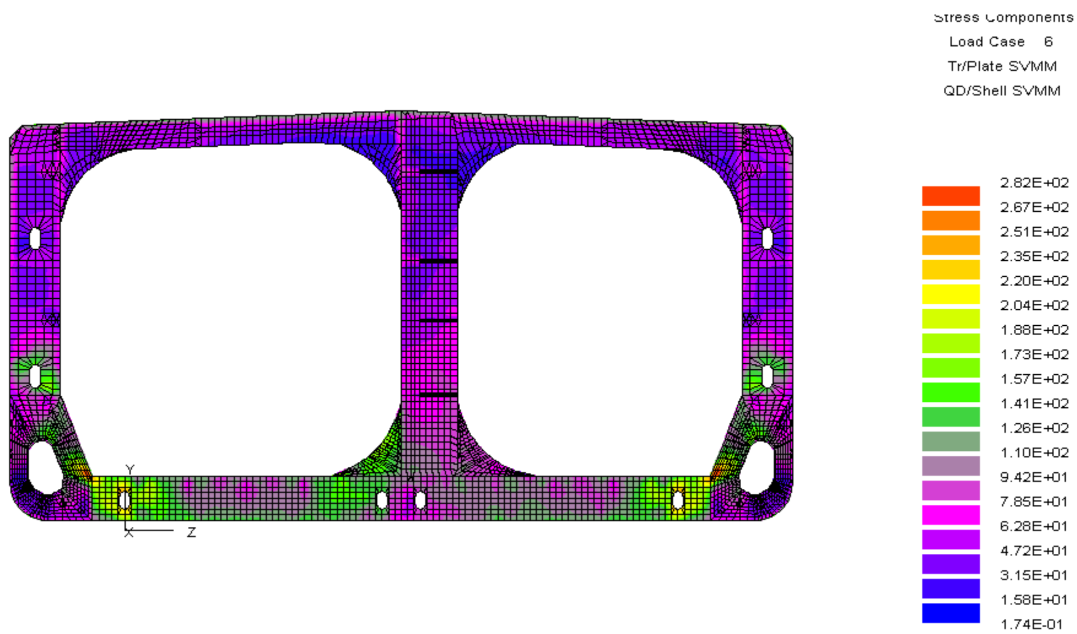
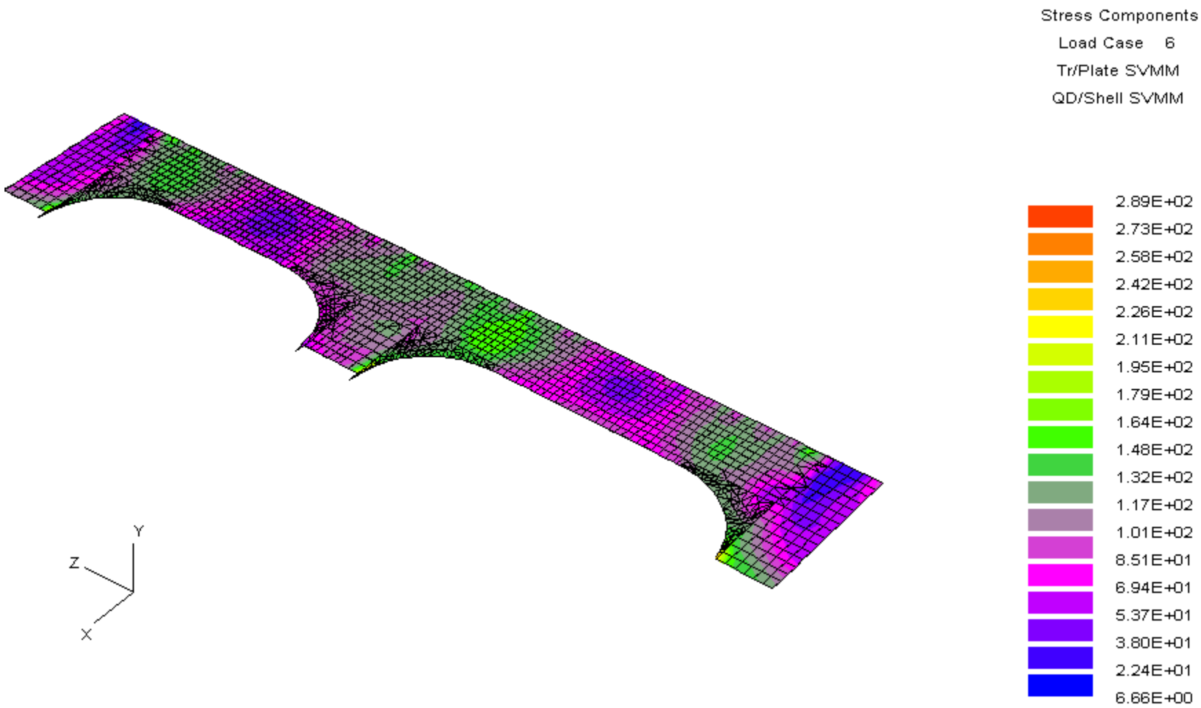


Fig. 8: Maximum Von Mises stresses' results of the "fine mesh" finite element analysis for the upper transverse bulkhead stringer.



Appendix 3
Structural arrangement of a VLCC

1. Midship section arrangement

1.1 30% HTS section

In order to investigate the possible 30% HTS design options and their effects in terms of structural strength and weight, several design criteria are considered:

- ***strength check criteria - 2 cases:***
  - all global and local strength check criteria results are within the Rule allowable limits,
  - the previous case to which is added the condition that the ultimate strength work ratios (i.e. the ratios between the applied bending moments in sagging or hogging conditions and the corresponding ultimate bending moment capacity of the section, calculated according to the Rule criteria) do not exceed approximately 85%,
- ***number of longitudinal ordinary stiffeners - 2 stiffener spacings:***
  - bottom and deck stiffener spacing = 0,910 m, side and inner side stiffener spacing = 0,920 m,
  - bottom and deck stiffener spacing = 1,046 m, side and inner side stiffener spacing = 1,058 m,
- ***span of longitudinal ordinary stiffeners – 2 cases:***
  - ordinary stiffener span = 5,120 m,
  - ordinary stiffener span = 5,688 m.This span value is relevant to a solution where the number of transverse web frames is reduced by one within each cargo tank, with respect to the previous solution.

Various designs of the 30% midship section are analysed, each one coming out from the combination of the different parameters presented above and summarised in Table 1, considering a HTS with yield stress of 315 MPa.

Table 1: 30% HTS midship section – Design solutions.

Midship section area	Parameter	Initial model	Initial model –1 web frame	Increased spacing model
		Bottom stiffener spacing 0,910 m	Bottom stiffener spacing 0,910 m	Bottom stiffener spacing 1,046 m
Deck	Thickness, in mm	20,0	20,0	21,0
	Spacing, in m	0,910	0,910	1,046
Inner bottom	Thickness, in mm	24,0	24,0	26,5
	Spacing, in m	0,910	0,910	1,046
Bottom	Thickness, in mm	18,0	18,0	20,5
	Spacing, in m	0,910	0,910	1,046

The ultimate strength check results are presented in Table 2 for all the considered design solutions, in terms of ultimate strength work ratios.

Table 2: 30% HTS midship section – Ultimate strength work ratios.

Ship's condition	Initial model	Initial model –1 web frame	Increased spacing model
	Bottom stiffener spacing 0,910 m	Bottom stiffener spacing 0,910 m	Bottom stiffener spacing 1,046 m
Sagging	85%	83%	86%
Hogging	73%	70%	72%

Furthermore, the steel areas provide the possibility to determine the weight variations. The results are presented in Table 3.

Table 3: 30% HTS midship section – Steel weight.

Design parts	Initial model	Initial model –1 web frame	Increased spacing model
	Bottom stiffener spacing 0,910 m	Bottom stiffener spacing 0,910 m	Bottom stiffener spacing 1,046 m
Strakes' weight, in t/m of ship's length	54,9	54,8	59,8
Secondary stiffeners' weight, in t/m of ship's length	29,9	32,9	27,0
Web frame's weight, in t/m of ship's length	23,2	21,9	23,0
Total weight, in t/m of ship's length	108,0	109,6	109,8
Steel weight variations (with respect to 30% HTS initial model)	0,0%	1,5%	1,7%

1.2 50% HTS section

In order to investigate the possible 50% HTS design options and their effects in terms of structural strength and weight, the number of longitudinal ordinary stiffeners (2 stiffener spacings) is considered:

- bottom and deck stiffener spacing = 0,910 m, side and inner side stiffener spacing = 0,920 m,

- bottom and deck stiffener spacing = 1,046 m, side and inner side stiffener spacing = 1,058 m.

Various designs of the 50% midship section are analysed, each one coming out from the combination of the different parameters presented above and summarised in Table 4, considering a HTS with yield stress of 315 MPa.

Table 4: 50% HTS midship section – Design solutions.

Midship section area	**Parameter**	**Initial model**	**Increased spacing model**
		Bottom stiffener spacing 0,910 m	Bottom stiffener spacing 1,046 m
Deck	Thickness, in mm	20,0	21,0
	Spacing, in m	0,910	1,046
Inner bottom	Thickness, in mm	20,0	23,0
	Spacing, in m	0,910	1,046
Bottom	Thickness, in mm	18,5	20,5
	Spacing, in m	0,910	1,046

The ultimate strength check results are presented in Table 5 for all the considered design solutions, in terms of ultimate strength work ratios.

Table 5: 50% HTS midship section – Ultimate strength work ratios.

Ship's condition	**Initial model**	**Increased spacing model**
	Bottom stiffener spacing 0,910 m	Bottom stiffener spacing 1,046 m
Sagging	85%	85%
Hogging	73%	72%

Furthermore, the steel areas provide the possibility to determine the weight variations. The results are presented in Table 6.

Table 6: 50% HTS midship section – Steel weight.

Design parts	Initial model	Increased spacing model
	Bottom stiffener spacing 0,910 m	Bottom stiffener spacing 1,046 m
Strakes' weight, in t/ m of ship's length	52,7	58,2
Secondary stiffeners' weight, in t/ m of ship's length	28,1	25,1
Web frame's weight, in t/m of ship's length	23,2	23,0
Total weight, in t/ m of ship's length	104,0	106,3
Steel weight variations (with respect to 50% HTS initial model)	0,0%	2,2%

1.3 Influence of parameters

In order to compare the considered design solutions, the following results are evaluated:

- steel weight,
- length of ordinary stiffener welds (double fillet welding is considered),
- length of ordinary stiffener free edges (no free edge for bulbs and laminated angles, 2 free edges for flat bars, 3 free edges for built-up angles and 4 free edges for built-up T profiles),
- coating surfaces, calculated by considering:
  - midship section ballast tank surfaces (all plating and ordinary stiffeners),
  - transverse web frame ballast tank surfaces (all plating and ordinary stiffeners),
  - cargo tank surfaces (plating of horizontal inner bottom to which is added plating and ordinary stiffeners of deck).

The different analysis and results are presented in Tables 7 and 8.

Table 7: Midship section - Design solutions – Parameter comparison.

Material	**Midship section design solution**	**Section weight, in t/m of ship's length**	**Transverse web frames weight, in t/m of ship's length**	**Total weight, in t/m of ship's length**	**N. of longitudinal ordinary stiffeners**	**N. of transverse web frame stiffeners**	**Length of stiffener double fillet weld, in m/m of ship's length**	**Length of stiffener free edges, in m/m of ship's length**	**Coating surface, in m^2/m of ship's length**
30 % HTS midship section	Initial model - s=0,910 m	84,8	23,2	108,0	362	118	474	1896	1017,2
	Initial model –1 web frame - s=0,910 m	87,7	21,9	109,6	362	118	463	1852	1018,0
	Increased spacing model - s=1,046 m	86,8	23,0	109,8	310	102	412	1648	946,4
50 % HTS midship section	Initial model - s=0,910 m	80,8	23,2	104,0	362	118	474	1896	995,3
	Increased spacing model - s=1,046 m	83,3	23,0	106,3	310	102	412	1648	937,9

Table 8: Midship section - Design solutions – Detail of coating surface calculation.

Material	**Midship section design solution**	**Ballast tank, in m^2/m of ship's length**				**Cargo tanks, in m^2/m of ship's length**			
		Strakes	Ordinary stiffeners	Web frames	Total	Strakes	Ordinary stiffeners	Web frames	Total
30% HTS midship section	Initial model - s=0,910 m	303,1	357,3	181,4	841,8	92,5	82,8	0,0	175,3
	Initial model –1 web frame - s=0,910 m	303,1	376,3	163,3	842,7	92,5	82,8	0,0	175,3
	Increased spacing model - s=1,046 m	303,1	303,4	177,2	783,7	92,5	70,3	0,0	162,8
50% HTS midship section	Initial model - s=0,910 m	303,1	335,5	181,4	820,0	92,5	82,8	0,0	175,3
	Increased spacing model - s=1,046 m	303,1	294,8	177,2	775,1	92,5	70,3	0,0	162,8

2. Bulkhead arrangement

2.1 Mild steel bulkhead

In order to investigate the possible mild steel bulkhead design options and their effects in terms of structural strength and weight, several design criteria are considered:

- ***number of stringers – 2 cases:***
  - 3 stringers,
  - 4 stringers,
- ***number of ordinary stiffeners – 2 stiffener spacings:***
  - stiffener spacing = 0,910 m,
  - stiffener spacing = 1,046 m.

Various design of the mild steel bulkhead are analysed, each one coming out from the combination of the different parameters presented above and summarised in Table 9, considering a mild steel with yield stress of 235 MPa.

Table 9: Mild steel plane bulkhead – Design solutions.

Stiffener spacing, in m	**0,910**	**1,046**	**0,910**
Stiffener type	Angle	Angle	Angle
Number of stringers	3 stringers	3 stringers	4 stringers
Strake 1 (lower strake) thickness, in mm	19,5	24,5	19,5
Strake 2 thickness, in mm	19,0	24,0	19,0
Strake 3 thickness, in mm	18,0	24,0	18,0
Strake 4 thickness, in mm	16,5	22,0	16,5
Strake 5 thickness, in mm	15,5	20,5	15,5
Strake 6 thickness, in mm	14,0	18,5	14,0
Strake 7 (upper strake) thickness, in mm	12,5	16,5	12,5

The comparison between the steel weights, calculated for the considered designs of the bulkhead, is reported in Table 10.

For each design, the bulkhead steel weight includes also the weight of brackets and of bulkhead stringers and of the corresponding watertight web frame fitted in the J-ballast tanks.

Table 10: Mild steel plane bulkhead – Steel weights.

Stiffener spacing, in m	**0,910**	**1,046**	**0,910**
Stiffener type	T-section	T-section	T-section
Number of stringers	3 stringers	3 stringers	4 stringers
Cargo strake weight, in t	172,5	200,5	172,5
Cargo stiffener weight, in t	143,8	143,8	126,7
Cargo stringer weight, in t	69,8	69,8	82,0
Bracket weight, in t	8,6	7,4	8,6
Ballast tank WT bulkhead weight, in t	59,2	65,4	59,2
Ballast tank WT bulkhead stiffener weight, in t	20,6	19,5	19,2
Ballast tank WT bulkhead stringer weight, in t (1)	-	-	11,3
Total weight, in t	474,5	506,4	479,5
Weight variation	0,0 %	6,7%	1,1 %

(1) Calculations for the 3 stringers are already included in the midship section ones when those latter are 3 stringer ballast midship section models. For the case of a 4 stringer plane bulkhead, an additional weight needs to be considered.

2.2 HTS bulkheads

In order to investigate the possible HTS bulkhead design options and their effects in terms of structural strength and weight, the number of ordinary stiffeners (2 stiffener spacings) is considered:

- stiffener spacing = 0,910 m,
- stiffener spacing = 1,046 m.

Various designs of the HTS bulkhead are analysed, each one coming out from the combination of the different parameters presented above and summarised in Table 11, considering a HTS with yield stress of 315 MPa.

Table 11: HTS plane bulkhead – Design solutions.

Stiffener spacing, in m	**0,910**	**1,046**
Stiffener type	Angle	Angle
Number of stringers	3	3
Strake 1 (lower strake) thickness, in mm	17,5	21,5
Strake 2 thickness, in mm	16,5	21,5
Strake 3 thickness, in mm	16,0	21,0
Strake 4 thickness, in mm	15,0	19,5
Strake 5 thickness, in mm	13,5	18,0
Strake 6 thickness, in mm	12,5	16,5
Strake 7 (upper strake) thickness, in mm	11,5	15,0

The comparison between the steel weights, calculated for the considered designs of the bulkhead, is reported in Table 12.

For each design, the bulkhead steel weight includes also the weight of brackets and of bulkhead stringers and of the corresponding watertight web frame fitted in the J-ballast tanks.

Table 12: HTS plane bulkheads – Steel weights.

Stiffener spacing, in m	**0,910**	**1,046**
Stiffener type	T-section	T-section
Number of stringers	3	3
Cargo strake weight, in t	154,9	176,6
Cargo stiffener weight, in t	128,4	127,2
Cargo stringer weight, in t	58,7	58,7
Bracket weight, in t	8,6	8,6
Ballast tank WT bulkhead weight, in t	53,1	58,2
Ballast tank WT bulkhead stiffener weight, in t	19,2	17,6
Ballast tank WT bulkhead stringer weight, in t	-	-
Total weight, in t	423,0	446,9
Weight variation	0,0 %	5,1 %
(1) Calculations for the 3 stringers are already included in the midship section ones when those latter are 3 stringer ballast midship section models. For the case of a 4 stringer plane bulkhead, an additional weight needs to be considered.		

2.3 Influence of parameters

In order to compare the considered design solutions, the following results are evaluated:

- steel weight,
- length of ordinary stiffener welds (double fillet welding is considered),
- length of ordinary stiffener free edges (no free edge for bulbs and laminated angles, 2 free edges for flat bars, 3 free edges for built-up angles and 4 free edges for built-up T profiles),
- coating surfaces, calculated by considering ballast tank surfaces (plating and ordinary stiffeners).

The different analysis results are presented in Table 13. For each design, the bulkhead results also include brackets, stringers and the corresponding watertight web frame fitted in the J-ballast tanks.

Table 13: Transverse bulkhead - Design solutions – Parameter comparison.

Material	Design solution	Weight, in t	N. of stiffeners	Length of stiffeners double fillet weld, in m	Length of stiffeners free edges, in m	Coating surface of ballast tank, in m^2			
						Strakes	Ordinary stiffeners	Stringers (1)	Total
Mild Steel	3 Stringers – s=0,910 m	470,0	219	2025	7628	781,7	373,3	-	1155,0
	3 stringers – s=1,046 m	535,5	187	1814	6834	781,7	336,8	-	1118,5
	4 stringers – s=0,910 m	475,3	205	2034	7686	781,7	355,4	143,4	1280,5
HTS	3 stringers – s=0,910 m	423,0	219	2025	7628	781,7	361,0	-	1142,7
	3 stringers – s=1,046 m	474,4	187	1814	6834	781,7	302,2	-	1083,9

(1) Calculations for the 3 stringers are already included in the midship section ones when those latter are 3 stringer ballast midship section models. For the case of a 4 stringer plane bulkhead, an additional surface needs to be considered.

3. Primary supporting member arrangement

3.1 Structural analysis

The scantlings of primary supporting members are checked through three dimensional finite element analysis. The finite element analysis is performed according to the calculation procedure presented in Ch 2, 3.1.1, summed up as follows:

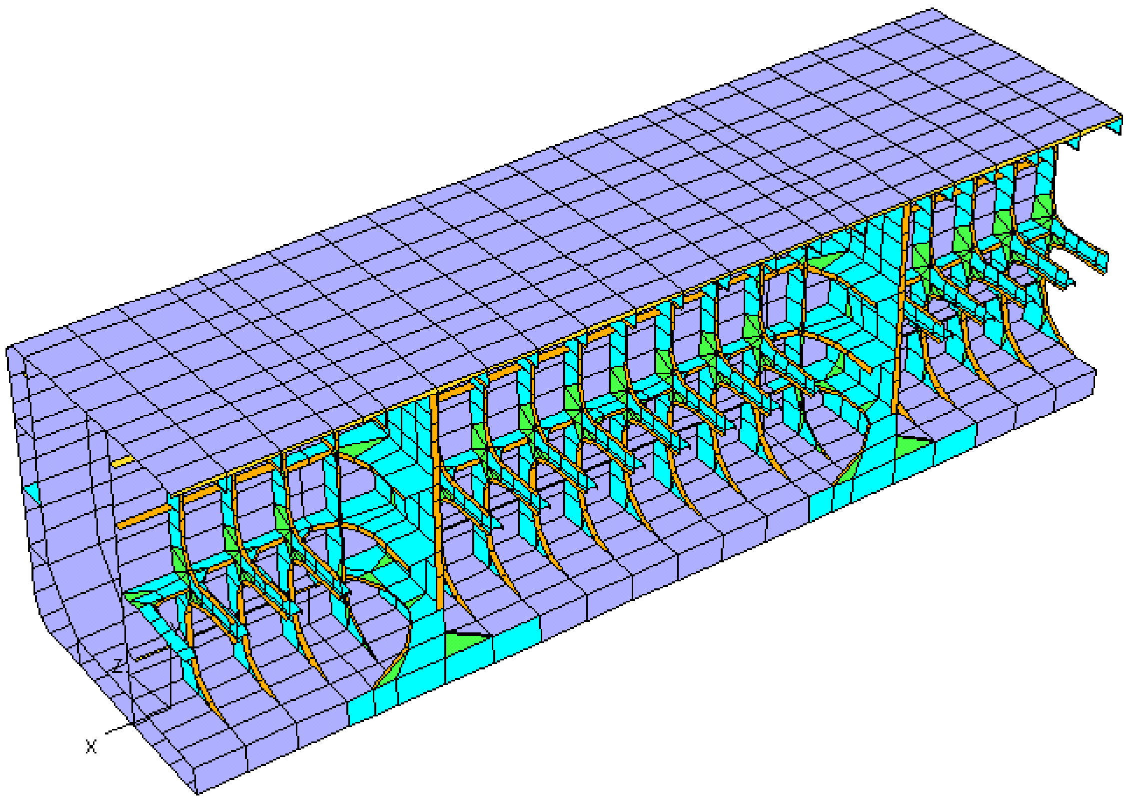
- analysis of a three cargo tank “coarse mesh” model,
- subsequent “fine mesh” analyses of the following localised structural areas:
  - the most stressed transverse web frame ring among those considered in the model,
  - the swash bulkhead, particular attention being paid to the upper part of the swash bulkhead in the wing tank,
  - the watertight bulkhead, particular attention being paid to the upper stringer.

3.2 Three cargo tank "coarse mesh" model

3.2.1 Structural model

The three dimensional three cargo tank "coarse mesh" model used for the finite element analysis is presented in Fig 1.

Figure 1: Three cargo tank "coarse mesh" model.



3.2.2 Combination between ship's loading conditions and load cases

The combinations between each one of the considered ship's loading conditions and load cases "a", "b", "c" and "d", which are needed for calculating the still water and wave induced loads acting on the hull structures (see also 3.1), are presented in Tab. 14. In that table, columns marked with M or Q refer to associations where either hull girder bending moment M or shear Q are correctly reproduced in the model area under investigation for the relevant loading condition.

Table 14: Combination between loading conditions and load cases considered in the structural analysis.

Loading condition	Load case							
	"a" crest		"a" trough		"b"		"c"	"d"
	M	Q	M	Q	M	Q		
Ballast	✔							✔
Homogeneous			✔		✔			✔
Alternate			✔	✔	✔	✔		
Non-homogeneous cargo	✔	✔			✔			✔
Chess cargo					✔		✔	✔

3.2.3 Analysis results

The results of the "coarse mesh" finite element analysis are presented in Figures 2 to 4 in terms of maximum Von Mises stress, calculated for the most severe combination between loading conditions and load cases among those considered.

Figure 2: Maximum Von Mises stresses' results of the "coarse mesh" three cargo tank finite element analysis on the outer shell and deck plating.

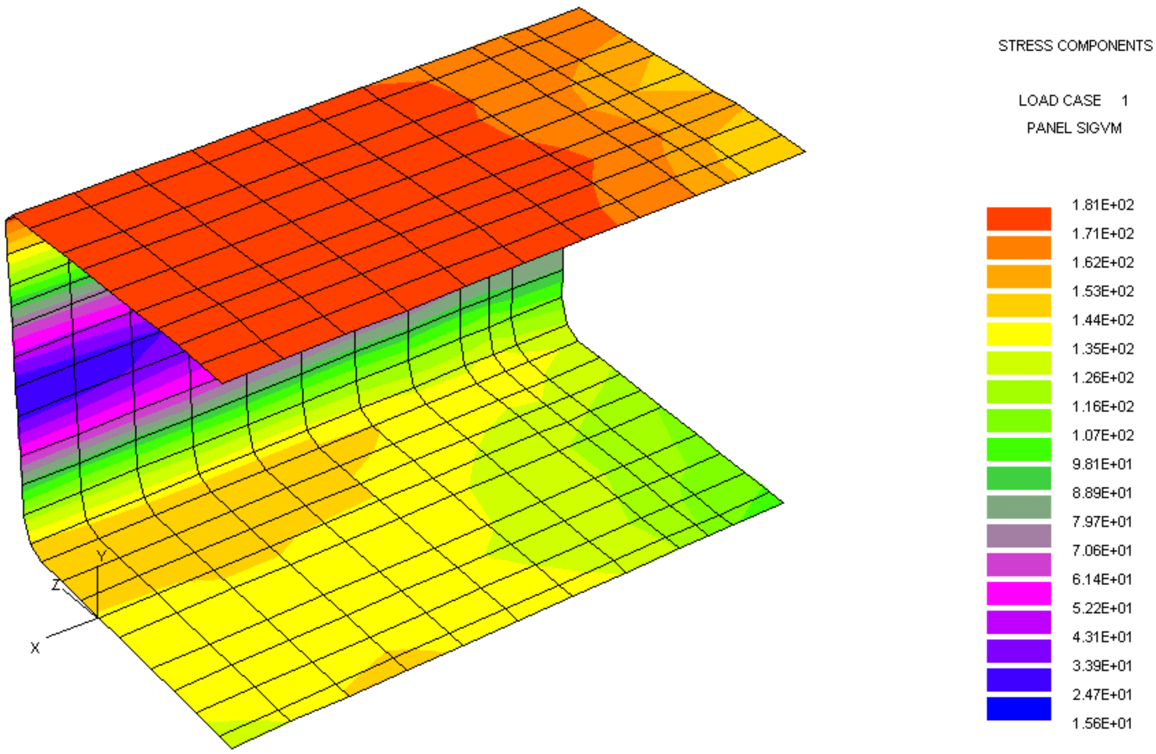


Figure 3: Maximum Von Mises stresses' results of the "coarse mesh" three cargo tank finite element analysis on the primary supporting members.

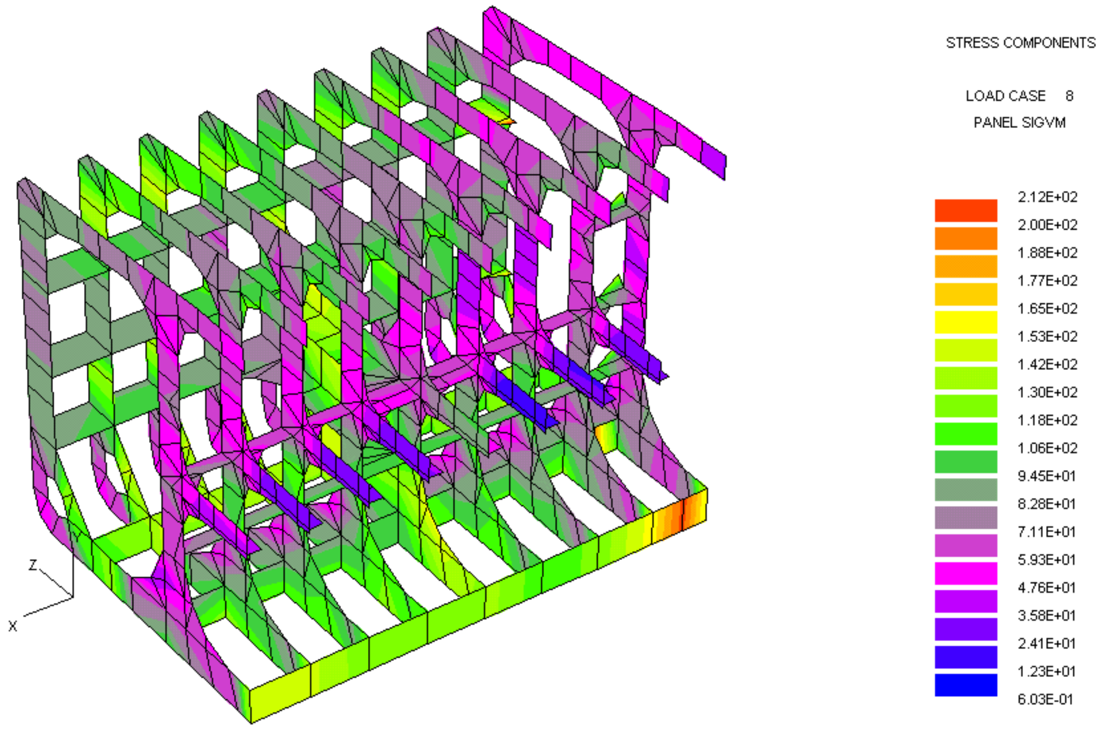
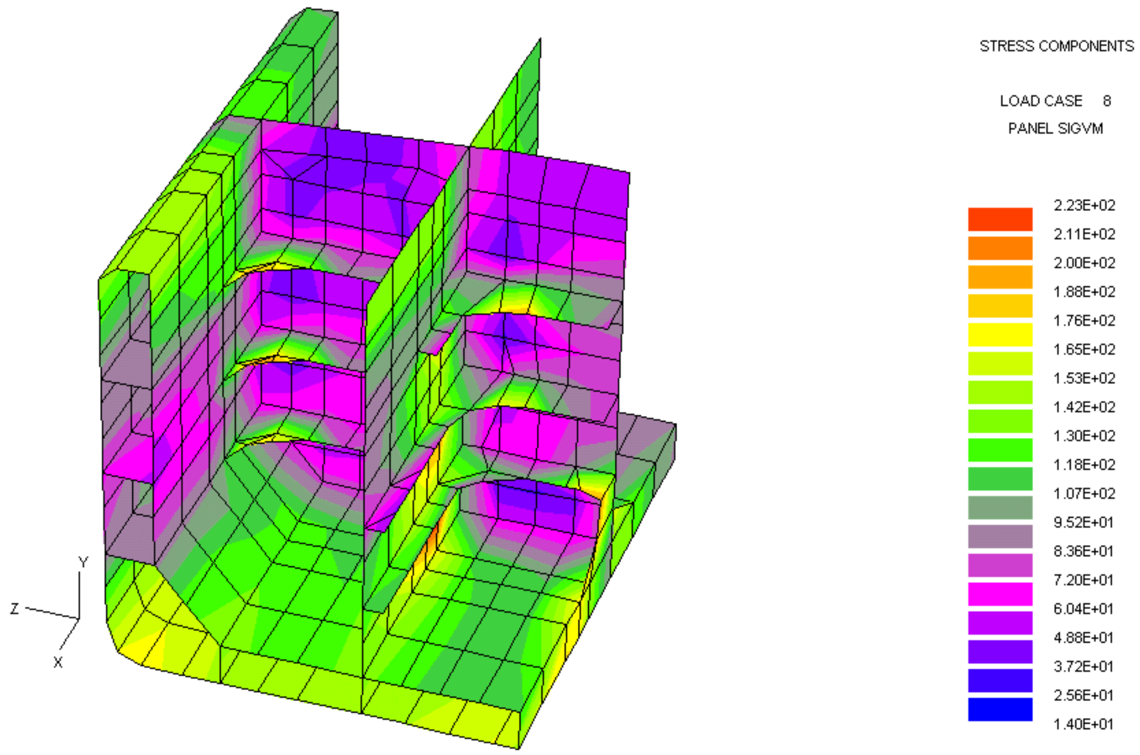


Figure 4: Maximum Von Mises stresses' results of the "coarse mesh" three cargo tank finite element analysis on the transverse and longitudinal bulkheads.



3.3 "Fine mesh" analyses

3.3.1 Analyses

The hull parts resulting from the three cargo tank "coarse mesh" model finite element analysis to be the ones subjected to the highest stress level and the hull parts deemed critical for the ship's tank structure arrangement are further analysed through more finely meshed three dimensional models.

In details, "fine mesh" finite element analyses are performed on the following hull parts:

- the most stressed transverse web frame ring among those considered in the model (see Fig 5),
- the swash bulkhead, particular attention being paid to the upper part of the swash bulkhead in the wing tank (see Fig 6),
- the watertight bulkhead, particular attention being paid to the upper stringer (see Fig 7).

Figure 5: "Fine mesh" finite element model of the most stressed transverse web frame ring.

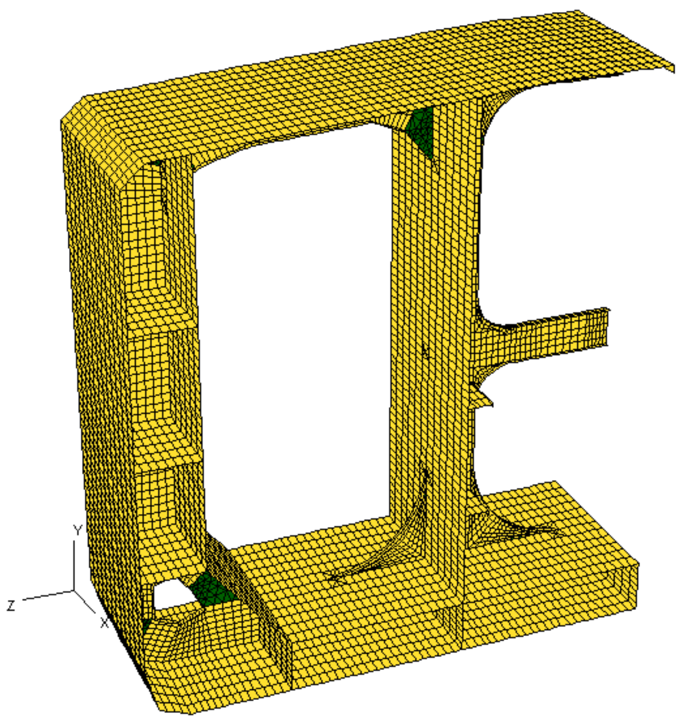


Figure 6: "Fine mesh" finite element model of the swash bulkhead.

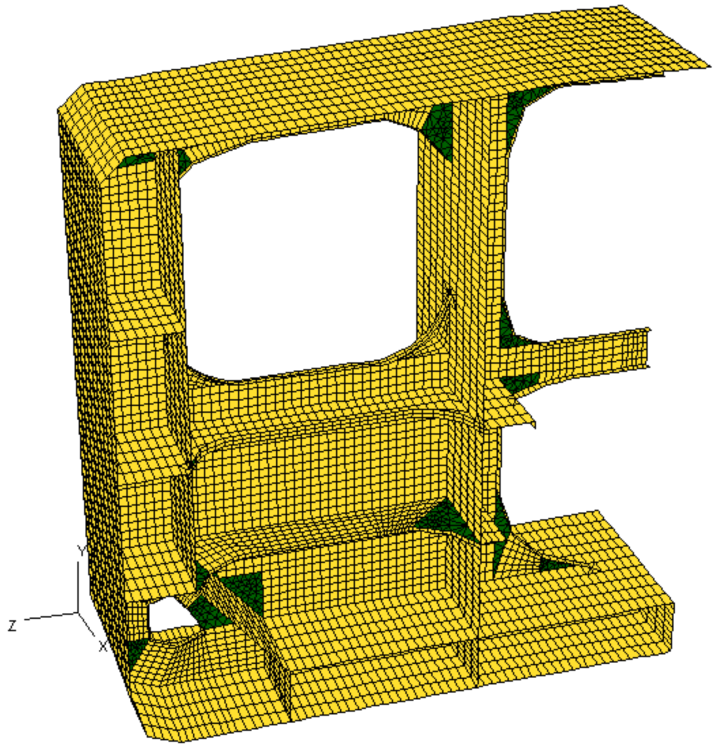
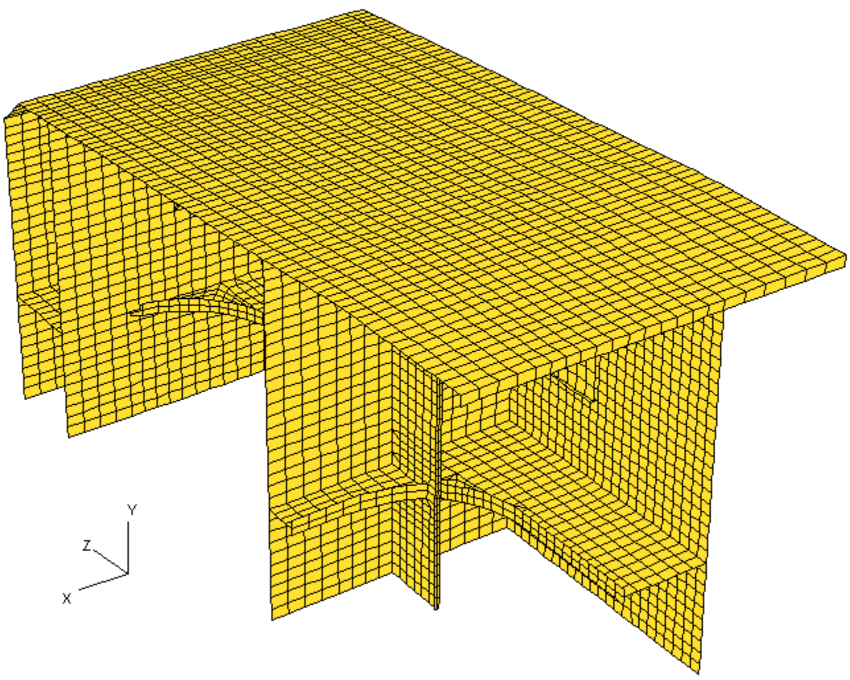


Figure 7: "Fine mesh" finite element model of a stringer detail.



3.3.2 Analysis results

The results of the "fine mesh" finite element analyses are presented in Figures 8 to 10, in terms of maximum Von Mises stresses, calculated for the most severe combination between loading conditions and load cases among those considered.

Figure 8: Maximum Von Mises stresses' results of "fine mesh" finite element analysis for the transverse web frame ring.

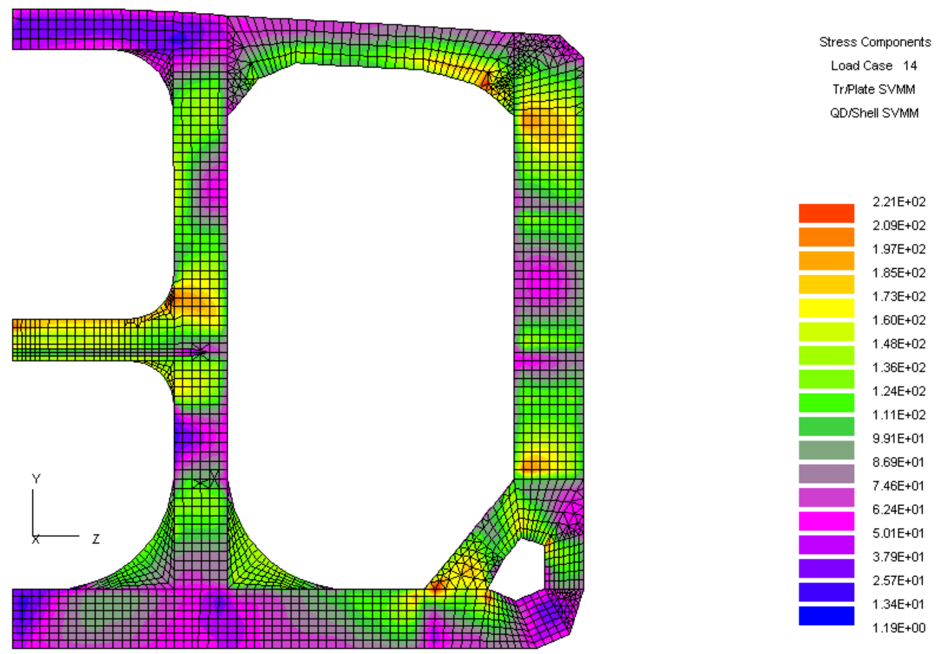


Figure 9: Maximum Von Mises stresses' results of "fine mesh" finite element analysis for the swash bulkhead.

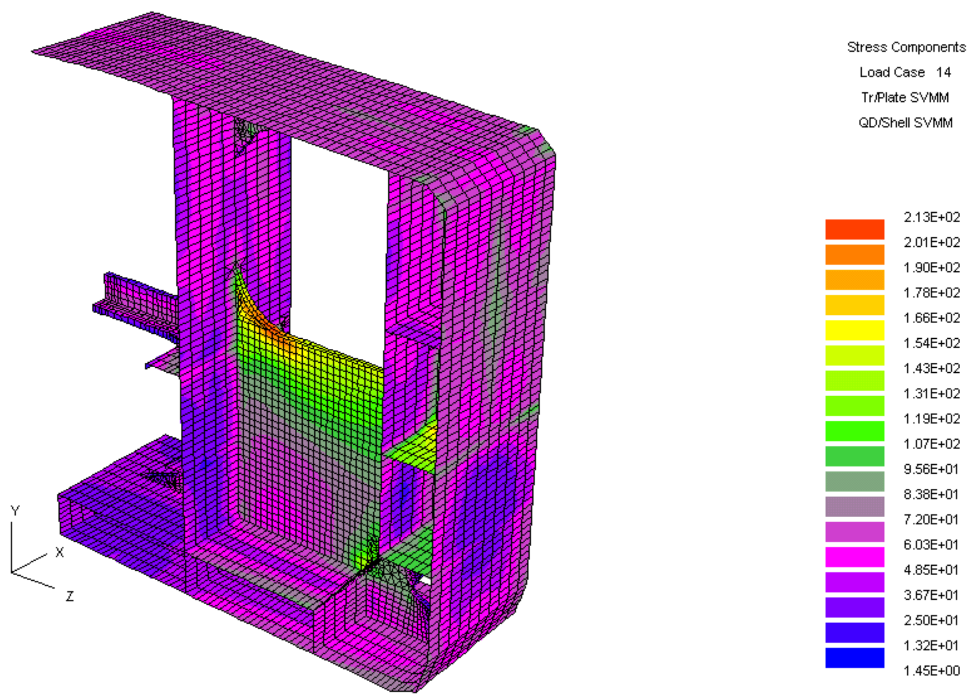
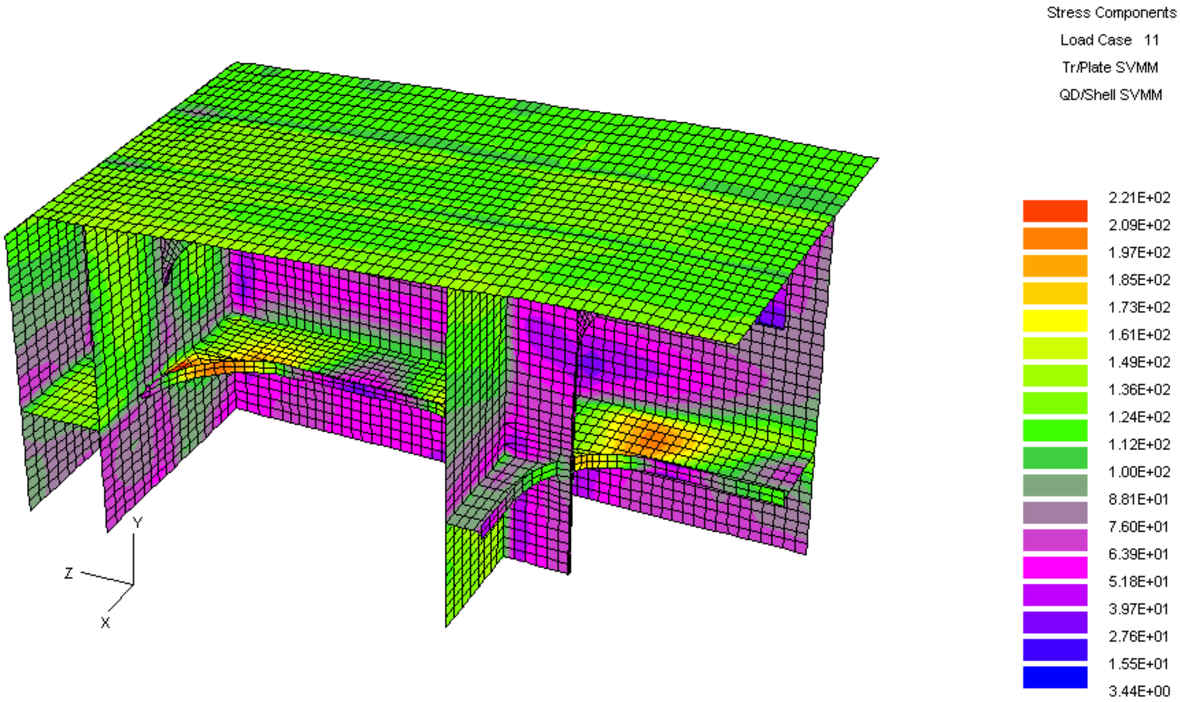


Figure 10: Maximum Von Mises stresses' results of "fine mesh" finite element analysis for the upper stringer of the watertight bulkhead.



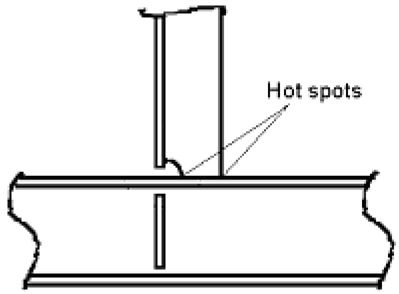
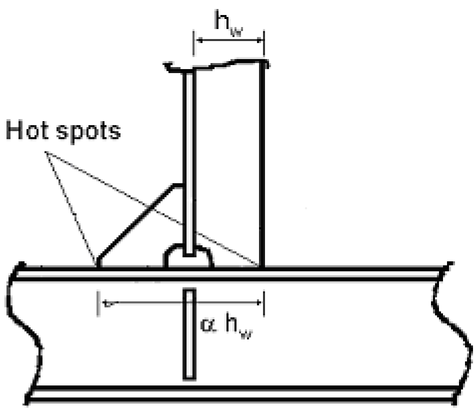
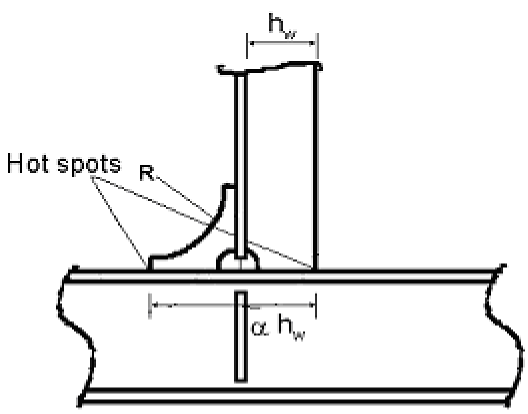
Appendix 4
Library of details for fatigue analysis

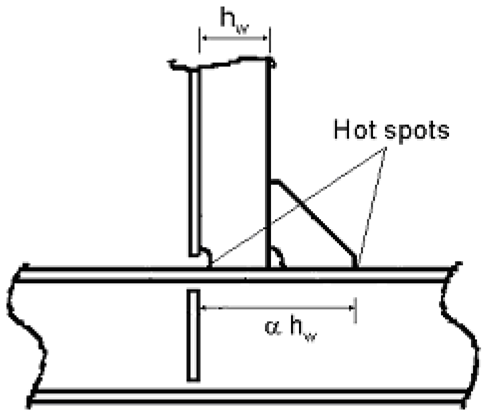
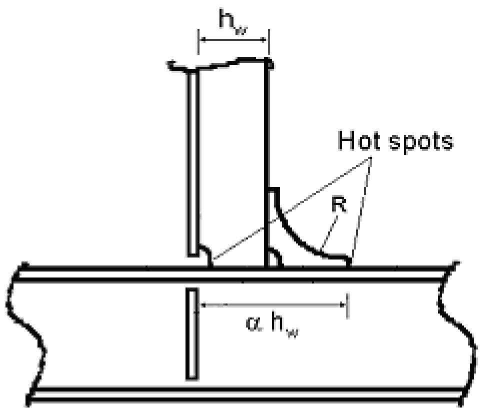
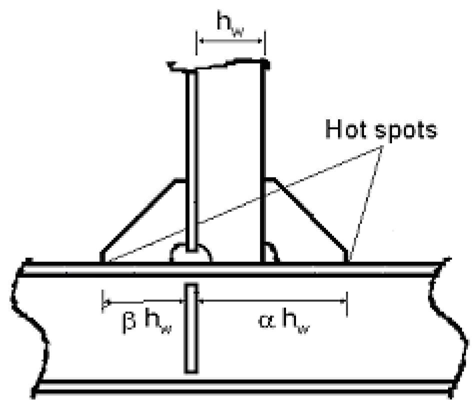
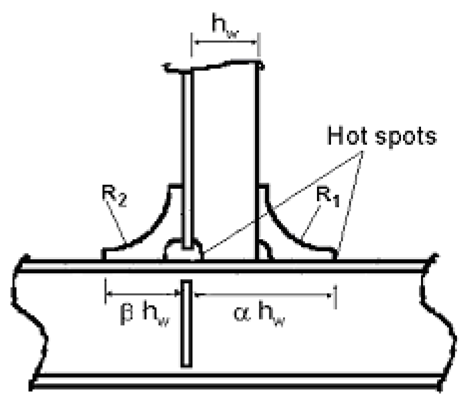
1. Connections of longitudinal ordinary stiffeners with transverse primary members

1.1 Type of details

The types of details used as a library for fatigue analysis are defined in the Table 1.

Table 1: Type of details for fatigue analysis.

Type of detail	Sketch of the detail	Comment
1		
2 & 3		Detail 2 : 2 ≤ α < 2,5 Detail 3 : α ≥ 2,5
4 & 5		Detail 4 : 2 ≤ α < 2,5 Detail 5 : α ≥ 2,5

6 & 7		Detail 6 : 2 ≤ α < 2,5 Detail 7 : α ≥ 2,5
8 & 9		Detail 8 : 2 ≤ α < 2,5 Detail 9 : α ≥ 2,5
10 & 11		Detail 10 : 2 ≤ α < 2,5 and 1 ≤ β < 1,5 Detail 11 : α ≥ 2,5 and β ≥ 1,5
12 & 13		Detail 12 : 2 ≤ α < 2,5 and 1 ≤ β < 1,5 Detail 13 : α ≥ 2,5 and β ≥ 1,5

Appendix 5
Accessibility - IMO Regulations & Documents

1. SOLAS regulation II-1/3.6 - Access to and within spaces in the cargo area of oil tankers and bulk carriers

1 Application

1.1 Except as provided for in paragraph 1.2, this regulation applies to oil tankers of 500 gross tonnage and over and bulk carriers, as defined in regulation IX/1, of 20,000 gross tonnage and over, constructed on or after 1 January 2005.

1.2 Oil tankers of 500 gross tonnage and over constructed on or after 1 October 1994 but before 1 January 2005 shall comply with the provisions of regulation II-1/12-2 adopted by resolution MSC.27(61).

2 Means of access to cargo and other spaces

2.1 Each space within the cargo area shall be provided with a permanent means of access to enable, throughout the life of a ship, overall and close-up inspections and thickness measurements of the ship's structures to be carried out by the Administration, the Company, as defined in regulation IX/1, and the ship's personnel and others as necessary. Such means of access shall comply with the requirements of paragraph 5 and with the Technical provisions for means of access for inspections, adopted by the Maritime Safety Committee by resolution MSC.133(76), as may be amended by the Organization, provided that such amendments are adopted, brought into force and take effect in accordance with the provisions of article VIII of the present Convention concerning the amendment procedures applicable to the Annex other than chapter I.

2.2 Where a permanent means of access may be susceptible to damage during normal cargo loading and unloading operations or where it is impracticable to fit permanent means of access, the administration may allow, in lieu thereof, the provision of movable or portable means of access, as specified in the Technical provisions, provided that the means of attaching, rigging, suspending or supporting the portable means of access forms a permanent part of the ship's structure. All portable equipment shall be capable of being readily erected or deployed by ship's personnel.

2.3 The construction and materials of all means of access and their attachment to the ship's structure shall be to the satisfaction of the Administration. The means of access shall be subject to survey prior to, or in conjunction with, its use in carrying out surveys in accordance with regulation I/10.

3 **Safe access to cargo holds, cargo tanks, ballast tanks and other spaces**

3.1 Safe access* to cargo holds, cofferdams, ballast tanks, cargo tanks and other spaces in the cargo area shall be direct from the open deck and such as to ensure their complete inspection. Safe access* to double bottom spaces may be from a pump-room, deep cofferdam, pipe tunnel, cargo hold, double hull space or similar compartment not intended for the carriage of oil or hazardous cargoes.

3.2 Tanks, and subdivisions of tanks, having a length of 35 m or more shall be fitted with at least two access hatchways and ladders, as far apart as practicable. Tanks less than 35 m in length shall be served by at least one access hatchway and ladder. When a tank is subdivided by one or more swash bulkheads or similar obstructions which do not allow ready means of access to the other parts of the tank, at least two hatchways and ladders shall be fitted.

3.3 Each cargo hold shall be provided with at least two means of access as far apart as practicable. In general, these accesses should be arranged diagonally, for example one access near the forward bulkhead on the port side, the other one near the aft bulkhead on the starboard side.

4 **Ship structure access manual**

4.1 A ship's means of access to carry out overall and close-up inspections and thickness measurements shall be described in a Ship structure access manual approved by the Administration, an updated copy of which shall be kept on board. The Ship structure access manual shall include the following for each space in the cargo area:

.1 plans showing the means of access to the space, with appropriate technical specifications and dimensions;

.2 plans showing the means of access within each space to enable an overall inspection to be carried out, with appropriate technical specifications and dimensions. The plans shall indicate from where each area in the space can be inspected;

.3 plans showing the means of access within the space to enable close-up inspections to be carried out, with appropriate technical specifications and dimensions. The plans shall indicate the positions of critical structural areas, whether the means of access is permanent or portable and from where each area can be inspected;

.4 instructions for inspecting and maintaining the structural strength of all means of access and means of attachment, taking into account any corrosive atmosphere that may be within the space;

* Refer to the Recommendations for entering enclosed spaces aboard ships, adopted by the Organization by resolution A.864(20).

.5 instructions for safety guidance when rafting is used for close-up inspections and thickness measurements;

.6 instructions for the rigging and use of any portable means of access in a safe manner;

.7 an inventory of all portable means of access; and

.8 records of periodical inspections and maintenance of the ship.s means of access.

4.2 For the purpose of this regulation .critical structural areas. are locations which have been identified from calculations to require monitoring or from the service history of similar or sister ships to be sensitive to cracking, buckling, deformation or corrosion which would impair the structural integrity of the ship.

5 General technical specifications

5.1 For access through horizontal openings, hatches or manholes, the dimensions shall be sufficient to allow a person wearing a self-contained air-breathing apparatus and protective equipment to ascend or descend any ladder without obstruction and also provide a clear opening to facilitate the hoisting of an injured person from the bottom of the space. The minimum clear opening shall not be less than 600 mm x 600 mm. When access to a cargo hold is arranged through the cargo hatch, the top of the ladder shall be placed as close as possible to the hatch coaming. Access hatch coamings having a height greater than 900 mm shall also have steps on the outside in conjunction with the ladder.

5.2 For access through vertical openings, or manholes, in swash bulkheads, floors, girders and web frames providing passage through the length and breadth of the space, the minimum opening shall be not less than 600 mm x 800 mm at a height of not more than 600 mm from the bottom shell plating unless gratings or other foot holds are provided.

5.3 For oil tankers of less than 5,000 tonnes deadweight, the Administration may approve, in special circumstances, smaller dimensions for the openings referred to in paragraphs 5.1 and 5.2, if the ability to traverse such openings or to remove an injured person can be proved to the satisfaction of the Administration.

2. IMO Technical provisions for means of access for inspections

Preamble

It has long been recognised that the only way of ensuring that the condition of a ship.s structure is maintained to conform with the applicable requirements is for all its components to be surveyed on a regular basis throughout their operational life so as to ensure that they are free from damage such as cracks, buckling or deformation due to corrosion, overloading or contact damage and that thickness diminution is within established limits. The provision of suitable means of access to the hull structure for the purpose of carrying out overall and close-up surveys and inspections is essential and such means should be considered and provided for at the ship design stage.

Ships should be designed and built with due consideration as to how they will be surveyed by flag State inspectors and classification society surveyors during their in-service life and how the crew will be able to monitor the condition of the ship. Without adequate access, the structural condition of the vessel can deteriorate undetected, and major structural failure can arise. A comprehensive approach to design and maintenance is required to cover the whole projected life of the ship.

In order to address this issue, the Organization has developed these Technical provisions for means of access for inspections, intended to facilitate close-up inspections and thickness measurements of the ship's structure referred to in SOLAS regulation II-1/ 3-6 on access to and within spaces in the cargo area of oil tankers and bulk carriers.

Definitions

Terms used in the Technical provisions have the same meaning as those defined in the 1974 SOLAS Convention, as amended, and in resolution A.744(18), as amended.

Technical provisions

1 Structural members subject to the close-up inspections and thickness measurements of the ship's structure referred to in SOLAS regulation II-1/ 3-6, except those in double bottom spaces shall be provided with a permanent means of access to the extent as specified in table 1 and table 2, as applicable. For oil tankers and wing ballast tanks of ore carriers rafting may be used in addition to the specified permanent means of access, provided that the structure allows for its safe and effective use.

2 Elevated passageways, where fitted, shall have a minimum width of 600 mm and be provided with toe boards of not less than 150 mm high and guard rails over both sides of their entire length. Sloping structure providing part of the access shall be of a non-skid construction. Guard rails shall be 1,000 mm in height and consist of a rail and intermediate bar 500 mm in height and of substantial construction. Stanchions shall be not more than 3 m apart.

3 Access to elevated passageways and vertical openings from the ship's bottom shall be provided by means of easily accessible passageways, ladders or treads. Treads shall be provided with lateral support for the foot. Where the rungs of ladders are fitted against a vertical surface, the distance from the centre of the rungs to the surface shall be at least 150 mm. Where vertical manholes are fitted higher than 600 mm above the walking level, access shall be facilitated by means of treads and hand grips with platform landings on both sides.

4 Tunnels passing through cargo holds shall be equipped with ladders or steps at each end of the hold so that personnel may easily cross such tunnels.

5 Permanent ladders except for vertical ladders which are fitted on vertical structures for close-up survey or thickness measurement shall be inclined at an angle less than 70º. There shall be no obstructions within 750 mm of the face of the inclined ladder except through openings when this may be reduced to 600 mm. The flights of ladders shall not be more than 9 m in actual length. Resting platforms of adequate dimensions shall be provided. Ladders and handrails shall be constructed of steel or equivalent material of adequate strength and stiffness and securely attached to the tank structure by stays. The method of support and length of stay shall be such that vibration is reduced to a practical minimum. In cargo holds ladders shall be designed and arranged so that the risk of damage from cargo handling gear is minimized.

6 The width of ladders between stringers shall not be less than 400 mm. The treads shall be equally spaced at a distance apart, measured vertically, of between 250 mm and 300 mm. When steel is used, the treads shall be formed of two square bars of not less that 22 mm by 22 mm in section, fitted to form a horizontal step with the edges pointing upward. The treads shall be carried through the side stringers and attached thereto by double continuous welding. All sloping ladders shall be provided with handrails of substantial construction on both sides fitted at a convenient distance above the treads.

7 No free-standing portable ladder shall be more than 5 m long.

8 Portable ladders more than 5 m long may only be utilized if fitted with a remotely controlled mechanical device to secure the upper end of the ladder.

9 Movable means of access includes such devices as:

.1 hydraulic arm fitted with a stable base and with local control at the safety cage. The operational conditions should be in accordance with applicable safety requirements of the manufacturer; and

.2 wire lift platform.

Table 1 - Means of access for oil tankers

1 Water ballast tanks, except those specified in the right column, and cargo oil tanks	**2 Wing water ballast tanks less than 5 m width forming double side spaces and their bilge hopper sections**
Access to the overhead structure	
1.1 For tanks of which the height is 6 m and over, permanent means of access shall be provided in accordance with .1 to .3: .1 continuous athwartship permanent access arranged at the transverse bulkheads and at every deck transverse, at a minimum of 1.8 m to a maximum of 2.5 m below the overhead structure. If the access is fitted on the side of the unobstructed side of the web plating, then lightening holes of at least 300 mm diameter shall be fitted in the web plating providing access adjacent to both sides of each tripping bracket; .2 at least one longitudinal permanent means of access at a minimum of 1.8 m to a maximum of 2.5 m below the overhead structure. Where the longitudinal bulkhead contains attached framing, the access shall be provided at that side; and .3 access between the arrangements specified in .1 and .2 and from the main deck to either .1 or .2. 1.2 For tanks of which the height is less than 6 m, raft or portable means may be utilized in lieu of the permanent means of access.	2.1 Where the vertical distance between horizontal upper stringer and deck head exceeds 6 m, one continuous permanent means of access shall be provided for the full length of the tank with a means to allow passing through transverse swash bulkheads installed a minimum of 1.8 m to a maximum of 2.5 m from the overhead structure with a vertical access ladder at each end and mid-span of tank. 2.2 For bilge hopper sections of which the vertical distance from baseline to the upper knuckle point is 6 m and over, one longitudinal permanent means of access shall be provided for the full length of the tank. It shall be accessible by vertical permanent means of access at both ends of the tank. 2.3 Where the vertical distance referred to in 2.2 is less than 6 m, portable means of access may be utilised in lieu of the permanent means of access. To facilitate the operation of the portable means of access, in-line openings in horizontal stringers should be provided. The openings should be of an adequate diameter and should have suitable protective railings. 2.4 Whenever practicable, the distance between the overhead structure and the uppermost longitudinal stringer and between the longitudinal stringers should not exceed 6 m.

Table 1 - Means of access for oil tankers (continued)

Access to the vertical structures	
1.3 For tanks of which the height is 6 m and over, containing internal structures, permanent means of access shall be provided to each transverse web. 1.4 For tanks of which the height is less than 6 m, raft or portable means may be utilized in lieu of the permanent means of access.	2.5 Vertical permanent means of access shall be provided to each transverse web in the following cases where the vertical distance is 6 m and over: .1 from baseline to the upper knuckle point of the bilge hopper section; .2 from the upper knuckle point of the bilge hopper section to main deck where no horizontal stringers are provided; and .3 between horizontal stringers. 2.6 Access holes within 600 mm of the stringer shall be provided in each transverse web/swash bulkhead above each stringer and tank base. 2.7 In the case where the vertical distance referred to in 2.5 is less than 6 m, portable means may be utilised in lieu of the permanent means of access.