Rules for the Classification of Ships

Effective from 1 January 2025

Part B

Hull and Stability

www.tasneefmaritime.ae

+971 2 6922333 +971 2 4454333 info@tasneef.ae 111155, Abu Dhabi, UAE

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 shipbuilder, 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 shipowner, 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, for example, rule variations or interpretations.

"Services" means the activities described in paragraph 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, for example, offshore structures, floating units and underwater craft.

"Society" or "TASNEEF" means TASNEEF Maritime

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

"**Force Majeure**" means damage to the ship; unforeseen inability of the Society to attend the ship due to government restrictions on right of access or movement of personnel; unforeseeable delays in port or inability to discharge cargo due to unusually lengthy periods of severe weather, strikes or civil strife; acts of war; or other force majeure.

1. Society Roles

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 is regulated by these general conditions unless expressly excluded in the particular contract.

هيئة الإمارات للتـصـنيف، (تـصـنيف) ا ص.ب ١١١١٥٥، ابوظبي، الإمارات العربية المـتـحـدة
Emirates Classification Society (TASNEEF) I P.O. Box 111155, Abu Dhabi, United Arab Emirates T +971 2 6922333 F +971 2 4454333
www.tasneef.ae

2. Rule Development, Implementation and Selection of Surveyor

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 also committed 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 based on 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. 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 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.

3. Class Report & Interested Parties Obligation

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 authorized bodies and no other purpose. Therefore, the Society cannot be held liable for any act made or document issued by other parties based on 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 certification 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 about 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, shipbuilders, 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 about 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 concerning the services rendered by the Society are described in the Rules applicable to the specific service rendered.

4. Service Request & Contract Management

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.

4.3 The contractor for the classification of a ship or for the services may be terminated and any certificates revoked at the request of one of the parties, subject to at least 30/60/90 days' notice, to be given in writing. Failure to pay, even in part, the fees due for services carried out by the society will entitled the society to immediately terminate the contract and suspend the service.
For every termination of the contract, the fees for the activities performed until the time of the termination shall be owned 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 society will be withdrawn in those cases where provided for by agreements between the society and the flag state.

5. Service Accuracy

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 **Rule Development, Implementation and Selection of Surveyor** 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.

6. Confidentiality & Document sharing

6.1. 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.

6.2. Notwithstanding the general duty of confidentiality owed by the Society to its clients in clause 7.1 below, 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.

6.3. 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 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 about the provision of plans and drawings to the new Society, either by way of the 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.

7. Health, Safety & Environment

7.1. The clients such as the designers, shipbuilders, manufacturers, repairers, suppliers, contractors or sub-contractors, or other product or system surveyed who have a registered office in ABU Dhabi; should have an approved OSHAD as per Abu Dhabi OHS Centre, or, if they do not need to have an approved OSHAD, they shall comply with TASNEEF standards and have procedures in place to manage the risks from their undertakings.

7.2. For the survey, audit and inspection activities onboard the ship, the ship's owner, the owner representative or the shipyard must follow TASNEEF rules regarding the safety aspects.

8. Validity of General Conditions

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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9. Force Majeure

9.1 Neither Party shall be responsible to the other party for any delay or failure to carry out their respective obligations insofar as such delay and failure derives, directly or indirectly, and at any time, from force majeure of any type whatsoever that lies outside the control of either Party.

9.2 The Party that is unable to fulfil the agreement due to Force Majeure shall inform the other party without delay and in all cases within 7 days from when such force majeure arose.

9.3 It is understood that if such force majeure continues for more than 30 days, the Party not affected by the event may terminate this agreement by registered letter. The rights matured until the day in which the force majeure occurred remain unaffected.

10. Governing Law and Jurisdiction

This Agreement shall be governed by and construed in accordance with the laws of Abu Dhabi and the applicable Federal Laws of the UAE.
Any dispute arising out of or in accordance with this Agreement shall be subject to the exclusive jurisdiction of the Abu Dhabi courts.

11. Code of Business conduct

The **CLIENT** declares to be aware of the laws in force about the responsibility of the legal persons for crimes committed in their interest or to their own advantage by persons who act on their behalf or cooperate with them, such as directors, employees or agents.
In this respect, the **CLIENT** declares to have read and fully understood the "**Ethical Code**" published by **TASNEEF** and available in the **TASNEEF** Web site.
The **CLIENT**, in the relationships with **TASNEEF**, guarantees to refrain from any behaviour that may incur risk of entry in legal proceedings for crimes or offences, whose commission may lead to the enforcement of the laws above.
The **CLIENT** also acknowledges, in case of non-fulfilment of the previous, the right of **TASNEEF** to unilaterally withdraw from the contract/agreement even if there would be a work in progress situation or too early terminate the contract/agreement. It's up to **TASNEEF** to choose between the two above mentioned alternatives, and in both cases a registered letter will be sent with a brief sum-up of the circumstances or of the legal procedures proving the failure in following the requirements of the above-mentioned legislation.

In light of the above, it is forbidden to all employees and co-operators to:
- receive any commission, percentage or benefits of any possible kind;
- Start and maintaining any business relationship with **Clients** that could cause conflict of interests with their task and function covered on behalf of **TASNEEF.**
- Receive gifts, travel tickets or any other kind of benefits different from monetary compensation, that could exceed the ordinary business politeness.
Violation of the above-mentioned principles allows **TASNEEF** to early terminate the contract and to be entitled to claim compensation for losses if any.

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EXPLANATORY NOTE TO PART B

1. Reference edition

The reference edition for Part B is the Tasneef Rules 2000 edition, which is effective from 1 June 2000.

2. Amendments after the reference edition

2.1 Tasneef Rules 2000 has been completely rewritten and reorganised.

2.2 Except in particular cases, the Rules are updated and published annually.

3. Effective date of the requirements

3.1 All requirements in which new or amended provisions with respect to those contained in the reference edition have been introduced are followed by a date shown in brackets.

The date shown in brackets is the effective date of entry into force of the requirements as amended by the last updating. The effective date of all those requirements not followed by any date shown in brackets is that of the reference edition.

3.2 Item 6 below provides a summary of the technical changes from the preceding edition. In general, this list does not include those items to which only editorial changes have been made not affecting the effective date of the requirements contained therein.

4. Rule Variations and Corrigenda

Until the next edition of the Rules is published, Rule Variations and/or corrigenda, as necessary, will be pub-lished on the Tasneef web site (www.Tasneef.ae). Except in particular cases, paper copies of Rule Variations or cor-rigenda are not issued.

5. Rule subdivision and cross-references

5.1 Rule subdivision

The Rules are subdivided into six parts, from A to F.

Part A: Classification and Surveys

Part B: Hull and Stability

Part C: Machinery, Systems and Fire Protection

Part D: Materials and Welding

Part E: Service Notations

Part F: Additional Class Notations

Each Part consists of:

- Chapters
- Sections and possible Appendices
- Articles
- Sub-articles
- Requirements

Figures (abbr. Fig) and Tables (abbr. Tab) are numbered in ascending order within each Section or Appendix.

5.2 Cross-references

Examples: Pt A, Ch 1, Sec 1, [3.2.1]or Pt A, Ch 1, App 1, [3.2.1]

- Pt A means Part A

The part is indicated when it is different from the part in which the cross-reference appears. Otherwise, it is not indicated.

- Ch 1 means Chapter 1

The Chapter is indicated when it is different from the chapter in which the cross-reference appears. Otherwise, it is not indicated.

- Sec 1 means Section 1 (or App 1 means Appendix 1)

The Section (or Appendix) is indicated when it is different from the Section (or Appendix) in which the cross-reference appears. Otherwise, it is not indicated.

- [3.2.1] refers to requirement 1, within sub-article 2 of article 3.

Cross-references to an entire Part or Chapter are not abbreviated as indicated in the following examples:

- Part A for a cross-reference to Part A
- Part A, Chapter 1 for a cross-reference to Chapter 1 of Part A.

6. Summary of amendments introduced in the edition effective from 1 January 2025

This edition of Part B contains amendments whose effective date is **1 January 2025**.

The date of entry into force of each new or amended item is shown in brackets after the number of the item concerned.

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RULES FOR THE CLASSIFICATION OF SHIPS

Part B
Hull and Stability

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Part B

Hull and Stability

Chapter 5

DESIGN LOADS

Symbols used in chapter 5

n, n_1 : Navigation coefficients, defined in Pt B, Ch 5, Sec 1, [2.6],

F : Froude's number:

$$F = 0,164 \frac{V}{\sqrt{L}}$$

V : Maximum ahead service speed, in knots,

T_1 : Draught, in m, defined in Pt B, Ch 5, Sec 1, [2.4.3] or Pt B, Ch 5, Sec 1, [2.5.3], as the case may be,

g : Gravity acceleration, in m/s^2:

$g = 9,81$ m/s^2,

x, y, z : X, Y and Z co-ordinates, in m, of the calculation point with respect to the reference co-ordinate system defined in Pt B, Ch 1, Sec 2, [4].

SECTION 1 GENERAL

1 Definitions

1.1 Still water loads

1.1.1 Still water loads are those acting on the ship at rest in calm water.

1.2 Wave loads

1.2.1 Wave loads are those due to wave pressures and ship motions, which can be assumed to have the same period of the inducing waves.

1.3 Dynamic loads

1.3.1 Dynamic loads are those that have a duration much shorter than the period of the inducing waves.

1.4 Local loads

1.4.1 Local loads are pressures and forces which are directly applied to the individual structural members: plating panels, ordinary stiffeners and primary supporting members.

- Still water local loads are constituted by the hydrostatic external sea pressures and the static pressures and forces induced by the weights carried in the ship spaces.
- Wave local loads are constituted by the external sea pressures due to waves and the inertial pressures and forces induced by the ship accelerations applied to the weights carried in the ship spaces.
- Dynamic local loads are constituted by the impact and sloshing pressures.

1.4.2 For the structures which constitute the boundary of spaces not intended to carry liquids and which do not belong to the outer shell, the still water and wave pressures in flooding conditions are also to be considered.

1.5 Hull girder loads

1.5.1 Hull girder loads are (still water, wave and dynamic) forces and moments which result as effects of local loads acting on the ship as a whole and considered as a girder.

1.6 Loading condition

1.6.1 A loading condition is a distribution of weights carried in the ship spaces arranged for their storage.

1.7 Load case

1.7.1 A load case is a state of the ship structures subjected to a combination of hull girder and local loads.

2 Application criteria

2.1 Fields of application

2.1.1 *(1/7/2019)*

The wave induced and dynamic loads defined in this Chapter correspond to an operating life of the ship equal to 20 years.

2.1.2 Requirements applicable to all types of ships

The still water, wave induced and dynamic loads defined in this Chapter are to be used for the determination of the hull girder strength and structural scantlings in the central part (see Ch 1, Sec 1) of ships equal to or greater than 90 m in length, according to the requirements in Chapter 6 and Chapter 7.

The design loads to be used for the determination of the hull girder strength and structural scantlings in the central part (see Ch 1, Sec 1) of ships less than 90 m in length are specified in Chapter 8.

2.1.3 Requirements applicable to specific ship types

The design loads applicable to specific ship types are to be defined in accordance with the requirements in Part E.

2.1.4 Load direct calculation *(1/7/2023)*

As an alternative to the formulae in Sec 2 and Sec 3, the Society may accept the values of wave induced loads and dynamic loads derived from direct calculations, when justified on the basis of the ship's characteristics and intended service.

A long-term approach is generally required, assuming for the calculations the wave scatter diagram, the wave spectrum and spreading function provided in the latest published version of IACS Rec. 34.

Seakeeping calculations are to rely preferably on a three dimensional methodology. A strip theory approach is also acceptable if its assumptions are satisfied. Non-linear effects can be assessed assuming linear radiation and diffraction forces and calculating the non-linear contributions of Froude-Krylov and hydrostatic forces.

Design loads are to be set applying an equivalent design wave approach with regular waves.

The calculations are to be submitted to the Society for approval.

2.2 Hull girder loads

2.2.1 The still water, wave and dynamic hull girder loads to be used for the determination of:

- the hull girder strength, according to the requirements of Chapter 6, and

- the structural scantling of plating, ordinary stiffeners and primary supporting members contributing to the hull girder strength, in combination with the local loads given in Sec 5 and Sec 6, according to the requirements in Chapter 7,

are specified in Sec 2.

2.3 Local loads

2.3.1 Load cases

The local loads defined in [1.4] are to be calculated in each of the mutually exclusive load cases described in Sec 4.

Dynamic loads are to be taken into account and calculated according to the criteria specified in Sec 5 and Sec 6.

2.3.2 Ship motions and accelerations

The wave local loads are to be calculated on the basis of the reference values of ship motions and accelerations specified in Sec 3.

2.3.3 Calculation and application of local loads

The criteria for calculating:

- still water local loads
- wave local loads on the basis of the reference values of ship motions and accelerations

are specified in Sec 5 for sea pressures and in Sec 6 for internal pressures and forces.

2.3.4 Flooding conditions

The still water and wave pressures in flooding conditions are specified in Sec 6, [9]. The pressures in flooding conditions applicable to specific ship types are to be defined in accordance with the requirements in Part E.

2.4 Load definition criteria to be adopted in structural analyses based on plate or isolated beam structural models

2.4.1 Application

The requirements of this sub-article apply for the definition of local loads to be used in the scantling checks of:

- plating, according to Ch 7, Sec 1
- ordinary stiffeners, according to Ch 7, Sec 2
- primary supporting members for which a three dimensional structural model is not required, according to Ch 7, Sec 3, [3].

2.4.2 Cargo and ballast distributions

When calculating the local loads for the structural scantling of an element which separates two adjacent compartments, the latter may not be considered simultaneously loaded. The local loads to be used are those obtained considering the two compartments individually loaded.

For elements of the outer shell, the local loads are to be calculated considering separately:

- the still water and wave external sea pressures, considered as acting alone without any counteraction from the ship interior
- the still water and wave differential pressures (internal pressure minus external sea pressure) considering the compartment adjacent to the outer shell as being loaded.

2.4.3 Draught associated with each cargo and ballast distribution

Local loads are to be calculated on the basis of the ship's draught T_1 corresponding to the cargo or ballast distribution considered according to the criteria in [2.4.2]. The ship draught is to be taken as the distance measured vertically on the hull transverse section at the middle of the length L, from the moulded base line to the waterline in:

- full load condition, when:
  - one or more cargo compartments (e.g. oil tank, dry cargo hold, vehicle space, passenger space) are considered as being loaded and the ballast tanks are considered as being empty
  - the still water and wave external pressures are considered as acting alone without any counteraction from the ship's interior
- light ballast condition, when one or more ballast tanks are considered as being loaded and the cargo compartments are considered as being empty. In the absence of more precise information, the ship's draught in light ballast condition may be obtained, in m, from the following formulae:
  - $T_B = 0{,}03L \le 7{,}5$ m in general
  - $T_B = 2 + 0{,}02L$ for ships with one of the service notations **bulk carrier ESP**, **ore carrier ESP**, **combination carrier ESP** and **oil tanker ESP**.

2.5 Load definition criteria to be adopted in structural analyses based on three dimensional structural models

2.5.1 Application

The requirements of this sub-article apply for the definition of local loads to be used in the scantling checks of primary supporting members for which a three dimensional structural model is required, according to Ch 7, Sec 3, [4].

2.5.2 Loading conditions

For all ship types for which analyses based on three dimensional models are required according to Ch 7, Sec 3, [4], the most severe loading conditions for the structural elements under investigation are to be considered. These loading conditions are to be selected among those envisaged in the ship loading manual.

For ships with the service notation **general cargo ship** or **bulk carrier ESP** completed by the additional service feature **nonhomload**, the loading conditions to be considered are to include the cases where the selected holds are empty at draught T, according to the indications specified in the ship notation.

Further criteria applicable to specific ship types are specified in Part E.

2.5.3 Draught associated with each loading condition

Local loads are to be calculated on the basis of the ship's draught T_1 corresponding to the loading condition considered according to the criteria in [2.5.2].

2.6 Navigation coefficients

2.6.1 The navigation coefficients, which appear in the formulae of this Chapter for the definition of wave hull girder and local loads, are defined in Tab 1 depending on the assigned navigation notation.

Table 1 : Navigation coefficients

Navigation notation	Navigation coefficient n	Navigation coefficient n_1
Unrestricted navigation	1,00	1,00
Summer zone	0,90	0,95
Tropical zone	0,80	0,90
Coastal area	0,80	0,90
Sheltered area	0,65	0,80

SECTION 2 HULL GIRDER LOADS

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

C : Wave parameter:

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

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

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

1 General

1.1 Application

1.1.1 The requirements of this Section apply to ships having the following characteristics:

- L < 500 m
- L / B > 5
- B / D < 2,5
- $C_B \ge 0{,}6$

Ships not having one or more of these characteristics, ships intended for the carriage of heated cargoes and ships of unusual type or design will be considered by the Society on a case by case basis.

1.2 Sign conventions of vertical bending moments and shear forces

1.2.1 The sign conventions of bending moments and shear forces at any ship transverse section are as shown in Fig 1, namely:

- the vertical bending moment M is positive when it induces tensile stresses in the strength deck (hogging bending moment); it is negative in the opposite case (sagging bending moment)
- the vertical shear force Q is positive in the case of downward resulting forces preceding and upward resulting forces following the ship transverse section under consideration; it is negative in the opposite case.

2 Still water loads

2.1 General

2.1.1 Still water load calculation *(1/7/2003)*

For all ships, the longitudinal distributions of still water bending moment and shear force are to be calculated, for each of the loading conditions in [2.1.2], on the basis of realistic data related to the amount of cargo, ballast, fuel, lubricating oil and fresh water. Except for docking condition afloat, departure and arrival conditions are to be considered.

Where the amount and disposition of consumables at any intermediate stage of the voyage are considered more severe, calculations for such intermediate conditions are to be performed in addition to those for departure and arrival conditions. Also, where any ballasting and/or deballasting is intended during the voyage, calculations of the intermediate condition just before and just after ballasting and/or deballasting any ballast tank are to be considered and where approved included in the loading manual for guidance.

The actual hull lines and lightweight distribution are to be taken into account in the calculations. The lightweight distribution may be replaced, if the actual values are not available, by a statistical distribution of weights accepted by the Society.

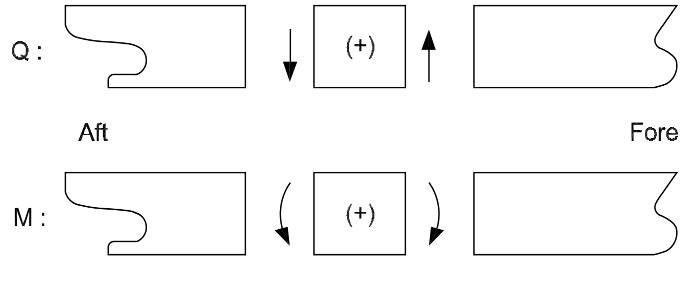
The designer is to supply the data necessary to verify the calculations of still water loads.

For ships with the service notation **container ship**, the torque due to non-uniform distribution of cargo, consumable liquids and ballast is also to be considered, as specified in Pt E, Ch 2, Sec 2.

2.1.2 Loading conditions *(1/1/2022)*

Still water loads are to be calculated for all the design loading conditions (cargo and ballast) subdivided into departure and arrival conditions, on which the approval of hull structural scantlings is based.

Figure 1 : Sign conventions for shear forces Q and bending moments M



For all ships, the following loading conditions are to be considered:

a) homogeneous loading conditions at maximum draught

b) ballast conditions. Ballast loading conditions involving partially filled peak and/or other ballast tanks at departure, arrival or during intermediate conditions are not permitted to be used as design conditions unless:
   - the allowable stress limits (defined in Ch 6, Sec 2, [3]) are satisfied for all filling levels between empty and full, and
   - for ships with the service notation **bulk carrier ESP**, the requirements in Pt E, Ch 4, Sec 3, [4.4] and in Pt E, Ch 4, Sec 3, [5.1], as applicable, are complied with for all filling levels between empty and full.

   To demonstrate compliance with all filling levels between empty and full, it is acceptable if, in each condition at departure, arrival and, where required in [2.1.1], any intermediate condition, the tanks intended to be partially filled are assumed to be:
   - empty
   - full
   - partially filled at the intended level.

   Where multiple tanks are intended to be partially filled, all combinations of empty, full or partially filled at intended level for those tanks are to be investigated.

   However, for ships with the service notation **ore carrier ESP** or **combination carrier/OOC ESP**, with large wing water ballast tanks in the cargo area, where empty or full ballast water filling levels of one or maximum two pairs of these tanks lead to the ship's trim exceeding one of the following conditions:
   - trim by stern equal to 3,0% of the ship's length
   - trim by bow equal to 1,5% of the ship's length
   - any trim that cannot maintain propeller immersion (I/D) of at least 25%, where:
     I : distance, in m, between the propeller centreline and the waterline, see Fig 2
     D : propeller diameter, in m, see Fig 2,

   It is sufficient to demonstrate compliance with maximum, minimum and intended partial filling levels of these one or maximum two pairs of ballast tanks such that the ship's condition does not exceed any of these trim limits. Filling levels of all other wing ballast tanks are to be considered between empty and full.

   The maximum and minimum filling levels of the above-mentioned pairs of side ballast tanks are to be indicated in the loading manual.

   App 2 contains the guidance for partially filled ballast tanks in ballast loading conditions.

c) cargo loading conditions. For cargo loading conditions involving partially filled peak and/or other ballast tanks, the requirements specified in b) apply to the peak tanks only

d) sequential ballast water exchange: the requirements specified in b) or c) are not applicable to ballast water exchange using the sequential method

e) special loadings (e.g. light load conditions at less than the maximum draught, deck cargo conditions, etc., where applicable)

f) short voyage or harbour conditions, where applicable

g) loading and unloading transitory conditions, where applicable

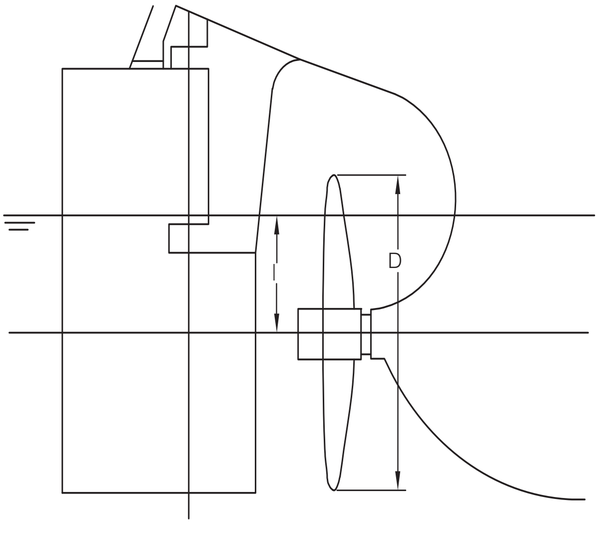
h) docking condition afloat

i) ballast exchange at sea, if applicable.

For ships with the service notation **general cargo ship** completed by the additional service feature **nonhomload**, the loading conditions to be considered are to include the cases where the selected holds are empty at draught T, according to the indications specified in the ship notation.

Part E specifies other loading conditions which are to be considered depending on the ship type.

Figure 2 : Propeller immersion and diameter *(1/7/2006)*



2.2 Still water bending moments

2.2.1 The design still water bending moments $M_{SW,H}$ and $M_{SW,S}$ at any hull transverse section are the maximum still water bending moments calculated, in hogging and sagging conditions, respectively, at that hull transverse section for the loading conditions specified in [2.1.2].

Where no sagging bending moments act in the hull section considered, the value of $M_{SW,S}$ is to be taken as specified in Chapter 6 and Chapter 7.

2.2.2 If the design still water bending moments are not defined, at a preliminary design stage, at any hull transverse section, the longitudinal distributions shown in:

- Fig 3, for ships with one of the service notations **bulk carrier ESP**, **ore carrier ESP**, **combination carrier ESP** and **oil tanker ESP**, or
- Fig 4, for other ship types,

may be considered.

In Fig 3 and Fig 4, M_{SW} is the design still water bending moment amidships, in hogging or sagging conditions, whose absolute values are to be taken not less than those obtained, in kN.m, from the following formulae:

- hogging conditions:

$$M_{SWM,H} = 175 n_1 C L^2 B (C_B + 0,7) 10^{-3} - M_{WV,H}$$

- sagging conditions:

$$M_{SWM,S} = 175 n_1 C L^2 B (C_B + 0,7) 10^{-3} + M_{WV,S}$$

where $M_{WV,H}$, $M_{WV,S}$ are the vertical wave bending moments, in kN.m, defined in [3.1].

Figure 3 : Preliminary still water bending moment distribution for oil tankers, bulk carriers and ore carriers

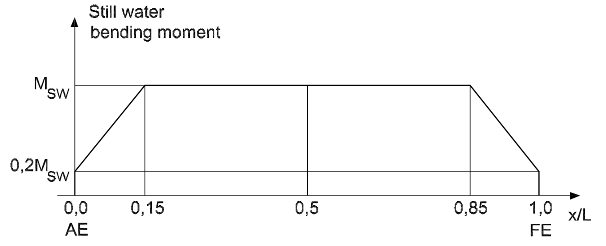
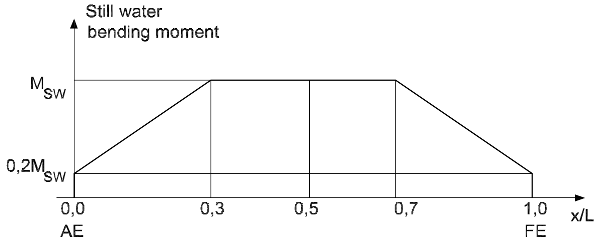


Figure 4 : Preliminary still water bending moment distribution for other ship types



2.3 Still water shear force

2.3.1 The design still water shear force Q_{SW} at any hull transverse section is the maximum positive or negative shear force calculated, at that hull transverse section, for the loading conditions specified in [2.1.2].

3 Wave loads

3.1 Vertical wave bending moments

3.1.1 The vertical wave bending moments at any hull transverse section are obtained, in kN.m, from the following formulae:

- hogging conditions:

$$M_{WV,H} = 190 F_M n C L^2 B C_B 10^{-3}$$

- sagging conditions:

$$M_{WV,S} = -110 F_M n C L^2 B (C_B + 0,7) 10^{-3}$$

where:

F_M : Distribution factor defined in Tab 1 (see also Fig 5).

3.1.2 The effects of bow flare impact are to be taken into account, for the cases specified in [4.1.1], according to [4.2.1].

3.2 Horizontal wave bending moment

3.2.1 The horizontal wave bending moment at any hull transverse section is obtained, in kN.m, from the following formula:

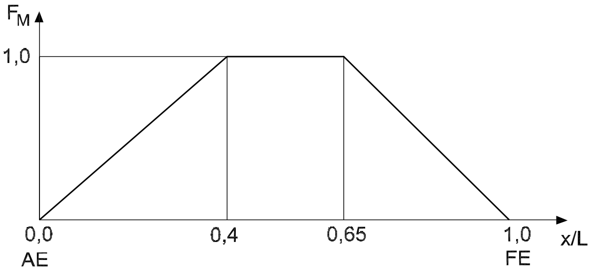
$$M_{WH} = 1,6 F_M n L^{2,1} T C_B$$

where F_M is the distribution factor defined in [3.1.1].

Table 1 : Distribution factor F_M

Hull transverse section location	Distribution factor F_M
$0 \le x < 0,4L$	$2,5\dfrac{x}{L}$
$0,4L \le x \le 0,65L$	1
$0,65L < x \le L$	$2,86\left(1 - \dfrac{x}{L}\right)$

Figure 5 : Distribution factor F_M



3.3 Wave torque

3.3.1 The wave torque at any hull transverse section is to be calculated considering the ship in two different conditions:

- condition 1: ship direction forming an angle of 60° with the prevailing sea direction
- condition 2: ship direction forming an angle of 120° with the prevailing sea direction.

The values of the wave torques in these conditions, calculated with respect to the section centre of torsion, are obtained, in kN.m, from the following formula:

$$M_{WT} = \frac{HL}{4} n (F_{TM} C_M + F_{TQ} C_Q d)$$

where:

H : Wave parameter:

$$H = 8{,}13 - \left(\frac{250 - 0{,}7L}{125}\right)^3$$

without being taken greater than 8,13

F_{TM}, F_{TQ} : Distribution factors defined in Tab 2 for ship conditions 1 and 2 (see also Fig 6 and Fig 7)

C_M : Wave torque coefficient:

$$C_M = 0{,}38 B^2 C_W^2$$

C_Q : Horizontal wave shear coefficient:

$$C_Q = 2{,}8 T C_B$$

C_W : Waterplane coefficient, to be taken not greater than the value obtained from the following formula:

$$C_W = 0{,}165 + 0{,}95 C_B$$

where C_B is to be assumed not less than 0,6. In the absence of more precise determination, C_W may be taken equal to the value provided by the above formula.

d : Vertical distance, in m, from the centre of torsion to a point located 0,6T above the baseline.

Table 2 : Distribution factors F_{TM} and F_{TQ}

Ship condition	Distribution factor F_{TM}	Distribution factor F_{TQ}
1	$1 - \cos\frac{2\pi x}{L}$	$\sin\frac{2\pi x}{L}$
2	$1 - \cos\frac{2\pi(L-x)}{L}$	$\sin\frac{2\pi(L-x)}{L}$

Figure 6 : Ship condition 1 - Distribution factors F_{TM} and F_{TQ}

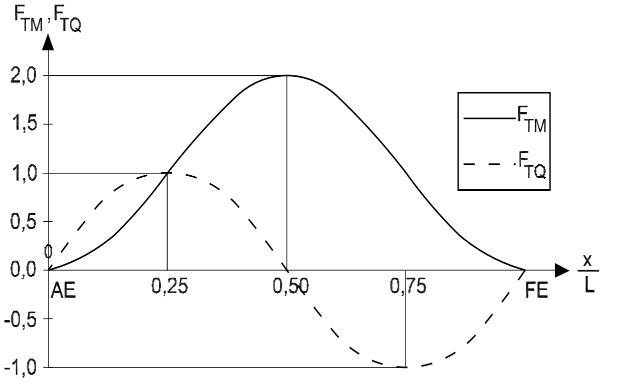
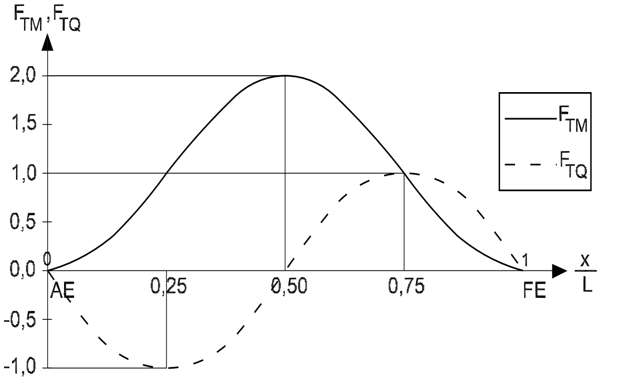


Figure 7 : Ship condition 2 - Distribution factors F_{TM} and F_{TQ}



3.4 Vertical wave shear force

3.4.1 The vertical wave shear force at any hull transverse section is obtained, in kN, from the following formula:

$$Q_{WV} = 30 F_Q n C L B (C_B + 0{,}7) 10^{-2}$$

where:

F_Q : Distribution factor defined in Tab 3 for positive and negative shear forces (see also Fig 8).

4 Dynamic loads due to bow flare impact

4.1 Application

4.1.1 The effects of bow flare impact are to be considered where all the following conditions occur:

- $120 \text{ m} \le L \le 180 \text{ m}$
- $V \ge 17{,}5$ knots
- $\frac{100 F A_S}{LB} > 1$

where:

A_S : Twice the shaded area shown in Fig 9, which is to be obtained, in m², from the following formula:

$$A_S = b a_0 + 0{,}1 L (a_0 + 2a_1 + a_2)$$

b, a_0, a_1, a_2: Distances, in m, shown in Fig 9.

For multideck ships, the upper deck shown in Fig 9 is to be taken as the deck (including superstructures) which extends up to the extreme forward end of the ship and has the largest breadth forward of 0,2L from the fore end.

Figure 8 : Distribution factor F_Q

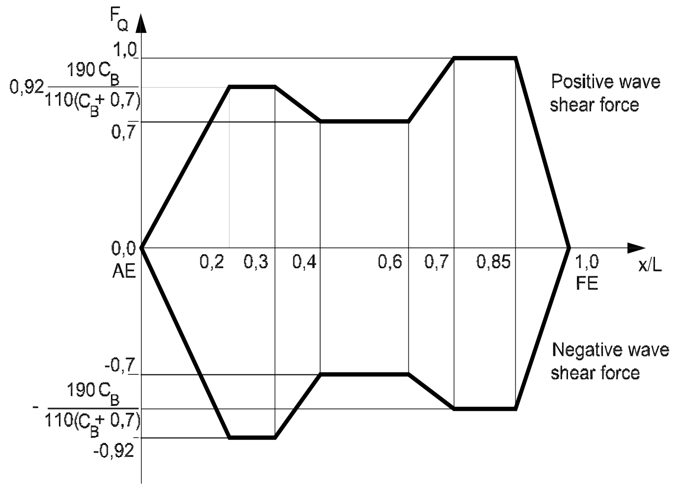


Table 3 : Distribution factor F_Q

Hull transverse section location	Distribution factor F_Q	
	Positive wave shear force	Negative wave shear force
$0 \le x < 0{,}2L$	$4{,}6A\frac{x}{L}$	$-4{,}6\frac{x}{L}$
$0{,}2L \le x \le 0{,}3L$	0,92A	- 0,92
$0{,}3L < x < 0{,}4L$	$(9{,}2A-7)\left(0{,}4-\frac{x}{L}\right)+0{,}7$	$-2{,}2\left(0{,}4-\frac{x}{L}\right)-0{,}7$
$0{,}4L \le x \le 0{,}6L$	0,7	- 0,7
$0{,}6L < x < 0{,}7L$	$3\left(\frac{x}{L}-0{,}6\right)+0{,}7$	$-(10A-7)\left(\frac{x}{L}-0{,}6\right)-0{,}7$
$0{,}7L \le x \le 0{,}85L$	1	- A
$0{,}85L < x \le L$	$6{,}67\left(1-\frac{x}{L}\right)$	$-6{,}67A\left(1-\frac{x}{L}\right)$
Note 1: $A = \frac{190C_B}{110(C_B+0{,}7)}$		

4.1.2 When the effects of bow flare impact are to be considered, according to [4.1.1], the sagging wave bending moment is to be increased as specified in [4.2.1] and [4.2.2].

4.1.3 The Society may require the effects of bow flare impact to be considered also when one of the conditions in [4.1.1] does not occur, if deemed necessary on the basis of the ship's characteristics and intended service.

In such cases, the increase in sagging wave bending moment is defined on a case by case basis.

4.2 Increase in sagging wave bending moment

4.2.1 General

The sagging wave bending moment at any hull transverse section, defined in [3.1], is to be multiplied by the coefficient F_D obtained from the formulae in Tab 4, which takes into account the dynamic effects of bow flare impact.

Where at least one of the conditions in [4.1.1] does not occur, the coefficient F_D may be taken equal to 1.

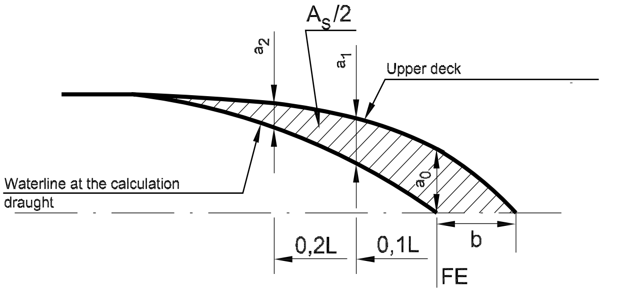
4.2.2 Direct calculations

As an alternative to the formulae in [4.2.1], the Society may accept the evaluation of the effects of bow flare impact from direct calculations, when justified on the basis of the ship's characteristics and intended service. The calculations are to be submitted to the Society for approval.

Table 4 : Coefficient F_D

Hull transverse section location	Coefficient F_D
$0 \le x < 0,4L$	1
$0,4L \le x < 0,5L$	$1 + 10(C_D - 1)\left(\frac{x}{L} - 0,4\right)$
$0,5L \le x \le L$	C_D
Note 1: $C_D = 262,5\frac{A_S}{CLB(C_B + 0,7)} - 0,6$ without being taken greater than 1,2; A_S : Area, in m², defined in [4.1.1].	

Figure 9 : Area A_S



SECTION 3 SHIP MOTIONS AND ACCELERATIONS

Symbols

For the symbols not defined in this Section, refer to the list at the beginning of this Chapter.

a_B : Motion and acceleration parameter:

$$a_B = n\left(0{,}76F + 1{,}875\frac{h_W}{L}\right)$$

h_W : Wave parameter, in m:

$$h_W = 11{,}44 - \left|\frac{L-250}{110}\right|^3 \quad \text{for} \quad L < 350 \text{ m}$$

$$h_W = \frac{200}{\sqrt{L}} \quad \text{for} \quad L \geq 350 \text{ m}$$

a_{SU} : Surge acceleration, in m/s², defined in [2.1]

a_{SW} : Sway acceleration, in m/s², defined in [2.2]

a_H : Heave acceleration, in m/s², defined in [2.3]

α_R : Roll acceleration, in rad/s², defined in [2.4]

α_P : Pitch acceleration, in rad/s², defined in [2.5]

α_Y : Yaw acceleration, in rad/s², defined in [2.6]

T_{SW} : Sway period, in s, defined in [2.2]

T_R : Roll period, in s, defined in [2.4]

T_P : Pitch period, in s, defined in [2.5]

A_R : Roll amplitude, in rad, defined in [2.4]

A_P : Pitch amplitude, in rad, defined in [2.5].

1 General

1.1

1.1.1 Ship motions and accelerations are defined, with their signs, according to the reference co-ordinate system in Ch 1, Sec 2, [4].

1.1.2 Ship motions and accelerations are assumed to be periodic. The motion amplitudes, defined by the formulae in this Section, are half of the crest to through amplitudes.

1.1.3 As an alternative to the formulae in this Section, the Society may accept the values of ship motions and accelerations derived from direct calculations, when justified on the basis of the ship's characteristics and intended service. In general, the values of ship motions and accelerations to be calculated are those which can be reached with a probability of 10^{-5} per cycle. In any case, the calculations, including the assumed sea scatter diagrams and spectra, are to be submitted to the Society for approval.

2 Ship absolute motions and accelerations

2.1 Surge

2.1.1 The surge acceleration a_{SU} is to be taken equal to 0,5 m/s².

2.2 Sway

2.2.1 The sway period and acceleration are obtained from the formulae in Tab 1.

Table 1 : Sway period and acceleration

Period T_{SW}, in s	Acceleration a_{SW}, in m/s²
$\dfrac{0{,}8\sqrt{L}}{1{,}22F+1}$	$0{,}775\, a_B\, g$

2.3 Heave

2.3.1 The heave acceleration is obtained, in m/s², from the following formula:

$$a_H = a_B g$$

2.4 Roll

2.4.1 The roll amplitude, period and acceleration are obtained from the formulae in Tab 2.

Table 2 : Roll amplitude, period and acceleration

Amplitude A_R, in rad	Period T_R, in s	Acceleration α_R, in rad/s²
$a_B\sqrt{E}$	$2{,}2\dfrac{\delta}{\sqrt{GM}}$	$A_R\left(\dfrac{2\pi}{T_R}\right)^2$

The meaning of symbols in Tab 2 is as follows:

$$E = 1{,}39\frac{GM}{\delta^2}B \quad \text{to be taken not less than 1,0}$$

GM : Distance, in m, from the ship's centre of gravity to the transverse metacentre, for the loading considered; when GM is not known, the following values may be assumed:

GM = 0,07 B in general

GM = 0,12 B for ships with the service notation **bulk carrier ESP** or **oil tanker ESP**

GM = 0,16 B for ships with the service notation **ore carrier ESP**

δ : roll radius of gyration, in m, for the loading considered; when δ is not known, the following values may be assumed:

δ = 0,35 B in general

δ = 0,30 B for ships with the service notation **ore carrier ESP**.

2.5 Pitch

2.5.1 The pitch amplitude, period and acceleration are obtained from the formulae in Tab 3.

Table 3 : Pitch amplitude, period and acceleration

Amplitude A_P, in rad	Period T_P, in s	Acceleration α_P, in rad/s²
$0{,}328 a_B \left(1{,}32 - \frac{h_W}{L}\right)\left(\frac{0{,}6}{C_B}\right)^{0{,}75}$	$0{,}575\sqrt{L}$	$A_p\left(\frac{2\pi}{T_p}\right)^2$

2.6 Yaw

2.6.1 The yaw acceleration is obtained, in rad/s², from the following formula:

$$\alpha_Y = 1{,}581\frac{a_B g}{L}$$

3 Ship relative motions and accelerations

3.1 Definitions

3.1.1 Ship relative motions

The ship relative motions are the vertical oscillating translations of the sea waterline on the ship side. They are measured, with their sign, from the waterline at draught T_1.

3.1.2 Accelerations

At any point, the accelerations in X, Y and Z direction are the acceleration components which result from the ship motions defined in [2.1] to [2.6].

3.2 Ship conditions

3.2.1 General

Ship relative motions and accelerations are to be calculated considering the ship in the following conditions:

- upright ship condition
- inclined ship condition.

3.2.2 Upright ship condition

In this condition, the ship encounters waves which produce ship motions in the X-Z plane, i.e. surge, heave and pitch.

3.2.3 Inclined ship condition

In this condition, the ship encounters waves which produce ship motions in the X-Y and Y-Z planes, i.e. sway, roll and yaw.

3.3 Ship relative motions

3.3.1 The reference value of the relative motion in the upright ship condition is obtained, at any hull transverse section, from the formulae in Tab 4.

Table 4 : Reference value of the relative motion h_1 in the upright ship condition

Location	Reference value of the relative motion h_1 in the upright ship condition, in m
x = 0	$0{,}7\left(\frac{4{,}35}{\sqrt{C_B}} - 3{,}25\right)h_{1,M}$ if $C_B < 0{,}875$ $h_{1,M}$ if $C_B \geq 0{,}875$
0 < x < 0,3L	$h_{1,AE} - \frac{h_{1,AE} - h_{1,M}}{0{,}3}\frac{x}{L}$
0,3L ≤ x ≤ 0,7L	$0{,}42nC(C_B + 0{,}7)$ without being taken greater than D-0,9T
0,7L < x < L	$h_{1,M} + \frac{h_{1,FE} - h_{1,M}}{0{,}3}\left(\frac{x}{L} - 0{,}7\right)$
x = L	$\left(\frac{4{,}35}{\sqrt{C_B}} - 3{,}25\right)h_{1,M}$

Note 1:
C : Wave parameter defined in Sec 2
$h_{1,AE}$: Reference value h_1 calculated for x = 0
$h_{1,M}$: Reference value h_1 calculated for x = 0,5L
$h_{1,FE}$: Reference value h_1 calculated for x = L

3.3.2 The reference value, in m, of the relative motion in the inclined ship condition is obtained, at any hull transverse section, from the following formula:

$$h_2 = 0{,}5h_1 + A_R\frac{B_W}{2}$$

where:

h_1 : Reference value, in m, of the relative motion in the upright ship, calculated according to [3.3.1]

B_W : Moulded breadth, in m, measured at the waterline at draught T_1 at the hull transverse section considered.

3.4 Accelerations

3.4.1 The reference values of the longitudinal, transverse and vertical accelerations at any point are obtained from the formulae in Tab 5 for upright and inclined ship conditions.

Table 5 : Reference values of the accelerations a_X, a_Y and a_Z

Direction	Upright ship condition	Inclined ship condition
X - Longitudinal a_{X1} and a_{X2} in m/s²	$a_{X1} = \sqrt{a_{SU}^2 + [A_P g + \alpha_p (z - T_1)]^2}$	$a_{x2} = 0$
Y - Transverse a_{Y1} and a_{Y2} in m/s²	$a_{Y1} = 0$	$a_{Y2} = \sqrt{a_{SW}^2 + [A_R g + \alpha_R (z - T_1)]^2 + \alpha_Y^2 K_X L^2}$
Z - Vertical a_{Z1} and a_{Z2} in m/s²	$a_{Z1} = \sqrt{a_H^2 + \alpha_p^2 K_X L^2}$	$a_{Z2} = \alpha_R y$

Note 1:

$K_X = 1{,}2\left(\frac{x}{L}\right)^2 - 1{,}1\frac{x}{L} + 0{,}2$ without being taken less than 0,018

SECTION 4 LOAD CASES

Symbols

h_1 : Reference value of the ship relative motion in the upright ship condition, defined in Sec 3, [3.3]

h_2 : Reference value of the ship relative motion in the inclined ship condition, defined in Sec 3, [3.3]

a_{X1},a_{Y1},a_{Z1}: Reference values of the accelerations in the upright ship condition, defined in Sec 3, [3.4]

a_{X2},a_{Y2},a_{Z2}: Reference values of the accelerations in the inclined ship condition, defined in Sec 3, [3.4]

M_{WV} : Reference value of the vertical wave bending moment, defined in Sec 2, [3.1]

M_{WH} : Reference value of the horizontal wave bending moment, defined in Sec 2, [3.2]

M_{WT} : Reference value of the wave torque, defined in Sec 2, [3.3]

Q_{WV} : Reference value of the vertical wave shear force, defined in Sec 2, [3.4].

1 General

1.1 Load cases for structural analyses based on partial ship models

1.1.1 The load cases described in this section are those to be used for structural element analyses which do not require complete ship modelling. They are:

- the analyses of plating (see Ch 7, Sec 1)
- the analyses of ordinary stiffeners (see Ch 7, Sec 2)
- the analyses of primary supporting members analysed through isolated beam structural models or three dimensional structural models (see Ch 7, Sec 3)
- the fatigue analysis of the structural details of the above elements (see Ch 7, Sec 4).

1.1.2 These load cases are the mutually exclusive load cases “a”, “b”, “c” and “d” described in [2].

Load cases “a” and “b” refer to the ship in upright conditions (see Sec 3, [3.2]), i.e. at rest or having surge, heave and pitch motions.

Load cases “c” and “d” refer to the ship in inclined conditions (see Sec 3, [3.2]), i.e. having sway, roll and yaw motions.

1.2 Load cases for structural analyses based on complete ship models

1.2.1 When primary supporting members are to be analysed through complete ship models, according to Ch 7, Sec 3, [1.1.4], specific load cases are to be considered.

These load cases are to be defined considering the ship as sailing in regular waves with different length, height and heading angle, each wave being selected in order to maximise a design load parameter. The procedure for the determination of these load cases is specified in Ch 7, App 3.

2 Load cases

2.1 Upright ship conditions (Load cases “a” and “b”)

2.1.1 Ship condition

The ship is considered to encounter a wave which produces (see Fig 1 for load case “a” and Fig 2 for load case “b”) a relative motion of the sea waterline (both positive and negative) symmetric on the ship sides and induces wave vertical bending moment and shear force in the hull girder. In load case “b”, the wave is also considered to induce heave and pitch motions.

2.1.2 Local loads

The external pressure is obtained by adding to or subtracting from the still water head a wave head corresponding to the relative motion.

The internal loads are the still water loads induced by the weights carried, including those carried on decks. For load case “b”, those induced by the accelerations are also to be taken into account.

2.1.3 Hull girder loads

The hull girder loads are:

- the vertical still water bending moment and shear force
- the vertical wave bending moment and the shear force.

Figure 1 : Wave loads in load case "a"

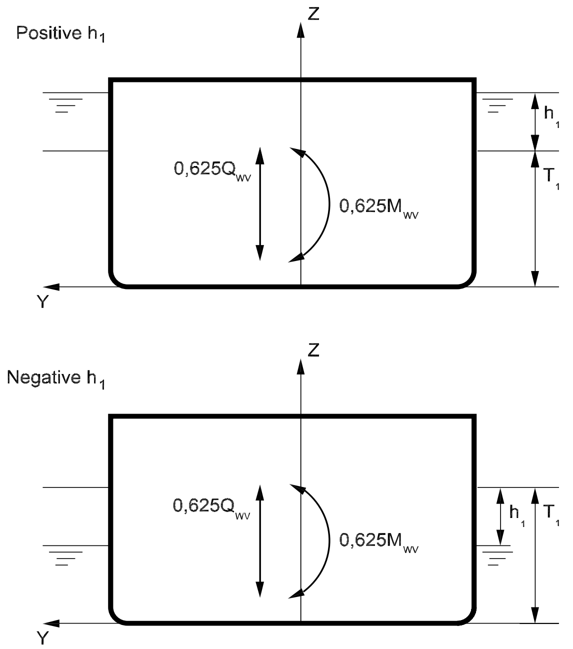
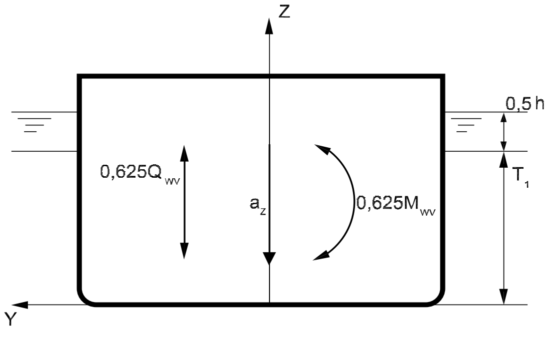


Figure 2 : Wave loads in load case "b"



2.2 Inclined ship conditions (Load cases "c" and "d")

2.2.1 Ship condition

The ship is considered to encounter a wave which produces (see Fig 3 for load case "c" and Fig 4 for load case "d"):

- sway, roll and yaw motions
- a relative motion of the sea waterline anti-symmetric on the ship sides

and induces:

- vertical wave bending moment and shear force in the hull girder
- horizontal wave bending moment in the hull girder
- in load case "c", torque in the hull girder.

2.2.2 Local loads

The external pressure is obtained by adding or subtracting from the still water head a wave head linearly variable from positive values on one side of the ship to negative values on the other.

The internal loads are the still water loads induced by the weights carried, including those carried on decks, and the wave loads induced by the accelerations.

Figure 3 : Wave loads in load case "c"

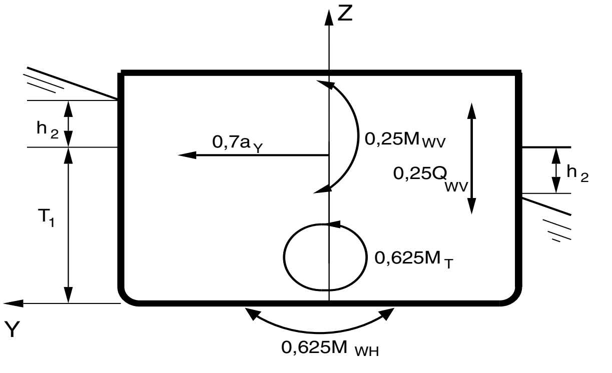
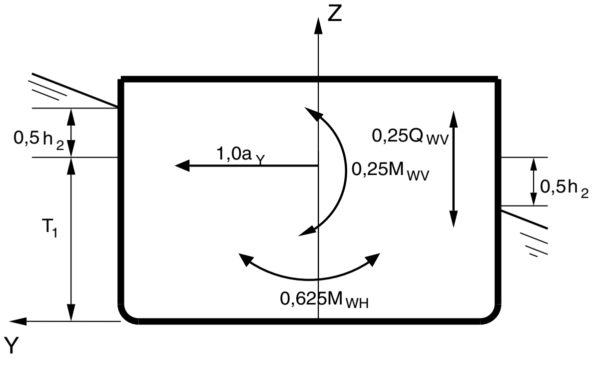


Figure 4 : Wave loads in load case "d"



2.2.3 Hull girder loads

The hull girder loads are:

- the still water bending moment and shear force
- the vertical wave bending moment and shear force
- the horizontal wave bending moment
- the wave torque (for load case "c").

2.3 Summary of load cases

2.3.1 The wave local and hull girder loads to be considered in each load case are summarised in Tab 1 and Tab 2, respectively.

These loads are obtained by multiplying, for each load case, the reference value of each wave load by the relevant combination factor.

Table 1 : Wave local loads in each load case

Ship condition	Load case	Relative motions		Accelerations a_X, a_Y, a_Z	
		Reference value	Combination factor	Reference value	Combination factor
Upright	"a"	h_1	1,0	a_{X1}; 0; a_{Z1}	0,0
	"b" **(1)**	h_1	0,5	a_{X1}; 0; a_{Z1}	1,0
Inclined	"c" **(2)**	h_2	1,0	0; a_{Y2}; a_{Z2}	0,7
	"d" **(2)**	h_2	0,5	0; a_{Y2}; a_{Z2}	1,0

(1) For a ship moving with a positive heave motion:
- h_1 is positive
- the cargo acceleration a_{X1} is directed towards the positive part of the X axis
- the cargo acceleration a_{Z1} is directed towards the negative part of the Z axis

(2) For a ship rolling with a negative roll angle:
- h_2 is positive for the points located in the positive part of the Y axis and, vice-versa, it is negative for the points located in the negative part of the Y axis
- the cargo acceleration a_{Y2} is directed towards the positive part of the Y axis
- the cargo acceleration a_{Z2} is directed towards the negative part of the Z axis for the points located in the positive part of the Y axis and, vice-versa, it is directed towards the positive part of the Z axis for the points located in the negative part of the Y axis.

Table 2 : Wave hull girder loads in each load case

Ship condition	Load case	Vertical bending moment		Vertical shear force		Horizontal bending moment		Torque	
		Reference value	Comb. factor	Reference value	Comb. factor	Reference value	Comb. factor	Reference value	Comb. factor
Upright	"a"	0,625 M_{WV}	1,0	0,625Q_{WV}	1,0	0,625 M_{WH}	0,0	0,625M_T	0,0
	"b"	0,625 M_{WV}	1,0	0,625Q_{WV}	1,0	0,625 M_{WH}	0,0	0,625M_T	0,0
Inclined	"c"	0,625 M_{WV}	0,4	0,625Q_{WV}	0,4	0,625 M_{WH}	1,0	0,625M_T	1,0
	"d"	0,625 M_{WV}	0,4	0,625Q_{WV}	0,4	0,625 M_{WH}	1,0	0,625M_T	0,0

Note 1: The sign of the hull girder loads, to be considered in association with the wave local loads for the scantling of plating, ordinary stiffeners and primary supporting members contributing to the hull girder longitudinal strength, is defined in Chapter 7.

SECTION 5 SEA PRESSURES

Symbols

For the symbols not defined in this Section, refer to the list at the beginning of this Chapter.

ρ : Sea water density, taken equal to 1,025 t/m^3

h_1 : Reference values of the ship relative motions in the upright ship condition, defined in Sec 3, [3.3]

h_2 : Reference values of the ship relative motions in the inclined ship conditions, defined in Sec 3, [3.3].

1 Still water pressure

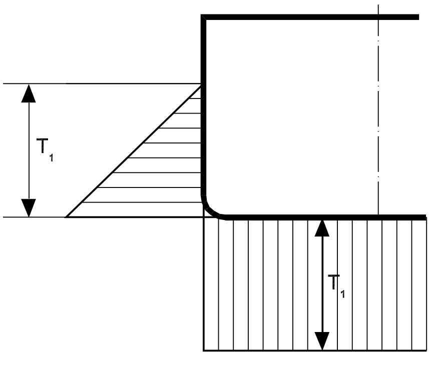
1.1 Pressure on sides and bottom

1.1.1 The still water pressure at any point of the hull is obtained from the formulae in Tab 1 (see also Fig 1).

Table 1 : Still water pressure

Location	Still water pressure p_S, in kN/m^2
Points at and below the waterline ($z \leq T_1$)	$\rho g(T_1 - z)$
Points above the waterline ($z > T_1$)	0

Figure 1 : Still water pressure



1.2 Exposed decks

1.2.1 Application *(1/1/2023)*

The still water and wave sea pressures defined in [1.2.2] and [2.1.2] for exposed decks are to be considered independently of the pressures due to dry uniform cargoes, dry unit cargoes or wheeled cargoes, if any, as defined in Sec 6, [4], [5] and [6] respectively.

1.2.2 Still water pressure on exposed decks *(1/1/2023)*

The still water pressure on exposed decks is to be taken equal to $10 \cdot \varphi$, where φ is defined in Tab 2.

Table 2 : Coefficient for pressure on exposed decks *(1/7/2011)*

Exposed deck location	φ
Freeboard deck	1,00
Superstructure deck	0,75
1st tier of deckhouse	0,56
2nd tier of deckhouse	0,42
3rd tier of deckhouse	0,32
4th tier of deckhouse	0,25
5th tier of deckhouse	0,20
6th tier of deckhouse	0,15
7th tier of deckhouse and above	0,10

2 Wave pressure

2.1 Upright ship conditions (Load cases "a" and "b")

2.1.1 Pressure on sides and bottom

The wave pressure at any point of the hull is obtained from the formulae in Tab 3 (see also Fig 2 for load case "a" and Fig 3 for load case "b").

Figure 2 : Wave pressure in load case "a"

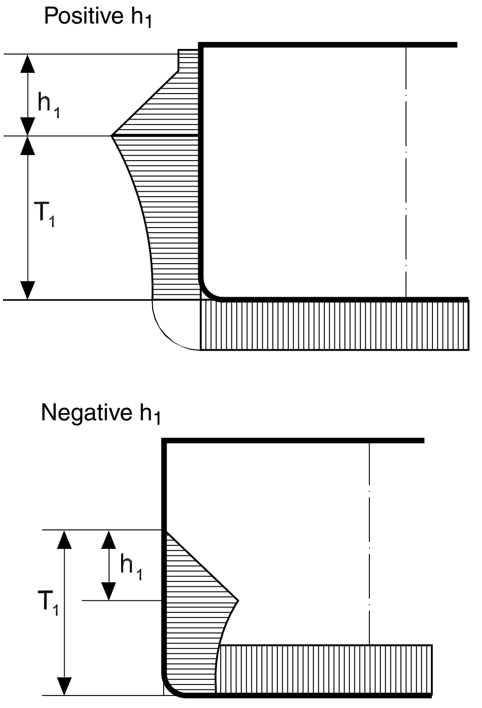
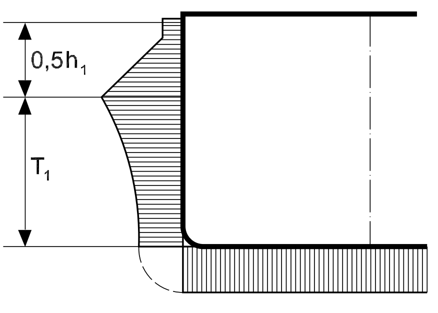


Figure 3 : Wave pressure in load case "b"



2.1.2 Pressure on exposed decks

The wave pressure on exposed decks is to be considered for load cases "a, crest" and "b" only. This pressure is obtained from the formulae in Tab 4.

2.2 Inclined ship conditions (Load cases "c" and "d")

2.2.1 The wave pressure at any point of the hull is obtained from the formulae in Tab 5 (see also Fig 4 for load case "c" and Fig 5 for load case "d").

Figure 4 : Wave pressure in load case "c"

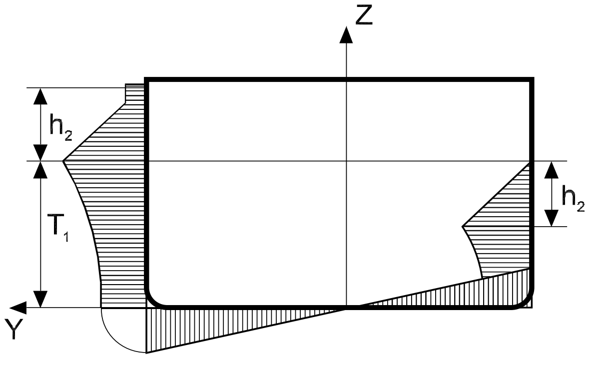


Figure 5 : Wave pressure in load case "d"

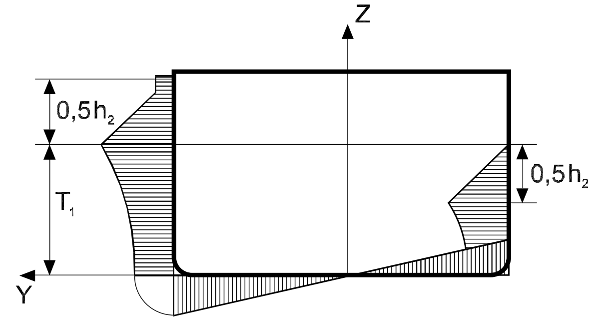


Table 3 : Wave pressure on sides and bottom in upright ship conditions (load cases “a” and “b”)

Location	Wave pressure p_W, in kN/m^2	C_1	
		crest	trough **(1)**
Bottom and sides below the waterline with: $z \le T_1 - h$	$C_1 \rho g h e^{\frac{-2\pi(T_1 - z)}{L}}$	1,0	-1,0
Sides below the waterline with: $T_1 - h < z \le T_1$	$C_1 \rho g h e^{\frac{-2\pi(T_1 - z)}{L}}$	1,0	$\frac{z - T_1}{h}$
Sides above the waterline: $z > T_1$	$C_1 \rho g (T_1 + h - z)$ without being taken less than 0,15 C_1 L for load case "a" only	1,0	0,0

(1) The wave pressure for load case “b, trough” is to be used only for the fatigue check of structural details according to Ch 7, Sec 4.

Note 1:

$h = C_{F1} h_1$

C_{F1} : Combination factor, to be taken equal to:
- C_{F1} = 1,0 for load case “a”
- C_{F1} = 0,5 for load case “b”.

Table 4 : Wave pressure on exposed decks in upright ship conditions (load cases “a” and “b”)

Location	Wave pressure p_W, in kN/m^2
$0 \le x \le 0{,}5\,L$	$17{,}5 n \varphi$
0,5 L < x < 0,75 L	$\left\{17{,}5 + \left[\frac{19{,}6\sqrt{H_F} - 17{,}5}{0{,}25}\right]\left(\frac{x}{L} - 0{,}5\right)\right\} n \varphi$
$0{,}75\,L \le x \le L$	$19{,}6 n \varphi \sqrt{H}$

Note 1:

$$H = C_{F1}\left[2{,}66\left(\frac{x}{L} - 0{,}7\right)^2 + 0{,}14\right]\sqrt{\frac{VL}{C_B}} - (z - T_1)$$ without being taken less than 0,8

φ : Coefficient defined in Tab 2

H_F : Value of H calculated at x = 0,75L

C_{F1} : Combination factor, to be taken equal to:
- C_{F1} = 1,0 for load case “a, crest”
- C_{F1} = 0,5 for load case “b”

V : Maximum ahead service speed, in knots, to be taken not less than 13 knots.

Table 5 : Wave pressure in inclined ship conditions (load cases “c” and “d”)

Location	Wave pressure p_W, in kN/m²	C_2 (negative roll angle)	
		$y \geq 0$	$y < 0$
Bottom and sides below the waterline with: $z \leq T_1 - h$	$C_2 C_{F2} \rho g \left[\frac{y}{B_W} h_1 e^{\frac{-2\pi(T_1 - z)}{L}} + A_R y e^{\frac{-\pi(T_1 - z)}{L}}\right]$	1,0	1,0
Sides below the waterline with: $T_1 - h < z \leq T_1$	$C_2 C_{F2} \rho g \left[\frac{y}{B_W} h_1 e^{\frac{-2\pi(T_1 - z)}{L}} + A_R y e^{\frac{-\pi(T_1 - z)}{L}}\right]$	1,0	$\frac{T_1 - z}{h}$
Sides above the waterline: $z > T_1$	$C_2 \rho g \left[T_1 + C_{F2}\left(\frac{y}{B_W} h_1 + A_R y\right) - z\right]$ without being taken less than 0,15 C_2 L for load case "c" only	1,0	0,0
Exposed decks	$C_2 \rho g \left[T_1 + C_{F2}\left(\frac{y}{B_W} h_1 + A_R y\right) - z\right]$ without being taken less than 0,15φ C_2 L for load case "c" only	0,4	0,0

Note 1:

$h = C_{F2} h_2$

C_{F2} : Combination factor, to be taken equal to:
- C_{F2} = 1,0 for load case “c”
- C_{F2} = 0,5 for load case “d”.

B_W : Moulded breadth, in m, measured at the waterline at draught T_1, at the hull transverse section considered

A_R : Roll amplitude, defined in Sec 3, [2.4.1].

SECTION 6 INTERNAL PRESSURES AND FORCES

Symbols

For the symbols not defined in this Section, refer to the list at the beginning of this Chapter.

ρ_L : Density, in t/m^3, of the liquid carried

ρ_B : Density, in t/m^3, of the dry bulk cargo carried (see also [3]); in certain cases, such as spoils, the water held by capillarity is to be taken into account

z_{TOP} : Z co-ordinate, in m, of the highest point of the tank in the z direction

z_L : Z co-ordinate, in m, of the highest point of the liquid:

$$z_L = z_{TOP} + 0{,}5(z_{AP} - z_{TOP})$$

z_{AP} : Z co-ordinate, in m, of the top of air pipe, to be taken not less than z_{TOP}

p_{PV} : Setting pressure, in bar, of safety valves

M : Mass, in t, of a dry unit cargo carried

a_{X1}, a_{Y1}, a_{Z1}: Reference values of the accelerations in the upright ship condition, defined in Sec 3, [3.4], calculated in way of:

- the centre of gravity of the compartment, in general
- the centre of gravity of any dry unit cargo, in the case of this type of cargo

a_{X2}, a_{Y2}, a_{Z2}: Reference values of the accelerations in the inclined ship condition, defined in Sec 3, [3.4], calculated in way of:

- the centre of gravity of the compartment, in general
- the centre of gravity of any dry unit cargo, in the case of this type of cargo

C_{FA} : Combination factor, to be taken equal to:

- C_{FA} = 0,7 for load case "c"
- C_{FA} = 1,0 for load case "d"

H : Height, in m, of a tank, to be taken as the vertical distance from the bottom to the top of the tank, excluding any small hatchways

d_F : Filling level, in m, of a tank, to be taken as the vertical distance, measured with the ship at rest, from the bottom of the tank to the free surface of the liquid

ℓ_C : Longitudinal distance, in m, between transverse watertight bulkheads or transverse wash bulkheads, if any, or between a transverse watertight bulkhead and the adjacent transverse wash bulkhead; to this end, wash bulkheads are those satisfying the requirements in Ch 4, Sec 7, [5]

b_C : Transverse distance, in m, between longitudinal watertight bulkheads or longitudinal wash bulkheads, if any, or between a longitudinal watertight bulkhead and the adjacent longitudinal wash bulkhead; to this end, wash bulkheads are those satisfying the requirements in Ch 4, Sec 7, [5]

d_{TB} : Vertical distance, in m, from the baseline to the tank bottom.

1 Liquids

1.1 Still water pressure

1.1.1 Still water pressure for completely filled tanks

The still water pressure to be used in combination with the inertial pressure in [1.2] is the greater of the values obtained, in kN/m^2, from the following formulae:

$$p_S = \rho_L g(z_L - z)$$

$$p_S = \rho_L g(z_{TOP} - z) + 100 p_{PV}$$

In no case is it to be taken, in kN/m^2, less than:

$$p_S = \rho_L g\left(\frac{0,8L_1}{420 - L_1}\right)$$

1.1.2 Still water pressure for partly filled tanks

The still water pressure to be used in combination with the dynamic pressure in [2] is to be obtained, in kN/m^2, from the following formulae:

- in the case of no restrictions on the filling level (see [2.2]):

  $$p_s = 0,2\rho_L g(z - d_{TB})$$

- in the case of restrictions on the filling level (see [2.3]):

  $$p_S = \rho_L g(d_F + d_{TB} - z)$$

1.2 Inertial pressure

1.2.1 Inertial pressure

The inertial pressure is obtained from the formulae in Tab 1, and is to be taken such that:

$$p_S + p_W \geq 0$$

where p_S is defined in [1.1].

For typical tank arrangements, see also App 1.

Table 1 : Liquids - Inertial pressure

Ship condition	Load case	Inertial pressure p_W, in kN/m^2
Upright	"a"	No inertial pressure
	"b"	$\rho_L[0,5a_{X1}\ell_B + a_{Z1}(z_{TOP} - z)]$
Inclined (negative roll angle)	"c"	$\rho_L[a_{TY}(y - y_H) + a_{TZ}(z - z_H) + g(z - z_{TOP})]$
	"d"	

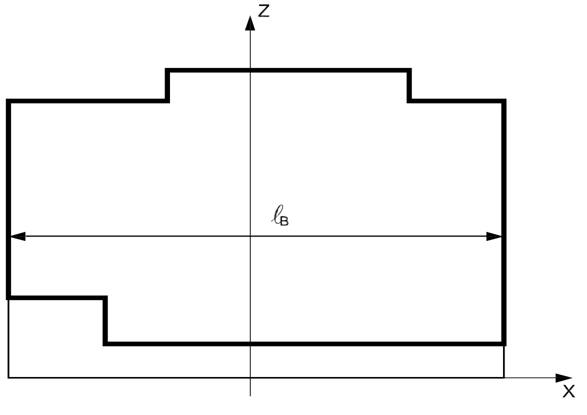
Note 1:

ℓ_B : Longitudinal distance, in m, between the transverse tank boundaries, without taking into account small recesses in the lower part of the tank (see Fig 1)

a_{TY}, a_{TZ} : Y and Z components, in m/s^2, of the total acceleration vector defined in [1.2.2] for load case "c" and load case "d"

y_H, z_H : Y and Z co-ordinates, in m, of the highest point of the tank in the direction of the total acceleration vector, defined in [1.2.3] for load case "c" and load case "d".

Figure 1 : Upright ship conditions - Distance ℓ_B



1.2.2 Total acceleration vector

The total acceleration vector is the vector obtained from the following formula:

$$\vec{A_T} = \vec{A} + \vec{G}$$

where:

A : Acceleration vector whose absolute values of X, Y and Z components are the longitudinal, transverse and vertical accelerations defined in Sec 3, [3.4]

G : Gravity acceleration vector.

The Y and Z components of the total acceleration vector and the angle it forms with the z direction are defined in Tab 2.

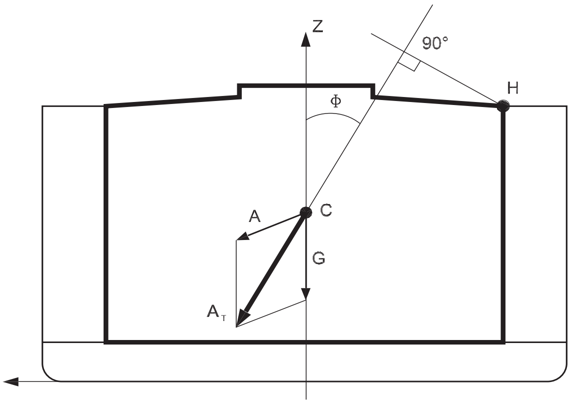
Table 2 : Inclined ship conditions Y and Z components of the total acceleration vector and angle Φ it forms with the z direction

Components (negative roll angle)		Angle Φ, in rad
a_{TY}, in m/s^2	a_{TZ}, in m/s^2	
$0{,}7C_{FA}a_{Y2}$	$-0{,}7C_{FA}a_{Z2} - g$	$\operatorname{atan}\frac{a_{TY}}{a_{TZ}}$

1.2.3 Highest point of the tank in the direction of the total acceleration vector

The highest point of the tank in the direction of the total acceleration vector A_T, defined in [1.2.2], is the point of the tank boundary whose projection on the direction forming the angle Φ with the vertical direction is located at the greatest distance from the tank's centre of gravity. It is to be determined for the inclined ship condition, as indicated in Fig 2, where A and G are the vectors defined in [1.2.2] and C is the tank's centre of gravity.

Figure 2 : Inclined ship conditions Highest point H of the tank in the direction of the total acceleration vector



2 Dynamic pressure in partly filled tanks intended for the carriage of liquid cargoes or ballast

2.1 Risk of resonance

2.1.1 Where tanks are partly filled at a level $0{,}1H \le d_F \le 0{,}95H$, the risk of resonance between:

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

is to be evaluated on the basis of the criteria specified in Tab 3.

Table 3 : Criteria for the evaluation of the risk of resonance

Ship condition	Risk of resonance if:	Resonance due to:
Upright	$\frac{T_X}{T_P} > 0,7$ and $\frac{d_F}{\ell_C} > 0,1$	Pitch
Inclined	$0,7 < \frac{T_Y}{T_R} < 1,3$ and $\frac{d_F}{b_C} > 0,1$	Roll
	$\frac{T_Y}{T_{SW}} > 0,7$ and $\frac{d_F}{b_C} > 0,1$	Sway

where:

T_X : Natural period, in s, of the liquid motion in the longitudinal direction:

$$T_X = \sqrt{\frac{4\pi\ell_S}{g\tanh\frac{\pi d_F}{\ell_S}}}$$

T_Y : Natural period, in s, of the liquid motion in the transverse direction:

$$T_Y = \sqrt{\frac{4\pi b_S}{g\tanh\frac{\pi d_F}{b_S}}}$$

ℓ_S : Length, in m, of the free surface of the liquid, measured horizontally with the ship at rest and depending on the filling level d_F, as shown in Fig 3; in this figure, wash bulkheads are those satisfying the requirements in Ch 4, Sec 7, [5]

b_S : Breadth, in m, of the free surface of the liquid, measured horizontally with the ship at rest and depending on the filling level d_F, as shown in Fig 4 for ships without longitudinal watertight or wash bulkheads; for ships fitted with longitudinal watertight or wash bulkheads (see Fig 5), b_S is delimited by these bulkheads (to this end, wash bulkheads are those satisfying the requirements in Ch 4, Sec 7, [5])

T_P : Pitch period, in s, defined in Sec 3, [2]

T_R : Roll period, in s, defined in Sec 3, [2]

T_{SW} : Sway period, in s, defined in Sec 3, [2].

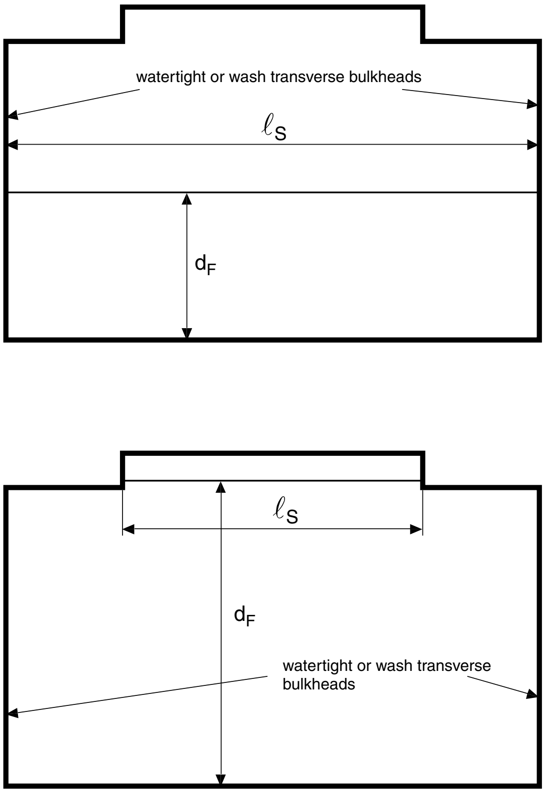
2.1.2 The Society may accept that the risk of resonance is evaluated on the basis of dynamic calculation procedures, where deemed necessary in relation to the tank's dimensions and the ship's characteristics. The calculations are to be submitted to the Society for approval.

2.2 Dynamic pressure in the case of no restrictions on the filling level

2.2.1 Evaluation of the risk of resonance

Where there are no restrictions on the filling level d_F, the risk of resonance is to be evaluated, according to the procedure in [2.1], for various filling levels between 0,1H and 0,95H. In general, filling levels spaced at intervals of 0,1H are to be considered with the additional level of 0,95H. The Society may require examination of other filling levels where deemed necessary on the basis of the tank's shape and the ship's characteristics.

Figure 3 : Length ℓ_S of the free surface of the liquid



2.2.2 Risk of resonance in upright ship condition

Where there is a risk of resonance in upright ship condition, the sloshing pressure calculated according to [2.2.4] is to be considered as acting on the transverse bulkheads which form tank boundaries.

Where tank bottom transverses or wash transverses are fitted, the sloshing pressure calculated according to [2.2.5] is to be considered as acting on them.

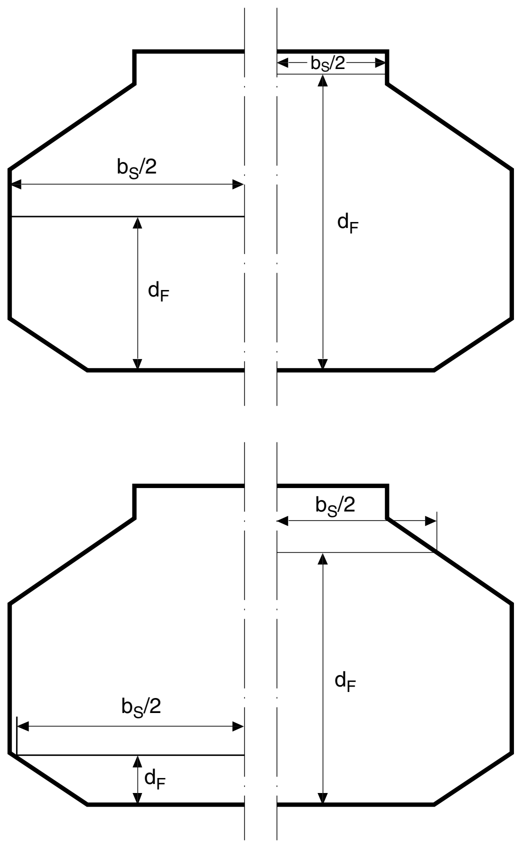
The Society may also require the sloshing pressure to be considered when there is no risk of resonance, but the tank arrangement is such that $\ell_C/L > 0,15$.

2.2.3 Risk of resonance in inclined ship condition

Where there is a risk of resonance in inclined ship condition, the sloshing pressure calculated according to [2.2.4] is to be considered as acting on longitudinal bulkheads, inner sides or sides which, as the case may be, form tank boundaries.

If sloped longitudinal topsides are fitted, they are to be considered as subjected to the sloshing pressure if their height is less than 0,3H.

Figure 4 : Breadth b_S of the free surface of the liquid, for ships without longitudinal bulkheads



2.2.4 Sloshing pressure

The sloshing pressure is obtained, in kN/m², from the following formulae (see Fig 6):

$$p_{SL} = \frac{z - d_{TB}}{0,6H} p_0 \qquad \text{for} \quad z < 0,6H + d_{TB}$$

$$p_{SL} = p_0 \qquad \text{for} \quad 0,6H + d_{TB} \le z \le 0,7H + d_{TB}$$

$$p_{SL} = \frac{H + d_{TB} - z}{0,3H} p_0 \qquad \text{for} \quad z > 0,7H + d_{TB}$$

where p_0 is the reference pressure, in kN/m², defined in Tab 4 for upright and inclined ship conditions.

2.2.5 Sloshing pressure on tank bottom transverses in the case of resonance in upright ship condition

Where there is a risk of resonance in upright ship condition, the sloshing pressure to be considered as acting on tank bottom transverses is obtained, in kN/m², from the following formula:

$$p_{SL,W} = 0,8\rho_L g)(2,95\ )(0,1d_{TB}$$

where n is the number of bottom transverses in the tank.

Figure 5 : Breadth b_S of the free surface of the liquid, for ships with longitudinal bulkheads

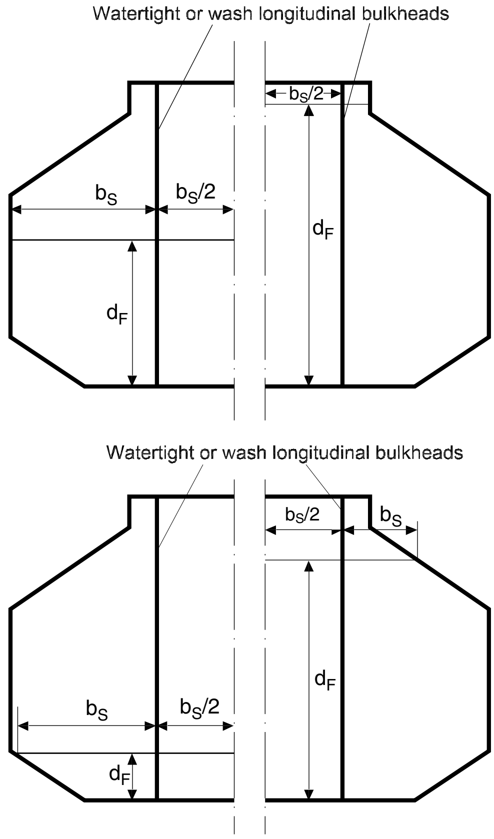


Figure 6 : Sloshing pressure p_{SL} in the case of no restrictions on the filling level

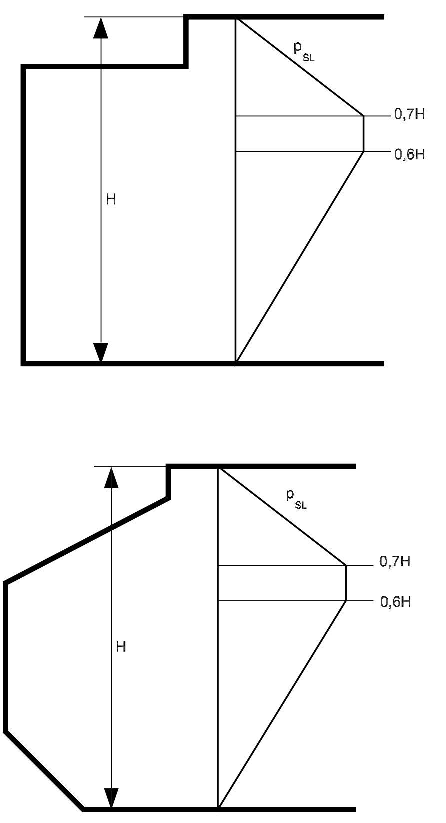


Table 4 : Reference pressure for calculation of sloshing pressures

Ship condition	Reference pressure p_0 , in kN/m²	Meaning of symbols used in the definition of p_0
Upright	$\varphi_U \rho_L g S \ell_C A_P$	φ_U : Coefficient defined as follows: φ_U = 1,0 in the case of smooth tanks or tanks with bottom transverses whose height, in m, measured from the tank bottom, is less than 0,1H φ_U = 0,4 in the case of tanks with bottom transverses whose height, in m, measured from the tank bottom, is not less than 0,1H S : Coefficient defined as follows: S = 0,4 + 0,008 L if L ≤ 200 m S = 1,2 + 0,004 L if L > 200 m A_P : Pitch amplitude, in rad, defined in Sec 3, [2].
Inclined	$1{,}15\varphi_I \rho_L g C_S \sqrt{B}\left(1 - 0{,}3\frac{B}{b_C}\right)$	φ_I : Coefficient defined as follows: • if b_C / B ≤ 0,3: $\varphi_I = 0$ • if b_C / B > 0,3: φ_I = 1 in the case of smooth tanks or tanks with bottom girders whose height, in m, measured from the tank bottom, is less than 0,1H φ_I = 0,4 in the case of tanks with bottom girders whose height, in m, measured from the tank bottom, is not less than 0,1H C_S : Coefficient defined as follows: C_S =0,8 b_C A_R if there is a risk of resonance due to roll (see [2.1.1]) C_S = 4,9 - 0,01L if there is a risk of resonance due to sway (see [2.1.1]) A_R : Roll amplitude, in rad, defined in Sec 3, [2].

2.2.6 Impact pressure in the case of resonance in upright ship condition

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

- transverse bulkheads which form tank boundaries, in the area extended vertically 0,15 H from the tank top
- the tank top in the area extended longitudinally 0,3 ℓ_C from the above transverse bulkheads.

The Society may also require the impact pressure to be considered as acting on the above structures when there is no risk of resonance, but the tank arrangement is such that ℓ_C/L > 0,15.

Where the upper part of a transverse bulkhead is sloped, the impact pressure is to be considered as acting on the sloped part of the transverse bulkhead and the tank top (as the case may be) in the area extended longitudinally 0,3 ℓ_C from the transverse bulkhead.

The impact pressure is obtained, in kN/m², from the following formula:

$$p_{I,U} = \varphi_U \rho_L g \ell_C A_P\left(0{,}9 + \frac{\ell_C}{L}\right)(2{,}6 + 0{,}007L)$$

where:

φ_U : Coefficient defined in Tab 4

A_P : Pitch amplitude, in rad, defined in Sec 3, [2].

Where the upper part of a transverse bulkhead is sloped, the pressure $p_{I,U}$ may be multiplied by the coefficient ϕ obtained from the following formula:

$$\phi = 1 - \frac{h_T}{0{,}3H}$$

to be taken not less than zero,

where h_T is the height, in m, of the sloped part of the transverse bulkhead.

2.2.7 Impact pressure in the case of resonance in inclined ship condition

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

- longitudinal bulkheads, inner sides or sides which, as the case may be, form tank boundaries, in the area extended vertically 0,15 H from the tank top
- the tank top in the area extended transversely 0,3b_C from the above longitudinal bulkheads, inner sides or sides.

Where the upper part of a longitudinal bulkhead, inner side or side is sloped, the impact pressure is to be considered as acting on this sloped part and the tank top (as the case may be) in the area extended transversely 0,3b_C from the longitudinal bulkhead, inner side or side.

The impact pressure is obtained, in kN/m², from the following formula:

$$p_{I,I} = 0{,}8\varphi_I \rho_L g C_S (0{,}375B - 4)$$

where:

φ_I, C_S : Coefficients defined in Tab 4.

Where the upper part of a longitudinal bulkhead, inner side or side is sloped, the pressure $p_{I,I}$ may be multiplied by the coefficient ϕ obtained from the following formula:

$$\phi = 1 - \frac{h_T}{0,3H}$$

to be taken not less than zero,

where h_T is the height, in m, of the sloped part of the longitudinal bulkhead, inner side or side.

2.2.8 Alternative methods

The Society may accept that the dynamic pressure is evaluated on the basis of dynamic calculation procedures, where deemed necessary in relation to the tank's dimensions and the ship's characteristics. The calculations are to be submitted to the Society for verification.

2.3 Dynamic pressure in the case of restrictions on the filling level

2.3.1 Evaluation of the risk of resonance

Where there are restrictions on the filling level d_F, the risk of resonance is to be evaluated, according to the procedure in [2.1], for the permitted filling levels where these are between 0,1H and 0,95H.

2.3.2 Risk of resonance in upright ship condition

Where there is a risk of resonance in upright ship condition for a permitted d_F, the sloshing pressure calculated according to [2.3.4] is to be considered as acting on transverse bulkheads which form tank boundaries, in the area extended vertically $0,2d_F$ above and below d_F (see Fig 7).

The Society may also require the sloshing pressure to be considered when there is no risk of resonance, but the tank arrangement is such that $\ell_C/L > 0,15$.

2.3.3 Risk of resonance in inclined ship condition

Where there is a risk of resonance in inclined ship condition for a permitted d_F, the sloshing pressure calculated according to [2.3.4] is to be considered as acting on longitudinal bulkheads, inner sides or sides which, as the case may be, form tank boundaries, in the area extended vertically $0,2d_F$ above and below d_F (see Fig 7).

If sloped longitudinal topsides are fitted, they are to be considered as subjected to the sloshing pressure if their height is less than 0,3H.

2.3.4 Sloshing pressure

Where there is a risk of resonance for a permitted d_F, the sloshing pressure is obtained, in kN/m², from the following formulae:

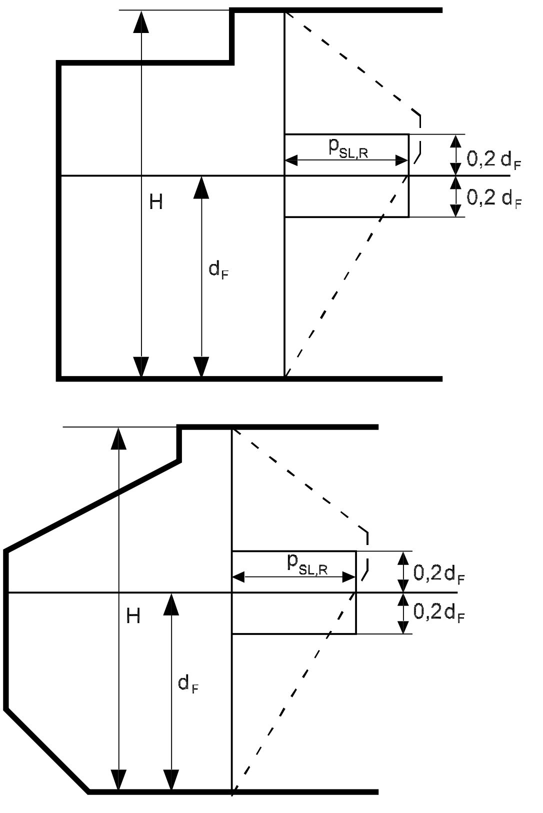
$$p_{SL,R} = \frac{d_F}{0,6H} p_0 \quad \text{for} \quad d_F < 0,6H$$

$$p_{SL,R} = p_0 \quad \text{for} \quad 0,6H \le d_F \le 0,7H$$

$$p_{SL,R} = \frac{H - d_F}{0,3H} p_0 \quad \text{for} \quad d_F > 0,7H$$

where p_0 is the reference pressure defined in Tab 4 for upright and inclined ship conditions.

Figure 7 : Sloshing pressure $p_{SL,R}$ in the case of restrictions on the filling level



2.3.5 Impact pressure

Where there is a risk of resonance for a permitted d_F, the impact pressure due to the liquid motions is to be calculated as per [2.2.6] and [2.2.7] for upright and inclined ship conditions, respectively.

The Society may also require the impact pressure for upright ship condition to be considered when there is no risk of resonance, but the tank arrangement is such that $\ell_C/L > 0,15$.

3 Dry bulk cargoes

3.1 Still water and inertial pressures

3.1.1 Pressures transmitted to the hull structures

The still water and inertial pressures (excluding those acting on the sloping plates of topside tanks, which may be taken equal to zero) are obtained, in kN/m², as specified in Tab 5.

Table 5 : Dry bulk cargoes - Still water and inertial pressures

Ship condition	Load case	Still water pressure p_S and inertial pressure p_W, in kN/m²
Still water		$p_S = \rho_B g (z_B - z)\left\{(\sin\alpha)^2\left[\tan\left(45^o - \frac{\varphi}{2}\right)\right]^2 + (\cos\alpha)^2\right\}$
Upright	"a"	No inertial pressure
	"b"	$p_W = \rho_B a_{Z1} (z_B - z)\left\{(\sin\alpha)^2\left[\tan\left(45^o - \frac{\varphi}{2}\right)\right]^2 + (\cos\alpha)^2\right\}$
Inclined	"c"	The inertial pressure transmitted to the hull structures in inclined condition may generally be disregarded. Specific cases in which this simplification is not deemed permissible by the Society are considered individually.
	"d"	

Note 1:

z_B : Z co-ordinate, in m, of the rated upper surface of the bulk cargo (horizontal ideal plane of the volume filled by the cargo); see [3.1.2]

α : Angle, in degrees, between the horizontal plane and the surface of the hull structure to which the calculation point belongs

φ : Angle of repose, in degrees, of the bulk cargo (considered drained and removed); in the absence of more precise evaluation, the following values may be taken:
- $\varphi = 30^o$ in general
- $\varphi = 35^o$ for iron ore
- $\varphi = 25^o$ for cement.

3.1.2 Rated upper surface of the bulk cargo

The Z co-ordinate of the rated upper surface of the bulk cargo is obtained, in m, from the following formula (see Fig 8):

$$z_B = \frac{\frac{M_C}{\rho_B \ell_H} + \frac{V_{LS}}{\ell_H} + (h_{HT} - h_{DB}) b_{HT}}{2 y_{HT}} + h_{DB}$$

where:

M_C : Mass of cargo, in t, in the hold considered

ℓ_H : Length, in m, of the hold, to be taken as the longitudinal distance between the transverse bulkheads which form boundaries of the hold considered

V_{LS} : Volume, in m³, of the transverse bulkhead lower stool (above the inner bottom), to be taken equal to zero in the case of bulkheads fitted without lower stool

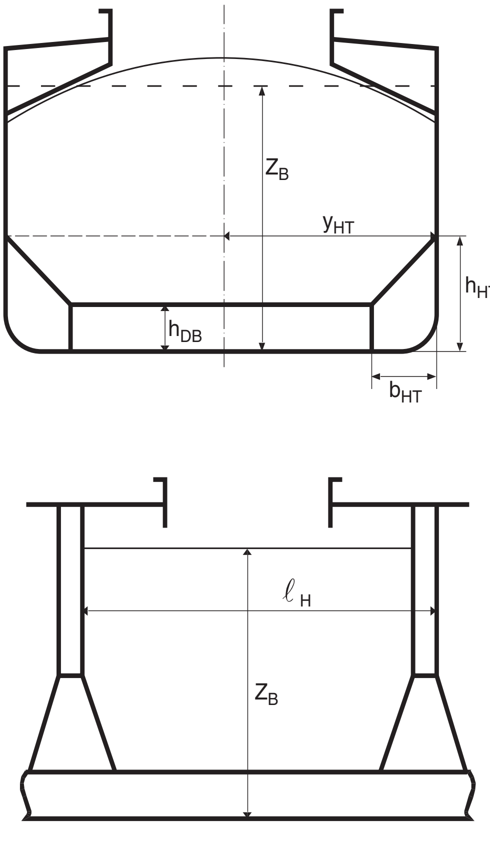
h_{HT} : Height, in m, of the hopper tank, to be taken as the vertical distance from the baseline to the top of the hopper tank

h_{DB} : Height, in m, of the double bottom, to be taken as the vertical distance from the baseline to the inner bottom

b_{HT} : Breadth, in m, of the hopper tank, to be taken as the transverse distance from the outermost double bottom girder to the outermost point of the hopper tank

y_{HT} : Half breadth, in m, of the hold, measured at the middle of ℓ_H and at a vertical level corresponding to the top of the hopper tank.

Figure 8 : Rated upper surface of the bulk cargo



4 Dry uniform cargoes

4.1 Still water and inertial pressures

4.1.1 General

The still water and inertial pressures are obtained, in kN/m², as specified in Tab 6.

In ships with two or more decks, the pressure transmitted to the deck structures by the dry uniform cargoes in cargo compartments is to be considered.

4.1.2 General cargo ships with the service notation completed with the additional service feature heavycargo *(1/7/2005)*

For ships with the service notation **general cargo ship** completed by the additional service feature **heavycargo [AREA1, X1 kN/m² -AREA2, X2 kN/m² - ....]** (see Pt A, Ch 1, Sec 2, [4.2.2]), the values of p_S, in kN/m², are to be specified by the Designer for each AREAi, according to [4.1.1], and introduced as Xi values in the above service feature.

The values of Xi, in kN/m² , are to be greater than10 kN/m² or 6,9 h_{TD}, as applicable, where h_{TD} is the compartment 'tweendeck height at side, in m.

Table 6 : Dry uniform cargoes Still water and inertial pressures

Ship condition	Load case	Still water pressure p_S and inertial pressure p_W, in kN/m²
Still water		The value of p_S is generally specified by the Designer; in any case, it may not be taken less than 10 kN/m². When the value of p_S is not specified by the Designer, it may be taken, in kN/m², equal to 6,9 h_{TD} , where h_{TD} is the compartment 'tweendeck height at side, in m.
Upright (positive heave motion)	"a"	No inertial pressure
	"b"	$p_{W,Z} = p_S \frac{a_{Z1}}{g}$ in z direction
Inclined (negative roll angle)	"c"	$p_{W,Y} = p_S \frac{C_{FA} a_{Y2}}{g}$ in y direction
	"d"	$p_{W,Z} = p_S \frac{C_{FA} a_{Z2}}{g}$ in z direction

Table 7 : Dry unit cargoes Still water and inertial forces *(1/7/2005)*

Ship condition	Load case	Still water force F_S and inertial force F_W, in kN
Still water		$F_S = Mg$
Upright (positive heave motion)	"a"	No inertial force
	"b"	$F_{W,X} = M a_{X1}$ in x direction $F_{W,Z} = M a_{Z1}$ in z direction
Inclined (negative roll angle)	"c"	$F_{W,Y} = M C_{FA} a_{Y2}$ in y direction
	"d"	$F_{W,Z} = M C_{FA} a_{Z2}$ in z direction

5 Dry unit cargoes

5.1 Still water and inertial forces

5.1.1 The still water and inertial forces transmitted to the hull structures are to be determined on the basis of the forces obtained, in kN, as specified in Tab 7, taking into account the elastic characteristics of the lashing arrangement and/or the structure which contains the cargo.

6 Wheeled cargoes

6.1 Still water and inertial forces

6.1.1 General

Caterpillar trucks and unusual vehicles are considered by the Society on a case by case basis.

The load supported by the crutches of semi-trailers, handling machines and platforms is considered by the Society on a case by case basis.

6.1.2 Tyred vehicles

The forces transmitted through the tyres are comparable to pressure uniformly distributed on the tyre print, whose dimensions are to be indicated by the Designer together with information concerning the arrangement of wheels on axles, the load per axles and the tyre pressures.

With the exception of dimensioning of plating, such forces may be considered as concentrated in the tyre print centre.

The still water and inertial forces transmitted to the hull structures are to be determined on the basis of the forces obtained, in kN, as specified in Tab 8.

6.1.3 Non-tyred vehicles

The requirements of [6.1.2] also apply to tracked vehicles; in this case the print to be considered is that below each wheel or wheelwork.

For vehicles on rails, all the forces transmitted are to be considered as concentrated.

7 Accommodation

7.1 Still water and inertial pressures

7.1.1 The still water and inertial pressures transmitted to the deck structures are obtained, in kN/m², as specified in Tab 9.

8 Machinery

8.1 Still water and inertial pressures

8.1.1 The still water and inertial pressures transmitted to the deck structures are obtained, in kN/m², as specified in Tab 11.

Table 8 : Wheeled cargoes Still water and inertial forces

Ship condition	Load case	Still water force F_S and inertial force F_W , in kN
Still water **(1) (2)**		$F_S = Mg$
Upright (positive heave motion) **(1)**	"a"	No inertial force
	"b" **(3)**	$F_{W,Z} = Ma_{Z1}$ in z direction
Inclined (negative roll angle) **(2)**	"c"	$F_{W,Y} = MC_{FA}a_{Y2}$ in y direction $F_{W,Z} = MC_{FA}a_{Z2}$ in z direction
	"d"	

(1) This condition defines the force, applied by one wheel, to be considered for the determination of scantlings of plating, ordinary stiffeners and primary supporting members, as defined in Chapter 7, with M obtained, in t, from the following formula:

$$M = \frac{Q_A}{n_W}$$

where:

Q_A : Axle load, in t. For fork-lift trucks, the value of Q_A is to be taken equal to the total mass of the vehicle, including that of the cargo handled, applied to one axle only.

n_W : Number of wheels for the axle considered.

(2) This condition is to be considered for the racking analysis of ships with the service notation **ro-ro cargo ship** or **ro-ro passenger ship**, as defined in Ch 7, App 1, with M taken equal to the mass, in t, of wheeled loads located on the structural member under consideration.

(3) For fork-lift trucks operating in harbour conditions, the inertial force may be reduced by 50%.

Table 9 : Accommodation Still water and inertial pressures

Ship condition	Load case	Still water pressure p_S and inertial pressure p_W, in kN/m²
Still water		The value of p_S is defined in Tab 10 depending on the type of the accommodation compartment.
Upright (positive heave motion)	"a"	No inertial pressure
	"b"	$p_W = p_S \frac{a_{Z1}}{g}$
Inclined	"c"	The inertial pressure transmitted to the deck structures in inclined condition may generally be disregarded. Specific cases in which this simplification is not deemed permissible by the Society are considered individually.
	"d"	

Table 10 : Still water deck pressure in accommodation compartments

Type of accommodation compartment	p_S , in kN/m²
Large public spaces, such as: restaurants, halls, cinemas, lounges	5,0
Large rooms, such as: games and hobbies rooms, hospitals	3,0
Cabins	3,0
Other compartments	2,5

Table 11 : Machinery Still water and inertial pressures

Ship condition	Load case	Still water pressure p_S and inertial pressure p_W , in kN/m²
Still water		$p_S = 10$
Upright (positive heave motion)	"a"	No inertial pressure
	"b"	$p_W = p_S \frac{a_{Z1}}{g}$
Inclined	"c"	The inertial pressure transmitted to the deck structures in inclined condition may generally be disregarded. Specific cases in which this simplification is not deemed permissible by the Society are considered individually.
	"d"	

9 Flooding

9.1 Still water and inertial pressures

9.1.1 *(1/7/2011)*

Unless otherwise specified, the still water and inertial pressures to be considered as acting on bulkheads, inner sides or internal decks, which constitute boundaries of compartments not intended to carry liquids are obtained, in kN/m², from the formulae in Tab 12.

Table 12 : Flooding
Still water and inertial pressures *(1/7/2022)*

Still water pressure p_{SF} , in kN/m²	Inertial pressure p_{WF} , in kN/m²
$\rho g(z_F - z)$ without being taken less than 0,4 g d_0	$0,6\rho a_{Z1}(z_F - z)$ without being taken less than 0,4 g d_0
Note 1: z_F : Z co-ordinate, in m, of the deepest equilibrium waterline, taking into account the transient conditions. The deepest equilibrium waterlines are to be provided by the Designer under his own responsibility. In case the deepest equilibrium waterline is not known, e.g. at the preliminary design stage, the Z co-ordinate, in m, of the freeboard deck at side in way of the transverse section considered may be used in lieu. d_0 : Distance, in m, to be taken equal to: d_0 = 0,02L for 90 m ≤ L < 120 m d_0 = 2,4 for L ≥ 120 m.	

10 Testing

10.1 Still water pressures

10.1.1 *(1/7/2020)*

The still water pressure is to be considered as acting on plates and stiffeners subject to tank testing is obtained, in kN/m², from the formulae in Tab 13.

No inertial pressure is to be considered as acting on plates and stiffeners subject to tank testing.

Table 13 : Testing -
Still water pressures *(1/7/2020)*

Compartment or structure to be tested	Still water pressure p_{ST} , in kN/m²
Double bottom tanks	The greater of the following: p_{ST} = 10 [(z_{TOP} - z) + d_{AP}] p_{ST} = 10 [(z_{TOP} - z) + 2,4] p_{ST} = 10 (z_{BD} - z)
Double side tanks	The greater of the following: p_{ST} = 10 [(z_{TOP} - z) + d_{AP}] p_{ST} = 10 [(z_{TOP} - z) + 2,4] p_{ST} = 10 (z_{BD} - z)
Deep tanks other than those listed elsewhere in this Table	The greater of the following: p_{ST} = 10 [(z_{TOP} - z) + d_{AP}] p_{ST} = 10 [(z_{TOP} - z) + 2,4]
Cargo oil tanks	The greater of the following: p_{ST} = 10 [(z_{TOP} - z) + d_{AP}] p_{ST} = 10 [(z_{TOP} - z) + 2,4] p_{ST} = 10 [(z_{TOP} - z) + 10p_{pv}]
Ballast holds of ships with service notation: **bulk carrier ch xii** or **bulk carrier ch xii - double side-skin** or **bulk carrier ESP** or **self-unloading bulk carrier ESP**	The greater of the following: p_{ST} = 10 [(z_{TOP} - z) + d_{AP}] p_{ST} = 10 (z_h - z) Where: z_h: Z co-ordinate, in m, of the top of hatch coaming
Peak tanks	The greater of the following: p_{ST} = 10 [(z_{TOP} - z) + d_{AP}] p_{ST} = 10 [(z_{TOP} - z) + 2,4]
Chain locker	p_{ST} = 10 (z_{cp} - z) Where: z_{cp}: Z co-ordinate, in m, of the top of chain pipe
Ballast ducts	The greater of the following: p_{ST} = 10 [(z_{TOP} - z) + 10p_{pv}] Ballast pump maximum pressure
Integral or independent cargo tanks of ships with service notation **chemical tanker**	The greater of the following: p_{ST} = 10 [(z_{TOP} - z) + 2,4] p_{ST} = 10 [(z_{TOP} - z) + 10p_{pv}]

Compartment or structure to be tested	Still water pressure p_{ST} , in kN/m²
Fuel oil tanks	The greater of the following: $p_{ST} = 10 [(z_{TOP} - z) + d_{AP}]$ $p_{ST} = 10 [(z_{TOP} - z) + 2,4]$ $p_{ST} = 10 [(z_{TOP} - z) + 10p_{PV}]$ $p_{ST} = 10 (z_{BD} - z)$
Note 1: d_{AP}: Distance from the top of air pipe to the top of compartment, in m z_{BD} : Z co-ordinate, in m, of the bulkhead deck	

APPENDIX 1 INERTIAL PRESSURE FOR TYPICAL TANK ARRANGEMENT

1 Liquid cargoes and ballast - Inertial pressure

1.1 Introduction

1.1.1 Sec 6, [1] defines the criteria to calculate the inertial pressure p_W induced by liquid cargoes and ballast in any type of tank. The relevant formulae are specified in Sec 6, Tab 1 and entail the definition of the highest point of the tank in the direction of the total acceleration vector. As specified in Sec 6, [1.2], this point depends on the geometry of the tank and the values of the acceleration. For typical tank arrangements, the highest point of the tank in the direction of the total acceleration vector can easily be identified and the relevant formulae written using the tank geometric characteristics.

1.1.2 This Appendix provides the formulae for calculating the inertial pressure p_W in the case of typical tank arrangements.

1.2 Formulae for the inertial pressure calculation

1.2.1 For typical tank arrangements, the inertial pressure transmitted to the hull structures at the calculation point P in inclined ship condition may be obtained from the formulae in Tab 1, obtained by applying to those tanks the general formula in Sec 6, Tab 1.

Table 1 : Liquid cargoes and ballast - Inertial pressure for typical tank arrangements

Ship condition	Load case	Inertial pressure p_W , in kN/m²
Inclined (negative roll angle)	“c”	$0,7C_{FA}\rho_L(a_{Y2}b_L + a_{Z2}d_H)$
	“d”	

Note 1:

- C_{FA} : Combination factor, to be taken equal to:
  - C_{FA} = 0,7 for load case “c”
  - C_{FA} = 1,0 for load case “d”
- ρ_L : Density, in t/m³, of the liquid cargo carried
- a_{Y2}, a_{Z2} : Reference values of the acceleration in the inclined ship condition, defined in Sec 3, [3.4], calculated in way of the centre of gravity of the tank
- b_L, d_H : Transverse and vertical distances, in m, to be taken as indicated in Fig 1 to Fig 6 for various types of tanks; for the cases in Fig 1 to Fig 4, where the central cargo area is divided into two or more tanks by longitudinal bulkheads, b_L and d_H for calculation points inside each tank are to be taken as indicated in Fig 5 for the double side. The angle Φ which appears in Fig 3 and Fig 4 is defined in Sec 6, Tab 2.

Figure 1 : Distances b_L and d_H

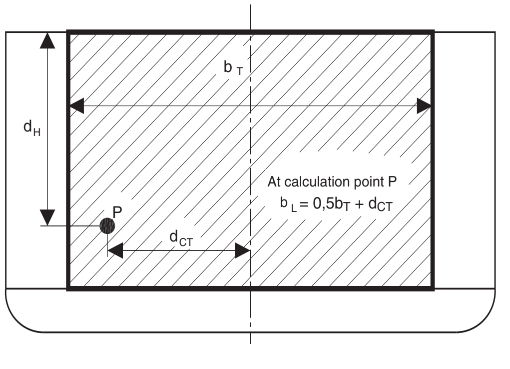


Figure 2 : Distances b_L and d_H

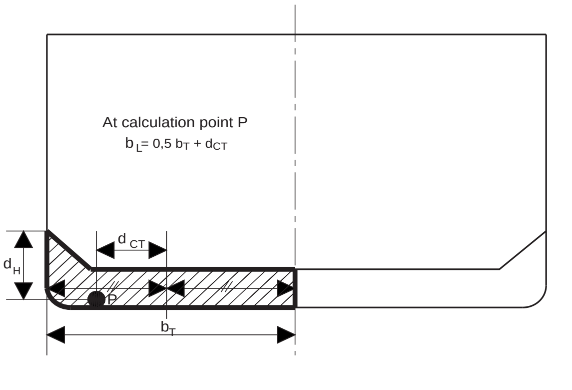


Figure 3 : Distances b_L and d_H

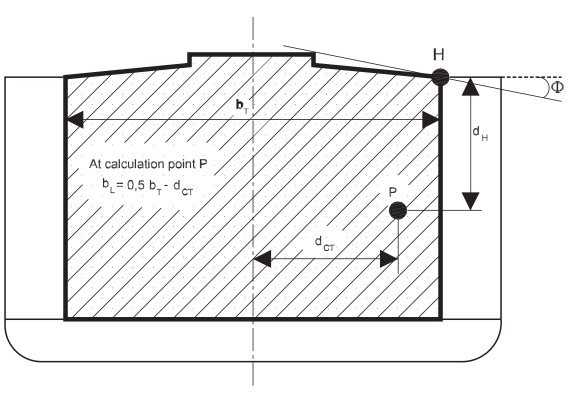


Figure 5 : Distances b_L and d_H

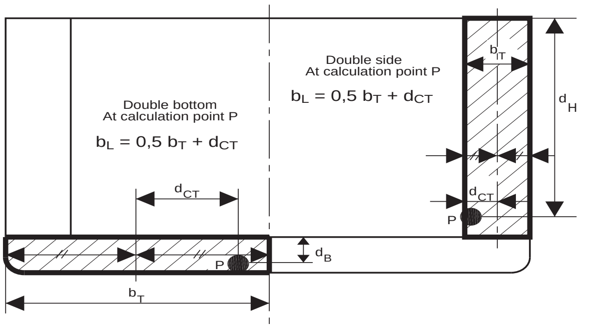


Figure 4 : Distances b_L and d_H

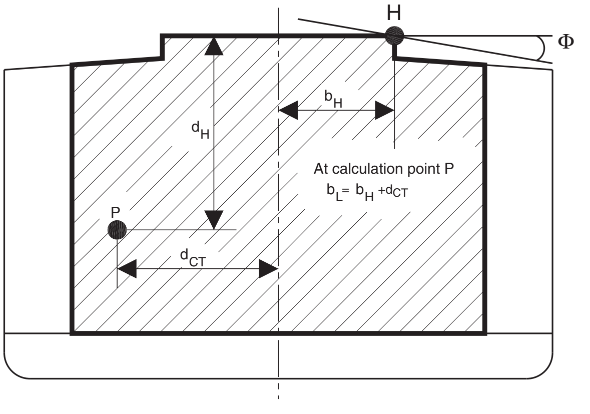
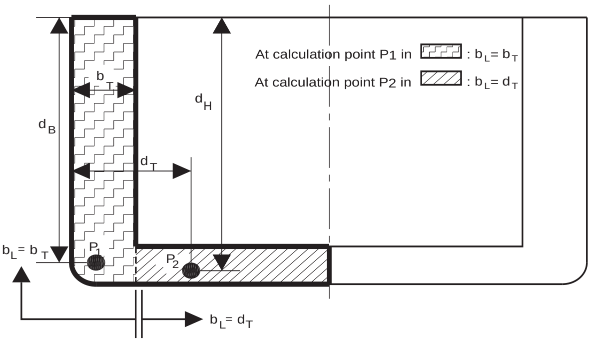


Figure 6 : Distances b_L and d_H



APPENDIX 2 GUIDELINES FOR BALLAST LOADING CONDITIONS OF CARGO VESSELS INVOLVING PARTIALLY FILLED BALLAST TANKS

1 General guidance note

1.1 Introduction

1.1.1 *(1/1/2022)*
This Appendix is intended to provide guidance and interpretation of "Partially filled ballast tanks in ballast loading conditions" in Sec 2, [2.1.2] b).

1.1.2 *(1/1/2022)*
Case A and B are generally applicable for ballast loading conditions for any cargo vessel which might have one Ballast Water (BW) Tank (or one pair of BW Tanks) partially filled.

1.1.3 *(1/1/2022)*
Where applicable, similar considerations are to be given to other cargo vessels covered by Sec 2 where ballast loading conditions involving partially filled ballast tanks may cause concerns for the longitudinal strength of the vessels.

1.1.4 *(1/1/2022)*
This Appendix does not apply to CSR Bulk Carriers and Oil Tankers or to container ships to which Pt E, Ch 2, App 1 is applicable.

1.1.5 *(1/1/2022)*
In the Figures, the conditions only intended for strength verification (not operational) are marked with a star (*).

2 Case A and B

2.1 Case A

2.1.1 *(1/1/2022)*
Fig 1 and Fig 2 shows Case A, with a cargo vessel where partial filling of BW Tank no. 6 (P/S) is permitted and may take place at any time during the ballast voyage. Intermediate condition(s) should be specified as shown in the Figures, however filling/partial filling of BW Tank no. 6 (P/S) may be done at any step to keep acceptable trim and propeller immersion during the ballast voyage.

To obtain full operational flexibility regarding the filling level of BW Tank no. 6 (P/S), loading conditions A2 (full at departure)* and A8 (empty at arrival)* is to be added for strength verification. Additional conditions (full and empty BW Tank no. 6 (P/S)) related to the intermediate conditions A3-A6 are not necessary as A2* and A8* will be the most critical one.

2.2 Case B

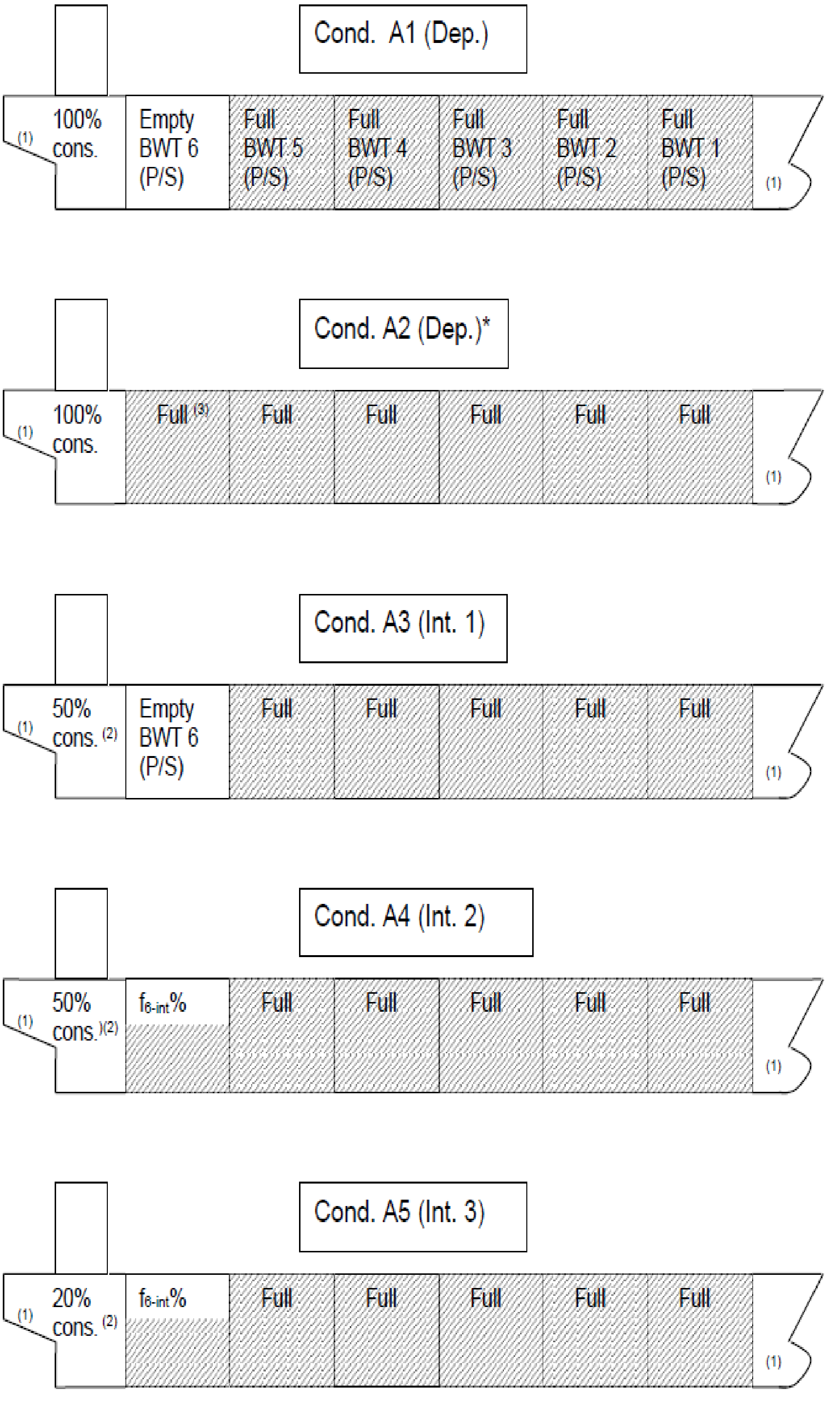
2.2.1 *(1/1/2022)*
Fig 3 and Fig 4 shows Case B, with a cargo vessel where partial filling of BW Tank no. 6 (P/S) to a given level ($f_{6\text{-int}\%}$) will be done after a specified % consumables is reached, see conditions B2 and B3. Before this % consumables (shown as 50% in this Figure) is reached, BW Tank no. 6 (P/S) is to be kept empty. When reaching a given level of consumables (shown as 20% in Fig 2), BW Tank no. 6 (P/S) is to be kept full, see conditions B5 and B6. Two additional intermediate conditions (B4* and B7*) are to be added for longitudinal strength verification.

In order to categorize a vessel according to Case B, clear operational guidance for partial filling of ballast tanks, in association with the consumption level as shown in Fig 3 and Fig 4, is to be given in the loading manual. If such operational guidance is not given, Case A is to be applied.

2.3 Limitation of consumables

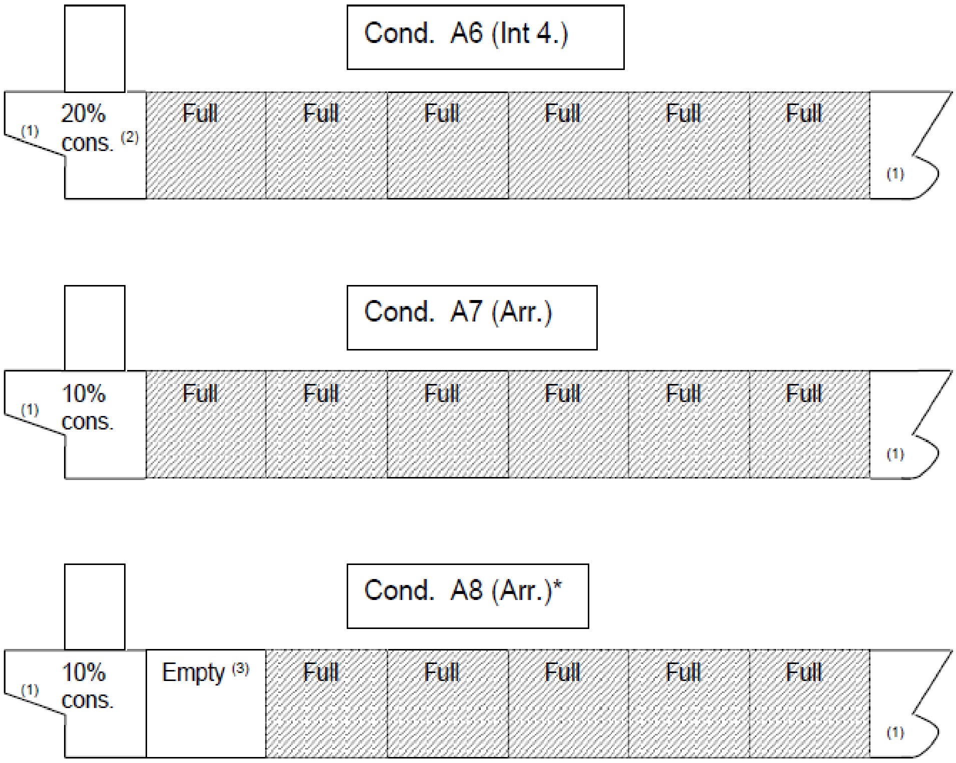
2.3.1 *(1/1/2022)*
Case A has no limitation of consumables, whereas Case B has limitation of consumables.

Figure 1 : Case A *(1/1/2022)*



Case A, Partial filling of ballast tank no. 6 (P/S) is permitted at any stage during voyage. The intermediate conditions are specified, however other partial filling of BW Tank no. 6 (P/S) may be applied to keep acceptable trim and propeller immersion during the ballast voyage. Conditions only intended for strength verification (not operational) are marked: *

Figure 2 : Case A (continued) *(1/1/2022)*



Case A, Partial filling of ballast tank no. 6 (P/S) is permitted at any stage during voyage. The intermediate conditions are specified, however other partial filling of BW Tank no. 6 (P/S) may be applied to keep acceptable trim and propeller immersion during the ballast voyage. Conditions only intended for strength verification (not operational) are marked: *

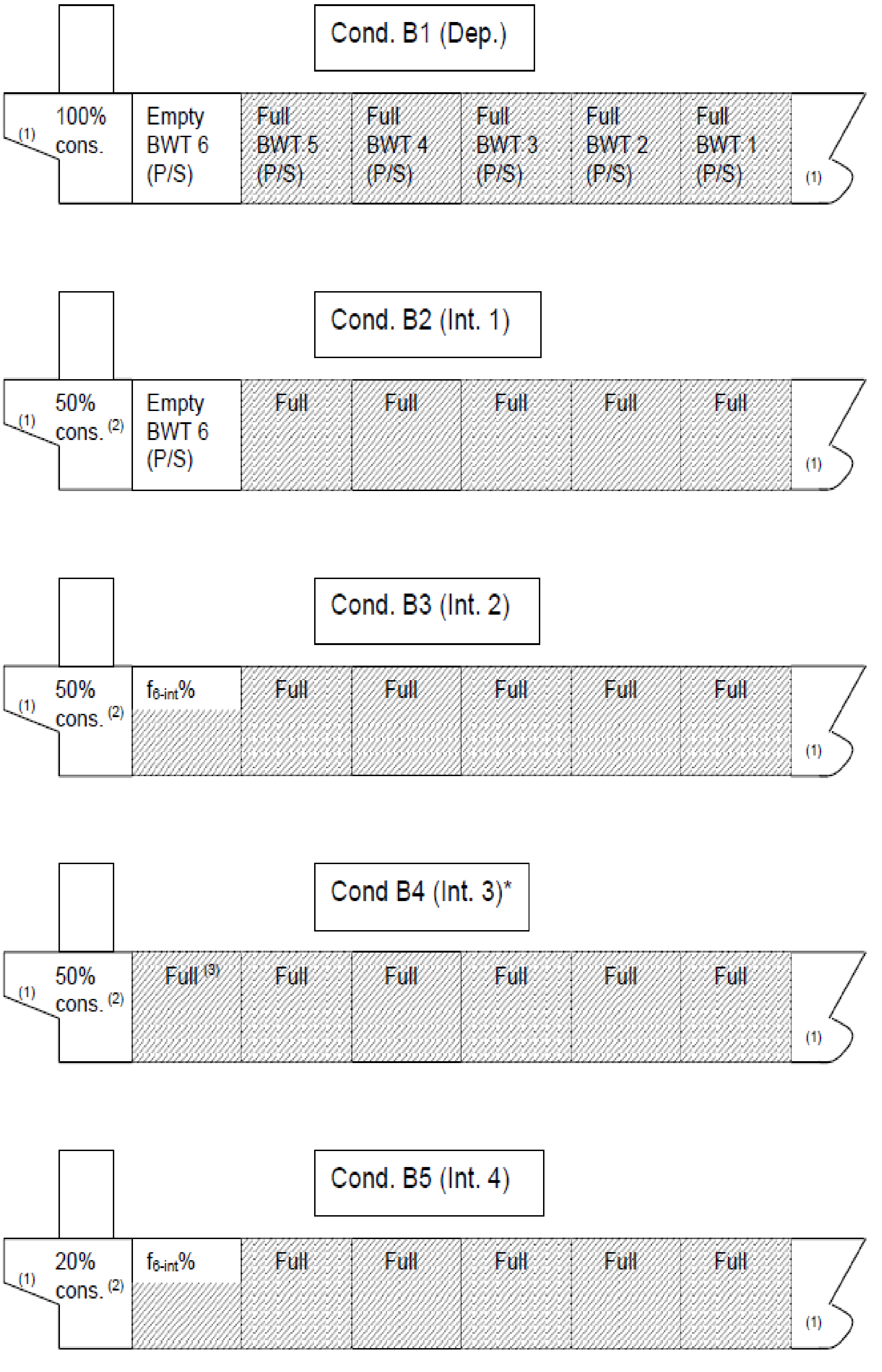
Notes:

(1) For peak tanks intended to be partially filled, all combinations of full or partially filled at intended level for those tanks are to be investigated.

(2) The intermediate condition(s) to be specified incl. % consumables

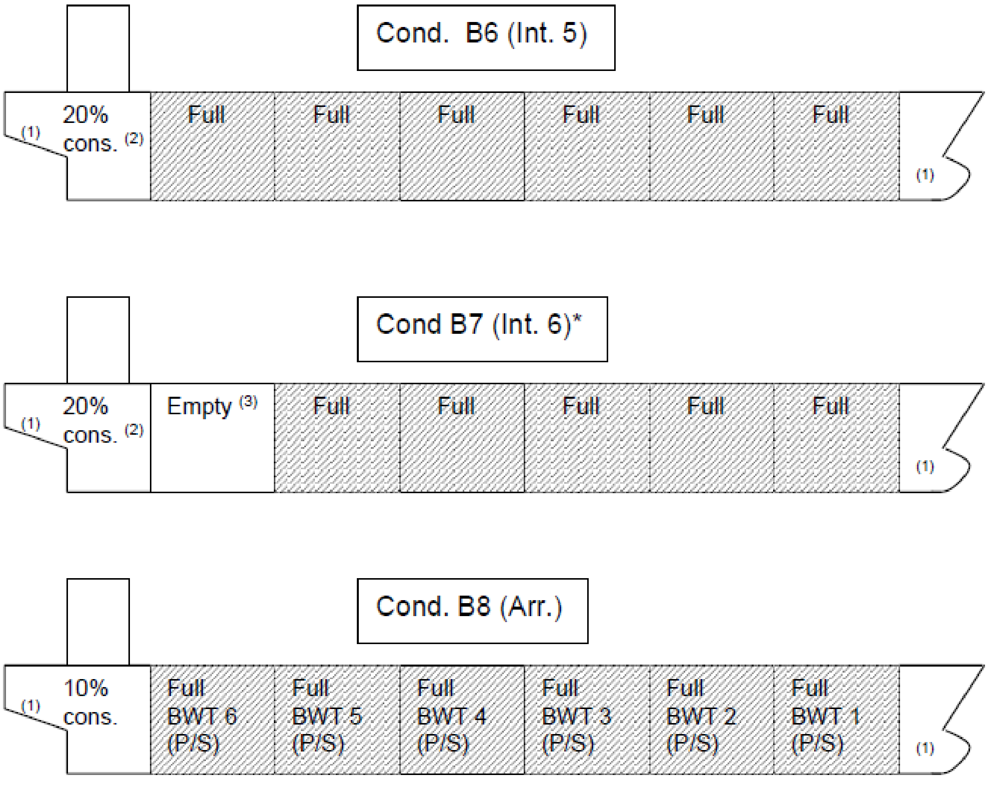
(3) For bulk carriers carrying ore and with large wing water ballast tanks full/empty may be replaced with maximum/minimum filling levels according to trim limitations given in Sec 2, [2.1.2], b).

Figure 3 : Case B *(1/1/2022)*



Case B, Partial filling of BW Tank no. 6 (P/S) only allowed during intermediate conditions, in this example between 50-20% consumables. Conditions only intended for strength verification (not operational) are marked: *

Figure 4 : Case B (continued) *(1/1/2022)*



Case B, Partial filling of BW Tank no. 6 (P/S) only allowed during intermediate conditions, in this example between 50-20% consumables. Conditions only intended for strength verification (not operational) are marked: *

Notes:

(1) For peak tanks intended to be partially filled, all combinations of full or partially filled at intended level for those tanks are to be investigated.

(2) The intermediate condition(s) to be specified incl.% consumables

(3) For bulk carriers carrying ore and with large wing water ballast tanks full/empty may be replaced with maximum/minimum filling levels according to trim limitations given in Sec 2, [2.1.2], b).

Part B
Hull and Stability

Chapter 6
HULL GIRDER STRENGTH

Symbols used in chapter 6

E : Young's modulus, in N/mm^2, to be taken equal to:
- for steels in general:
  $E = 2,06.10^5$ N/mm^2
- for stainless steels:
  $E = 1,95.10^5$ N/mm^2
- for aluminium alloys:
  $E = 7,0.10^4$ N/mm^2

M_{SW} : Still water bending moment, in kN.m:
- in hogging conditions:
  $M_{SW} = M_{SW,H}$
- in sagging conditions:
  $M_{SW} = M_{SW,S}$

$M_{SW,H}$: Design still water bending moment, in kN.m, in hogging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [2.2],

$M_{SW,S}$: Design still water bending moment, in kN.m, in sagging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [2.2], when the ship in still water is always in hogging condition, $M_{SW,S}$ is to be taken equal to 0,

M_{WV} : Vertical wave bending moment, in kN.m:
- in hogging conditions:
  $M_{WV} = M_{WV,H}$
- in sagging conditions:
  $M_{WV} = M_{WV,S}$

$M_{WV,H}$: Vertical wave bending moment, in kN.m, in hogging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [3.1],

$M_{WV,S}$: Vertical wave bending moment, in kN.m, in sagging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [3.1],

g : Gravity acceleration, in m/s^2:
$g = 9,81$ m/s^2.

SECTION 1 STRENGTH CHARACTERISTICS OF THE HULL GIRDER TRANSVERSE SECTIONS

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

1 Application

1.1

1.1.1 This Section specifies the criteria for calculating the hull girder strength characteristics to be used for the checks in Sec 2 and Sec 3, in association with the hull girder loads specified in Ch 5, Sec 2.

2 Calculation of the strength characteristics of hull girder transverse sections

2.1 Hull girder transverse sections

2.1.1 General

Hull girder transverse sections are to be considered as being constituted by the members contributing to the hull girder longitudinal strength, i.e. all continuous longitudinal members below the strength deck defined in [2.2], taking into account the requirements in [2.1.2] to [2.1.9].

These members are to be considered as having (see also Ch 4, Sec 2):

- gross scantlings, when the hull girder strength characteristics to be calculated are used for the yielding checks in Sec 2
- net scantlings, when the hull girder strength characteristics to be calculated are used for the ultimate strength checks in Sec 3 and for calculating the hull girder stresses for the strength checks of plating, ordinary stiffeners and primary supporting members in Chapter 7.

2.1.2 Continuous trunks and continuous lngitudinal hatch coamings

Continuous trunks and continuous longitudinal hatch coamings may be included in the hull girder transverse sections, provided they are effectively supported by longitudinal bulkheads or primary supporting members.

2.1.3 Longitudinal ordinary stiffeners or girders welded above the decks

Longitudinal ordinary stiffeners or girders welded above the decks (including the deck of any trunk fitted as specified in [2.1.2]) may be included in the hull girder transverse sections.

2.1.4 Longitudinal girders between hatchways

Where longitudinal girders are fitted between hatchways, the sectional area that can be included in the hull girder transverse sections is obtained, in m², from the following formula:

$A_{EFF} = A_{LG} a$

where:

A_{LG} : Sectional area, in m², of longitudinal girders,

a : Coefficient:

- for longitudinal girders effectively supported by longitudinal bulkheads or primary supporting members:

  a = 1

- for longitudinal girders not effectively supported by longitudinal bulkheads or primary supporting members and having dimensions and scantlings such that $\ell_0 / r \le 60$:

  $$a = 0,6\left(\frac{s}{b_1} + 0,15\right)^{0,5}$$

- for longitudinal girders not effectively supported by longitudinal bulkheads or primary supporting members and having dimensions and scantlings such that $\ell_0 / r > 60$:

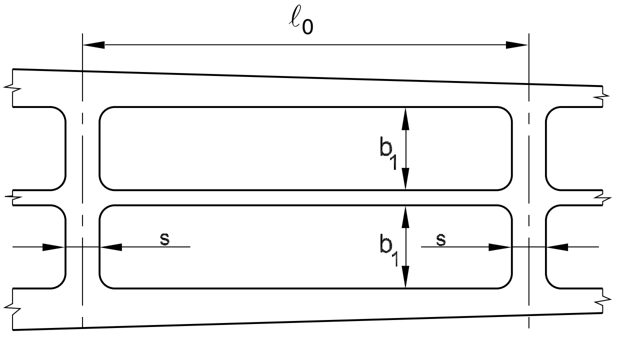
  a = 0

ℓ_0 : Span, in m, of longitudinal girders, to be taken as shown in Fig 1

r : Minimum radius of gyration, in m, of the longitudinal girder transverse section

s, b_1 : Dimensions, in m, defined in Fig 1.

Figure 1 : Longitudinal girders between hatchways



2.1.5 Longitudinal bulkheads with vertical corrugations

Longitudinal bulkheads with vertical corrugations may not be included in the hull girder transverse sections.

2.1.6 Members in materials other than steel

Where a member contributing to the longitudinal strength is made in material other than steel with a Young's modulus E equal to 2,06 10^5 N/mm^2, the steel equivalent sectional area that may be included in the hull girder transverse sections is obtained, in m^2, from the following formula:

$$A_{SE} = \frac{E}{2,06 \cdot 10^5} A_M$$

where:

A_M : Sectional area, in m^2, of the member under consideration.

2.1.7 Large openings

Large openings are:

- elliptical openings exceeding 2,5 m in length or 1,2 m in breadth
- circular openings exceeding 0,9 m in diameter.

Large openings and scallops, where scallop welding is applied, are always to be deducted from the sectional areas included in the hull girder transverse sections.

2.1.8 Small openings

Smaller openings than those in [2.1.7] in one transverse section in the strength deck or bottom area need not be deducted from the sectional areas included in the hull girder transverse sections, provided that:

$$\Sigma b_S \leq 0,06(B - \Sigma b)$$

where:

Σb_S : Total breadth of small openings, in m, in the strength deck or bottom area at the transverse section considered, determined as indicated in Fig 2

Σb : Total breadth of large openings, in m, at the transverse section considered, determined as indicated in Fig 2

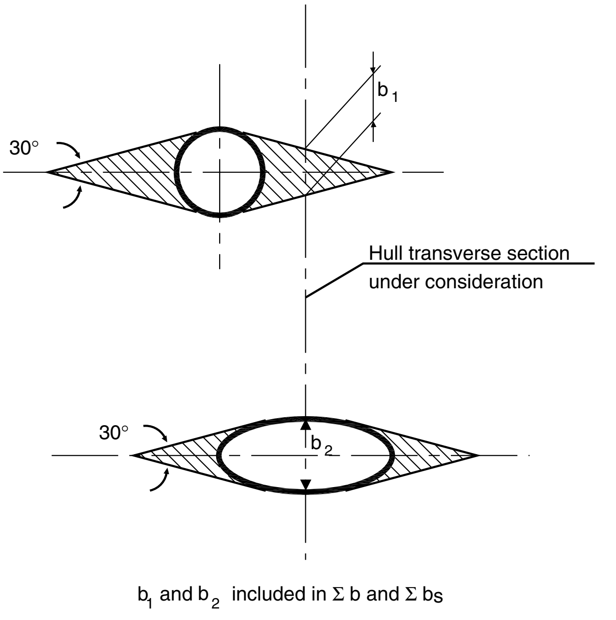
Where the total breadth of small openings Σb_S does not fulfil the above criteria, only the excess of breadth is to be deducted from the sectional areas included in the hull girder transverse sections.

2.1.9 Lightening holes, draining holes and single scallops

Lightening holes, draining holes and single scallops in longitudinals need not be deducted if their height is less than 0,25 h_W 10^{-3}, without being greater than 75 mm, where h_W is the web height, in mm, defined in Ch 4, Sec 3.

Otherwise, the excess is to be deducted from the sectional area or compensated.

Figure 2 : Calculation of Σb and Σb_S



2.2 Strength deck

2.2.1 The strength deck is, in general, the uppermost continuous deck.

In the case of a superstructure or deckhouses contributing to the longitudinal strength, the strength deck is the deck of the superstructure or the deck of the uppermost deckhouse.

2.2.2 A superstructure extending at least 0,15 L within 0,4 L amidships may generally be considered as contributing to the longitudinal strength. For other superstructures and for deckhouses, their contribution to the longitudinal strength is to be assessed on a case by case basis, through a finite element analysis of the whole ship, which takes into account the general arrangement of the longitudinal elements (side, decks, bulkheads).

The presence of openings in the side shell and longitudinal bulkheads is to be taken into account in the analysis. This may be done in two ways:

- by including these openings in the finite element model
- by assigning to the plate panel between the side frames beside each opening an equivalent thickness, in mm, obtained from the following formula:

$$t_{EQ} = 10^3 \left[\ell_P \left(\frac{Gh^2}{12EI_J} + \frac{1}{A_J} \right) \right]^{-1}$$

where (see Fig 3):

ℓ_P : Longitudinal distance, in m, between the frames beside the opening

h : Height, in m, of openings

I_J : Moment of inertia, in m^4, of the opening jamb about the transverse axis y-y

A_J : Shear area, in m^2, of the opening jamb in the direction of the longitudinal axis x-x

G : Coulomb's modulus, in N/mm^2, of the material used for the opening jamb, to be taken equal to:

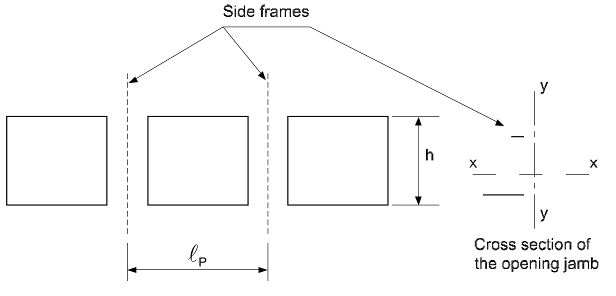
- for steels:

  $G = 8,0.10^4$ N/mm^2

- for aluminium alloys:

  $G = 2,7.10^4$ N/mm^2.

Figure 3 : Side openings



2.3 Section modulus

2.3.1 The section modulus at any point of a hull transverse section is obtained, in m^3, from the following formula:

$$Z_A = \frac{I_Y}{|z - N|}$$

where:

I_Y : Moment of inertia, in m^4, of the hull transverse section defined in [2.1], about its horizontal neutral axis

z : Z co-ordinate, in m, of the calculation point with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]

N : Z co-ordinate, in m, of the centre of gravity of the hull transverse section defined in [2.1], with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4].

2.3.2 The section moduli at bottom and at deck are obtained, in m^3, from the following formulae:

- at bottom:

$$Z_{AB} = \frac{I_Y}{N}$$

- at deck:

$$Z_{AD} = \frac{I_Y}{V_D}$$

where:

I_Y, N : Defined in [2.3.1]

V_D : Vertical distance, in m:

- in general:

  $V_D = z_D - N$

  where:

  z_D : Z co-ordinate, in m, of strength deck, defined in [2.2], with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]

- if continuous trunks or hatch coamings are taken into account in the calculation of I_Y, as specified in [2.1.2]:

$$V_D = (z_T - N)\left(0,9 + 0,2\frac{y_T}{B}\right) \geq z_D - N$$

  where:

  y_T, z_T : Y and Z co-ordinates, in m, of the top of continuous trunk or hatch coaming with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]; y_T and z_T are to be measured for the point which maximises the value of V

- if longitudinal ordinary stiffeners or girders welded above the strength deck are taken into account in the calculation of I_Y, as specified in [2.1.3], V_D is to be obtained from the formula given above for continuous trunks and hatch coamings. In this case, y_T and z_T are the Y and Z co-ordinates, in m, of the top of the longitudinal stiffeners or girders with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4].

2.4 Moments of inertia

2.4.1 The moments of inertia I_Y and I_Z, in m^4, are those, calculated about the horizontal and vertical neutral axes, respectively, of the hull transverse sections defined in [2.1].

2.5 First moment

2.5.1 The first moment S, in m^3, at a level z above the baseline is that, calculated with respect to the horizontal neutral axis, of the portion of the hull transverse sections defined in [2.1] located above the z level.

2.6 Structural models for the calculation of normal warping stresses and shear stresses

2.6.1 The structural models that can be used for the calculation of normal warping stresses, induced by torque, and shear stresses, induced by shear forces or torque, are:

- three dimensional finite element models
- thin walled beam models

representing the members which constitute the hull girder transverse sections according to [2.1].

SECTION 2 YIELDING CHECKS

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

M_{WH} : Horizontal wave bending moment, in kN.m, defined in Ch 5, Sec 2, [3.2]

M_{WT} : Wave torque, in kN.m, defined in Ch 5, Sec 2, [3.3]

Q_{SW} : Design still water shear force, in kN, defined in Ch 5, Sec 2, [2.3]

Q_{WV} : Vertical wave shear force, to be calculated according to Ch 5, Sec 2, [3.4]:

- if $Q_{SW} \geq 0$, Q_{WV} is the positive wave shear force
- if $Q_{SW} < 0$, Q_{WV} is the negative wave shear force

k : Material factor, as defined in Ch 4, Sec 1, [2.3]

x : X co-ordinate, in m, of the calculation point with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]

I_Y : Moment of inertia, in m^4, of the hull transverse section about its horizontal neutral axis, to be calculated according to Sec 1, [2.4]

I_Z : Moment of inertia, in m^4, of the hull transverse section about its vertical neutral axis, to be calculated according to Sec 1, [2.4]

S : First moment, in m^3, of the hull transverse section, to be calculated according to Sec 1, [2.5]

Z_A : Section modulus, in m^3, at any point of the hull transverse section, to be calculated according to Sec 1, [2.3.1]

Z_{AB},Z_{AD} : Section moduli, in m^3, at bottom and deck, respectively, to be calculated according to Sec 1, [2.3.2]

n_1 : Navigation coefficient defined in Ch 5, Sec 1, Tab 1

C : Wave parameter defined in Ch 5, Sec 2.

1 Application

1.1

1.1.1 *(1/7/2016)*

The requirements of this Section apply to ships having the following characteristics:

- L < 500 m
- L / B > 5
- B / D < 2,5
- $C_B \geq 0,6$

Ships not having one or more of these characteristics, ships intended for the carriage of heated cargoes and ships of unusual type or design are considered by the Society on a case by case basis.

Ships with the service notation **container ship**, in addition to the requirements of this Section, are to comply with the requirements of Pt E, Ch 2, Sec 2, [5].

2 Hull girder stresses

2.1 Normal stresses induced by vertical bending moments

2.1.1 The normal stresses induced by vertical bending moments are obtained, in N/mm^2, from the following formulae:

- at any point of the hull transverse section:

$$\sigma_1 = \frac{M_{SW} + M_{WV}}{Z_A} 10^{-3}$$

- at bottom:

$$\sigma_1 = \frac{M_{SW} + M_{WV}}{Z_{AB}} 10^{-3}$$

- at deck:

$$\sigma_1 = \frac{M_{SW} + M_{WV}}{Z_{AD}} 10^{-3}$$

2.1.2 The normal stresses in a member made in material other than steel with a Young's modulus E equal to 2,06 10^5 N/mm^2, included in the hull girder transverse sections as specified in Sec 1, [2.1.6], are obtained from the following formula:

$$\sigma_1 = \frac{E}{2,06 \cdot 10^5} \sigma_{1S}$$

where:

σ_{1S} : Normal stress, in N/mm^2, in the member under consideration, calculated according to [2.1.1] considering this member as having the steel equivalent sectional area A_{SE} defined in Sec 1, [2.1.6].

2.2 Normal stresses induced by torque and bending moments

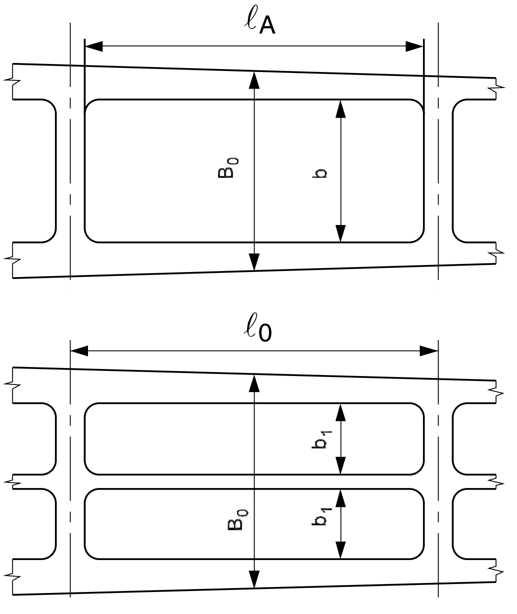
2.2.1 Ships having large openings in the strength deck

The normal stresses induced by torque and bending moments are to be considered for ships having large openings in the strength decks, i.e. ships for which at least one of the three following conditions occur:

- $b / B_0 > 0,7$
- $\ell_A / \ell_0 > 0,89$
- $b / B_0 > 0,6$ and $\ell_A / \ell_0 > 0,7$

where b, B_0, ℓ_A and ℓ_0 are the dimensions defined in Fig 1. In the case of two or more openings in the same hull transverse section, b is to be taken as the sum of the breadth b_1 of each opening.

Figure 1 : Ships with large openings



2.2.2 Normal stresses

The normal stresses are to be calculated for the load case constituted by the hull girder loads specified in Tab 1 together with their combination factors. They are to be obtained, in N/mm², from the following formula:

$$\sigma_1 = \frac{M_{SW}}{Z_A} + \frac{0,4 M_{WV}}{Z_A} + \frac{M_{WH}}{I_Z}|y| + \sigma_\Omega$$

where:

σ_Ω : Warping stress, in N/mm², induced by the torque M_{WT} and obtained through direct calculation analyses based on a structural model in accordance with Sec 1, [2.6]; for ships with the service notation **container ship**, it includes the contribution due to the still water torque $M_{T,SW}$ defined in Pt E, Ch 2, Sec 2, [4.1]

y : Y co-ordinate, in m, of the calculation point with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4].

2.3 Shear stresses

2.3.1 The shear stresses induced by shear forces and torque are obtained through direct calculation analyses based on a structural model in accordance with Sec 1, [2.6].

The shear force corrections ΔQ_C and ΔQ are to be taken into account, in accordance with [2.4.1] and [2.4.2], respectively.

2.3.2 The hull girder loads to be considered in these analyses are:

- for all ships, the vertical shear forces Q_{SW} and Q_{WV}
- for ships having large openings in the strength decks, also the torques M_T and $M_{T,SW}$ as specified in [2.2].

When deemed necessary by the Society on the basis of the ship's characteristics and intended service, the horizontal shear force is also to be calculated, using direct calculations, and taken into account in the calculation of shear stresses.

2.3.3 As an alternative to the above procedure, the shear stresses induced by the vertical shear forces QSW and QWV may be obtained through the simplified procedure in [2.4].

2.4 Simplified calculation of shear stresses induced by vertical shear forces

2.4.1 Ships without effective longitudinal bulkheads or with one effective longitudinal bulkhead

In this context, effective longitudinal bulkhead means a bulkhead extending from the bottom to the strength deck.

The shear stresses induced by the vertical shear forces in the calculation point are obtained, in N/mm², from the following formula:

$$\tau_1 = (Q_{SW} + Q_{WV} - \varepsilon \Delta Q_C)\frac{S}{I_Y t}\delta$$

where:

t : Minimum thickness, in mm, of side, inner side and longitudinal bulkhead plating, as applicable according to Tab 2

δ : Shear distribution coefficient defined in Tab 2

$\varepsilon = \text{sgn}(Q_{SW})$

Table 1 : Torque and bending moments

Still water loads				Wave loads					
Torque **(1)**		Vertical bending moment		Torque		Vertical bending moment		Horizontal bending moment	
Reference value	Comb. factor	Reference value	Comb. factor	Reference value	Comb. factor	Reference value	Comb. factor	Reference value	Comb. factor
$M_{T,SW}$ **(2)**	1,0	M_{SW}	1,0	M_{WT}	1,0	M_{WV}	0,4	M_{WH}	1,0

(1) To be considered only for ships with the service notation **container ship**.
(2) $M_{T,SW}$: Still water torque defined in Pt E, Ch 2, Sec 2, [4.1].

Table 2 : Shear stresses induced by vertical shear forces

Ship typology	Location	t, in mm	δ	Meaning of symbols used in the definition of δ
Single side ships without effective longitudinal bulkheads - see Fig 3 (a)	Sides	t_S	0,5	
Double side ships without effective longitudinal bulkheads - see Fig 3 (b)	Sides	t_S	$(1-\Phi)/2$	$\Phi = 0,275 + 0,25\,\alpha$; $\alpha = t_{ISM} / t_{SM}$
	Inner sides	t_{IS}	$\Phi / 2$	
Double side ships with one effective longitudinal bulkhead - see Fig 3 (c)	Sides	t_S	$(1-\Phi)\Psi/2$	$\Phi = 0,275 + 0,25\,\alpha$; $\alpha = t_{ISM} / t_{SM}$
	Inner sides	t_{IS}	$\Phi\Psi/2$	$\Psi = 1,9\beta\left[\gamma\left(2\delta+1+\frac{1}{\alpha_0}\right)-0,17\right]$; $\chi = \frac{\Psi}{0,85+0,17\alpha}$
	Longitudinal bulkhead	t_B	$1-\chi$	$\alpha_0 = \frac{0,5t_{BM}}{t_{SM}+t_{ISM}}$; $\beta = \frac{0,75}{3\delta+\alpha_0+1}$; $\gamma = \frac{2\delta+1}{4\delta+1+\frac{1}{\alpha_0}}$; $\delta = \frac{B}{2D}$

Note 1:
t_S, t_{IS}, t_B : Minimum thicknesses, in mm, of side, inner side and longitudinal bulkhead plating, respectively
t_{SM}, t_{ISM}, t_{BM} : Mean thicknesses, in mm, over all the strakes of side, inner side and longitudinal bulkhead plating, respectively. They are calculated as $\Sigma(\ell_i t_i)/\Sigma\ell_i$, where ℓ_i and t_i are the length, in m, and the thickness, in mm, of the i^{th} strake of side, inner side and longitudinal bulkhead.

ΔQ_C : Shear force correction (see Fig 2), which takes into account, when applicable, the portion of loads transmitted by the double bottom girders to the transverse bulkheads:

- for ships with double bottom in alternate loading conditions:

$$\Delta Q_C = \alpha\left|\frac{P}{B_H\ell_C} - \rho T_1\right|$$

- for other ships:

$$\Delta Q_C = 0$$

$$\alpha = g\frac{\ell_0 b_0}{2+\varphi\frac{\ell_0}{b_0}}$$

$$\varphi = 1,38 + 1,55\frac{\ell_0}{b_0} \leq 3,7$$

ℓ_0, b_0 : Length and breadth, respectively, in m, of the flat portion of the double bottom in way of the hold considered; b_0 is to be measured on the hull transverse section at the middle of the hold

ℓ_C : Length, in m, of the hold considered, measured between transverse bulkheads

B_H : Ship's breadth, in m, measured on the hull transverse section at the middle of the hold considered

P : Total mass of cargo, in t, in the transversely adjacent holds in the section considered

ρ : Sea water density, in t/m^3:

$\rho = 1,025$ t/m^3

T_1 : Draught, in m, measured vertically on the hull transverse section at the middle of the hold considered, from the moulded baseline to the waterline in the loading condition considered.

Figure 2 : Shear force correction ΔQ_C

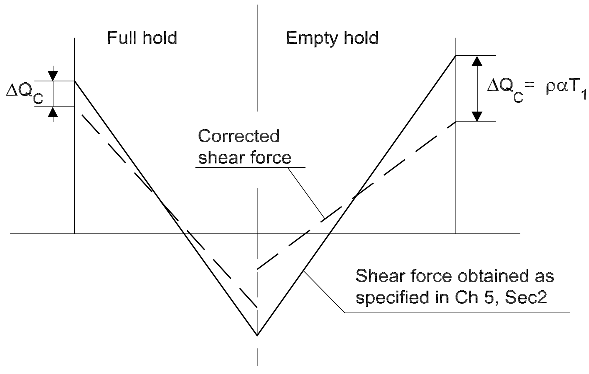
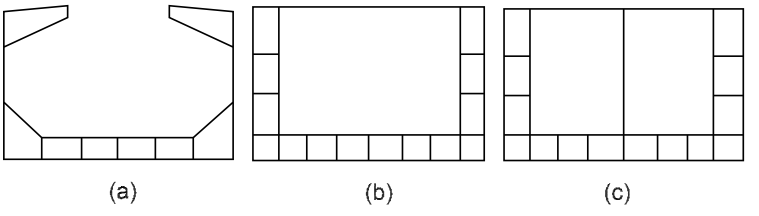


Figure 3 : Ship typologies (with reference to Tab 2)



2.4.2 Ships with two effective longitudinal bulkheads

In this context, effective longitudinal bulkhead means a bulkhead extending from the bottom to the strength deck.

The shear stresses induced by the vertical shear force in the calculation point are obtained, in N/mm², from the following formula:

$$\tau_1 = [(Q_{SW} + Q_{WV})\delta + \varepsilon_Q \Delta Q]\frac{S}{I_Y t}$$

where:

δ : Shear distribution coefficient defined in Tab 3

$$\varepsilon_Q = \text{sgn}\left(\frac{Q_F - Q_A}{\ell_C}\right)$$

Q_F, Q_A : Value of Q_{SW}, in kN, in way of the forward and aft transverse bulkhead, respectively, of the hold considered

ℓ_C : Length, in m, of the hold considered, measured between transverse bulkheads

t : Minimum thickness, in mm, of side, inner side and longitudinal bulkhead plating, as applicable according to Tab 3

ΔQ : Shear force correction, in kN, which takes into account the redistribution of shear force between sides and longitudinal bulkheads due to possible transverse non-uniform distribution of cargo:

- in sides:

$$\Delta Q = \frac{g\varepsilon(p_C - p_W)\ell_C b_C}{4}\left[\frac{n}{3(n+1)} - (1-\Phi)\right]$$

- in longitudinal bulkheads:

$$\Delta Q = \frac{g\varepsilon(p_C - p_W)\ell_C b_C}{4}\left[\frac{2n}{3(n+1)} - \Phi\right]$$

$$\varepsilon = \text{sgn}(Q_{SW})$$

p_C : Pressure, in kN/m², acting on the inner bottom in way of the centre hold in the loading condition considered

p_W : Pressure, in kN/m², acting on the inner bottom in way of the wing hold in the loading condition considered, to be taken not greater than p_C

b_C : Breadth, in m, of the centre hold, measured between longitudinal bulkheads

n : Number of floors in way of the centre hold

Φ : Coefficient defined in Tab 3.

3 Checking criteria

3.1 Normal stresses induced by vertical bending moments

3.1.1 It is to be checked that the normal stresses σ_1 calculated according to [2.1] and, when applicable, [2.2] are in compliance with the following formula:

$\sigma_1 \leq \sigma_{1,ALL}$

where:

$\sigma_{1,ALL}$: Allowable normal stress, in N/mm²:

$\sigma_{1,ALL} = 175/k$ N/mm²

3.2 Shear stresses

3.2.1 It is to be checked that the normal stresses τ_1 calculated according to [2.3] are in compliance with the following formula:

$\tau_1 \leq \tau_{1,ALL}$

where:

$\tau_{1,ALL}$: Allowable shear stress, in N/mm²:

$\tau_{1,ALL}$ = 110/k N/mm².

4 Section modulus and moment of inertia

4.1 General

4.1.1 The requirements in [4.2] to [4.5] provide for the minimum hull girder section modulus, complying with the checking criteria indicated in [3], and the midship section moment of inertia required to ensure sufficient hull girder rigidity.

Table 3 : Shear stresses induced by vertical shear forces

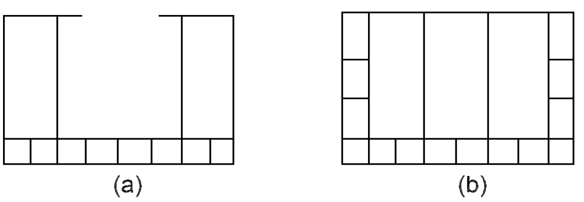
Ship typology	Location	t, in mm	δ	Meaning of symbols used in the definition of δ
Single side ships with two effective longitudinal bulkheads - see Fig 4 (a)	Sides	t_S	$(1-\Phi)/2$	$\Phi = 0,3 + 0,21\,\alpha$ $\alpha = t_{BM} / t_{SM}$
	Longitudinal bulkheads	t_B	$\Phi/2$	
Double side ships with two effective longitudinal bulkheads - see Fig 4 (b)	Sides	t_S	$(1-\Phi)/4$	$\Phi = 0,275 + 0,25\,\alpha$ $\alpha = \dfrac{t_{BM}}{t_{SM} + t_{ISM}}$
	Inner sides	t_{IS}	$(1-\Phi)/4$	
	Longitudinal bulkheads	t_B	$\Phi/2$	

Note 1:

t_S, t_{IS}, t_B : Minimum thicknesses, in mm, of side, inner side and longitudinal bulkhead plating, respectively

t_{SM}, t_{ISM}, t_{BM} : Mean thicknesses, in mm, over all the strakes of side, inner side and longitudinal bulkhead plating, respectively. They are calculated as $\Sigma(\ell_i t_i)/\Sigma\ell_i$, where ℓ_i and t_i are the length, in m, and the thickness, in mm, of the i[th] strake of side, inner side and longitudinal bulkheads.

Figure 4 : Ship typologies (with reference to Tab 3)



4.2 Section modulus within 0,4L amidships

4.2.1 For ships with C_B greater than 0,8, the gross section moduli Z_{AB} and Z_{AD} within 0,4L amidships are to be not less than the greater value obtained, in m³, from the following formulae:

- $Z_{R,MIN} = n_1 C L^2 B (C_B + 0,7) k 10^{-6}$
- $Z_R = \dfrac{M_{SW} + M_{WV}}{175/k} 10^{-3}$

4.2.2 For ships with C_B less than or equal to 0,8, the gross section moduli Z_{AB} and Z_{AD} at the midship section are to be not less than the value obtained, in m³, from the following formula:

$$Z_{R,MIN} = n_1 C L^2 B (C_B + 0,7) k 10^{-6}$$

In addition, the gross section moduli Z_{AB} and Z_{AD} within 0,4L amidships are to be not less than the value obtained, in m³, from the following formula:

$$Z_R = \frac{M_{SW} + M_{WV}}{175/k} 10^{-3}$$

4.2.3 The k material factors are to be defined with respect to the materials used for the bottom and deck members contributing to the longitudinal strength according to Sec 1, [2]. When material factors for higher strength steels are used, the requirements in [4.5] apply.

4.2.4 Where the total breadth Σb_S of small openings, as defined in Sec 1, [2.1.8], is deducted from the sectional areas included in the hull girder transverse sections, the values Z_R and $Z_{R,MIN}$ defined in [4.2.3] may be reduced by 3%.

4.2.5 Scantlings of members contributing to the longitudinal strength (see Sec 1, [2]) are to be maintained within 0,4L amidships.

4.3 Section modulus outside 0,4L amidships

4.3.1 *(1/7/2020)*

Scantlings of members contributing to the hull girder longitudinal strength (see Sec 1, [2]) may be gradually reduced, outside 0,4L amidships, to the minimum required for local strength purposes at fore and aft parts, as specified in Chapter 9.

As a minimum, hull girder bending strength checks are to be carried out at the following locations:

- in way of the forward end of the engine room
- in way of the forward end of the foremost cargo hold
- at any locations where there are significant changes in hull cross-section
- at any locations where there are changes in the framing system.

Buckling strength of members contributing to the longitudinal strength and subjected to compressive and shear stresses is to be checked, in particular in regions where changes in the framing system or significant changes in the hull cross-section occur. The buckling evaluation criteria used for this check are determined by the Society.

Continuity of structure is be maintained throughout the length of the ship. Where significant changes in structural arrangement occur, adequate transitional structure is to be provided.

For ships with large deck openings sections at or near to the aft and forward quarter length positions are to be checked. For such ships with cargo holds aft of the superstructure, deckhouse or engine room, strength checks of sections in way of the aft end of the aft-most holds, and the aft end of the deckhouse or engine room are to be performed.

4.4 Midship section moment of inertia

4.4.1 The gross midship section moment of inertia about its horizontal neutral axis is to be not less than the value obtained, in m^4, from the following formula:

$$I_{YR} = 3Z'_{R,MIN} L 10^{-2}$$

where $Z'_{R,MIN}$ is the required midship section modulus $Z_{R,MIN}$, in m^3, calculated as specified in [4.2.3], but assuming k = 1.

4.5 Extent of higher strength steel

4.5.1 When a material factor for higher strength steel is used in calculating the required section modulus at bottom or deck according to [4.2] or [4.3], the relevant higher strength steel is to be adopted for all members contributing to the longitudinal strength (see Sec 1, [2]), at least up to a vertical distance, in m, obtained from the following formulae:

- above the baseline (for section modulus at bottom):

$$V_{HB} = \frac{\sigma_{1B} - 175}{\sigma_{1B} + \sigma_{1D}} z_D$$

- below a horizontal line located at a distance V_D (see Sec 1, [2.3.2]) above the neutral axis of the hull transverse section (for section modulus at deck):

$$V_{HD} = \frac{\sigma_{1D} - 175}{\sigma_{1B} + \sigma_{1D}} (N + V_D)$$

where:

σ_{1B}, σ_{1D} : Normal stresses, in N/mm^2, at bottom and deck, respectively, calculated according to [2.1.1]

z_D : Z co-ordinate, in m, of the strength deck, defined in Sec 1, [2.2], with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]

N : Z co-ordinate, in m, of the centre of gravity of the hull transverse section defined in Sec 1, [2.1], with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]

V_D : Vertical distance, in m, defined in Sec 1, [2.3.2].

4.5.2 When a higher strength steel is adopted at deck, members not contributing to the longitudinal strength and welded on the strength deck (e.g. hatch coamings, strengthening of deck openings) are also generally to be made of the same higher strength steel.

4.5.3 The higher strength steel is to extend in length at least throughout the whole midship area where it is required for strength purposes according to the provisions of Part B.

5 Permissible still water bending moment and shear force during navigation

5.1 Permissible still water bending moment

5.1.1 The permissible still water bending moment at any hull transverse section during navigation, in hogging or sagging conditions, is the value M_{SW} considered in the hull girder section modulus calculation according to [4].

In the case of structural discontinuities in the hull transverse sections, the distribution of permissible still water bending moments is considered on a case by case basis.

5.2 Permissible still water shear force

5.2.1 Direct calculations

Where the shear stresses are obtained through calculation analyses according to [2.3], the permissible positive or negative still water shear force at any hull transverse section is obtained, in kN, from the following formula:

$$Q_P = \varepsilon |Q_T| - Q_{WV}$$

where:

$$\varepsilon = \text{sgn}(Q_{SW})$$

Q_T : Shear force, in kN, which produces a shear stress τ = 110/k N/mm^2 in the most stressed point of the hull transverse section, taking into account the shear force correction ΔQ_C and ΔQ in accordance with [2.4.1] and [2.4.2], respectively.

5.2.2 Ships without effective longitudinal bulkheads or with one effective longitudinal bulkhead

Where the shear stresses are obtained through the simplified procedure in [2.4.1], the permissible positive or negative still water shear force at any hull transverse section is obtained, in kN, from the following formula:

$$Q_P = \varepsilon \left(\frac{110}{k\delta} \cdot \frac{I_Y t}{S} + \Delta Q_C \right) - Q_{WV}$$

where:

$$\varepsilon = \text{sgn}(Q_{SW})$$

δ : Shear distribution coefficient defined in Tab 2

t : Minimum thickness, in mm, of side, inner side and longitudinal bulkhead plating, as applicable according to Tab 2

ΔQ_C : Shear force correction defined in [2.4.1].

5.2.3 Ships with two effective longitudinal bulkheads

Where the shear stresses are obtained through the simplified procedure in [2.4.2], the permissible positive or negative still water shear force at any hull transverse section is obtained, in kN, from the following formula:

$$Q_P = \frac{1}{\delta}\left(\varepsilon\frac{110}{k}\cdot\frac{I_Y t}{S} - \varepsilon_Q \Delta Q\right) - Q_{WV}$$

where:

δ : Shear distribution coefficient defined in Tab 3

$\varepsilon = \mathrm{sgn}(Q_{SW})$

t : Minimum thickness, in mm, of side, inner side and longitudinal bulkhead plating, as applicable according to Tab 3

ε_Q : Defined in [2.4.2]

ΔQ : Shear force correction defined in [2.4.2].

6 Permissible still water bending moment and shear force in harbour conditions

6.1 Permissible still water bending moment

6.1.1 *(1/7/2002)*

The permissible still water bending moment at any hull transverse section in harbour conditions, in hogging or sagging conditions, is obtained, in kN.m, from the following formula:

$$M_{P,H} = M_P + 0,6 M_{WV}$$

where M_P is the permissible still water bending moment during navigation, in kN.m, to be calculated according to [5.1.1].

6.2 Permissible shear force

6.2.1 The permissible positive or negative still water shear force at any hull transverse section, in harbour conditions, is obtained, in kN, from the following formula:

$$Q_{P,H} = \varepsilon Q_P + 0,7\, Q_{WV}$$

where:

$\varepsilon = \mathrm{sgn}(Q_{SW})$

Q_P : Permissible still water shear force during navigation, in kN, to be calculated according to [5.2].

SECTION 3 ULTIMATE STRENGTH CHECK

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

1 Application

1.1

1.1.1 *(1/7/2016)*
The requirements of this Section apply to ships equal to or greater than 150 m in length other than ships with the service notation **container ship**.

For ships with the service notation **container ship** the requirements in Pt E, Ch 2, Sec 2, [7] apply.

2 Partial safety factors

2.1

2.1.1 The partial safety factors to be considered for checking the ultimate strength of the hull girder are specified in Tab 1.

Table 1 : Partial safety factors

Partial safety factor covering uncertainties on:	Symbol	Value
Still water hull girder loads	γ_{S1}	1,00
Wave induced hull girder loads	γ_{W1}	1,15
Material	γ_m	1,02
Resistance	γ_R	1,08

3 Hull girder ultimate strength check

3.1 Hull girder loads

3.1.1 Bending moments
The bending moment in sagging and hogging conditions, to be considered in the ultimate strength check of the hull girder, is to be obtained, in kN.m, from the following formula:

$\gamma = M_{S1} M_{SW} + \gamma_{W1} M_{WV}$

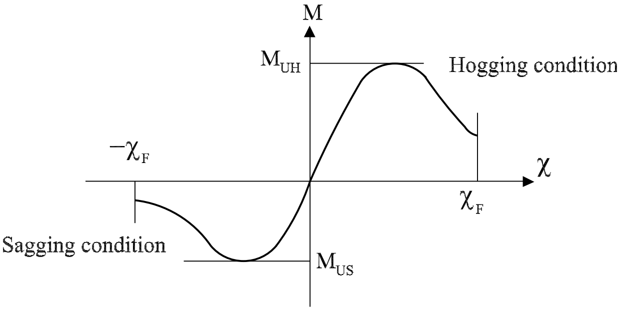
3.2 Hull girder ultimate bending moment capacities

3.2.1 Curve M-χ
The ultimate bending moment capacities of a hull girder transverse section, in hogging and sagging conditions, are defined as the maximum values of the curve of bending moment capacity M versus the curvature χ of the transverse section considered (see Fig 1).

The curvature χ is positive for hogging condition and negative for sagging condition.

The curve M-χ is to be obtained through an incremental-iterative procedure according to the criteria specified in App 1.

Figure 1 : Curve bending moment capacity M versus curvature χ



3.2.2 Hull girder transverse sections
The hull girder transverse sections are constituted by the elements contributing to the hull girder longitudinal strength, considered with their net scantlings, according to Sec 1, [2].

3.3 Checking criteria

3.3.1 It is to be checked that the hull girder ultimate bending capacity at any hull transverse section is in compliance with the following formula:

$$\frac{M_U}{\gamma_R \gamma_m} \geq M$$

where:

M_U : Ultimate bending moment capacity of the hull transverse section considered, in kN.m:
- in hogging conditions:
  $M_U = M_{UH}$
- in sagging conditions:
  $M_U = M_{US}$

M_{UH} : Ultimate bending moment capacity in hogging conditions, defined in [3.2.1]

M_{US} : Ultimate bending moment capacity in sagging conditions, defined in [3.2.1]

M : Bending moment, in kN.m, defined in [3.1.1].

APPENDIX 1 HULL GIRDER ULTIMATE STRENGTH

Symbols

For symbols not defined in this Appendix, refer to the list at the beginning of this Chapter.

R_{eH_S} : Minimum yield stress, in N/mm², of the material of the considered stiffener

R_{eH_p} : Minimum yield stress, in N/mm², of the material of the considered plate

I_Y : Moment of inertia, in m⁴, of the hull transverse section around its horizontal neutral axis, to be calculated according to Sec 1, [2.4]

Z_{AB} ,Z_{AD} : Section moduli, in cm³, at bottom and deck, respectively, defined in Sec 1, [2.3.2]

s : Spacing, in m, of ordinary stiffeners

ℓ : Span, in m, of ordinary stiffeners, measured between the supporting members (see Ch 4, Sec 3, Fig 2 to Ch 4, Sec 3, Fig 5)

h_w : Web height, in mm, of an ordinary stiffener

t_w : Web net thickness, in mm, of an ordinary stiffener

b_f : Face plate width, in mm, of an ordinary stiffener

t_f : Face plate net thickness, in mm, of an ordinary stiffener

A_S : Net sectional area, in cm², of stiffener, without attached plating

t_p : Net thickness, in mm, of the plating attached to an ordinary stiffener of the plate of an hard corner or of the plate of a stiffened plate as applicable.

1 General

1.1

1.1.1 *(1/7/2016)*

The method for calculating the ultimate hull girder capacity is to identify the critical failure modes of all main longitudinal structural elements.

1.1.2 *(1/7/2016)*

Structures compressed beyond their buckling limit have reduced load carrying capacity. All relevant failure modes for individual structural elements, such as plate buckling, torsional stiffener buckling, stiffener web buckling, lateral or global stiffener buckling and their interactions, are to be considered in order to identify the weakest inter-frame failure mode.

2 Incremental-iterative method

2.1 Assumptions

2.1.1 Procedure *(1/7/2016)*

In applying the incremental-iterative method, the following assumptions are generally to be made:

- the ultimate strength is calculated at hull transverse sections between two adjacent transverse webs;
- the hull girder transverse section remains plane during each curvature increment;
- the hull material has an elasto-plastic behaviour;
- the hull girder transverse section is divided into a set of elements, see [2.2.2], which are considered to act independently.

According to the iterative procedure, the bending moment M_γ acting on the transverse section at each curvature value χ_ι is obtained by summing the contribution given by the stress σ acting on each element. The stress σ correspond to the element strain, ε is to be obtained for each curvature increment from the non-linear load-end shortening curves σ-ε of the element.

These curves are to be calculated, for the failure mechanisms of the element, from the formulae specified in [2.3]. The stress σ is selected as the lowest among the values obtained from each of the considered load-end shortening curves σ-ε.

The procedure is to be repeated for each step, until the value of the imposed curvature reaches the value χ_F, in m⁻¹, in hogging and sagging condition, obtained from the following formula:

$$\chi_F = \pm 0,003\left(\frac{M_\gamma}{EI_\gamma}\right)$$

where:

M_γ : the lesser of the values $M_{\gamma 1}$ and $M_{\gamma 2}$, in kN·m

$M_{\gamma 1}$: $10^{-3}\, R_{eH}\, Z_{AB}$

$M_{\gamma 2}$: $10^{-3}\, R_{eH}\, Z_{AD}$

If the value γ_F is not sufficient to evaluate the peaks of the curve M-γ the procedure is to be repeated until the value of the imposed curvature permits the calculation of the maximum bending moments of the curve.

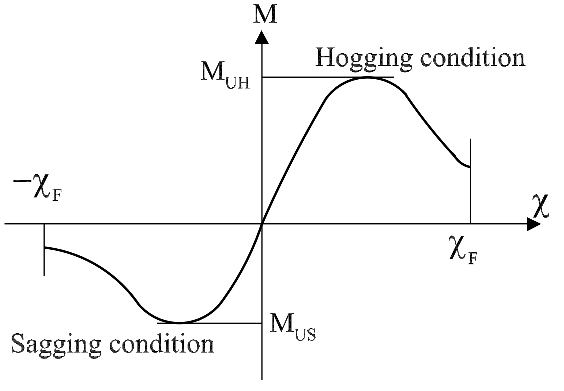
2.2 Procedure

2.2.1 General *(1/7/2016)*

The curve M-χ is to be obtained by means of an incremental-iterative approach, summarised in the flow chart in Fig 2.

In this procedure, the ultimate hull girder bending moment capacity, MU is defined as the peak value of the curve with vertical bending moment M versus the curvature χ of the ship cross section as shown in Fig 1. The curve is to be obtained through an incremental-iterative approach.

Figure 1 : Curve bending moment capacity M versus curvature χ



Each step of the incremental procedure is represented by the calculation of the bending moment M_i which acts on the hull transverse section as the effect of an imposed curvature χ_i.

For each step, the value χ_i is to be obtained by summing an increment of curvature $\gamma\Delta$to the value relevant to the previous step χ_i-1.This increment of curvature corresponds to an increment of the rotation angle of the hull girder transverse section around its horizontal neutral axis.

This rotation increment induces axial strains ε in each hull structural element, whose value depends on the position of the element. In hogging condition, the structural elements above the neutral axis are lengthened, while the elements below the neutral axis are shortened. Vice-versa in sagging condition.

The stress σ induced in each structural element by the strain ε is to be obtained from the load-end shortening curve ε-σ of the element, which takes into account the behaviour of the element in the non-linear elasto-plastic domain.

The distribution of the stresses induced in all the elements composing the hull transverse section determines, for each step, a variation of the neutral axis position, since the relationship σ-ε is non-linear. The new position of the neutral axis relevant to the step considered is to be obtained by means of an iterative process, imposing the equilibrium among the stresses acting in all the hull elements on the transverse section.

Once the position of the neutral axis is known and the relevant stress distribution in the section structural elements is obtained, the bending moment of the section M_i around the new position of the neutral axis, which corresponds to the curvature χ_i imposed in the step considered, is to be obtained by summing the contribution given by each element stress.

The main steps of the incremental-iterative approach described above are summarised as follows (see also Fig 2):

a) Step 1: Divide the transverse section of hull into stiffened plate elements

b) Step 2: Define stress-strain relationships for all elements

c) Step 3: Initialise curvature χ1 and neutral axis for the first incremental step with the value of incremental curvature (i.e. curvature that induces a stress equal to 1% of yield strength in strength deck) as:

$$\chi_1 = \Delta_\chi = 0,01\frac{R_{eH}}{E}\frac{1}{z_D - z_n}$$

where:

z_D : Z coordinate, in m, of strength deck at side.

z_n : Z coordinate, in m, of horizontal neutral axis of the hull transverse section.

d) Step 4: Calculate for each element the corresponding strain, $\varepsilon i = \chi(zi - zn)$ and the corresponding stress σi

e) Step 5: Determine the neutral axis z_{NA_cur} at each incremental step by establishing force equilibrium over the whole transverse section as:

$\Sigma Ai\ \sigma i = \Sigma Aj\ \sigma j$ (i-th element is under compression, j-th element under tension).

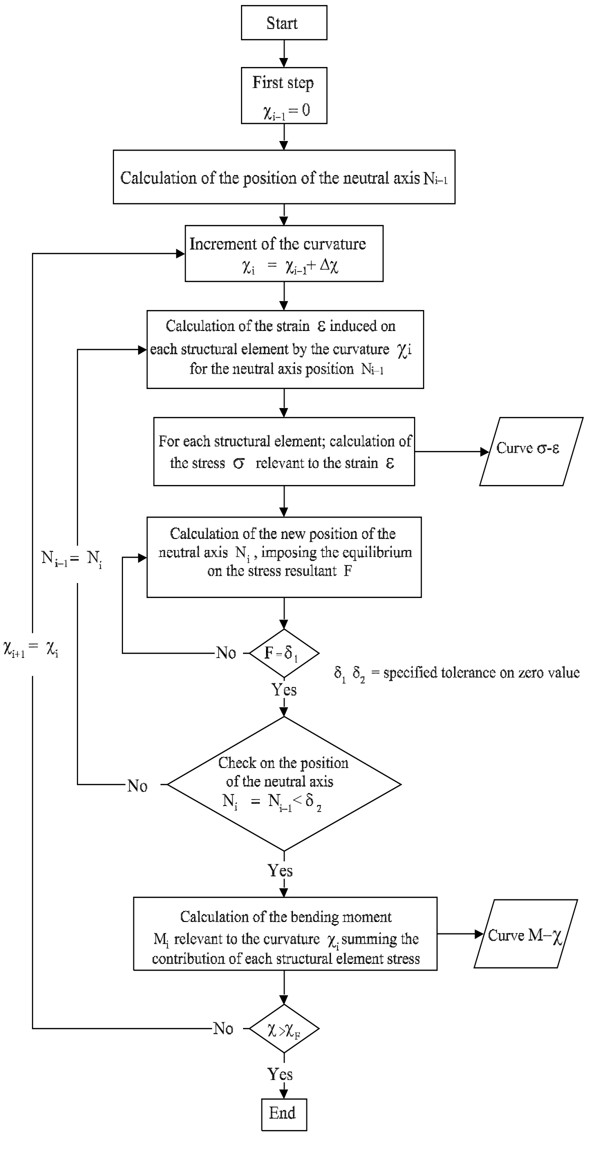
f) Step 6: Calculate the corresponding moment by summing the contributions of all elements as:

$$M_U = \sum \sigma_{\upsilon i} A_i |(z_i - z_{NAcur})|$$

g) Step 7: Compare the moment in the current incremental step with the moment in the previous incremental step. If the slope in M-χ relationship is less than a negative fixed value, terminate the process and define the peak value MU.

Otherwise, increase the curvature by the amount of $\Delta\chi$ and go to Step 4.

Figure 2 : Flow chart of the procedure for the evaluation of the curve M-χ



2.2.2 Modelling of the hull girder cross section *(1/7/2016)*

Hull girder transverse sections are to be considered as being constituted by the members contributing to the hull girder ultimate strength.

Sniped stiffeners are also to be modelled, taking account that they do not contribute to the hull girder strength.

The structural members are categorised into a stiffener element, a stiffened plate element or a hard corner element.

The plate panel including web plate of girder or side stringer is idealised into a stiffened plate element, an attached plate of a stiffener element or a hard corner element.

The plate panel is categorised into the following two kinds:

- Longitudinally stiffened panel of which the longer side is in ship's longitudinal direction, and
- Transversely stiffened panel of which the longer side is in the perpendicular direction to ship's longitudinal direction.

a) Hard corner element:

Hard corner elements are sturdier elements composing the hull girder transverse section, which collapse mainly according to an elasto-plastic mode of failure (material yielding); they are generally constituted by two plates not lying in the same plane.

The extent of a hard corner element from the point of intersection of the plates is taken equal to 20 tp on a transversely stiffened panel and to 0.5 s on a longitudinally stiffened panel, see Fig 3.

Bilge, sheer strake-deck stringer elements, girder-deck connections and face plate-web connections on large girders are typical hard corners.

b) Stiffener element:

The stiffener constitutes a stiffener element together with the attached plate.

The attached plate width is in principle:

- Equal to the mean spacing of the stiffener when the panels on both sides of the stiffener are longitudinally stiffened, or
- Equal to the width of the longitudinally stiffened panel when the panel on one side of the stiffener is longitudinally stiffened and the other panel is of the transversely stiffened, see Fig 3.

c) Stiffened plate element:

The plate between stiffener elements, between a stiffener element and a hard corner element or between hard corner elements is to be treated as a stiffened plate element, see Fig 3.

- In case of the knuckle point as shown in Fig 4, the plating area adjacent to knuckles in the plating with an angle greater than 30 degrees is defined as a hard corner. The extent of one side of the corner is taken equal to 20 t_p on transversely framed panels and to 0.5 s on longitudinally framed panels from the knuckle point.
- Where the plate members are stiffened by non-continuous longitudinal stiffeners, the non- continuous stiffeners are considered only as dividing a plate into various elementary plate panels.
- Where the opening is provided in the stiffened plate element, the openings are to be considered in accordance with Sec 1, [2.1]
- Where attached plating is made of steels having different thicknesses and/or yield stresses, an average thickness and/or average yield stress obtained from the following formula are to be used for the calculation.

$$t_p = \frac{t_{p1} S_1 + t_{p2} S_2}{s}$$

$$R_{eHp} = \frac{R_{eHp1} t_{p1} S_1 + R_{eHp2} t_{p2} S_2}{t_p S}$$

where $R_{eH\_P1\_}$ $R_{eH\_P2\_}$, tp_1, tp_2, s_1, s_2 and s are shown in Fig 5.

Figure 3 : Extension of the breadth of the attached plating and hard corner element *(1/7/2016)*

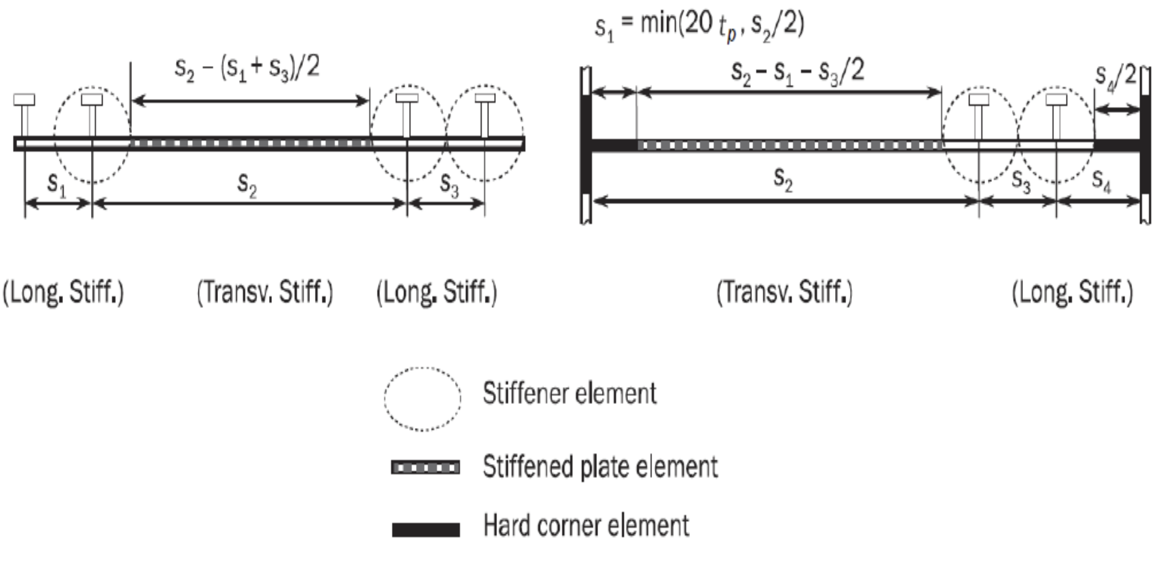


Figure 4 : Plating with knuckle point *(1/7/2016)*

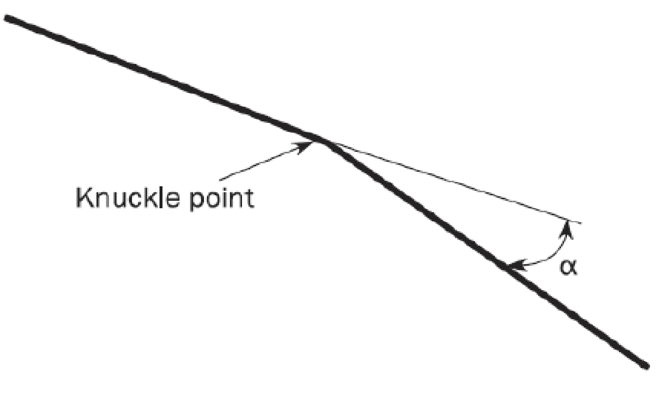
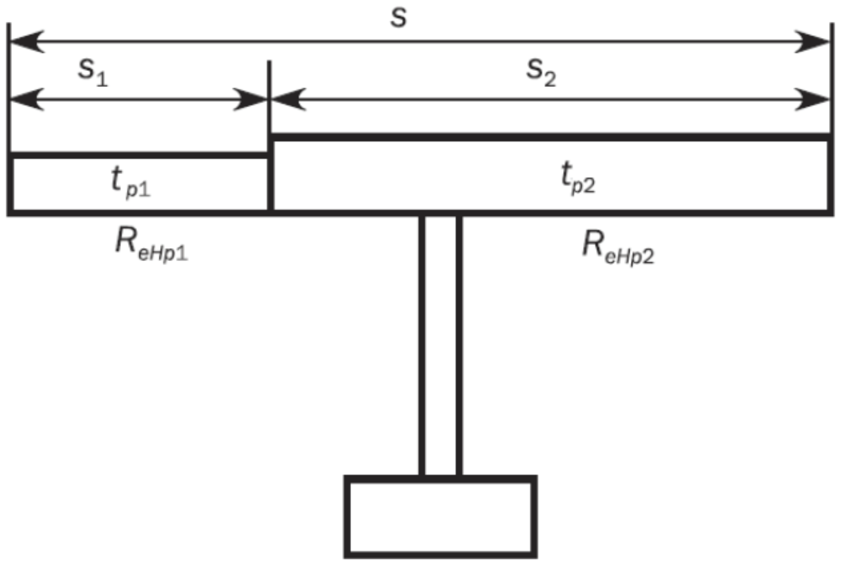


Figure 5 : Element with different thickness and yield strength *(1/7/2016)*



2.3 Load-end shortening curves

2.3.1 Stiffened plate element and stiffeners element *(1/7/2016)*

Stiffened plate element and stiffener element composing the hull girder transverse sections may collapse following one of the modes of failure specified in Tab 1.

- Where the plate members are stiffened by non-continuous longitudinal stiffeners, the stress of the element is to be obtained in accordance with [2.3.3] to [2.3.8], taking into account the non-continuous longitudinal stiffener. In calculating the total forces for checking the hull girder ultimate strength, the area of non-continuous longitudinal stiffener is to be assumed as zero.
- Where the opening is provided in the stiffened plate element, the considered area of the stiffened plate element is to be obtained by deducting the opening area from the plating in calculating the total forces for checking the hull girder ultimate strength.
- For stiffened plate element, the effective width of plate for the load shortening portion of the stress-strain curve is to be taken as full plate width, i.e. to the intersection of other plate or longitudinal stiffener - neither from the end of the hard corner element nor from the attached plating of stiffener element, if any. In calculating the total forces for checking the hull girder ultimate strength, the area of the stiffened plate element is to be taken between the hard corner element and the stiffener element or between the hard corner elements, as applicable.

2.3.2 Hard corners element *(1/7/2016)*

The relevant load-end shortening curve σ-ε is to be obtained for lengthened and shortened hard corners according to [2.3.3].

Table 1 : Modes of failure of plating panels and ordinary stiffeners

Element	Mode of failure	Curve σ-ε defined in
Lengthened transversely framed plating panel or ordinary stiffeners	Elasto-plastic collapse	[2.3.3]
Shortened ordinary stiffeners	Beam column buckling	[2.3.4]
	Torsional buckling	[2.3.5]
	Web local buckling of flanged profiles	[2.3.6]
	Web local buckling of flat bars	[2.3.7]
Shortened transversely framed plating panel	Plate buckling	[2.3.8]

2.3.3 Elasto-plastic collapse of structural elements *(1/7/2016)*

The equation describing the load-end shortening curve σ-ε for the elasto-plastic collapse of structural elements composing the hull girder transverse section is to be obtained from the following formula, valid for both positive (shortening) and negative (lengthening) strains (see Fig 6):

$$\sigma = \Phi R_{eHA}$$

where:

R_{eHA} : Equivalent minimum yield stress, in N/mm², of the considered element, obtained by the following formula:

$$R_{eHA} = \frac{10 b_{E1} t_p l_{pe} R_{EHS} + A_S l_{sE} R_{EHS}}{R_{EHS} + A_S l_{sE}}$$

Φ : Edge function:

$\Phi = -1$ for $\varepsilon < -1$

$\Phi = \varepsilon$ for $-1 < \varepsilon < 1$

$\Phi = 1$ for $\varepsilon > 1$

ε : Relative strain:

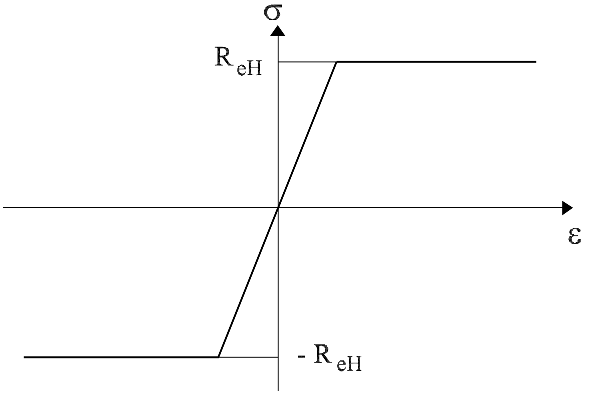
$$\varepsilon = \frac{\varepsilon_E}{\varepsilon_Y}$$

ε_E : Element strain

ε_Y : Strain inducing yield stress in the element:

$$\varepsilon_Y = \frac{R_{eHA}}{E}$$

Figure 6 : Load-end shortening curve σ-ε for elasto-plastic collapse



2.3.4 Beam column buckling *(1/7/2016)*

The positive strain portion of the average stress - average strain curve σ_{CR1}-ε based on beam column buckling of plate-stiffener combinations is described according to the following (see Fig 6).

$$\sigma_{CR1} = \Phi\sigma_{C1}\frac{A_S + 10b_Et_P}{A_S + 10st_P}$$

where:

Φ : Edge function defined in [2.3.3]

σ_{C1} : Critical stress, in N/mm²:

$$\sigma_{C1} = \frac{\sigma_{E1}}{\varepsilon} \quad \text{for} \quad \sigma_{E1} \le \frac{R_{eHB}}{2}\varepsilon$$

$$\sigma_{C1} = R_{eH}\left(1 - \frac{R_{eH}\varepsilon}{4\sigma_{E1}}\right) \quad \text{for} \quad \sigma_{E1} > \frac{R_{eHB}}{2}\varepsilon$$

where:

R_{eHB} : Equivalent minimum yield stress, in N/mm², of the considered element, obtained by the following formula:

$$R_{eHB} = \frac{10b_{E1}t_pl_{pE}R_{EHS} + A_Sl_{sE}R_{EHS}}{R_{EHS} + A_Sl_{sE}}$$

l_{pE} : Distance, in mm, measured from the neutral axis of the stiffener with attached plate of width b_{E1} to the bottom of the attached plate

l_{sE} : Distance, in mm, measured from the neutral axis of the stiffener with attached plate of width b_{E1} to the top of stiffener

ε : Relative strain defined in [2.3.3]

σ_{E1} : Euler column buckling stress, in N/mm² equal to:

$$\sigma_{E1} = \pi^2E\frac{I_E}{A_El^2}10^{-4}$$

I_E : Net moment of inertia of ordinary stiffeners, in cm⁴, with attached shell plating of width b_{E1}

b_{E1} : Effective width, in m, of the attached shell plating, equal to:

$$b_{E1} = \frac{s}{\beta_E} \quad \text{for} \quad \beta_E > 1{,}0$$

$$b_{E1} = s \quad \text{for} \quad \beta_E \le 1{,}0$$

$$\beta_E = 10^3\frac{s}{t_p}\sqrt{\frac{\varepsilon R_{eH}}{E}}$$

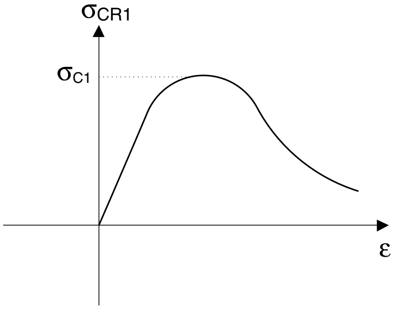
A_E : Net sectional area, in cm², of ordinary stiffeners with attached shell plating of width b_E

b_E : Width, in m, of the attached shell plating:

$$b_E = \left(\frac{2{,}25}{\beta_E} - \frac{1{,}25}{\beta_E^2}\right)s \quad \text{for} \quad \beta_E > 1{,}25$$

$$b_E = s \quad \text{for} \quad \beta_E \le 1{,}25$$

Figure 7 : Load-end shortening curve σ_{CR1}-ε for beam column buckling



2.3.5 Torsional buckling *(1/7/2016)*

The load-end shortening curve σ_{CR2}-ε for the flexural-torsional buckling of stiffeners composing the hull girder transverse section is to be obtained according to the following formula (see Fig 8):

$$\sigma_{CR2} = \Phi\frac{A_S\sigma_{C2} + 10st_P\sigma_{CP}}{A_S + 10st_P}$$

where:

Φ : Edge function defined in [2.3.3]

σ_{C2} : Critical stress, in N/mm²:

$$\sigma_{C2} = \frac{\sigma_{E2}}{\varepsilon} \quad \text{for} \quad \sigma_{E2} \le \frac{R_{eH}}{2}\varepsilon$$

$$\sigma_{C2} = R_{eH}\left(1 - \frac{R_{eH}\varepsilon}{4\sigma_{E2}}\right) \quad \text{for} \quad \sigma_{E2} > \frac{R_{eH}}{2}\varepsilon$$

σ_{E2} : Euler torsional buckling stress, in N/mm², defined in Ch 7, Sec 2, [4.3.3]

ε : Relative strain defined in [2.3.3]

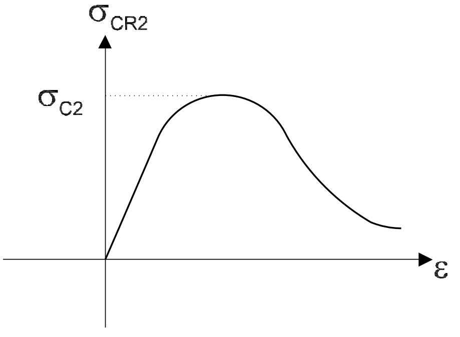
σ_{CP} : Buckling stress of the attached plating, in N/mm²:

$$\sigma_{CP} = \left(\frac{2,25}{\beta_E} - \frac{1,25}{\beta_E^2}\right) R_{eHp} \quad \text{for} \quad \beta_E > 1,25$$

$$\sigma_{CP} = R_{eHp} \quad \text{for} \quad \beta_E \leq 1,25$$

β_E : Coefficient defined in [2.3.4].

Figure 8 : Load-end shortening curve σ_{CR2}-ε for flexural-torsional buckling



2.3.6 Web local buckling of stiffeners made of flanged profiles *(1/7/2016)*

The load-end shortening curve σ_{CR3}-ε for the web local buckling of flanged stiffeners composing the hull girder transverse section is to be obtained from the following formula:

$$\sigma_{CR3} = \Phi \frac{10^3 b_E t_P + R_{eHp} + (h_{WE} t_W + b_F t_F) R_{eHS}}{10^3 s t_P + h_W t_W + b_F t_F}$$

where:

Φ : Edge function defined in [2.3.3]

b_E : Effective width, in m, of the attached shell plating, defined in [2.3.4]

h_{WE} : Effective height, in mm, of the web:

$$h_{WE} = \left(\frac{2,25}{\beta_E} - \frac{1,25}{\beta_E^2}\right) h_W \quad \text{for} \quad \beta_W > 1,25$$

$$h_{WE} = h_W \quad \text{for} \quad \beta_W \leq 1,25$$

β_E : Coefficient defined in [2.3.4]

$$\beta_W = \frac{h_W}{t_W}\sqrt{\frac{\varepsilon R_{eHS}}{E}}$$

2.3.7 Web local buckling of stiffeners made of flat bars *(1/7/2016)*

The load-end shortening curve σ_{CR4}-ε for the web local buckling of flat bar stiffeners composing the hull girder transverse section is to be obtained from the following formula (see Fig 9):

$$\sigma_{CR4} = \Phi \frac{10 s t_P \sigma_{CP} + A_S \sigma_{C4}}{A_S + 10 s t_P}$$

where:

Φ : Edge function defined in [2.3.3]

σ_{CP} : Buckling stress of the attached plating, in N/mm², defined in [2.3.5]

σ_{C4} : Critical stress, in N/mm²:

$$\sigma_{C4} = \frac{\sigma_{E4}}{\varepsilon} \quad \text{for} \quad \sigma_{E4} \leq \frac{R_{eHS}}{2}\varepsilon$$

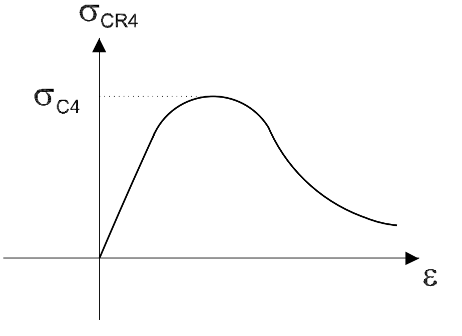
$$\sigma_{C4} = R_{eHS}\left(1 - \frac{R_{eHS}\varepsilon}{4\sigma_{E4}}\right) \quad \text{for} \quad \sigma_{E4} > \frac{R_{eHS}}{2}\varepsilon$$

σ_{E4} : Local Euler buckling stress, in N/mm²:

$$\sigma_{E4} = 160000\left(\frac{t_W}{h_W}\right)^2$$

ε : Relative strain defined in [2.3.3].

Figure 9 : Load-end shortening curve σ_{CR4}-ε for web local buckling of flat bars



2.3.8 Plate buckling *(1/7/2016)*

The load-end shortening curve σ_{CR5}-ε for the buckling of transversely stiffened panels composing the hull girder transverse section is to be obtained from the following formula:

$$\sigma_{CR5} = \min\begin{cases} R_{eHp}\phi \\ \phi R_{eHp}\left[\frac{s}{l}\left(\frac{2,25}{\beta_E} - \frac{1,25}{\beta_E^2}\right) + 0,1\left(1 - \frac{s}{l}\right)\left(1 + \frac{1}{\beta_E^2}\right)^2\right] \end{cases}$$

where:

β_E : Coefficient defined in [2.3.4].

ϕ : Edge function defined in [2.3.3].

3 Alternative methods

3.1 Non-linear finite element analysis

3.1.1 *(1/7/2016)*

Advanced non-linear finite element analyses models may be used for the assessment of the hull girder ultimate capacity. Such models are to consider the relevant effects important to the non-linear responses.

3.1.2 *(1/7/2016)*

Particular attention is to be given to modelling the shape and size of geometrical imperfections. It is to be ensured that the shape and size of geometrical imperfections trigger the most critical failure modes.

Part B
Hull and Stability

Chapter 7
HULL SCANTLINGS

Symbols used in chapter 7

L_1, L_2 : Lengths, in m, defined in Pt B, Ch 1, Sec 2, [2.1.1],

E : Young's modulus, in N/mm^2, to be taken equal to:

- for steels in general: $E = 2{,}06.10^5$ N/mm^2
- for stainless steels: $E = 1{,}95.10^5$ N/mm^2
- for aluminium alloys: $E = 7{,}0.10^4$ N/mm^2

ν : Poisson's ratio. Unless otherwise specified, a value of 0,3 is to be taken into account,

k : material factor, defined in:

- Pt B, Ch 4, Sec 1, [2.3], for steel,
- Pt B, Ch 4, Sec 1, [4.4], for aluminium alloys,

R_y : Minimum yield stress, in N/mm^2, of the material, to be taken equal to 235/k N/mm^2, unless otherwise specified,

t_c : Corrosion addition, in mm, defined in Pt B, Ch 4, Sec 2, Tab 2,

I_Y : Net moment of inertia, in m^4, of the hull transverse section around its horizontal neutral axis, to be calculated according to Pt B, Ch 6, Sec 1, [2.4] considering the members contributing to the hull girder longitudinal strength as having their net scantlings,

I_Z : Net moment of inertia, in m^4, of the hull transverse section around its vertical neutral axis, to be calculated according to Pt B, Ch 6, Sec 1, [2.4] considering the members contributing to the hull girder longitudinal strength as having their net scantlings,

x, y, z : X, Y and Z co-ordinates, in m, of the calculation point with respect to the reference co-ordinate system defined in Pt B, Ch 1, Sec 2, [4],

N : Z co-ordinate, in m, with respect to the reference co-ordinate system defined in Pt B, Ch 1, Sec 2, [4], of the centre of gravity of the hull transverse section constituted by members contributing to the hull girder longitudinal strength considered as having their net scantlings (see Pt B, Ch 6, Sec 1, [2]),

$M_{SW,H}$: Design still water bending moment, in kN.m, in hogging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [2.2],

$M_{SW,S}$: Design still water bending moment, in kN.m, in sagging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [2.2],

$M_{SW,Hmin}$: Minimum still water bending moment, in kN.m, in hogging condition, at the hull transverse section considered, without being taken greater than $0{,}3M_{WV,S}$,

$M_{WV,H}$: Vertical wave bending moment, in kN.m, in hogging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [3.1],

$M_{WV,S}$: Vertical wave bending moment, in kN.m, in sagging condition, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [3.1],

M_{WH} : Horizontal wave bending moment, in kN.m, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [3.2],

M_{WT} : Wave torque, in kN.m, at the hull transverse section considered, defined in Pt B, Ch 5, Sec 2, [3.3].

SECTION 1 PLATING

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

p_S : Still water pressure, in kN/m², see [3.2.2]

p_W : Wave pressure and, if necessary, dynamic pressures, according to the criteria in Ch 5, Sec 5 and Ch 5, Sec 6, [2], in kN/m² (see [3.2.2])

p_{SF}, p_{WF} : Still water and wave pressure, in kN/m², in flooding conditions, defined in Ch 5, Sec 6, [9] (see [3.2.3])

F_S : Still water wheeled force, in kN, see [4.2.2]

$F_{W,Z}$: Inertial wheeled force, in kN, see [4.2.2]

σ_{X1} : In-plane hull girder normal stress, in N/mm², defined in:

- [3.2.5] for the strength check of plating subjected to lateral pressure
- [5.2.2] for the buckling check of plating

τ_1 : In-plane hull girder shear stress, in N/mm², defined in [3.2.6]

R_{eH} : Minimum yield stress, in N/mm², of the plating material, defined in Ch 4, Sec 1, [2]

ℓ : Length, in m, of the longer side of the plate panel

s : Length, in m, of the shorter side of the plate panel

a, b : Lengths, in m, of the sides of the plate panel, as shown in Fig 2 to Fig 4

c_a : Aspect ratio of the plate panel, equal to:

$$c_a = 1{,}21\sqrt{1+0{,}33\left(\frac{s}{\ell}\right)^2} - 0{,}69\frac{s}{\ell}$$

to be taken not greater than 1,0

c_r : Coefficient of curvature of the panel, equal to:

$$c_r = 1 - 0{,}5s/r$$

to be taken not less than 0,75

r : Radius of curvature, in m

t_{net} : Net thickness, in mm, of a plate panel

1 General

1.1 Net thicknesses

1.1.1 As specified in Ch 4, Sec 2, [1], all thicknesses referred to in this Section are net, i.e. they do not include any margin for corrosion.

The gross thicknesses are obtained as specified in Ch 4, Sec 2.

1.2 Partial safety factors

1.2.1 The partial safety factors to be considered for the checking of the plating are specified in Tab 1.

1.3 Elementary plate panel

1.3.1 The elementary plate panel is the smallest unstiffened part of plating.

1.4 Load point

1.4.1 Unless otherwise specified, lateral pressure and hull girder stresses are to be calculated:

- for longitudinal framing, at the lower edge of the elementary plate panel or, in the case of horizontal plating, at the point of minimum y-value among those of the elementary plate panel considered
- for transverse framing, at the lower edge of the strake.

Table 1 : Plating - Partial safety factors *(1/7/2020)*

Partial safety factors covering uncertainties regarding:	Symbol	Strength check of plating subjected to lateral pressure			Buckling check (see [5])
		General (see [3.2], [3.3.1], [3.4.1], [3.5.1] and [4])	Flooding pressure **(1)** (see [3.2] [3.3.2], [3.4.2] and [3.5.2])	Testing check (see (see [3.2] [3.3.2], [3.4.2] and [3.5.2])	
Still water hull girder loads	γ_{S1}	1,00	1,00	Not applicable	1,00
Wave hull girder loads	γ_{W1}	1,15	1,15	Not applicable	1,15
Still water pressure	γ_{S2}	1,00	1,00	1,00	Not applicable

(1) Applies only to plating to be checked in flooding conditions.
(2) For plating of the collision bulkhead, γ_R =1,25

Partial safety factors covering uncertainties regarding:	Symbol	Strength check of plating subjected to lateral pressure			Buckling check (see [5])
		General (see [3.2], [3.3.1], [3.4.1], [3.5.1] and [4])	Flooding pressure **(1)** (see [3.2] [3.3.2], [3.4.2] and [3.5.2])	Testing check (see (see [3.2] [3.3.2], [3.4.2] and [3.5.2])	
Wave pressure	γ_{W2}	1,20	1,20	Not applicable	Not applicable
Material	γ_m	1,02	1,02	1,02	1,02
Resistance	γ_R	1,20	1,05 **(2)**	1,05	1,10

(1) Applies only to plating to be checked in flooding conditions.
(2) For plating of the collision bulkhead, γ_R =1,25

2 General requirements

2.1 General

2.1.1 The requirements in [2.2] and [2.3] are to be applied to plating in addition of those in [3] to [5].

2.2 Minimum net thicknesses

2.2.1 The net thickness of plating is to be not less than the values given in Tab 2.

2.3 Bilge plating

2.3.1 The bilge plating net thickness is to be not less than the values obtained from:

- strength check of plating subjected to lateral pressure:
  - criteria in [3.3.1] for longitudinally framed bilges
  - criteria in [3.4.1] for transversely framed bilges
- buckling check:
  - criteria in [5] for longitudinally framed bilge, to be checked as plane plating
  - criteria in [5.3.4] for transversely framed bilge, considering only the case of compression stresses perpendicular to the curved edges.

The net thickness of longitudinally framed bilge plating is to be not less than that required for the adjacent bottom or side plating, whichever is the greater.

The net thickness of transversely framed bilge plating may be taken not greater than that required for the adjacent bottom or side plating, whichever is the greater.

2.4 Inner bottom of cargo holds intended to carry dry cargo

2.4.1 For ships with one of the following service notations:

- **general cargo ship**, intended to carry dry bulk cargo in holds
- **bulk carrier ESP**
- **ore carrier ESP**
- **combination carrier ESP**

the inner bottom and sloping plating net thickness is to be increased by 2 mm unless they are protected by a continuous wooden ceiling.

2.5 Sheerstrake

2.5.1 Welded sheerstrake

The net thickness of a welded sheerstrake is to be not less than that of the adjacent side plating, taking into account higher strength steel corrections if needed.

In general, the required net thickness of the adjacent side plating is to be taken as a reference. In specific case, depending on its actual net thickness, this latter may be required to be considered when deemed necessary by the Society.

Table 2 : Minimum net thickness of plating

Plating	Minimum net thickness, in mm
Keel	$3,8 + 0,040Lk^{1/2} + 4,5s$
Bottom	
• longitudinal framing	$1,9 + 0,032Lk^{1/2} + 4,5s$
• transverse framing	$2,8 + 0,032Lk^{1/2} + 4,5s$
Inner bottom	
• outside the engine room **(1)**	$1,9 + 0,024Lk^{1/2} + 4,5s$
• engine room	$3,0 + 0,024Lk^{1/2} + 4,5s$
Side	
• below freeboard deck **(1)**	$2,1 + 0,031Lk^{1/2} + 4,5s$
• between freeboard deck and strength deck	$2,1 + 0,013Lk^{1/2} + 4,5s$
Inner side	
• L < 120 m	$1,7 + 0,013Lk^{1/2}+ 4,5s$
• L ≥ 120 m	$3,6 + 2,2k^{1/2} + s$

(1) Not applicable to ships with one of the service notations **passenger ship** and **ro-ro passenger ship**. For such ships, refer to the applicable requirements of Part E.
(2) Not applicable to ships with one of the following service notations:
- **ro-ro cargo ship**
- **liquefied gas carrier**
- **passenger ship**
- **ro-ro passenger ship**.

For such ships, refer to the applicable requirements of Part E.
(3) The minimum net thickness is to be obtained by linearly interpolating between that required for the area within 0,4 L amidships and that at the fore and aft part.

Plating	Minimum net thickness, in mm
Weather strength deck and trunk deck, if any **(2)** • area within 0,4 L amidships - longitudinal framing - transverse framing • area outside 0,4 L amidships • between hatchways • at fore and aft part	 $1,6 + 0,032Lk^{1/2} + 4,5s$ $1,6 + 0,040Lk^{1/2} + 4,5s$ **(3)** $2,1 + 0,013Lk^{1/2} + 4,5s$ $2,1 + 0,013Lk^{1/2} + 4,5s$
Cargo deck • general • wheeled load only	 $8sk^{1/2}$ 4,5
Accommodation deck • L < 120 m • L ≥ 120 m	 $1,3 + 0,004Lk^{1/2} + 4,5s$ $2,1 + 2,2k^{1/2} + s$
Platform in engine room • L < 120 m • L ≥ 120 m	 $1,7 + 0,013Lk^{1/2} + 4,5s$ $3,6 + 2,2k^{1/2} + s$
Transverse watertight bulkhead • L < 120 m • L ≥ 120 m	 $1,3 + 0,004Lk^{1/2} + 4,5s$ $2,1 + 2,2k^{1/2} + s$
Longitudinal watertight bulkhead • L < 120 m • L ≥ 120 m	 $1,7 + 0,013Lk^{1/2} + 4,5s$ $3,6 + 2,2k^{1/2} + s$
Tank and wash bulkheads • L < 120 m • L ≥ 120 m	 $1,7 + 0,013Lk^{1/2} + 4,5s$ $3,6 + 2,2k^{1/2} + s$

(1) Not applicable to ships with one of the service notations **passenger ship** and **ro-ro passenger ship**. For such ships, refer to the applicable requirements of Part E.

(2) Not applicable to ships with one of the following service notations:
- **ro-ro cargo ship**
- **liquefied gas carrier**
- **passenger ship**
- **ro-ro passenger ship**.

For such ships, refer to the applicable requirements of Part E.

(3) The minimum net thickness is to be obtained by linearly interpolating between that required for the area within 0,4 L amidships and that at the fore and aft part.

2.5.2 Rounded sheerstrake

The net thickness of a rounded sheerstrake is to be not less than the actual net thickness of the adjacent deck plating.

2.5.3 Net thickness of the sheerstrake in way of breaks of long superstructures

The net thickness of the sheerstrake is to be increased in way of breaks of long superstructures occurring within 0,5L amidships, over a length of about one sixth of the ship's breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 40%, but need not exceed 4,5 mm.

Where the breaks of superstructures occur outside 0,5L amidships, the increase in net thickness may be reduced to 30%, but need not exceed 2,5 mm.

2.5.4 Net thickness of the sheerstrake in way of breaks of short superstructures

The net thickness of the sheerstrake is to be increased in way of breaks of short superstructures occurring within 0,6L amidships, over a length of about one sixth of the ship's breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 15%, but need not exceed 4,5 mm.

2.6 Stringer plate

2.6.1 General

The net thickness of the stringer plate is to be not less than the actual net thickness of the adjacent deck plating.

2.6.2 Net thickness of the stringer plate in way of breaks of long superstructures

The net thickness of the stringer plate is to be increased in way of breaks of long superstructures occurring within 0,5L amidships, over a length of about one sixth of the ship's breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 40%, but need not exceed 4,5 mm.

Where the breaks of superstructures occur outside 0,5L amidships, the increase in net thickness may be reduced to 30%, but need not exceed 2,5 mm.

2.6.3 Net thickness of the stringer plate in way of breaks of short superstructures

The net thickness of the stringer plate is to be increased in way of breaks of short superstructures occurring within 0,6L amidships, over a length of about one sixth of the ship breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 15%, but need not exceed 4,5 mm.

3 Strength check of plating subjected to lateral pressure

3.1 General

3.1.1 The requirements of this Article apply for the strength check of plating subjected to lateral pressure and, for plating contributing to the longitudinal strength, to in-plane hull girder normal and shear stresses.

3.2 Load model

3.2.1 General

The still water and wave lateral pressures induced by the sea and the various types of cargoes and ballast in intact conditions are to be considered, depending on the location of the plating under consideration and the type of the compartments adjacent to it, in accordance with Ch 5, Sec 1, [2.4].

The plating of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids is to be subjected to lateral pressure in flooding conditions.

The wave lateral pressures and hull girder loads are to be calculated in the mutually exclusive load cases “a”, “b”, “c” and “d” in Ch 5, Sec 4.

3.2.2 Lateral pressure in intact conditions

The lateral pressure in intact conditions is constituted by still water pressure and wave pressure.

Still water pressure (p_S) includes:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave pressure (p_W) includes:

- the wave pressure, defined in Ch 5, Sec 5, [2] for each load case “a”, “b”, “c” and “d”
- the inertial pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast, and for each load case “a”, “b”, “c” and “d”
- the dynamic pressures, according to the criteria in Ch 5, Sec 6, [2].

3.2.3 Lateral pressure in flooding conditions

The lateral pressure in flooding conditions is constituted by the still water pressure p_{SF} and wave pressure p_{WF} defined in Ch 5, Sec 6, [9].

3.2.4 Lateral pressure in testing conditions *(1/7/2020)*

The lateral pressure (p_T), in kN/m². in testing conditions is taken equal to:

- p_{ST} - p_S for bottom shell plating and side shell plating
- p_{ST} otherwise

Where:

p_{ST} : Still water pressure defined in Ch 5, Sec 6, Tab 13

p_S : Still water sea pressure defined in Ch 5, Sec 5, [1.1.1] for the draught T_1 at which the testing is carried out.

If the draught T_1 is not defined by the Designer, it may be taken equal to the light ballast draught T_B defined in Ch 5, Sec 1, [2.4.3].

3.2.5 In-plane hull girder normal stresses

The in-plane hull girder normal stresses to be considered for the strength check of plating are obtained, in N/mm², from the following formulae:

- for plating contributing to the hull girder longitudinal strength:

$$\sigma_{X1} = \gamma_{S1}\sigma_{S1} + \gamma_{W1}(C_{FV}\sigma_{WV1} + C_{FH}\sigma_{WH1} + C_{F\Omega}\sigma_{\Omega})$$

- for plating not contributing to the hull girder longitudinal strength:

$$\sigma_{X1} = 0$$

where:

σ_{S1}, σ_{WV1}, σ_{WH1} : Hull girder normal stresses, in N/mm², defined in Tab 3

σ_{Ω} : Absolute value of the warping stress, in N/mm², induced by the torque $0,625M_{WT}$ and obtained through direct calculation analyses based on a structural model in accordance with Ch 6, Sec 1, [2.6]

C_{FV}, C_{FH}, $C_{F\Omega}$: Combination factors defined in Tab 4.

Table 3 : Hull girder normal stresses

Condition	σ_{S1}, in N/mm² **(1)**	σ_{WV1}, in N/mm²	σ_{WH1}, in N/mm²
$\frac{\lvert\gamma_{S1}M_{SW,S} + 0,625\gamma_{W1}C_{FV}M_{WV,S}\rvert}{\gamma_{S1}M_{SW,H} + 0,625\gamma_{W1}C_{FV}M_{WV,H}} \geq 1$	$\left\lvert\frac{M_{SW,S}}{I_Y}(z-N)\right\rvert 10^{-3}$	$\left\lvert\frac{0,625F_D M_{WV,S}}{I_Y}(z-N)\right\rvert 10^{-3}$	$\left\lvert\frac{0,625M_{WH}}{I_Z}y\right\rvert 10^{-3}$
$\frac{\lvert\gamma_{S1}M_{SW,S} + 0,625\gamma_{W1}C_{FV}M_{WV,S}\rvert}{\gamma_{S1}M_{SW,H} + 0,625\gamma_{W1}C_{FV}M_{WV,H}} < 1$	$\left\lvert\frac{M_{SW,H}}{I_Y}(z-N)\right\rvert 10^{-3}$	$\left\lvert\frac{0,625M_{WV,H}}{I_Y}(z-N)\right\rvert 10^{-3}$	

(1) When the ship in still water is always in hogging condition, $M_{SW,S}$ is to be taken equal to 0.
Note 1:
F_D : Coefficient defined in Ch 5, Sec 2, [4].

Table 4 : Combination factors C_{FV}, C_{FH} and $C_{F\Omega}$

Load case	C_{FV}	C_{FH}	$C_{F\Omega}$
“a”	1,0	0	0
“b”	1,0	0	0
“c”	0,4	1,0	1,0
“d”	0,4	1,0	0

3.2.6 In-plane hull girder shear stresses

The in-plane hull girder shear stresses to be considered for the strength check of plating which contributes to the longitudinal strength are obtained, in N/mm², from the following formula:

$$\tau_1 = \gamma_{S1}\tau_{S1} + 0,625C_{FV}\gamma_{W1}\tau_{W1}$$

where:

τ_{S1} : Absolute value of the hull girder shear stresses, in N/mm², induced by the maximum still water hull girder vertical shear force

τ_{W1} : Absolute value of the hull girder shear stresses, in N/mm², induced by the maximum wave hull girder vertical shear force

C_{FV} : Combination factor defined in Tab 4.

τ_{S1} and τ_{W1} may be calculated as indicated in Tab 5 where, at a preliminary design stage, the still water hull girder vertical shear force is not defined.

3.3 Longitudinally framed plating contributing to the hull girder longitudinal strength

3.3.1 General

The net thickness of laterally loaded plate panels subjected to in-plane normal stress acting on the shorter sides is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{\lambda_L R_y}}$$

where:

- for bottom, bilge, inner bottom and decks (excluding possible longitudinal sloping plates):

$$\lambda_L = \sqrt{1 - 0{,}95\left(\gamma_m \frac{\sigma_{x1}}{R_y}\right)^2} - 0{,}225\gamma_m \frac{\sigma_{x1}}{R_y}$$

- for side, inner side and longitudinal bulkheads (including possible longitudinal sloping plates):

$$\lambda_L = \sqrt{1 - 3\left(\gamma_m \frac{\tau_1}{R_y}\right)^2 - 0{,}95\left(\gamma_m \frac{\sigma_{x1}}{R_y}\right)^2} - 0{,}225\gamma_m \frac{\sigma_{x1}}{R_y}$$

3.3.2 Flooding conditions

The plating of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids is to be checked in flooding conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{\lambda_L R_y}}$$

where λ_L is defined in [3.3.1].

Table 5 : Hull girder shear stresses

Structural element	τ_{S1}, τ_{W1} in N/mm²
Bottom, bilge, inner bottom and decks (excluding possible longitudinal sloping plates)	0
Side, inner side and longitudinal bulkheads (including possible longitudinal sloping plates):	
• $0 \le z \le 0{,}25D$	$\tau_0\left(0{,}5 + 2\frac{z}{D}\right)$
• $0{,}25D < z \le 0{,}75D$	τ_0
• $0{,}75D < z \le D$	$\tau_0\left(2{,}5 - 2\frac{z}{D}\right)$
Note 1: $\tau_0 = \frac{47}{k}\left\{1 - \frac{6{,}3}{\sqrt{L_1}}\right\}$ N/mm²	

3.3.3 Testing conditions *(1/1/2021)*

The plating of compartments or structures as defined in Ch 5, Sec 6, Tab 13 is to be checked in testing conditions. Its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_T}{R_y}}$$

3.4 Transversely framed plating contributing to the hull girder longitudinal strength

3.4.1 General

The net thickness of laterally loaded plate panels subjected to in-plane normal stress acting on the longer sides is to be not less than the value obtained, in mm, from the following formula:

$$t = C_T c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{\lambda_T R_y}}$$

where:

- for bottom, bilge, inner bottom and decks (excluding possible longitudinal sloping plates):

  C_T : Coefficient equal to 17,2

$$\lambda_T = 1 - 0{,}89\gamma_m \frac{\sigma_{x1}}{R_y}$$

- for side, inner side and longitudinal bulkheads (including possible longitudinal sloping plates):

  C_T : Coefficient equal to:

  17,2 for side

  14,9 for inner side and longitudinal bulkheads (including possible longitudinal sloping plates)

$$\lambda_T = \sqrt{1 - 3\left(\gamma_m \frac{\tau_1}{R_y}\right)^2} - 0{,}89\gamma_m \frac{\sigma_{x1}}{R_y}$$

3.4.2 Flooding conditions

The plating of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids is to be checked in flooding conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{\lambda_T R_y}}$$

where λ_T is defined in [3.4.1].

3.4.3 Testing conditions *(1/1/2021)*

The plating of compartments or structures as defined in Ch 5, Sec 6, Tab 13 is to be checked in testing conditions. Its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_T}{R_y}}$$

3.5 Plating not contributing to the hull girder longitudinal strength

3.5.1 General

The net thickness of plate panels subjected to lateral pressure is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{R_y}}$$

3.5.2 Flooding conditions

The plating of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids is to be checked in flooding conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{R_y}}$$

3.5.3 Testing conditions *(1/1/2021)*

The plating of compartments or structures as defined in Ch 5, Sec 6, Tab 13 is to be checked in testing conditions. Its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_T}{R_y}}$$

4 Strength check of plating subjected to wheeled loads

4.1 General

4.1.1 The requirements of this Article apply for the strength check of plating subjected to wheeled loads.

4.2 Load model

4.2.1 General

The still water and inertial forces induced by the sea and the various types of wheeled vehicles are to be considered, depending on the location of the plating.

The inertial forces induced by the sea are to be calculated in load case “b”, as defined in Ch 5, Sec 4.

4.2.2 Wheeled forces

The wheeled force applied by one wheel is constituted by still water force and inertial force.

Still water force is the vertical force (F_S) defined in Ch 5, Sec 6, [6.1].

Inertial force is the vertical force ($F_{W,Z}$) defined in Ch 5, Sec 6, [6.1], for load case “b”, with the acceleration a_{Z1} calculated at x = 0,5L.

4.3 Plating

4.3.1 *(1/7/2009)*

The net thickness of plate panels subjected to wheeled loads is to be not less than the value obtained, in mm, from the following formula:

$$t = C_{WL}(nP_0k)^{0,5} - t_c$$

where:

C_{WL} : Coefficient to be taken equal to:

$$C_{WL} = 2,15 - \frac{0,05\ell}{s} + 0,02\left(4 - \frac{\ell}{s}\right)\alpha^{0,5} - 1,7\alpha^{0,25}$$

where ℓ/s is to be taken not greater than 3

$\alpha = \frac{A_T}{\ell s}$ where ℓ is to be taken not greater than 5s

A_T : Tyre print area, in m². In the case of double or triple wheels, the area is that corresponding to the group of wheels.

n : Number of wheels on the plate panel, taken equal to:

- 1 in the case of a single wheel
- the number of wheels in a group of wheels in the case of double or triple wheels

P_0 : wheeled force, in kN, taken equal to:

$$P_0 = \gamma_{S2} F_S + 0{,}4 \gamma_{W2} F_{W,Z}$$

4.3.2 When the tyre print area is not known, it may be taken equal to:

$$A_T = 9,81 \frac{nQ_A}{n_W p_T}$$

where:

n : Number of wheels on the plate panel, defined in [4.3.1]

Q_A : Axle load, in t

n_W : Number of wheels for the axle considered

p_T : Tyre pressure, in kN/m². When the tyre pressure is not indicated by the designer, it may be taken as defined in Tab 6.

Table 6 : Tyre pressures p_T for vehicles

Vehicle type	Tyre pressure p_T, in kN/m²	
	Pneumatic tyres	Solid rubber tyres
Private cars	250	Not applicable
Vans	600	Not applicable
Trucks and trailers	800	Not applicable
Handling machines	1100	1600

4.3.3 For vehicles with the four wheels of the axle located on a plate panel as shown in Fig 1, the net thickness of deck plating is to be not less than the greater of the values obtained, in mm, from the following formulae:

$$t = t_1$$

$$t = t_2(1 + \beta_2 + \beta_3 + \beta_4)^{0,5}$$

where:

t_1 : Net thickness obtained from [4.3.1] for n = 2, considering one group of two wheels located on the plate panel

t_2 : Net thickness obtained from [4.3.1] for n = 1, considering one wheel located on the plate panel

β_2, β_3, β_4: Coefficients obtained from the following formula, by replacing i by 2, 3 and 4, respectively (see Fig 1):

- for $x_i/b < 2$:

$$\beta_i = 0,8(1,2 - 2,02\alpha_i + 1,17\alpha_i^2 - 0,23\alpha_i^3)$$

- for $x_i/b \geq 2$:

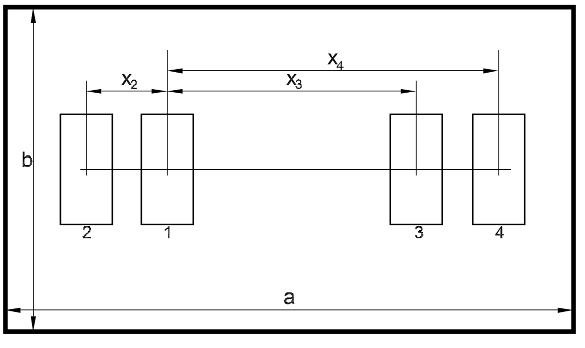
$$\beta_i = 0$$

x_i : Distance, in m, from the wheel considered to the reference wheel (see Fig 1)

b : Dimension, in m, of the plate panel side perpendicular to the axle

$$\alpha_i = \frac{x_i}{b}$$

Figure 1 : Four wheel axle located on a plate panel



5 Buckling check

5.1 General

5.1.1 Application *(1/7/2016)*

The requirements of this Article apply for the buckling check of plating subjected to in-plane compression stresses, acting on one or two sides, or to shear stress.

Rectangular plate panels are considered as being simply supported. For specific designs, other boundary conditions may be considered, at the Society's discretion, provided that the necessary information is submitted for review.

Ships with the service notation **container ship**, in addition to the requirements of this Article, are to comply with the requirements of Pt E, Ch 2, Sec 2, [6].

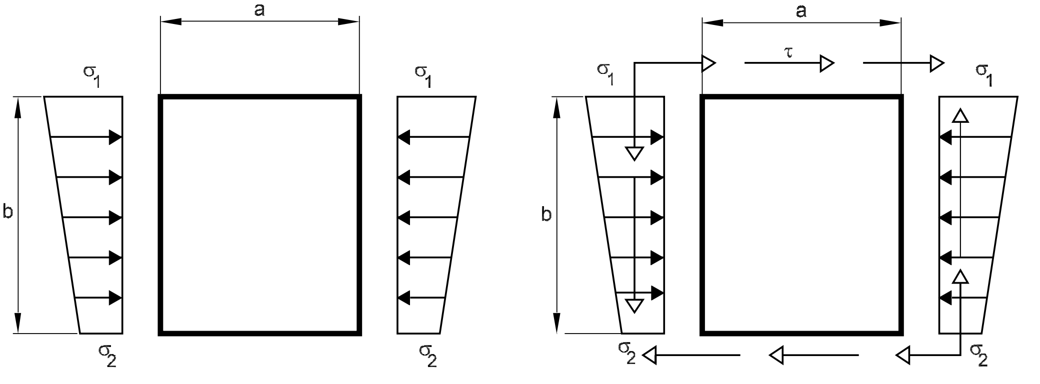
5.1.2 Compression and bending with or without shear

For plate panels subjected to compression and bending along one side, with or without shear, as shown in Fig 2, side "b" is to be taken as the loaded side. In such case, the compression stress varies linearly from σ_1 to $\sigma_2 = \psi\, \sigma_1$ ($\psi \leq 1$) along edge "b".

5.1.3 Shear

For plate panels subjected to shear, as shown in Fig 3, side "b" may be taken as either the longer or the shorter side of the panel.

Figure 2 : Buckling of a simply supported rectangular plate panel subjected to compression and bending, with and without shear



5.1.4 Bi-axial compression and shear

For plate panels subjected to bi-axial compression along sides "a" and "b", and to shear, as shown in Fig 4, side "a" is to be taken as the side in the direction of the primary supporting members.

Figure 3 : Buckling of a simply supported rectangular plate panel subjected to shear

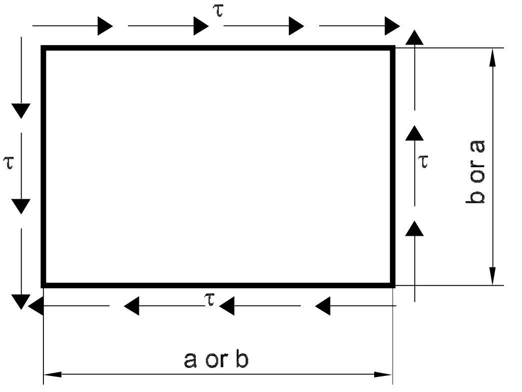
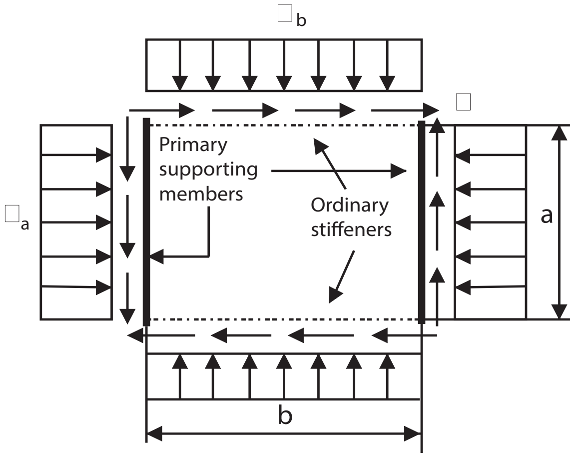


Figure 4 : Buckling of a simply supported rectangular plate panel subjected to bi-axial compression and shear *(1/7/2011)*



5.2 Load model

5.2.1 Sign convention for normal stresses

The sign convention for normal stresses is as follows:

- tension: positive
- compression: negative.

5.2.2 In-plane hull girder compression normal stresses

The in-plane hull girder compression normal stresses to be considered for the buckling check of plating contributing to the longitudinal strength are obtained, in N/mm², from the following formula:

$$\sigma_{X1} = \gamma_{S1}\sigma_{S1} + \gamma_{W1}(C_{FV}\sigma_{WV1} + C_{FH}\sigma_{WH1} + C_{F\Omega}\sigma_{\Omega})$$

where:

σ_{S1}, σ_{WV1}, σ_{WH1} : Hull girder normal stresses, in N/mm², defined in Tab 7

σ_{Ω} : Compression warping stress, in N/mm², induced by the torque $0,625M_{WT}$ and obtained through direct calculation analyses based on a structural model in accordance with Ch 6, Sec 1, [2.6]

C_{FV}, C_{FH}, $C_{F\Omega}$:Combination factors defined in Tab 4.

σ_{X1} is to be taken as the maximum compression stress on the plate panel considered.

In no case may σ_{X1} be taken less than 30/k N/mm².

When the ship in still water is always in hogging condition, σ_{X1} may be evaluated by means of direct calculations when justified on the basis of the ship's characteristics and intended service. The calculations are to be submitted to the Society for approval.

5.2.3 In-plane hull girder shear stresses

The in-plane hull girder shear stresses to be considered for the buckling check of plating are obtained as specified in [3.2.6] for the strength check of plating subjected to lateral pressure, which contributes to the longitudinal strength.

5.2.4 Combined in-plane hull girder and local compression normal stresses

The combined in-plane compression normal stresses to be considered for the buckling check of plating are to take into account the hull girder stresses and the local stresses resulting from the bending of the primary supporting members. These local stresses are to be obtained from a direct structural analysis using the design loads given in Chapter 5.

With respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4.1], the combined stresses in x and y direction are obtained, in N/mm², from the following formulae:

$$\sigma_X = \sigma_{X1} + \gamma_{S2}\sigma_{X2,S} + \gamma_{W2}\sigma_{X2,W}$$

$$\sigma_Y = \gamma_{S2}\sigma_{Y2,S} + \gamma_{W2}\sigma_{Y2,W}$$

where:

σ_{X1} : Compression normal stress, in N/mm², induced by the hull girder still water and wave loads, defined in [5.2.2]

$\sigma_{X2,S}$,$\sigma_{Y2,S}$: Compression normal stress in x and y direction, respectively, in N/mm², induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the still water design loads given in Chapter 5

$\sigma_{X2,W}$,$\sigma_{Y2,W}$: Compression normal stress in x and y direction, respectively, in N/mm², induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the wave design loads given in Chapter 5.

Table 7 : Hull girder normal compression stresses

Condition	σ_{S1} in N/mm² **(1)**	σ_{WV1} in N/mm²	σ_{WH1} in N/mm²
$z \geq N$	$\frac{M_{SW,S}}{I_Y}(z-N)10^{-3}$	$\frac{0,625 F_D M_{WV,S}}{I_Y}(z-N)10^{-3}$	$-\left\lvert\frac{0,625 M_{WH}}{I_Z}y\right\rvert 10^{-3}$
$z < N$	$\frac{M_{SW,H}}{I_Y}(z-N)10^{-3}$	$\frac{0,625 M_{WV,H}}{I_Y}(z-N)10^{-3}$	

(1) When the ship in still water is always in hogging condition, σ_{S1} for $z \geq N$ is to be obtained, in N/mm², from the following formula, unless σ_{X1} is evaluated by means of direct calculations (see [5.2.2]):

$$\sigma_{S1} = \frac{M_{SW,Hmin}}{I_Y}(z-N)10^{-3}$$

Note 1:

F_D : Coefficient defined in Ch 5, Sec 2, [4].

5.2.5 Combined in-plane hull girder and local shear stresses

The combined in-plane shear stresses to be considered for the buckling check of plating are to take into account the hull girder stresses and the local stresses resulting from the bending of the primary supporting members. These local stresses are to be obtained from a direct structural analysis using the design loads given in Chapter 5.

The combined stresses are obtained, in N/mm², from the following formula:

$$\tau = \tau_1 + \gamma_{S2}\tau_{2,S} + \gamma_{W2}\tau_{2,W}$$

where:

τ_1 : Shear stress, in N/mm², induced by the hull girder still water and wave loads, defined in [5.2.3]

$\tau_{2,S}$: Shear stress, in N/mm², induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the still water design loads given in Chapter 5

$\tau_{2,W}$: Shear stress, in N/mm², induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the wave design loads given in Chapter 5.

5.3 Critical stresses

5.3.1 Compression and bending for plane panel

The critical buckling stress is to be obtained, in N/mm², from the following formulae:

$$\sigma_c = \sigma_E \quad \text{for} \quad \sigma_E \leq \frac{R_{eH}}{2}$$

$$\sigma_c = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_E}\right) \quad \text{for} \quad \sigma_E > \frac{R_{eH}}{2}$$

where:

σ_E : Euler buckling stress, to be obtained, in N/mm², from the following formula:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_{net}}{b}\right)^2 K_1 \varepsilon \cdot 10^{-6}$$

K_1 : Buckling factor defined in Tab 8

ε : Coefficient to be taken equal to:

- $\varepsilon = 1$ for $\alpha \geq 1$,
- $\varepsilon = 1,05$ for $\alpha < 1$ and side “b” stiffened by flat bar
- $\varepsilon = 1,10$ for $\alpha < 1$ and side “b” stiffened by bulb section
- $\varepsilon = 1,21$ for $\alpha < 1$ and side “b” stiffened by angle or T-section
- $\varepsilon = 1,30$ for $\alpha < 1$ and side “b” stiffened by primary supporting members.

$\alpha = a/b$

5.3.2 Shear for plane panel

The critical shear buckling stress is to be obtained, in N/mm², from the following formulae:

$$\tau_c = \tau_E \quad \text{for} \quad \tau_E \leq \frac{R_{eH}}{2\sqrt{3}}$$

$$\tau_c = \frac{R_{eH}}{\sqrt{3}}\left(1 - \frac{R_{eH}}{4\sqrt{3}\tau_E}\right) \quad \text{for} \quad \tau_E > \frac{R_{eH}}{2\sqrt{3}}$$

where:

τ_E : Euler shear buckling stress, to be obtained, in N/mm², from the following formula:

$$\tau_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_{net}}{b}\right)^2 K_2 \cdot 10^{-6}$$

K_2 : Buckling factor to be taken equal to:

$$K_2 = 5,34 + \frac{4}{\alpha^2} \quad \text{for} \quad \alpha > 1$$

$$K_2 = \frac{5,34}{\alpha^2} + 4 \quad \text{for} \quad \alpha \leq 1$$

α : Coefficient defined in [5.3.1].

Table 8 : Buckling factor K_1 for plate panels

Load pattern	Aspect ratio	Buckling factor K_1
$0 \le \psi \le 1$	$\alpha \ge 1$ $\alpha < 1$	$\frac{8,4}{\psi + 1,1}$ $\left(\alpha + \frac{1}{\alpha}\right)^2 \frac{2,1}{\psi + 1,1}$
$-1 < \psi < 0$		$(1+\psi)K_1' - \psi K_1'' + 10\psi(1+\psi)$
$\psi \le -1$	$\alpha\frac{1-\psi}{2} \ge \frac{2}{3}$	$23,9\left(\frac{1-\psi}{2}\right)^2$
	$\alpha\frac{1-\psi}{2} < \frac{2}{3}$	$\left(15,87 + \frac{1,87}{\left(\alpha\frac{1-\psi}{2}\right)^2} + 8,6\left(\alpha\frac{1-\psi}{2}\right)^2\right)\left(\frac{1-\psi}{2}\right)^2$

Note 1:

$\psi = \frac{\sigma_2}{\sigma_1}$

K_1' : Value of K_1 calculated for $\psi = 0$

K_1'' : Value of K_1 calculated for $\psi = -1$

5.3.3 Bi-axial compression and shear for plane panel

The critical buckling stress $\sigma_{c,a}$ for compression on side "a" of the panel is to be obtained, in N/mm², from the following formula:

$$\sigma_{c,a} = \left(\frac{2,25}{\beta} - \frac{1,25}{\beta^2}\right)R_{eH}$$

where:

β : Slenderness of the panel, to be taken equal to:

$$\beta = 10^3 \frac{a}{t_{net}}\sqrt{\frac{R_{eH}}{E}}$$

without being taken less than 1,25.

The critical buckling stress $\sigma_{c,b}$ for compression on side "b" of the panel is to be obtained, in N/mm², from the formulae in [5.3.1].

The critical shear buckling stress is to be obtained, in N/mm², from the formulae in [5.3.2].

5.3.4 Compression and shear for curved panels

For curved panels, the effects of lateral pressure are also to be taken into account.

The critical buckling stress of curved panels subjected to compression on curved edges and to lateral pressure is to be obtained, in N/mm², from the following formulae:

$$\sigma_c = \sigma_E \quad \text{for} \quad \sigma_E \le \frac{R_{eH}}{2}$$

$$\sigma_c = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_E}\right) \quad \text{for} \quad \sigma_E > \frac{R_{eH}}{2}$$

where:

σ_E : Euler buckling stress, to be obtained, in N/mm², from the following formula:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_{net}}{b}\right)^2 K_3 \cdot 10^{-6}$$

b : Width of curved panel, in mm, measured on arc

K_3 : Buckling factor defined in Tab 9, depending on the load acting on the panel.

Table 9 : Buckling factor K_3 for curved panels

Load	Buckling factor K_3
Compression stress perpendicular to the curved edges	$2\left\{1 + \sqrt{1 + \frac{12(1-\nu^2)}{\pi^4}\frac{b^4}{r^2 t_{net}^2} \cdot 10^{-6}}\right\}$
Lateral pressure perpendicular to the panel	$4 - \left(\frac{b}{\pi r}\right)^2$

Note 1:
r : radius of curvature, in mm.

The critical shear buckling stress is to be obtained, in N/mm², from the following formulae:

$$\tau_c = \tau_E \quad \text{for} \quad \tau_E \le \frac{R_{eH}}{2\sqrt{3}}$$

$$\tau_c = \frac{R_{eH}}{\sqrt{3}}\left(1 - \frac{R_{eH}}{4\sqrt{3}\tau_E}\right) \quad \text{for} \quad \tau_E > \frac{R_{eH}}{2\sqrt{3}}$$

where:

τ_E : Euler shear buckling stress, to be obtained, in N/mm², from the following formula:

$$\tau_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_{net}}{b}\right)^2 K_4 \cdot 10^{-6}$$

K_4 : Buckling factor to be taken equal to:

$$K_4 = \frac{12(1-\nu^2)}{\pi^2}\left(5 + 0{,}1\left(\frac{b^2}{rt_{net}} \cdot 10^2\right)\right)$$

b, r : Defined above.

5.3.5 Compression for corrugation flanges *(1/7/2003)*

The critical buckling stress is to be obtained, in N/mm², from the following formulae:

$$\sigma_c = \sigma_E \quad \text{for} \quad \sigma_E \le \frac{R_{eH}}{2}$$

$$\sigma_c = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_E}\right) \quad \text{for} \quad \sigma_E > \frac{R_{eH}}{2}$$

where:

σ_E : Euler buckling stress, to be obtained, in N/mm², from the following formula:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_f}{V}\right)^2 (K_5 \cdot 10^{-6})$$

K_5 : Buckling factor to be taken equal to:

$$K_5 = \left(1 + \frac{t_w}{t_f}\right)\left\{3 + 0{,}5\frac{V'}{V} - 0{,}33\left(\frac{V'}{V}\right)^2\right\}$$

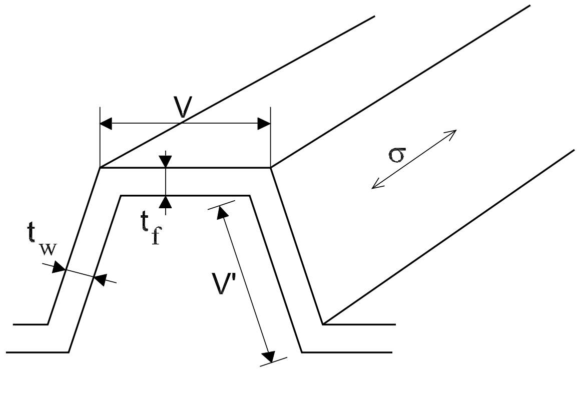
t_f : Net thickness, in mm, of the corrugation flange

t_w : Net thickness, in mm, of the corrugation web

V, V' : Dimensions of a corrugation, in m, shown in Fig 5.

When the thicknesses t_f and t_w of the corrugation flange and web varies along the corrugation span, σ_C is to be calculated for every adjacent actual pair of t_f and t_w.

Figure 5 : Dimensions of a corrugation



5.4 Checking criteria

5.4.1 Acceptance of results

The net thickness of plate panels is to be such as to satisfy the buckling check, as indicated in [5.4.2] to [5.4.5] depending on the type of stresses acting on the plate panel considered. When the buckling criteria is exceeded by less than 15 %, the scantlings may still be considered as acceptable, provided that the stiffeners located on the plate panel satisfy the buckling and the ultimate strength checks as specified in Sec 2, [4] and Sec 2, [5].

5.4.2 Compression and bending *(1/7/2003)*

For plate panels subjected to compression and bending on one side, the critical buckling stress is to comply with the following formula:

$$\frac{\sigma_c}{\gamma_R \gamma_m} \ge |\sigma_b|$$

where:

σ_c : Critical buckling stress, in N/mm², defined in [5.3.1], [5.3.4] or [5.3.5], as the case may be

σ_b : Compression stress, in N/mm², acting on side "b" of the plate panel, to be calculated, as specified in [5.2.2] or [5.2.4], as the case may be.

In the case of corrugation flanges, when the thicknesses t_f and t_w of the corrugation flange and web varies along the corrugation span, σ_b is to be taken as the maximum compression stress calculated in each zone of adjacent actual pairs of t_f and t_w.

5.4.3 Shear

For plate panels subjected to shear, the critical shear buckling stress is to comply with the following formula:

$$\frac{\tau_c}{\gamma_R \gamma_m} \ge |\tau_b|$$

where:

τ_c : Critical shear buckling stress, in N/mm², defined in [5.3.2] or [5.3.4], as the case may be

τ_b : Shear stress, in N/mm², acting on the plate panel, to be calculated as specified in [5.2.3] or [5.2.5], as the case may be.

5.4.4 Compression, bending and shear

For plate panels subjected to compression, bending and shear, the combined critical stress is to comply with the following formulae:

$$F \le 1 \quad \text{for} \quad \frac{\sigma_{comb}}{F} \le \frac{R_{eH}}{2\gamma_R\gamma_m}$$

$$F \le \frac{4\sigma_{comb}}{R_{eH}/\gamma_R\gamma_m}\left(1 - \frac{\sigma_{comb}}{R_{eH}/\gamma_R\gamma_m}\right) \quad \text{for} \quad \frac{\sigma_{comb}}{F} > \frac{R_{eH}}{2\gamma_R\gamma_m}$$

where:

$$\sigma_{comb} = \sqrt{\sigma_1^2 + 3\tau^2}$$

$$F = \gamma_R\gamma_m\left[\frac{1+\psi}{4}\frac{|\sigma_1|}{\sigma_E} + \sqrt{\left(\frac{3-\psi}{4}\right)^2\left(\frac{\sigma_1}{\sigma_E}\right)^2 + \left(\frac{\tau}{\tau_E}\right)^2}\right]$$

σ_E : Euler buckling stress, in N/mm², defined in [5.3.1], [5.3.4] or [5.3.5] as the case may be,

τ_E : Euler shear buckling stress, in N/mm², defined in [5.3.2] or [5.3.4], as the case may be,

$$\psi = \frac{\sigma_2}{\sigma_1}$$

σ_1, σ_2 and τ are defined in Fig 2 and are to be calculated, in N/mm², as specified in [5.2].

5.4.5 Bi-axial compression, taking account of shear stress

For plate panels subjected to bi-axial compression and shear, the critical buckling stresses are to comply with the following formula:

$$\left|\frac{\sigma_a}{\frac{\sigma_{c,a}}{\gamma_R \gamma_m} R_a}\right|^n + \left|\frac{\sigma_b}{\frac{\sigma_{c,b}}{\gamma_R \gamma_m} R_b}\right|^n \le 1$$

where:

$\sigma_{c,a}$: Critical buckling stress for compression on side “a”, in N/mm², defined in [5.3.3]

$\sigma_{c,b}$: Critical buckling stress for compression on side “b”, in N/mm², defined in [5.3.3]

σ_a : Compression stress acting on side “a”, in N/mm², to be calculated as specified in [5.2.2] or [5.2.4], as the case may be

σ_b : Compression stress acting on side “b”, in N/mm², to be calculated as specified in [5.2.2] or [5.2.4], as the case may be

n : Coefficient to be taken equal to:

$n = 1$ for $\alpha \ge 1/\sqrt{2}$

$n = 2$ for $\alpha < 1/\sqrt{2}$

$\alpha = a/b$

$$R_a = 1 - \left|\frac{\tau}{\tau_c}\right|^{n_a}$$

$$R_b = 1 - \left|\frac{\tau}{\tau_c}\right|^{n_b}$$

τ : Shear stress, in N/mm², to be calculated as specified in [5.2.3] or [5.2.5], as the case may be

τ_c : Critical shear buckling stress, in N/mm², defined in [5.3.2]

n_a : Coefficient to be taken equal to:

$n_a = 1 + 1/\alpha$ for $\alpha \ge 0,5$

$n_a = 3$ for $\alpha < 0,5$

n_b : Coefficient to be taken equal to:

$n_b = 1,9 + 0,1/\alpha$ for $\alpha \ge 0,5$

$n_b = 0,7(1 + 1/\alpha)$ for $\alpha < 0,5$

SECTION 2 ORDINARY STIFFENERS

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

p_S : Still water pressure, in kN/m², see [3.3.2] and [5.3.2]

p_W : Wave pressure and, if necessary, dynamic pressures, according to the criteria in Ch 5, Sec 5 and Ch 5, Sec 6, [2], in kN/m² (see [3.3.2] and [5.3.2])

p_{SF}, p_{WF} : Still water and wave pressures, in kN/m², in flooding conditions, defined in Ch 5, Sec 6, [9]

F_S : Still water wheeled force, in kN, see [3.3.5]

$F_{W,Z}$: Inertial wheeled force, in kN, see [3.3.5]

σ_{X1} : Hull girder normal stress, in N/mm², defined in:

- [3.3.6] for the yielding check of ordinary stiffeners
- [4.2.2] for the buckling check of ordinary stiffeners
- [5.3.3] for the ultimate strength check of ordinary stiffeners

σ_N : Normal stress, in N/mm², defined in [3.3.6]

$R_{eH,P}$: Minimum yield stress, in N/mm², of the plating material, defined in Ch 4, Sec 1, [2]

$R_{eH,S}$: Minimum yield stress, in N/mm², of the stiffener material, defined in Ch 4, Sec 1, [2]

s : Spacing, in m, of ordinary stiffeners

ℓ : Span, in m, of ordinary stiffeners, measured between the supporting members, see Ch 4, Sec 3, [3.2]

ℓ_b : Length, in m, of one bracket, see [3.2.2], Ch 4, Sec 3, Fig 4 and Ch 4, Sec 3, Fig 5

h_w : Web height, in mm

t_w : Net web thickness, in mm

b_f : Face plate width, in mm

t_f : Net face plate thickness, in mm

b_p : Width, in m, of the plating attached to the stiffener, for the yielding check, defined in Ch 4, Sec 3, [3.3.1]

b_e : Width, in m, of the plating attached to the stiffener, for the buckling check, defined in [4.1]

b_U : Width, in m, of the plating attached to the stiffener, for the ultimate strength check, defined in [5.2]

t_p : Net thickness, in mm, of the attached plating

w : Net section modulus, in cm³, of the stiffener, with an attached plating of width b_p, to be calculated as specified in Ch 4, Sec 3, [3.3]

A_S : Net sectional area, in cm², of the stiffener with attached plating of width s

A_e : Net sectional area, in cm², of the stiffener with attached plating of width b_e

A_U : Net sectional area, in cm², of the stiffener with attached plating of width b_U

A_{Sh} : Net shear sectional area, in cm², of the stiffener, to be calculated as specified in Ch 4, Sec 3, [3.4]

I : Net moment of inertia, in cm⁴, of the stiffener without attached plating, about its neutral axis parallel to the plating (see Ch 4, Sec 3, Fig 4 and Ch 4, Sec 3, Fig 5)

I_S : Net moment of inertia, in cm⁴, of the stiffener with attached shell plating of width s, about its neutral axis parallel to the plating

I_e : Net moment of inertia, in cm⁴, of the stiffener with attached shell plating of width b_e, about its neutral axis parallel to the plating

I_U : Net moment of inertia, in cm⁴, of the stiffener with attached shell plating of width b_U, about its neutral axis parallel to the plating

I_B : Net moment of inertia, in cm⁴, of the stiffener with bracket and without attached plating, about its neutral axis parallel to the plating, calculated at mid-length of the bracket (see Ch 4, Sec 3, Fig 4 and Ch 4, Sec 3, Fig 5)

ρ_S : Radius of gyration, in cm, of the stiffener with attached plating of width s

ρ_U : Radius of gyration, in cm, of the stiffener with attached plating of width b_U.

c_c : Coefficient which takes into account the effects of stiffener connections, equal to:

c_c = 1,0 in general,

c_c = 0,9 when the stiffener is provided with a soft toe connection with the supporting structure and no brackets are fitted.

$\chi = I_B / I$

$\alpha = \ell_b / \ell$

1 General

1.1 Net scantlings

1.1.1 As specified in Ch 4, Sec 2, [1], all scantlings referred to in this Section are net, i.e. they do not include any margin for corrosion.

The gross scantlings are obtained as specified in Ch 4, Sec 2.

1.2 Partial safety factors

1.2.1 The partial safety factors to be considered for the checking of ordinary stiffeners are specified in Tab 1.

1.3 Load point

1.3.1 Lateral pressure

Unless otherwise specified, lateral pressure is to be calculated at mid-span of the ordinary stiffener considered.

1.3.2 Hull girder stresses

For longitudinal ordinary stiffeners contributing to the hull girder longitudinal strength, the hull girder normal stresses are to be calculated in way of the neutral axis of the stiffener considered.

1.4 Net dimensions of ordinary stiffeners

1.4.1 Flat bar

The net dimensions of a flat bar ordinary stiffener (see Fig 1) are to comply with the following requirement:

$$\frac{h_w}{t_w} \le 20\sqrt{k}$$

1.4.2 T-section

The net dimensions of a T-section ordinary stiffener (see Fig 2) are to comply with the following two requirements:

$$\frac{h_w}{t_w} \le 55\sqrt{k}$$

$$\frac{b_f}{t_f} \le 33\sqrt{k}$$

$$b_f t_f \ge \frac{h_w t_w}{6}$$

1.4.3 Angle

The net dimensions of an angle ordinary stiffener (see Fig 3) are to comply with the following two requirements:

$$\frac{h_w}{t_w} \le 55\sqrt{k}$$

$$\frac{b_f}{t_f} \le 16{,}5\sqrt{k}$$

$$b_f t_f \ge \frac{h_w t_w}{6}$$

Figure 1 : Net dimensions of a flat bar

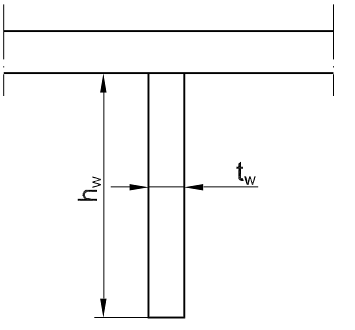


Figure 2 : Net dimensions of a T-section

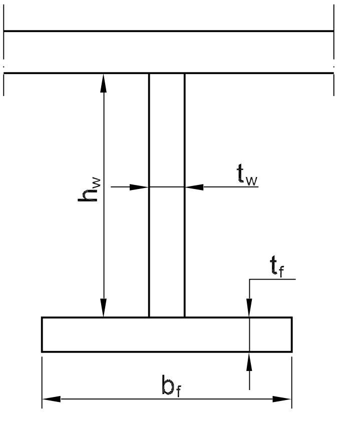


Table 1 : Ordinary stiffeners - Partial safety factors *(1/7/2020)*

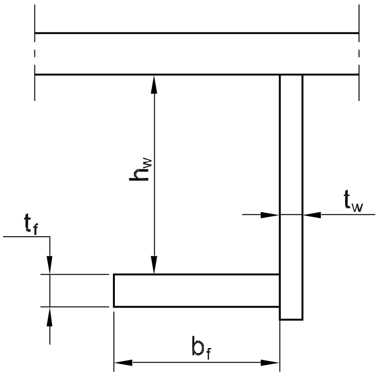
Partial safety factors covering uncertainties regarding:	Symbol	Yielding check			Buckling check (see [4])	Ultimate strength check of ordinary stiffeners contributing to the longitudinal strength (see [5])
		General (see [3.3] to [3.7])	Flooding pressure **(1)** (see [3.8])	Testing check (see [3.3] and [3.9])		
Still water hull girder loads	γ_{S1}	1,00	1,00	Not applicable	1,00	1,00
Wave hull girder loads	γ_{W1}	1,15	1,15	Not applicable	1,15	1,30
Still water pressure	γ_{S2}	1,00	1,00	1,00	Not applicable	1,00
Wave pressure	γ_{W2}	1,20	1,05	Not applicable	Not applicable	1,40

(1) Applies only to ordinary stiffeners to be checked in flooding conditions.
(2) For ordinary stiffeners of the collision bulkhead, γ_R =1,25.

Partial safety factors covering uncertainties regarding:	Symbol	Yielding check			Buckling check (see [4])	Ultimate strength check of ordinary stiffeners contributing to the longitudinal strength (see [5])
		General (see [3.3] to [3.7])	Flooding pressure **(1)** (see [3.8])	Testing check (see [3.3] and [3.9])		
Material	γ_m	1,02	1,02	1,02	1,02	1,02
Resistance	γ_R	1,02	1,02 **(2)**	1,20	1,10	1,02

(1) Applies only to ordinary stiffeners to be checked in flooding conditions.
(2) For ordinary stiffeners of the collision bulkhead, γ_R =1,25.

Figure 3 : Net dimensions of an angle



2 General requirements

2.1 General

2.1.1 *(1/1/2020)*

The requirements in [2.2], [2.3] and where needed [2.4] are to be applied to ordinary stiffeners in addition of those in [3] to [5].

2.2 Minimum net thicknesses

2.2.1 The net thickness of the web of ordinary stiffeners is to be not less than the lesser of:

- the value obtained, in mm, from the following formulae:

  $t_{MIN} = 0,8 + 0,004Lk^{1/2} + 4,5s$ for L < 120 m

  $t_{MIN} = 1,6 + 2,2k^{1/2} + s$ for L ≥ 120 m

- the net as built thickness of the attached plating.

2.3 Struts connecting ordinary stiffeners

2.3.1 *(1/7/2020)*

The sectional area A_{SR}, in cm², and the moment of inertia I_{SR} about the main axes, in cm⁴, of struts connecting ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$A_{SR} = \frac{p_{SR} s \ell}{20}$$

$$I_{SR} = \frac{0,75 s \ell (p_{SR1} + p_{SR2}) A_{ASR} \ell_{SR}^2}{47,2 A_{ASR} - s \ell (p_{SR1} + p_{SR2})}$$

where:

p_{SR} : Pressure to be taken equal to the greater of the values obtained, in kN/m², from the following formulae:

$p_{SR} = 0,5\,(p_{SR1} + p_{SR2})$

$p_{SR} = p_{SR3}$

p_{SR1} : External pressure in way of the strut, in kN/m², acting on one side, outside the compartment in which the strut is located, equal to:

$p_{SR1} = \gamma_{S2} p_S + \gamma_{W2} p_W$

p_{SR2} : External pressure in way of the strut, in kN/m², acting on the opposite side, outside the compartment in which the strut is located, equal to:

$p_{SR2} = \gamma_{S2} p_S + \gamma_{W2} p_W$

p_{SR3} : Internal pressure at mid-span of the strut, in kN/m², in the compartment in which the strut is located, equal to:

$p_{SR3} = \gamma_{S2} p_S + \gamma_{W2} p_W$

ℓ : Span, in m, of ordinary stiffeners connected by the strut (see Ch 4, Sec 3, [3.2.2])

ℓ_{SR} : Length, in m, of the strut

A_{ASR} : Actual net sectional area, in cm², of the strut.

2.4 Deck ordinary stiffeners in way of launching appliances used for survival craft or rescue boat

2.4.1 *(1/1/2020)*

The scantlings of deck ordinary stiffeners are to be determined by direct calculations, considering the following load cases as appropriate:

- vertical forces
- overturning moment
- slewing moment

Calculations models based on beam elements are in general considered to be adequate.

2.4.2 *(1/1/2020)*

The loads exerted by launching appliance on relevant deck stiffeners are to correspond to the SWL of the launching appliance.

2.4.3 *(1/1/2020)*

The combined Von Mises stress, in N/mm², is not to exceed the smaller of $R_{eH}/2,2$ and $R_m/4,5$ where R_m is the ultimate minimum tensile strength of the ordinary stiffener material, in N/mm².

3 Yielding check

3.1 General

3.1.1 The requirements of this Article apply for the yielding check of ordinary stiffeners subjected to lateral pressure or to wheeled loads and, for ordinary stiffeners contributing to the hull girder longitudinal strength, to hull girder normal stresses.

3.1.2 The yielding check is also to be carried out for ordinary stiffeners subjected to specific loads, such as concentrated loads.

3.2 Structural model

3.2.1 Boundary conditions

The requirements in [3.4], [3.7.3], [3.7.4] and [3.8] apply to stiffeners considered as clamped at both ends, whose end connections comply with the requirements in [3.2.2].

The requirements in [3.5] and [3.7.5] apply to stiffeners considered as simply supported at both ends. Other boundary conditions may be considered by the Society on a case by case basis, depending on the distribution of wheeled loads.

For other boundary conditions, the yielding check is to be considered on a case by case basis.

3.2.2 Bracket arrangement

The requirements of this Article apply to ordinary stiffeners without end brackets, with a bracket at one end or with two equal end brackets, where the bracket length is not greater than $0,2\ell$.

In the case of ordinary stiffeners with two different end brackets of length not greater than $0,2\ell$, the determination of normal and shear stresses due to design loads and the required section modulus and shear sectional area are considered by the Society on a case by case basis. In general, an acceptable solution consists in applying the criteria for equal brackets, considering both brackets as having the length of the smaller one.

In the case of ordinary stiffeners with end brackets of length greater than $0,2\ell$, the determination of normal and shear stresses due to design loads and the required section modulus and shear sectional area are considered by the Society on a case by case basis.

3.3 Load model

3.3.1 General

The still water and wave lateral loads induced by the sea and the various types of cargoes and ballast in intact conditions are to be considered, depending on the location of the ordinary stiffener under consideration and the type of compartments adjacent to it, in accordance with Ch 5, Sec 1, [2.4].

Ordinary stiffeners of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids are to be subjected to the lateral pressure in flooding conditions.

The wave lateral loads and hull girder loads are to be calculated in the mutually exclusive load cases “a”, “b”, “c” and “d” in Ch 5, Sec 4.

3.3.2 Lateral pressure in intact conditions

The lateral pressure in intact conditions is constituted by still water pressure and wave pressure.

Still water pressure (p_S) includes:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave pressure (p_W) includes:

- the wave pressure, defined in Ch 5, Sec 5, [2] for each load case “a”, “b”, “c” and “d”
- the inertial pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast, and for each load case “a”, “b”, “c” and “d”
- the dynamic pressures, according to the criteria in Ch 5, Sec 6, [2].

3.3.3 Lateral pressure in flooding conditions

The lateral pressure in flooding conditions is constituted by the still water pressure p_{SF} and wave pressure p_{WF} defined in Ch 5, Sec 6, [9].

3.3.4 Lateral pressure in testing conditions *(1/7/2020)*

The lateral pressure (p_T) in testing conditions is taken equal to:

- p_{ST} - p_S for bottom shell plating and side shell plating
- p_{ST} otherwise

where p_S is the still water sea pressure defined in Ch 5, Sec 5, [1.1.1] for the draught T_1 at which the testing is carried out.

If the draught T_1 is not defined by the Designer, it may be taken equal to the light ballast draught T_B defined in Ch 5, Sec 1, [2.4.3].

3.3.5 Wheeled forces

The wheeled force applied by one wheel is constituted by still water force and inertial force:

- Still water force is the vertical force (F_S) defined in Ch 5, Sec 6, [6.1]
- Inertial force is the vertical force ($F_{W,Z}$) defined in Ch 5, Sec 6, [6.1], for load case “b”.

3.3.6 Normal stresses *(1/1/2001)*

The normal stresses to be considered for the yielding check of ordinary stiffeners are obtained, in N/mm², from the following formulae:

- for longitudinal stiffeners contributing to the hull girder longitudinal strength:

$$\sigma_N = \sigma_{X1} = \gamma_{S1}\sigma_{S1} + \gamma_{W1}(C_{FV}\sigma_{WV1} + C_{FH}\sigma_{WH1} + C_{F\Omega}\sigma_{\Omega})$$

  to be taken not less than 60/k N/mm².

- for longitudinal stiffeners not contributing to the hull girder longitudinal strength, transverse stiffeners and vertical stiffeners, excluding side frames:

$$\sigma_N = 45 / k N / mm^2$$

- for side frames:

$\sigma_N = 0$ for load cases "a" and "c"

$\sigma_N = 30/k$ for load cases "b" and "d"

where:

σ_{S1}, σ_{WV1}, σ_{WH1} : Hull girder normal stresses, in N/mm², defined in:
- Tab 2 for ordinary stiffeners subjected to lateral pressure,
- Tab 3 for ordinary stiffeners subjected to wheeled loads

σ_Ω : Absolute value of the warping stress, in N/mm², induced by the torque $0{,}625 M_{WT}$ and obtained through direct calculation analyses based on a structural model in accordance with Ch 6, Sec 1, [2.6]

C_{FV}, C_{FH}, $C_{F\Omega}$: Combination factors defined in Tab 4.

Table 2 : Hull girder normal stresses - Ordinary stiffeners subjected to lateral pressure

Condition	σ_{S1}, in N/mm² **(1)**	σ_{WV1}, in N/mm²	σ_{WH1}, in N/mm²
Lateral pressure applied on the side opposite to the ordinary stiffener, with respect to the plating:			$\left\|\frac{0{,}625 M_{WH}}{I_Z} y\right\| 10^{-3}$
• $z \geq N$	$\left\|\frac{M_{SW,S}}{I_Y}(z-N)\right\| 10^{-3}$	$\left\|\frac{0{,}625 F_D M_{WV,S}}{I_Y}(z-N)\right\| 10^{-3}$	
• $z < N$	$\left\|\frac{M_{SW,H}}{I_Y}(z-N)\right\| 10^{-3}$	$\left\|\frac{0{,}625 M_{WV,H}}{I_Y}(z-N)\right\| 10^{-3}$	
Lateral pressure applied on the same side as the ordinary stiffener:			
• $z \geq N$	$\left\|\frac{M_{SW,H}}{I_Y}(z-N)\right\| 10^{-3}$	$\left\|\frac{0{,}625 M_{WV,H}}{I_Y}(z-N)\right\| 10^{-3}$	
• $z < N$	$\left\|\frac{M_{SW,S}}{I_Y}(z-N)\right\| 10^{-3}$	$\left\|\frac{0{,}625 F_D M_{WV,S}}{I_Y}(z-N)\right\| 10^{-3}$	

(1) When the ship in still water is always in hogging condition, $M_{SW,S}$ is to be taken equal to 0.

Note 1:

F_D : Coefficient defined in Ch 5, Sec 2, [4].

Table 3 : Hull girder normal stresses - Ordinary stiffeners subjected to wheeled loads

Condition	σ_{S1} in N/mm² **(1)**	σ_{WV1} in N/mm²	σ_{WH1} in N/mm²
• $z \geq N$	$\left\|\frac{M_{SW,H}}{I_Y}(z-N)\right\| 10^{-3}$	$\left\|\frac{0{,}625 M_{WV,H}}{I_Y}(z-N)\right\| 10^{-3}$	$\left\|\frac{0{,}625 M_{WH}}{I_Z} y\right\| 10^{-3}$
• $z < N$	$\left\|\frac{M_{SW,S}}{I_Y}(z-N)\right\| 10^{-3}$	$\left\|\frac{0{,}625 F_D M_{WV,S}}{I_Y}(z-N)\right\| 10^{-3}$	

(1) When the ship in still water is always in hogging condition, $M_{SW,S}$ is to be taken equal to 0.

Note 1:

F_D : Coefficient defined in Ch 5, Sec 2, [4].

Table 4 : Combination factors C_{FV}, C_{FH} and $C_{F\Omega}$

Load case	C_{FV}	C_{FH}	$C_{F\Omega}$
“a”	1,0	0	0
“b”	1,0	0	0
“c”	0,4	1,0	1,0
“d”	0,4	1,0	0

3.4 Normal and shear stresses due to lateral pressure in intact conditions

3.4.1 General

Normal and shear stresses, induced by lateral pressures, in ordinary stiffeners without end brackets are to be obtained from the formulae in:

- [3.4.2] in the case of longitudinal and transverse stiffeners
- [3.4.5] in the case of vertical stiffeners.

Normal and shear stresses, induced by lateral pressures, in ordinary stiffeners with a bracket at one end or with two equal end brackets, are to be obtained from the formulae in:

- [3.4.3] and [3.4.4] in the case of longitudinal and transverse stiffeners
- [3.4.6] and [3.4.7] in the case of vertical stiffeners.

Normal and shear stresses, induced by lateral pressures, in multispan ordinary stiffeners are to be obtained from the formulae in [3.4.8].

3.4.2 Longitudinal and transverse ordinary stiffeners without brackets at ends *(1/7/2001)*

The maximum normal stress σ and shear stress τ are to be obtained, in N/mm², from the following formulae:

$$\sigma = c_c \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{12w}\left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3 + \sigma_N$$

$$\tau = 5 \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{A_{Sh}}\left(1 - \frac{s}{2\ell}\right) s \ell$$

3.4.3 Longitudinal and transverse ordinary stiffeners with a bracket at one end *(1/1/2001)*

The maximum normal stress σ and shear stress τ are to be obtained, in N/mm², from the following formulae:

$$\sigma = \beta_{b1} \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{12w}\left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3 + \sigma_N$$

$$\tau = 5\beta_{s1} \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{A_{Sh}}\left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

$$\beta_{b1} = \frac{\chi(1-\alpha)^5 + \alpha(1-\alpha)(6 - 3\alpha + 8\alpha^2)}{\chi(1-\alpha)^3 + 2\alpha(2-\alpha)}$$

to be taken not less than 0,55

$$\beta_{s1} = \frac{\chi(1-\alpha)^4 + 5\alpha(1 - \alpha + \alpha^2)}{\chi(1-\alpha)^3 + 2\alpha(2-\alpha)}$$

3.4.4 Longitudinal and transverse ordinary stiffeners with equal brackets at ends *(1/1/2001)*

The maximum normal stress σ and shear stress τ are to be obtained, in N/mm², from the following formulae:

$$\sigma = \beta_{b2} \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{12w}\left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3 + \sigma_N$$

$$\tau = 5\beta_{s2} \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{A_{Sh}}\left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

$$\beta_{b2} = \frac{\chi(1-2\alpha)^3 + 2\alpha^2(4\alpha - 3)}{\chi(1-2\alpha) + 2\alpha}\Bigg):$$

to be taken not less than 0,55

$$\beta_{s2} = 1 - 2\alpha$$

3.4.5 Vertical ordinary stiffeners without brackets at ends *(1/7/2001)*

The maximum normal stress σ and shear stress τ are to be obtained, in N/mm², from the following formulae:

$$\sigma = c_c \frac{\gamma_{S2}\lambda_{bS} p_S + \gamma_{W2}\lambda_{bW} p_W}{12w}\left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3 + \sigma_N$$

$$\tau = 5 \frac{\gamma_{S2}\lambda_{sS} p_S + \gamma_{W2}\lambda_{sW} p_W}{A_{Sh}}\left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

$$\lambda_{bS} = 1 + 0{,}2\frac{p_{Sd} - p_{Su}}{p_{Sd} + p_{Su}}$$

$$\lambda_{bW} = 1 + 0{,}2\frac{p_{Wd} - p_{Wu}}{p_{Wd} + p_{Wu}}$$

$$\lambda_{sS} = 1 + 0{,}4\frac{p_{Sd} - p_{Su}}{p_{Sd} + p_{Su}}$$

$$\lambda_{sW} = 1 + 0{,}4\frac{p_{Wd} - p_{Wu}}{p_{Wd} + p_{Wu}}$$

p_{Sd} : Still water pressure, in kN/m², at the lower end of the ordinary stiffener considered

p_{Su} : Still water pressure, in kN/m², at the upper end of the ordinary stiffener considered

p_{Wd} : Wave pressure, in kN/m², at the lower end of the ordinary stiffener considered.

p_{Wu} : Wave pressure, in kN/m², at the upper end of the ordinary stiffener considered

3.4.6 Vertical ordinary stiffeners with a bracket at lower end *(1/1/2001)*

The maximum normal stress σ and shear stress τ are to be obtained, in N/mm², from the following formulae:

$$\sigma = \beta_{b1} \frac{\gamma_{S2}\lambda_{bS} p_S + \gamma_{W2}\lambda_{bW} p_W}{12w}\left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3 + \sigma_N$$

$$\tau = 5\beta_{s1} \frac{\gamma_{S2}\lambda_{sS} p_S + \gamma_{W2}\lambda_{sW} p_W}{A_{Sh}}\left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

β_{b1}, β_{s1} : Coefficients defined in [3.4.3]

λ_{bS}, λ_{bW}, λ_{sS}, λ_{sW}: Coefficients defined in [3.4.5].

3.4.7 Vertical ordinary stiffeners with equal brackets at ends *(1/1/2001)*

The maximum normal stress σ and shear stress τ are to be obtained, in N/mm², from the following formulae:

$$\sigma = \beta_{b2} \frac{\gamma_{S2}\lambda_{bS} p_S + \gamma_{W2}\lambda_{bW} p_W}{12w}\left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3 + \sigma_N$$

$$\tau = 5\beta_{s2} \frac{\gamma_{S2}\lambda_{sS} p_S + \gamma_{W2}\lambda_{sW} p_W}{A_{Sh}}\left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

β_{b2}, β_{s2} : Coefficients defined in [3.4.4]

λ_{bS}, λ_{bW}, λ_{sS}, λ_{sW}: Coefficients defined in [3.4.5].

3.4.8 Multispan ordinary stiffeners

The maximum normal stress σ and shear stress τ in a multispan ordinary stiffener are to be determined by a direct calculation taking into account:

- the distribution of still water and wave pressure and forces, to be determined on the basis of the criteria specified in Ch 5, Sec 5 and Ch 5, Sec 6
- the number of intermediate decks or girders
- the condition of fixity at the ends of the stiffener and at intermediate supports
- the geometrical characteristics of the stiffener on the intermediate spans.

3.5 Normal and shear stresses due to wheeled loads

3.5.1 General

Normal and shear stresses, induced by the wheeled loads, in ordinary stiffeners are to be determined from the formulae given in [3.5.2] for longitudinal and transverse stiffeners.

3.5.2 Longitudinal and transverse ordinary stiffeners subjected to wheeled loads *(1/1/2001)*

The maximum normal stress σ and shear stress τ are to be obtained, in N/mm², from the following formulae:

$$\sigma = \frac{\alpha_S P_0 \ell}{6w} 10^3 + \sigma_N$$

$$\tau = 10 \frac{\alpha_T P_0}{A_{Sh}}$$

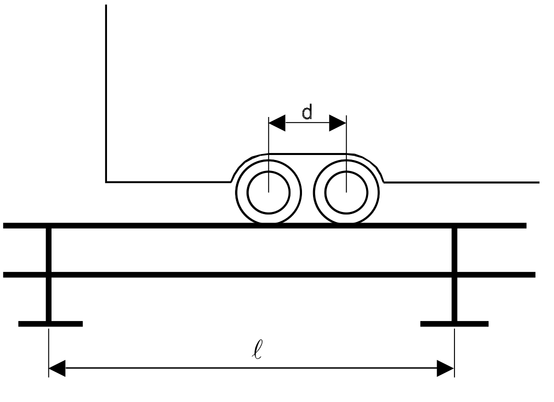
where:

P_0 : Wheeled force, in kN, taken equal to:

$$P_0 = \gamma_{S2} F_S + 0{,}4 \gamma_{W2} F_{W,Z}$$

α_S, α_T : Coefficients taking account of the number of axles and wheels per axle considered as acting on the stiffener, defined in Tab 5 (see Fig 4).

Figure 4 : Wheeled load on stiffeners - Double axles



3.6 Checking criteria

3.6.1 General

It is to be checked that the normal stress σ and the shear stress τ, calculated according to [3.4] and [3.5], are in compliance with the following formulae:

$$\frac{R_y}{\gamma_R \gamma_m} \geq \sigma$$

$$0{,}5 \frac{R_y}{\gamma_R \gamma_m} \geq \tau$$

3.7 Net section modulus and net shear sectional area of ordinary stiffeners, complying with the checking criteria

3.7.1 General

The requirements in [3.7.3] and [3.7.4] provide the minimum net section modulus and net shear sectional area of ordinary stiffeners subjected to lateral pressure in intact conditions, complying with the checking criteria indicated in [3.6].

The requirements in [3.7.5] provide the minimum net section modulus and net shear sectional area of ordinary stiffeners subjected to wheeled loads, complying with the checking criteria indicated in [3.6].

3.7.2 Groups of equal ordinary stiffeners

Where a group of equal ordinary stiffeners is fitted, it is acceptable that the minimum net section modulus in [3.7.1] is calculated as the average of the values required for all the stiffeners of the same group, but this average is to be taken not less than 90% of the maximum required value.

The same applies for the minimum net shear sectional area.

3.7.3 Longitudinal and transverse ordinary stiffeners subjected to lateral pressure *(1/7/2001)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh} , in cm², of longitudinal or transverse ordinary stiffeners subjected to lateral pressure are to be not less than the values obtained from the following formulae:

$$w = c_c \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{12(R_y - \gamma_R \gamma_m \sigma_N)} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{R_y} \left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

β_b : Coefficient to be taken equal to:

$\beta_b = 1$ in the case of an ordinary stiffener without brackets at ends

$\beta_b = \beta_{b1}$ defined in [3.4.3], in the case of an ordinary stiffener with a bracket of length not greater than $0{,}2\ell$ at one end

$\beta_b = \beta_{b2}$ defined in [3.4.4], in the case of an ordinary stiffener with equal brackets of length not greater than $0{,}2\ell$ at ends

β_s : Coefficient to be taken equal to:

$\beta_s = 1$ in the case of an ordinary stiffener without brackets at ends

$\beta_s = \beta_{s1}$ defined in [3.4.3], in the case of an ordinary stiffener with a bracket of length not greater than $0{,}2\ell$ at one end

$\beta_s = \beta_{s2}$ defined in [3.4.4], in the case of an ordinary stiffener with equal brackets of length not greater than $0{,}2\ell$ at ends.

3.7.4 Vertical ordinary stiffeners subjected to lateral pressure *(1/7/2001)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh} , in cm², of vertical ordinary stiffeners subjected to lateral pressure are to be not less than the values obtained from the following formulae:

$$w = c_c \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} \lambda_{bS} p_S + \gamma_{W2} \lambda_{bW} p_W}{12(R_y - \gamma_R \gamma_m \sigma_N)} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} \lambda_{sS} p_S + \gamma_{W2} \lambda_{sW} p_W}{R_y} \left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

β_b, β_s : Coefficients defined in [3.7.3]

λ_{bS}, λ_{bW}, λ_{sS}, λ_{sW}:Coefficients defined in [3.4.5].

3.7.5 Ordinary stiffeners subjected to wheeled loads *(1/1/2001)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh} , in cm², of ordinary stiffeners subjected to wheeled loads are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \frac{\alpha_S P_0 \ell}{6(R_y - \gamma_R \gamma_m \sigma_N)} 10^3$$

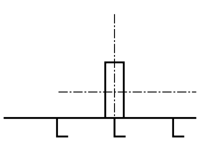
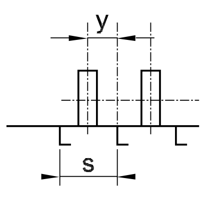
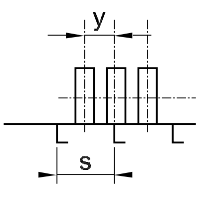
$$A_{Sh} = 20 \gamma_R \gamma_m \frac{\alpha_T P_0}{R_y}$$

where:

P_0 : Wheeled force, in kN, defined in [3.5.2]

α_S, α_T : Coefficients defined in [3.5.2].

Table 5 : Wheeled loads - Coefficients α_S and α_T

Configuration	Single axle		Double axles	
	α_S	α_T	α_S	α_T
Single wheel 	1	1	$0{,}5\left(2 - \frac{d}{\ell}\right)^2$	$2 + \frac{d}{\ell}$
Double wheels 	$2\left(1 - \frac{y}{s}\right)$	$2\left(1 - \frac{y}{s}\right)$	$\left(1 - \frac{y}{s}\right)\left(2 - \frac{d}{\ell}\right)^2$	$2\left(1 - \frac{y}{s}\right)\left(2 + \frac{d}{\ell}\right)$
Triple wheels 	$3 - 2\frac{y}{s}$	$3 - 2\frac{y}{s}$	$0{,}5\left(3 - 2\frac{y}{s}\right)\left(2 - \frac{d}{\ell}\right)^2$	$\left(3 - 2\frac{y}{s}\right)\left(2 + \frac{d}{\ell}\right)$

Note 1:
d : Distance, in m, between two axles (see Fig 4)
y : Distance, in m, from the external wheel of a group of wheels to the stiffener under consideration, to be taken equal to the distance from the external wheel to the centre of the group of wheels.

3.8 Net section modulus and net shear sectional area of ordinary stiffeners subjected to lateral pressure in flooding conditions

3.8.1 General

The requirements in [3.8.1] to [3.8.4] apply to ordinary stiffeners of bulkheads or inner side which constitute boundary of compartments not intended to carry liquids.

These ordinary stiffeners are to be checked in flooding conditions as specified in [3.8.3] and [3.8.4], depending on the type of stiffener.

3.8.2 Groups of equal ordinary stiffeners

Where a group of equal ordinary stiffeners is fitted, it is acceptable that the minimum net section modulus in [3.8.1] is calculated as the average of the values required for all the stiffeners of the same group, but this average is to be taken not less than 90% of the maximum required value.

The same applies for the minimum net shear sectional area.

3.8.3 Longitudinal and transverse ordinary stiffeners *(1/7/2020)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh} , in cm², of longitudinal or transverse ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{12 c_P (R_y - \gamma_R \gamma_m \sigma_N)} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{R_y} \left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

β_b , β_s : Coefficients defined in [3.7.3]

c_P : Ratio of the plastic section modulus to the elastic section modulus of the ordinary stiffeners with an attached shell plating b_p , to be taken equal to 1,16 in the absence of more precise evaluation.

3.8.4 Vertical ordinary stiffeners *(1/7/2020)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh} , in cm², of vertical ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} \lambda_{bS} p_{SF} + \gamma_{W2} \lambda_{bW} p_{WF}}{12 c_P (R_y - \gamma_R \gamma_m \sigma_N)} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} \lambda_{sS} p_{SF} + \gamma_{W2} \lambda_{sW} p_{WF}}{R_y} \left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

β_b , β_s : Coefficients defined in [3.7.3]

c_P : Ratio defined in [3.8.3]

$$\lambda_{bS} = 1 + 0{,}2 \frac{p_{SFd} - p_{SFu}}{p_{SFd} + p_{SFu}}$$

$$\lambda_{bW} = 1 + 0{,}2 \frac{p_{WFd} - p_{WFu}}{p_{WFd} + p_{WFu}}$$

$$\lambda_{sS} = 1 + 0{,}4 \frac{p_{SFd} - p_{SFu}}{p_{SFd} + p_{SFu}}$$

$$\lambda_{sW} = 1 + 0{,}4 \frac{p_{WFd} - p_{WFu}}{p_{WFd} + p_{WFu}}$$

p_{SFd} : Still water pressure, in kN/m², in flooding conditions, at the lower end of the ordinary stiffener considered

p_{SFu} : Still water pressure, in kN/m², in flooding conditions, at the upper end of the ordinary stiffener considered

p_{WFd} : Wave pressure, in kN/m², in flooding conditions, at the lower end of the ordinary stiffener considered.

p_{WFu} : Wave pressure, in kN/m², in flooding conditions, at the upper end of the ordinary stiffener considered

Table 6 : Hull girder normal compression stresses

Condition	σ_{S1} in N/mm² **(1)**	σ_{WV1} in N/mm²	σ_{WH1} in N/mm²
$z \ge N$	$\frac{M_{SW,S}}{I_Y}(z-N)10^{-3}$	$\frac{0{,}625 F_D M_{WV,S}}{I_Y}(z-N)10^{-3}$	$-\left\lvert\frac{0{,}625 M_{WH}}{I_Z} y\right\rvert 10^{-3}$
$z < N$	$\frac{M_{SW,H}}{I_Y}(z-N)10^{-3}$	$\frac{0{,}625 M_{WV,H}}{I_Y}(z-N)10^{-3}$	

(1) When the ship in still water is always in hogging condition, σ_{S1} for $z \ge N$ is to be obtained, in N/mm², from the following formula, unless σ_{X1} is evaluated by means of direct calculations (see [4.2.2]):

$$\sigma_{S1} = \frac{M_{SW,Hmin}}{I_Y}(z-N)10^{-3}$$

Note 1:
F_D : Coefficient defined in Ch 5, Sec 2, [4].

3.9 Net section modulus and net shear sectional area of ordinary stiffeners subjected to lateral pressure in testing conditions

3.9.1 General *(1/7/2020)*

The requirements in [3.9.3] to [3.9.5] provide the minimum net section modulus and net shear sectional area of ordinary stiffeners of compartments subject to testing conditions.

3.9.2 Groups of equal ordinary stiffeners *(1/7/2020)*

Where a group of equal ordinary stiffeners is fitted, it is acceptable that the minimum net section modulus in [3.9.1] is calculated as the average of the values required for all the stiffeners of the same group, but this average is to be taken not less than 90% of the maximum required value.

The same applies for the minimum net shear sectional area.

3.9.3 Single span longitudinal and transverse ordinary stiffeners *(1/1/2021)*

The net section modulus w, in cm^3, and the net shear sectional area A_{Sh}, in cm^2, of longitudinal or transverse ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} p_T}{12 R_y}\left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} p_T}{R_y}\left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

β_b , β_s : Coefficients defined in [3.7.3]

3.9.4 Single span vertical ordinary stiffeners *(1/1/2021)*

The net section modulus w, in cm^3, and the net shear sectional area A_{Sh}, in cm^2, of vertical ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \lambda_b \beta_b \frac{\gamma_{S2} p_T}{12 R_y}\left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \lambda_s \beta_s \frac{\gamma_{S2} p_T}{R_y}\left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

β_b , β_s : Coefficients defined in [3.7.3]

λ_b : Coefficient taken equal to the greater of the following values:

$$\lambda_b = 1 + 0{,}2 \frac{p_{Td} - p_{Tu}}{p_{Td} + p_{Tu}}$$

$$\lambda_b = 1 - 0{,}2 \frac{p_{Td} - p_{Tu}}{p_{Td} + p_{Tu}}$$

λ_s : Coefficient taken equal to the greater of the following values:

$$\lambda_s = 1 + 0{,}4 \frac{p_{Td} - p_{Tu}}{p_{Td} + p_{Tu}}$$

$$\lambda_s = 1 - 0{,}4 \frac{p_{Td} - p_{Tu}}{p_{Td} + p_{Tu}}$$

p_{Td} : Still water pressure, in kN/m^2, in testing conditions, at the lower end of the ordinary stiffener considered

p_{Tu} : Still water pressure, in kN/m^2, in testing conditions, at the upper end of the ordinary stiffener considered.

3.9.5 Multispan ordinary stiffeners *(1/7/2020)*

The minimum net section modulus and the net shear sectional area of multispan ordinary stiffeners are to be obtained from [3.4.8], considering the pressure in testing conditions and taking account of the checking criteria indicated in [3.6].

4 Buckling check

4.1 Application

4.1.1 *(1/7/2016)*

The requirements of this Article apply for the buckling check of ordinary stiffeners subjected to compression stresses.

Ships with the service notation container ship, in addition to the requirements of this Article, are to comply with the requirements of Pt E, Ch 2, Sec 2, [6].

The width of the attached plating to be considered for the buckling check of ordinary stiffeners is to be obtained, in m, from the following formulae:

- where no local buckling occurs on the attached plating (see Sec 1, [5.4.1]):

  $b_e = s$

- where local buckling occurs on the attached plating (see Sec 1, [5.4.1]):

  $$b_e = \left(\frac{2{,}25}{\beta_e} - \frac{1{,}25}{\beta_e^2}\right) s$$

  to be taken not greater than s

where:

$$\beta_e = \frac{s}{t_p}\sqrt{\frac{\sigma_b}{E}}10^3$$

σ_b : Compression stress σ_X or σ_Y, in N/mm^2, acting on the plate panel, defined in Sec 1, [5.2.4], according to the direction x or y considered.

4.2 Load model

4.2.1 Sign convention for normal stresses

The sign convention for normal stresses is as follows:

- tension: positive
- compression: negative.

4.2.2 Hull girder compression normal stresses

The hull girder compression normal stresses to be considered for the buckling check of ordinary stiffeners contributing to the hull girder longitudinal strength are obtained, in N/mm², from the following formula:

$$\sigma_{X1} = \gamma_{S1}\sigma_{S1} + \gamma_{W1}(C_{FV}\sigma_{WV1} + C_{FH}\sigma_{WH1} + C_{F\Omega}\sigma_{\Omega})$$

where:

σ_{S1}, σ_{WV1}, σ_{WH1} : Hull girder normal stresses, in N/mm², defined in Tab 6

σ_{Ω} : Compression warping stress, in N/mm², induced by the torque $0{,}625M_{WT}$ and obtained through direct calculation analyses based on a structural model in accordance with Ch 6, Sec 1, [2.6]

C_{FV}, C_{FH}, $C_{F\Omega}$: Combination factors defined in Tab 4.

For longitudinal stiffeners, σ_{X1} is to be taken as the maximum compression stress on the stiffener considered.

In no case may σ_{X1} be taken less than 30/k N/mm².

When the ship in still water is always in hogging condition, σ_{X1} may be evaluated by means of direct calculations when justified on the basis of the ship's characteristics and intended service. The calculations are to be submitted to the Society for approval.

4.2.3 Combined hull girder and local compression normal stresses

The combined compression normal stresses to be considered for the buckling check of ordinary stiffeners are to take into account the hull girder stresses and the local stresses resulting from the bending of the primary supporting members. These local stresses are to be obtained from a direct structural analysis using the design loads as given in Chapter 5.

With respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4.1], the combined stresses in x and y direction are obtained, in N/mm², from the following formulae:

$$\sigma_X = \sigma_{X1} + \gamma_{S2}\sigma_{X2,S} + \gamma_{W2}\sigma_{X2,W}$$

$$\sigma_Y = \gamma_{S2}\sigma_{Y2,S} + \gamma_{W2}\sigma_{Y2,W}$$

where:

σ_{X1} : Compression normal stress, in N/mm², induced by the hull girder still water and wave loads, defined in [4.2.2]

$\sigma_{X2,S}$, $\sigma_{Y2,S}$: Compression normal stress in x and y direction, respectively, in N/mm², induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the still water design loads as given in Chapter 5

$\sigma_{X2,W}$, $\sigma_{Y2,W}$: Compression normal stress in x and y direction, respectively, in N/mm², induced by the local bending of the primary supporting members and obtained from a direct structural analysis using the wave design loads as given in Chapter 5.

4.3 Critical stress

4.3.1 General

The critical buckling stress is to be obtained, in N/mm², from the following formulae:

$$\sigma_c = \sigma_E \quad \text{for } \sigma_E \le \frac{R_{eH,S}}{2}$$

$$\sigma_c = R_{eH,S}\left(1 - \frac{R_{eH,S}}{4\sigma_E}\right) \quad \text{for } \sigma_E > \frac{R_{eH,S}}{2}$$

where:

$\sigma_E = \min(\sigma_{E1}, \sigma_{E2}, \sigma_{E3})$

σ_{E1} : Euler column buckling stress, in N/mm², given in [4.3.2]

σ_{E2} : Euler torsional buckling stress, in N/mm², given in [4.3.3]

σ_{E3} : Euler web buckling stress, in N/mm², given in [4.3.4].

4.3.2 Column buckling of axially loaded stiffeners

The Euler column buckling stress is obtained, in N/mm², from the following formula:

$$\sigma_E = \pi^2 E \frac{I_e}{A_e \ell^2} 10^{-4}$$

4.3.3 Torsional buckling of axially loaded stiffeners

The Euler torsional buckling stresses is obtained, in N/mm², from the following formula:

$$\sigma_E = \frac{\pi^2 E I_w}{10^4 I_p \ell^2}\left(\frac{K_C}{m^2} + m^2\right) + 0{,}385 E \frac{I_t}{I_p}$$

where:

I_w : Net sectorial moment of inertia, in cm⁶, of the stiffener about its connection to the attached plating:

- for flat bars:

$$I_w = \frac{h_w^3 t_w^3}{36} 10^{-6}$$

- for T-sections:

$$I_w = \frac{t_f b_f^3 h_w^2}{12} 10^{-6}$$

- for angles and bulb sections:

$$I_w = \frac{b_f^3 h_w^2}{12(b_f + h_w)^2}[t_f b_f^2 + 2 b_f h_w + 4 h_w^2 + 3 t_w b_f h_w] 10^{-6}$$

I_p : Net polar moment of inertia, in cm⁴, of the stiffener about its connection to the attached plating:

- for flat bars:

$$I_p = \frac{h_w^3 t_w}{3} 10^{-4}$$

- for stiffeners with face plate:

$$I_p = \left(\frac{h_w^3 t_w}{3} + h_w^2 b_f t_f\right) 10^{-4}$$

I_t : St. Venant's net moment of inertia, in cm⁴, of the stiffener without attached plating:

- for flat bars:

$$I_t = \frac{h_w t_w^3}{3} 10^{-4}$$

- for stiffeners with face plate:

$$I_t = \frac{1}{3}\left[h_w t_w^3 + b_f t_f^3\left(1 - 0{,}63\frac{t_f}{b_f}\right)\right]10^{-4}$$

m : Number of half waves, to be taken equal to the integer number such that (see also Tab 7):

$$m^2(m-1)^2 \le K_C < m^2(m+1)^2$$

$$K_C = \frac{C_0 \ell^4}{\pi^4 E I_w} 10^6$$

C_0 : Spring stiffness of the attached plating:

$$C_0 = \frac{E t_p^3}{2{,}73 s} 10^{-3}$$

Table 7 : Torsional buckling of axially loaded stiffeners - Number m of half waves

K_C	$0 \le K_C < 4$	$4 \le K_C < 36$	$36 \le K_C < 144$
m	1	2	3

4.3.4 Web buckling of axially loaded stiffeners

The Euler buckling stress of the stiffener web is obtained, in N/mm², from the following formulae:

- for flat bars:

$$\sigma_E = 16\left(\frac{t_W}{h_W}\right)^2 10^4$$

- for stiffeners with face plate:

$$\sigma_E = 78\left(\frac{t_W}{h_W}\right)^2 10^4$$

4.4 Checking criteria

4.4.1 Stiffeners parallel to the direction of compression

The critical buckling stress of the ordinary stiffener is to comply with the following formula:

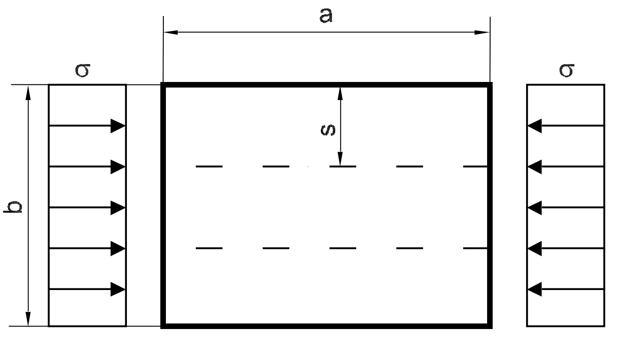
$$\frac{\sigma_c}{\gamma_R \gamma_m} \ge |\sigma_b|$$

where:

σ_c : Critical buckling stress, in N/mm², as calculated in [4.3.1]

σ_b : Compression stress σ_{xb} or σ_{yb}, in N/mm², in the stiffener, as calculated in [4.2.2] or [4.2.3].

Figure 5 : Buckling of stiffeners parallel to the direction of compression



4.4.2 Stiffeners perpendicular to the direction of compression

The net moment of inertia of stiffeners, in cm⁴, is to be not less than the greatest value obtained from the following formulae:

- $I = 360\ell^2$
- for $\sigma \le R_{eH,P}/2$:

$$I = \frac{s t_p^3}{485}\left[\frac{\left(\frac{\ell}{s}\right)^4 - 4}{\sigma_{E,1} - \sigma_{E,0}}\right](\sigma - \sigma_{E,0})$$

- for $\sigma > R_{eH,P}/2$:

$$I = \frac{s t_p^3}{485}\left[\frac{\left(\frac{\ell}{s}\right)^4 - 4}{\sigma_{E,1} - \sigma_{E,0}}\right]\left[\frac{R_{eH,P}}{4\left(1 - \frac{\sigma}{R_{eH,P}}\right)} - \sigma_{E,0}\right]$$

where:

ℓ/s : Ratio to be taken not less than 1,41

$\sigma_{E,0}$: Euler buckling stress, in N/mm², of the unstiffened plate taken equal to:

$$\sigma_{E,0} = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{\ell}\right)^2 \varepsilon K_{1,0} \cdot 10^{-6}$$

$K_{1,0}$: Coefficient defined in Sec 1, Tab 8 for: $0 \le \Psi \le 1$ and $\alpha = a/\ell$

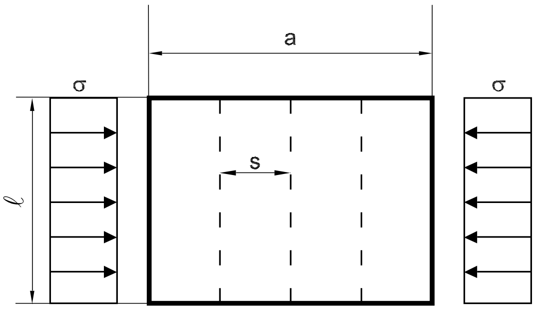
ε : Coefficient defined in Sec 1, [5.3.1]

$\sigma_{E,1}$: Euler buckling stress, in N/mm², of the plate panel taken equal to:

$$\sigma_{E,1} = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{\ell}\right)^2 \varepsilon (K_{1,1} \cdot 10^{-6})$$

$K_{1,1}$: Coefficient defined in Sec 1, Tab 8 for: $0 \le \Psi \le 1$ and $\alpha = s/\ell$.

Figure 6 : Buckling of stiffeners perpendicular to the direction of compression

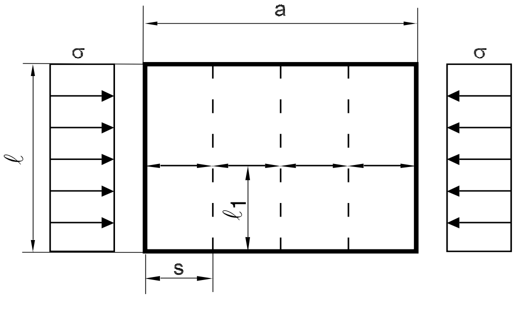


Where intercostal stiffeners are fitted, as shown in Fig 7, the check of the moment of inertia of stiffeners perpendicular to the direction of compression is to be carried out with the equivalent net thickness $t_{eq,net}$, in mm, obtained from the following formula:

$$t_{eq,net} = \frac{1+\left(\frac{s}{\ell_1}\right)^2}{1+\left(\frac{s}{\ell}\right)^2} t_{net}$$

where ℓ_1 is to be taken not less than s.

Figure 7 : Buckling of stiffeners perpendicular to the direction of compression (intercostal stiffeners)



5 Ultimate strength check of ordinary stiffeners contributing to the hull girder longitudinal strength

5.1 Application

5.1.1 The requirements of this Article apply to ships equal to or greater than 150 m in length. For such ships, the ultimate strength of stiffeners subjected to lateral pressure and to hull girder normal stresses is to be checked.

5.2 Width of attached plating

5.2.1 The width of the attached plating to be considered for the ultimate strength check of ordinary stiffeners is to be obtained, in m, from the following formulae:

- if $\beta_U \le 1{,}25$:

  $b_U = s$

- if $\beta_U > 1{,}25$:

  $b_U = \left(\frac{2{,}25}{\beta_U} - \frac{1{,}25}{\beta_U^2}\right)s$

where:

$$\beta_U = \frac{s}{t_p}\sqrt{\frac{\sigma_{X1E}}{E}}10^3$$

σ_{X1E} : Stress defined in [5.4].

5.3 Load model

5.3.1 General

The still water and wave lateral pressures induced by the sea and the various types of cargoes and ballast in intact conditions are to be considered, depending on the location of the ordinary stiffener under consideration and the type of compartments adjacent to it, in accordance with Ch 5, Sec 1, [2.4].

The wave lateral pressures and hull girder loads are to be calculated in the mutually exclusive load cases “a”, “b”, “c” and “d” in Ch 5, Sec 4.

5.3.2 Lateral pressure

Lateral pressure is constituted by still water pressure and wave pressure.

Still water pressure (p_S) includes:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave induced pressure (p_W) includes:

- the wave pressure, defined in Ch 5, Sec 5, [2] for each load case “a”, “b”, “c” and “d”
- the inertial pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast, and for each load case “a”, “b”, “c” and “d”.

5.3.3 Hull girder compression normal stresses

The hull girder compression normal stresses σ_{X1} to be considered for the ultimate strength check of stiffeners contributing to the longitudinal strength are those given in [4.2.2], where the partial safety factors are those specified in Tab 1 for the ultimate strength check.

5.4 Ultimate strength stress

5.4.1 The ultimate strength stress σ_U is to be obtained, in N/mm², from the formulae in Tab 8, for resultant lateral pressure acting either on the side opposite to the ordinary stiffener, with respect to the plating, or on the same side as the ordinary stiffener.

5.5 Checking criteria

5.5.1 The ultimate strength stress of the ordinary stiffener is to comply with the following formula:

$$\frac{\sigma_U}{\gamma_R\gamma_m} \ge |\sigma_{X1}|$$

where:

σ_U : Ultimate strength stress, in N/mm², as calculated in [5.4.1]

σ_{X1} : Compression stress, in N/mm², as calculated in [5.3.3].

Table 8 : Ultimate strength stress

Symbol	Resultant load pressure acting on the side opposite to the ordinary stiffener, with respect to the plating, in N/mm^2	Resultant load pressure acting on the same side as the ordinary stiffener, in N/mm^2
σ_U	$f\frac{A_U}{A_S}\left(1-\frac{s}{10b_U}\right)R_{eH,P}$	$R_{eH,S}\, f$
f	$\frac{\zeta}{2}-\sqrt{\frac{\zeta^2}{4}-\frac{1-\mu}{(1+\eta_P)\lambda_U^2}}$	
ζ	$\frac{1-\mu}{1+\eta_P}+\frac{1+\eta_P+\eta}{(1+\eta_P)\lambda_U^2}$	
μ	$\frac{125ps\ell^2 d_{P,U}}{R_{eH,P}I_U\left(1-\frac{s}{10b_U}\right)}$	$\frac{41,7ps\ell^2 d_{F,S}}{R_{eH,S}I_S}$
η	$\left(\delta_0+\frac{13ps\ell^4}{E_T I_S}10^4\right)\frac{d_{P,U}}{\rho_U^2}$	$\left(0,577\delta_0+\frac{1,5ps\ell^4}{E_T I_S}10^4\right)\frac{d_{F,S}}{\rho_S^2}$
η_P	$d_P A\left(\frac{1}{A_U}-\frac{1}{A_S}\right)\frac{d_{P,U}}{\rho_U^2}$	0
λ_U	$\frac{31,8\ell}{\rho_U}\sqrt{\frac{R_{eH,P}}{E_T}\left(1-\frac{s}{10b_U}\right)}$	$\frac{18,4\ell}{\rho_S}\sqrt{\frac{R_{eH,S}}{E_T}}$

Note 1:

σ_{C2} : Critical torsional buckling stress, in N/mm^2, defined in [4.3.1]

$d_{P,U}$: Distance, in cm, between the neutral axis of the cross-section of the stiffener with attached plating of width b_U and the fibre at half-thickness of the plating

$d_{F,S}$: Distance, in cm, between the neutral axis of the cross-section of the stiffener with attached plating of width s and the fibre at half-thickness of the face plate of the stiffener

d_P : Distance, in cm, between the neutral axis of the ordinary stiffener without attached plating and the fibre at half-thickness of the attached plating

A : Net sectional area, in cm^2, of the stiffener without attached plating

p : Lateral pressure acting on the stiffener, equal to: $p = \gamma_{S2}\, p_S + \gamma_{W2U}\, p_W$

δ_0 : Pre-deformation, in cm, of the ordinary stiffener, to be assumed, in the absence of more accurate evaluation:
$\delta_0 = 0,2\,\ell$

E_T : Structural tangent modulus, equal to:

$$E_T = 4E\frac{\sigma_{X1E}}{R_{eH,P}}\left(1-\frac{\sigma_{X1E}}{R_{eH,P}}\right) \quad \text{for} \quad \sigma_{X1E} > 0,5R_{eH,P}$$

$$E_T = E \quad \text{for} \quad \sigma_{X1E} \le 0,5R_{eH,P}$$

σ_{X1E} : Stress to be obtained, in N/mm^2, from the following formulae:

$$\sigma_{X1E} = \left\{\frac{-\frac{22,5st_P}{\alpha}+\sqrt{\left(\frac{22,5st_P}{\alpha}\right)^2+4A\left[(A_S+10st_P)\sigma_{X1}+\frac{12,5st_P}{\alpha^2}\right]}}{2A}\right\}^2 \quad \text{if} \quad \alpha > \frac{1,25}{\sqrt{|\sigma_{X1}|}}$$

$$\sigma_{X1E} = \sigma_{X1} \quad \text{if} \quad \alpha \le \frac{1,25}{\sqrt{|\sigma_{X1}|}}$$

$$\alpha = 1000\frac{s}{t_P\sqrt{E}}$$

σ_{X1} : Compression stress, in N/mm^2, acting on the stiffener, as defined in [5.3.3].

SECTION 3 PRIMARY SUPPORTING MEMBERS

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

p_S : Still water pressure, in kN/m^2, see [3.4.2] and [3.4.4]

p_W : Wave pressure, in kN/m^2, see [3.4.2] and [3.4.4]

p_{SF}, p_{WF} : Still water and wave pressures, in kN/m^2, in flooding conditions, defined in Ch 5, Sec 6, [9]

σ_{X1} : Hull girder normal stress, in N/mm^2, defined in [3.4.5]

σ_N : Normal stress, in N/mm^2, defined in [3.4.5]

s : Spacing, in m, of primary supporting members

ℓ : Span, in m, of primary supporting members, measured between the supporting elements, see Ch 4, Sec 3, [4.1]

ℓ_b : Length, in m, of one bracket, see [3.2] and Ch 4, Sec 3, [4.4]

b_p : Width, in m, of the plating attached to the primary supporting member, for the yielding check, defined in Ch 4, Sec 3, [4.2]

w : Net section modulus, in cm^3, of the primary supporting member, with an attached plating of width b_p , to be calculated as specified in Ch 4, Sec 3, [4.3]

A_{Sh} : Net shear sectional area, in cm^2, of the primary supporting member, to be calculated as specified in Ch 4, Sec 3, [4.3]

m : Boundary coefficient, to be taken equal to:
- m = 10 in general
- m = 12 for bottom and side girders

I : Net moment of inertia, in cm^4, of the primary supporting member without attached plating, about its neutral axis parallel to the plating

I_B : Net moment of inertia, in cm^4, of the primary supporting member with bracket and without attached plating, about its neutral axis parallel to the plating, calculated at mid-length of the bracket

$\chi = I_B / I$

$\ell = \alpha_b \ell /$

1 General

1.1 Application

1.1.1 Analysis criteria

The requirements of this Section apply for the yielding and buckling checks of primary supporting members.

Depending on their arrangement, primary supporting members are to be analysed through one of the following models:

- an isolated beam structural model
- a three dimensional structural model
- a complete ship structural model.

1.1.2 Isolated beam models

In general, an isolated beam model is to be adopted where the primary supporting member arrangement is not of a grillage type, i.e. where the primary supporting members are fitted in one direction, or where the primary supporting members are fitted in two directions and their inertia in one direction is at least three times that in the other direction.

1.1.3 Three dimensional models

Where the conditions in [1.1.2] do not occur, primary supporting members are to be analysed through three dimensional models, according to [4], unless analyses using complete ship models are required on the basis of the criteria in [5].

In general, a three dimensional model is to be adopted for the analysis of primary supporting members of ships greater than 120 m in length.

1.1.4 Complete ship models

Complete ship models may be required to be carried out in order to analyse primary supporting members for the cases specified in [5].

1.1.5 Analysis documentation

Adequate documentation of the analyses based on three dimensional models (structural model, load and stress calculation, strength checks) carried out by the Designer are to be submitted to the Society for review.

1.1.6 Yielding check

The yielding check is to be carried out according to:

- [3] for primary supporting members analysed through isolated beam models
- [4] for primary supporting members analysed through three dimensional models
- [5] for primary supporting members analysed through complete ship models.

1.1.7 Buckling check

The buckling check is to be carried out according to [6], on the basis of the stresses in primary supporting members calculated according to [3], [4] or [5], depending on the structural model adopted.

Table 1 : Primary supporting members analysed through isolated beam models - Partial safety factors *(1/1/2001)*

Partial safety factors covering uncertainties regarding:	Symbol	Yielding check		Buckling check	
		General (see [3.4] to [3.7])	Watertight bulkhead primary supporting members **(1)** (see [3.8])	Plate panels (see [6.1])	Pillars (see [6.2] and [6.3])
Still water hull girder loads	γ_{S1}	1,00	1,00	1,00	1,00
Wave hull girder loads	γ_{W1}	1,15	1,15	1,15	1,15
Still water pressure	γ_{S2}	1,00	1,00	1,00	1,00
Wave pressure	γ_{W2}	1,20	1,05	1,20	1,20
Material	γ_m	1,02	1,02	1,02	1,02
Resistance	γ_R	• 1,02 in general • 1,15 for bottom and side girders	1,02 **(2)**	1,10	For [6.2]: see Tab 13 For [6.3]: 1,15

(1) Applies also to primary supporting members of bulkheads or inner side which constitute boundary of compartments not intended to carry liquids.
(2) For primary supporting members of the collision bulkhead, γ_R =1,25

Table 2 : Primary supporting members analysed through three dimensional models - Partial safety factors *(1/1/2001)*

Partial safety factors covering uncertainties regarding:	Symbol	Yielding check (see [4])		Buckling check	
		General	Watertight bulkhead primary supporting members **(1)**	Plate panels (see [6.1])	Pillars (see [6.2] and [6.3])
Still water hull girder loads	γ_{S1}	1,05	1,05	1,05	1,05
Wave hull girder loads	γ_{W1}	1,05	1,05	1,05	1,05
Still water pressure	γ_{S2}	1,00	1,00	1,00	1,00
Wave pressure	γ_{W2}	1,10	1,10	1,10	1,10
Material	γ_m	1,02	1,02	1,02	1,02
Resistance	γ_R	Defined in Tab 4 and Tab 5	Defined in Tab 4 and Tab 5	1,02	For [6.2]: see Tab 13 For [6.3]: 1,15

(1) Applies also to primary supporting members of bulkheads or inner side which constitute boundary of compartments not intended to carry liquids.
Note 1: For primary supporting members of the collision bulkhead, γ_R =1,25

Table 3 : Primary supporting members analysed through complete ship models - Partial safety factors *(1/1/2001)*

Partial safety factors covering uncertainties regarding:	Symbol	Yielding check (see [5])	Buckling check	
			Plate panels (see [6.1])	Pillars (see [6.2] and [6.3])
Still water hull girder loads	γ_{S1}	1,00	1,00	1,00
Wave hull girder loads	γ_{W1}	1,10	1,10	1,10
Still water pressure	γ_{S2}	1,00	1,00	1,00
Wave pressure	γ_{W2}	1,10	1,10	1,10
Material	γ_m	1,02	1,02	1,02
Resistance	γ_R	Defined in Tab 4 and Tab 5	1,02	For [6.2]: see Tab 13 For [6.3]: 1,15

Table 4 : Primary supporting members analysed through three dimensional or complete ship models Resistance partial safety factor *(1/7/2018)*

Type of three dimensional model (see App 1)	Resistance partial safety factor γ_R (see [4.3.1] and [5.3.1])	
	General	Watertight bulkhead primary supporting members
Beam model	1,20	1,02
Coarse mesh finite element model	1,20	1,02
Fine mesh finite element model	1,10	1,02
Refined local mesh finite element model	1,10	1,02

Table 5 : Additional criteria for analyses based on fine mesh and refined local mesh finite element models
Resistance partial safety factor *(1/7/2018)*

Symbol	Resistance partial safety factor (see [4.3.2] and [5.3.2])	
	General	Watertight bulkhead primary supporting members
γ_R	1,10	1,02

1.1.8 Minimum net thicknesses

In addition to the above, the scantlings of primary supporting members are to comply with the requirements in [2].

1.2 Net scantlings

1.2.1 As specified in Ch 4, Sec 2, [1], all scantlings referred to in this Section are net, i.e. they do not include any margin for corrosion.

The gross scantlings are obtained as specified in Ch 4, Sec 2.

1.3 Partial safety factors

1.3.1 The partial safety factors to be considered for checking primary supporting members are specified in:

- Tab 1 for analyses based on isolated beam models
- Tab 2 for analyses based on three dimensional models
- Tab 3 for analyses based on complete ship models.

2 Minimum net thicknesses

2.1 General

2.1.1 The net thickness of plating which forms the webs of primary supporting members is to be not less than the value obtained, in mm, from the following formulae:

$t_{MIN} = 3,7 + 0,015Lk^{1/2}$ for $L < 120$ m

$t_{MIN} = 3,7 + 1,8k^{1/2}$ for $L \geq 120$ m

2.2 Double bottom

2.2.1 In addition to the requirements in [2.1], the net thickness of plating which forms primary supporting members of the double bottom is to be not less than the values given in Tab 6.

Table 6 : Minimum net thicknesses of double bottom primary supporting members

Primary supporting member	Minimum net thickness, in mm	
	Area within 0,4L amidships	Area outside 0,4L amidships
Centre girder	$2,2\ L^{1/3}\ k^{1/6}$	$1,8\ L^{1/3}\ k^{1/6}$
Side girders	$1,7\ L^{1/3}\ k^{1/6}$	$1,6\ L^{1/3}\ k^{1/6}$
Floors	$1,7\ L^{1/3}\ k^{1/6}$	$1,6\ L^{1/3}\ k^{1/6}$
Girder bounding a duct keel **(1)**	$1,5 + 0,8\ L^{1/2}\ k^{1/4}$	$1,5 + 0,8\ L^{1/2}\ k^{1/4}$
Margin plate	$L^{1/2}\ k^{1/4}$	$0,9\ L^{1/2}\ k^{1/4}$
(1) The minimum net thickness is to be taken not less than that required for the centre girder.		

2.3 Single bottom

2.3.1 In addition to the requirements in [2.1], the net thickness of plating which forms the webs of primary supporting members of the single bottom is to be not less than the values given in Tab 7.

Table 7 : Minimum net thicknesses of the webs of single bottom primary supporting members

Primary supporting member	Minimum net thickness, in mm	
	Area within 0,4L amidships	Area outside 0,4L amidships
Centre girder	$6,0 + 0,05L_2\ k^{1/2}$	$5,0 + 0,05L_2\ k^{1/2}$
Floors and side girders	$5,5 + 0,05L_2\ k^{1/2}$	$4,0 + 0,05L_2\ k^{1/2}$

2.4 Deck primary members in way of launching appliances used for survival craft or rescue boat

2.4.1 *(1/1/2020)*

The scantlings of deck primary supporting members are to be determined by direct calculations, considering the following load cases as appropriate:

- vertical forces
- overturning moment
- slewing moment

Calculations models based on beam elements are in general considered to be adequate.

2.4.2 *(1/1/2020)*

The loads exerted by launching appliance on relevant deck primary supporting members are to correspond to the SWL of the launching appliance.

2.4.3 *(1/1/2020)*

The combined Von Mises stress, in N/mm², is not to exceed the smaller of $R_{eH}/2,2$ and $R_m/4,5$ where R_m is the ultimate minimum tensile strength of the primary supporting member material, in N/mm².

3 Yielding check of primary supporting members analysed through an isolated beam structural model

3.1 General

3.1.1 The requirements of this Article apply for the yielding check of primary supporting members subjected to lateral pressure or to wheeled loads and, for those contributing to the hull girder longitudinal strength, to hull girder normal stresses, which are to be analysed through an isolated beam model, according to [1.1.2].

3.1.2 The yielding check is also to be carried out for primary supporting members subjected to specific loads, such as concentrated loads.

3.2 Bracket arrangement

3.2.1 The requirements of this Article apply to primary supporting members with brackets at both ends of length not greater than $0,2\ell$.

In the case of a significantly different bracket arrangement, the determination of normal and shear stresses due to design loads and the required section modulus and shear sectional area are considered by the Society on a case by case basis.

3.3 Load point

3.3.1 Lateral pressure

Unless otherwise specified, lateral pressure is to be calculated at mid-span of the primary supporting member considered.

3.3.2 Hull girder normal stresses

For longitudinal primary supporting members contributing to the hull girder longitudinal strength, the hull girder normal stresses are to be calculated in way of the face plate of the primary supporting member considered.

For bottom and deck girders, it may generally be assumed that the hull girder normal stresses in the face plate are equal to 0,75 times those in the relevant plating.

3.4 Load model

3.4.1 General

The still water and wave lateral pressures induced by the sea and the various types of cargoes and ballast in intact conditions are to be considered, depending on the location of the primary supporting member under consideration and the type of compartments adjacent to it, in accordance with Ch 5, Sec 1, [2.4].

Primary supporting members of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids are to be subjected to the lateral pressure in flooding conditions.

The wave lateral pressures and hull girder loads are to be calculated in the mutually exclusive load cases “a”, “b”, “c” and “d” in Ch 5, Sec 4.

3.4.2 Lateral pressure in intact conditions

The lateral pressure in intact conditions is constituted by still water pressure and wave pressure.

Still water pressure (p_S) includes:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave pressure (p_W) includes:

- the wave pressure, defined in Ch 5, Sec 5, [2] for each load case “a”, “b”, “c” and “d”
- the inertial pressure, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast, and for each load case “a”, “b”, “c” and “d”.

3.4.3 Lateral pressure in flooding conditions

The lateral pressure in flooding conditions is constituted by the still water pressure p_{SF} and the wave pressure p_{WF} defined in Ch 5, Sec 6, [9].

3.4.4 Wheeled loads *(1/7/2009)*

For primary supporting members subjected to wheeled loads, the yielding check may be carried out according to [3.5] to [3.7] considering uniform pressures equivalent to the distribution of vertical concentrated forces, when such forces are closely located.

For the determination of the equivalent uniform pressures, the most unfavourable case, i.e. where the maximum number of axles are located on the same primary supporting member, according to Fig 1 to Fig 3, is to be considered.

The equivalent still water pressure and inertial pressure are indicated in Tab 8.

For arrangements different from those shown in Fig 1 to Fig 3, the yielding check of primary supporting members is to be carried out by a direct calculation, taking into account the distribution of concentrated loads induced by vehicle wheels.

In particular, the load redistribution effect of longitudinal girders not supported by pillars is to be taken into account by a grillage direct calculation or, as an a alternative, an equivalent load obtained by previous analysis can be used.

Table 8 : Wheeled loads Equivalent uniform still water and inertial pressures *(1/7/2009)*

Ship condition	Load case	Still water pressure p_S and inertial pressure p_W, in kN/m^2
Still water condition		$p_S = 10\ p_{eq}$
Upright condition	"a"	No inertial pressure
	"b"	$p_W = p_{eq} a_{Z1}$
Inclined condition	"c"	The inertial pressure may be disregarded
	"d"	$p_W = p_{eq} a_{Z2}$

Note 1:

$$p_{eq} = \frac{n_V Q_A}{\ell s}\left(3 - \frac{X_1 + X_2}{s}\right)$$

- n_V : Maximum number of vehicles possible located on the primary supporting member
- Q_A : Maximum axle load, in t, defined in Ch 5, Sec 6, Tab 8
- X_1 : Minimum distance, in m, between two consecutive axles (see Fig 2 and Fig 3)
- X_2 : Minimum distance, in m, between axles of two consecutive vehicles (see Fig 3). In the case indicated in Fig 2, X_2 is to be taken equal to s.

Figure 1 : Wheeled loads - Distribution of vehicles on a primary supporting member

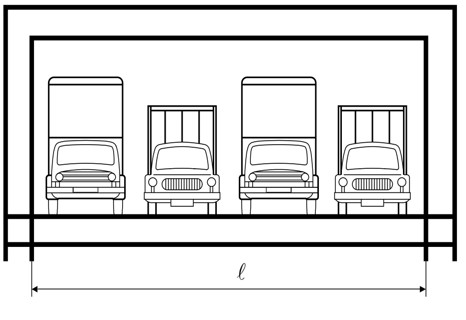


Figure 2 : Wheeled loads Distance between two consecutive axles

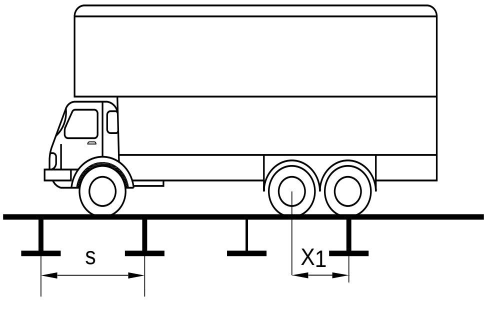
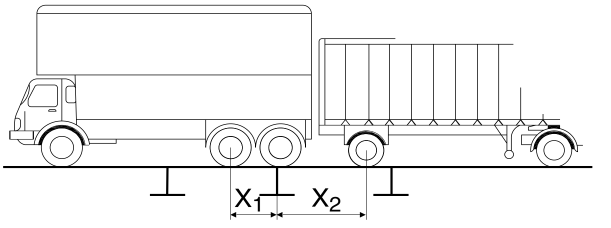


Figure 3 : Wheeled loads Distance between axles of two consecutive vehicles



3.4.5 Normal stresses *(1/1/2001)*

The normal stresses to be considered for the yielding check of primary supporting members are obtained, in N/mm^2, from the following formulae:

- for longitudinal primary supporting members contributing to the hull girder longitudinal strength:

$$\sigma_N = \sigma_{X1} = \gamma_{S1}\sigma_{S1} + \gamma_{W1}(C_{FV}\sigma_{WV1} + C_{FH}\sigma_{WH1} + C_{F\Omega}\sigma_{\Omega})$$

- for longitudinal primary supporting members not contributing to the hull girder longitudinal strength and for transverse primary supporting members:

$$\sigma_N = 45 / kN / mm^2$$

where:

σ_{S1}, σ_{WV1}, σ_{WH1} : Hull girder normal stresses, in N/mm^2, defined in:

- Tab 9 for primary supporting members subjected to lateral pressure,
- Tab 10 for primary supporting members subjected to wheeled loads

σ_{Ω} : absolute value of the warping stress, in N/mm^2, induced by the torque $0{,}625 M_{WT}$ and obtained through direct calculation analyses based on a structural model in accordance with Ch 6, Sec 1, [2.6],

C_{FV}, C_{FH}, $C_{F\Omega}$: Combination factors defined in Tab 11.

3.5 Normal and shear stresses due to lateral pressure in intact conditions

3.5.1 General

Normal and shear stresses, induced by lateral pressures, in primary supporting members are to be determined from the formulae given in:

- [3.5.2] in the case of longitudinal and transverse primary supporting members
- [3.5.3] in the case of vertical primary supporting members.

Table 9 : Hull girder normal stresses - Primary supporting members subjected to lateral pressure

Condition		σ_{S1}, in N/mm² **(1)**	σ_{WV1}, in N/mm²	σ_{WH1}, in N/mm²
Lateral pressure applied on the side opposite to the primary supporting member, with respect to the plating:	$z \geq N$	$\left\lvert \frac{M_{SW,S}}{I_Y}(z-N) \right\rvert 10^{-3}$	$\left\lvert \frac{0,625 F_D M_{WV,S}}{I_Y}(z-N) \right\rvert 10^{-3}$	$\left\lvert \frac{0,625 M_{WH}}{I_Z} y \right\rvert 10^{-3}$
	$z < N$	$\left\lvert \frac{M_{SW,H}}{I_Y}(z-N) \right\rvert 10^{-3}$	$\left\lvert \frac{0,625 M_{WV,H}}{I_Y}(z-N) \right\rvert 10^{-3}$	
Lateral pressure applied on the same side as the primary supporting member:	$z \geq N$	$\left\lvert \frac{M_{SW,H}}{I_Y}(z-N) \right\rvert 10^{-3}$	$\left\lvert \frac{0,625 M_{WV,H}}{I_Y}(z-N) \right\rvert 10^{-3}$	
	$z < N$	$\left\lvert \frac{M_{SW,S}}{I_Y}(z-N) \right\rvert 10^{-3}$	$\left\lvert \frac{0,625 F_D M_{WV,S}}{I_Y}(z-N) \right\rvert 10^{-3}$	

(1) When the ship in still water is always in hogging condition, $M_{SW,S}$ is to be taken equal to 0.
Note 1:
F_D : Coefficient defined in Ch 5, Sec 2, [4].

Table 10 : Hull girder normal stresses - Primary supporting members subjected to wheeled loads

Condition	σ_{S1} in N/mm² **(1)**	σ_{WV1} in N/mm²	σ_{WH1} in N/mm²
$z \geq N$	$\left\lvert \frac{M_{SW,H}}{I_Y}(z-N) \right\rvert 10^{-3}$	$\left\lvert \frac{0,625 M_{WV,H}}{I_Y}(z-N) \right\rvert 10^{-3}$	$\left\lvert \frac{0,625 M_{WH}}{I_Z} y \right\rvert 10^{-3}$
$z < N$	$\left\lvert \frac{M_{SW,S}}{I_Y}(z-N) \right\rvert 10^{-3}$	$\left\lvert \frac{0,625 F_D M_{WV,S}}{I_Y}(z-N) \right\rvert 10^{-3}$	

(1) When the ship in still water is always in hogging condition, $M_{SW,S}$ is to be taken equal to 0.
Note 1:
F_D : Coefficient defined in Ch 5, Sec 2, [4].

Table 11 : Combination factors C_{FV}, C_{FH} and $C_{F\Omega}$

Load case	C_{FV}	C_{FH}	$C_{F\Omega}$
"a"	1,0	0	0
"b"	1,0	0	0
"c"	0,4	1,0	1,0
"d"	0,4	1,0	0

3.5.2 Longitudinal and transverse primary supporting members *(1/1/2001)*

The maximum normal stress σ and shear stress τ are to be obtained, in N/mm², from the following formulae:

$$\sigma = \beta_b \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{m w} s \ell^2 10^3 + \sigma_N$$

$$\tau = 5 \beta_s \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{A_{Sh}} s \ell$$

where:

$$\beta_b = \frac{\chi(1-2\alpha)^3 + 2\alpha^2(4\alpha-3)}{\chi(1-2\alpha)+2\alpha}$$

to be taken not less than 0,55.

$$\beta_s = 1 - 2\alpha$$

3.5.3 Vertical primary supporting members

The maximum normal stress σ and shear stress τ are to be obtained, in N/mm², from the following formulae:

$$\sigma = \beta_b \frac{\gamma_{S2} \lambda_{bS} p_S + \gamma_{W2} \lambda_{bW} p_W}{m w} s \ell^2 10^3 + \sigma_A$$

$$\tau = 5 \beta_s \frac{\gamma_{S2} \lambda_{sS} p_S + \gamma_{W2} \lambda_{sW} p_W}{A_{Sh}} s \ell$$

where:

β_b, β_s : Coefficients defined in [3.5.2]

$$\lambda_{bS} = 1 + 0,2 \frac{p_{Sd} - p_{Su}}{p_{Sd} + p_{Su}}$$

$$\lambda_{bW} = 1 + 0,2 \frac{p_{Wd} - p_{Wu}}{p_{Wd} + p_{Wu}}$$

$$\lambda_{sS} = 1 + 0,4 \frac{p_{Sd} - p_{Su}}{p_{Sd} + p_{Su}}$$

$$\lambda_{sW} = 1 + 0,4 \frac{p_{Wd} - p_{Wu}}{p_{Wd} + p_{Wu}}$$

p_{Sd} : Still water pressure, in kN/m², at the lower end of the primary supporting member considered

p_{Su} : Still water pressure, in kN/m², at the upper end of the primary supporting member considered

p_{Wd} : Wave pressure, in kN/m², at the lower end of the primary supporting member considered

p_{Wu} : Wave pressure, in kN/m², at the upper end of the primary supporting member considered

σ_A : Axial stress, to be obtained, in N/mm², from the following formula:

$$\sigma_A = 10\frac{F_A}{A}$$

F_A : Axial load (still water and wave) transmitted to the vertical primary supporting members by the structures above. For multideck ships, the criteria in [6.2.1] for pillars are to be adopted.

A : Net sectional area, in cm², of the vertical primary supporting members with attached plating of width b_P.

3.6 Checking criteria

3.6.1 General

It is to be checked that the normal stress σ and the shear stress τ, calculated according to [3.5], are in compliance with the following formulae:

$$\frac{R_y}{\gamma_R\gamma_m} \geq \sigma$$

$$0{,}5\frac{R_y}{\gamma_R\gamma_m} \geq \tau$$

3.7 Net section modulus and net sectional shear area complying with the checking criteria

3.7.1 General

The requirements in [3.7.2] and [3.7.3] provide the minimum net section modulus and net shear sectional area of primary supporting members subjected to lateral pressure in intact conditions, complying with the checking criteria indicated in [3.6].

3.7.2 Longitudinal and transverse primary supporting members *(1/1/2001)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of longitudinal or transverse primary supporting members are to be not less than the values obtained from the following formulae:

$$w = \gamma_R\gamma_m\beta_b\frac{\gamma_{S2}p_S + \gamma_{W2}p_W}{m(R_y - \gamma_R\gamma_m\sigma_N)}s\ell^2 10^3$$

$$A_{Sh} = 10\gamma_R\gamma_m\beta_s\frac{\gamma_{S2}p_S + \gamma_{W2}p_W}{R_y}s\ell$$

where β_b and β_s are the coefficients defined in [3.5.2].

3.7.3 Vertical primary supporting members

The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of vertical primary supporting members are to be not less than the values obtained from the following formulae:

$$w = \gamma_R\gamma_m\beta_b\frac{\gamma_{S2}\lambda_{bS}p_S + \gamma_{W2}\lambda_{bW}p_W}{m(R_y - \gamma_R\gamma_m\sigma_A)}s\ell^2 10^3$$

$$A_{Sh} = 10\gamma_R\gamma_m\beta_s\frac{\gamma_{S2}\lambda_{sS}p_S + \gamma_{W2}\lambda_{sW}p_W}{R_y}s\ell$$

where:

β_b, β_s : Coefficients defined in [3.5.2]

λ_{bs}, λ_{bW}, λ_{sS}, λ_{sW} : Coefficients defined in [3.5.3]

σ_A : Defined in [3.5.3].

3.8 Net section modulus and net shear sectional area of primary supporting members subjected to lateral pressure in flooding conditions

3.8.1 General

The requirements in [3.8.1] to [3.8.3] apply to primary supporting members of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids.

These primary supporting members are to be checked in flooding conditions as specified in [3.8.2] and [3.8.3], depending on the type of member.

3.8.2 Longitudinal and transverse primary supporting members *(1/7/2020)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of longitudinal or transverse primary supporting members are to be not less than the values obtained from the following formulae:

$$w = \gamma_R\gamma_m\beta_b\frac{\gamma_{S2}p_{SF} + \gamma_{W2}p_{WF}}{12c_P(R_y - \gamma_R\gamma_m\sigma_N)}s\ell^2 10^3$$

$$A_{Sh} = 10\gamma_R\gamma_m\beta_s\frac{\gamma_{S2}p_{SF} + \gamma_{W2}p_{WF}}{R_y}s\ell$$

where:

β_b, β_s : Coefficients defined in [3.5.2]

c_P : Ratio of the plastic section modulus to the elastic section modulus of the primary supporting members with an attached plating b_p, to be taken equal to 1,16 in the absence of more precise evaluation.

3.8.3 Vertical primary supporting members *(1/7/2020)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of vertical primary supporting members are to be not less than the values obtained from the following formulae:

$$w = \gamma_R\gamma_m\beta_b\frac{\gamma_{S2}\lambda_{bS}p_{SF} + \gamma_{W2}\lambda_{bW}p_{WF}}{12c_P(R_y - \gamma_R\gamma_m\sigma_A)}s\ell^2 10^3$$

$$A_{Sh} = 10\gamma_R\gamma_m\beta_s\frac{\gamma_{S2}\lambda_{sS}p_{SF} + \gamma_{W2}\lambda_{sW}p_{WF}}{R_y}s\ell$$

where:

β_b, β_s : Coefficients defined in [3.5.2]

c_P : Ratio defined in [3.8.2]

$$\lambda_{bS} = 1 + 0{,}2\frac{p_{SFd} - p_{SFu}}{p_{SFd} + p_{SFu}}$$

$$\lambda_{bW} = 1 + 0{,}2\frac{p_{WFd} - p_{WFu}}{p_{WFd} + p_{WFu}}$$

$$\lambda_{sS} = 1 + 0{,}4\frac{p_{SFd} - p_{SFu}}{p_{SFd} + p_{SFu}}$$

$$\lambda_{sW} = 1 + 0{,}4\frac{p_{WFd} - p_{WFu}}{p_{WFd} + p_{WFu}}$$

p_{SFd} : Still water pressure, in kN/m², in flooding conditions, at the lower end of the primary supporting member considered

p_{SFu} : Still water pressure, in kN/m², in flooding conditions, at the upper end of the primary supporting member considered

p_{WFd} : Wave pressure, in kN/m², in flooding conditions, at the lower end of the primary supporting member considered.

p_{WFu} : Wave pressure, in kN/m², in flooding conditions, at the upper end of the primary supporting member considered

σ_A : Defined in [3.5.3].

4 Yielding check of primary supporting members analysed through a three dimensional structural model

4.1 General

4.1.1 The requirements of this Article apply for the yielding check of primary supporting members subjected to lateral pressure or to wheeled loads and, for those contributing to the hull girder longitudinal strength, to hull girder normal stresses, which are to be analysed through a three dimensional structural model, according to [1.1.3].

4.1.2 The yielding check is also to be carried out for primary supporting members subjected to specific loads, such as concentrated loads.

4.2 Analysis criteria

4.2.1 The analysis of primary supporting members based on three dimensional models is to be carried out according to:

- the requirements in App 1 for primary supporting members subjected to lateral pressure
- the requirements in App 2 for primary supporting members subjected to wheeled loads.

These requirements apply for:

- the structural modelling
- the load modelling
- the stress calculation.

4.3 Checking criteria

4.3.1 General

For all types of analysis (see App 1, [2]), it is to be checked that the equivalent stress σ_{VM} , calculated according to App 1, [5] is in compliance with the following formula:

$$\frac{R_y}{\gamma_R\gamma_m} \geq \sigma_{VM}$$

4.3.2 Additional criteria for analyses based on fine mesh finite element models

Fine mesh finite element models are defined with reference to App 1, [3.4].

For all the elements of the fine mesh models, it is to be checked that the normal stresses σ_1 and σ_2 and the shear stress τ_{12}, calculated according to App 1, [5], are in compliance with the following formulae:

$$\frac{R_y}{\gamma_R\gamma_m} \geq \max(\sigma_1, \sigma_2)$$

$$0,5\frac{R_y}{\gamma_R\gamma_m} \geq \tau_{12}$$

4.3.3 Specific case of primary supporting members subjected to wheeled loads

For all types of analysis (see App 2, [2]), it is to be checked that the equivalent stress σ_{VM}, calculated according to App 2, [5] is in compliance with the following formula:

$$\frac{R_y}{\gamma_R\gamma_m} \geq \sigma_{VM}$$

4.3.4 Specific criteria for analyses based on refined local mesh finite element models *(1/1/2020)*

Highly stressed areas investigated through a refined structural detail analysis according to App 1, [3.4.4] with a mesh based on 50 mm x 50 mm element size (or smaller), are to comply with both the two following requirements:

a) $a\frac{R_y}{\gamma_R\gamma_m} \geq (\sigma_{VM})_{MEAN50x50}$

where:

a : 1,6 away from welds

a : 1,4 adjacent to welds

γ_m and γ_R: partial safety factors to be taken as given in Tab 4 and Tab 5.

$(\sigma_{VM})_{MEAN\ 50x50}$: weighted average of Von Mises stress evaluated on an area of 50x50 mm, in in N/mm², to be obtained as follows:

$$(\sigma_{VM})_{MEAN50x50} = \frac{\sum_{i=1}^{n} A_i \cdot \sigma_{VM_i}}{\sum_{i=1}^{n} A_i}$$

σ_{VMi} : Von Mises stress at centrod of the i-th element within the evaluated area, in N/mm²

A_i : Area of the i-th element within the evaluated area, in mm²

n : Number of elements within the evaluated area

In performing the above summation the following procedures are to be followed:

- only the n elements which are completely inside the 50 x 50 mm area are to be included
- stress averaging is not to be carried across structural discontinuities and abutting structure.

b) In any case the average stress over an s x s evaluation area, with s being the relevant spacing of ordinary stiffeners, is not to exceed the unfactored allowable stress given by

$R_y / \gamma_m.\gamma_R$

In this case similar weighted-by-area averaging as per point a shall be applied.

For specific cases of rounded edges (openings and rounded brackets), the averaging has to include only the first row of elements adjacent to the free edge, over a length equal to s.

5 Yielding check of primary supporting members analysed through a complete ship structural model

5.1 General

5.1.1 The requirements of this Article apply for the yielding check of primary supporting members which are to be analysed through a complete ship structural model.

5.1.2 A complete ship structural model is to be carried out, when deemed necessary by the Society, to analyse primary supporting members of ships with one or more of the following characteristics:

- ships having large deck openings
- ships having large space arrangements
- multideck ships having series of openings in side or longitudinal bulkheads, when the stresses due to the different contribution of each deck to the hull girder strength are to be taken into account.

5.1.3 Based on the criteria in [5.1.2], analyses based on complete ship models may be required, in general, for the following ship types:

- ships with the service notation **general cargo ship**, having large deck openings
- ships with the service notation **container ship**
- ships with the service notation **ro-ro cargo ship**
- ships with the service notation **passenger ship**
- ships with the service notation **ro-ro passenger ship**.

5.2 Analysis criteria

5.2.1 The analysis of primary supporting members based on complete ship models is to be carried out according to App 3.

These requirements apply for:

- the structural modelling
- the load modelling
- the stress calculation.

5.3 Checking criteria

5.3.1 General

It is to be checked that the equivalent stress σ_{VM}, calculated according to App 3, [4] is in compliance with the following formula:

$$\frac{R_y}{\gamma_R \gamma_m} \geq \sigma_{VM}$$

5.3.2 Additional criteria for elements modelled with fine meshes

Fine meshes are defined with reference to App 3, [2.4].

For all the elements modelled with fine meshes, it is to be checked that the normal stresses σ_1 and σ_2 and the shear stress τ_{12}, calculated according to App 3, [4], are in compliance with the following formulae:

$$\frac{R_y}{\gamma_R \gamma_m} \geq \max(\sigma_1, \sigma_2)$$

$$0{,}5\frac{R_y}{\gamma_R \gamma_m} \geq \tau_{12}$$

6 Buckling check

6.1 Local buckling of plate panels

6.1.1 A local buckling check is to be carried out, according to Sec 1, [5], for plate panels which constitute primary supporting members.

In carrying out this check, the stresses in the plate panels are to be calculated according to [3], [4] or [5], depending on the structural model adopted for the analysis of primary supporting members.

6.2 Buckling of pillars subjected to compression axial load

6.2.1 Compression axial load

The compression axial load in the pillar is to be obtained, in kN, from the following formula:

$$F_A = A_D(\gamma_{S2} p_S + \gamma_{W2} p_W) + \sum_i r(\gamma_{S2} Q_{i,S} + \gamma_{W2} Q_{i,W})$$

where:

A_D : Area, in m², of the portion of the deck or the platform supported by the pillar considered

r : Coefficient which depends on the relative position of each pillar above the one considered, to be taken equal to:

- $r = 1{,}0$ for the pillar considered
- $r = 0{,}9$ for the pillar immediately above that considered
- $r = 0{,}9^i$ for the i^{th} pillar of the line above the pillar considered, to be taken not less than 0,478

$Q_{i,S}, Q_{i,W}$: Still water and wave load, respectively, in kN, from the i^{th} pillar of the line above the pillar considered, if any.

6.2.2 Critical column buckling stress of pillars

The critical column buckling stress of pillars is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cB} = \sigma_{E1} \quad \text{for} \quad \sigma_{E1} \leq \frac{R_{eH}}{2}$$

$$\sigma_{cB} = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_{E1}}\right) \quad \text{for} \quad \sigma_{E1} > \frac{R_{eH}}{2}$$

where:

σ_{E1} : Euler column buckling stress, to be obtained, in N/mm², from the following formula:

$$\sigma_{E1} = \pi^2 E \frac{I}{A(f\ell)^2} 10^{-4}$$

I : Minimum net moment of inertia, in cm⁴, of the pillar

A : Net cross-sectional area, in cm², of the pillar

ℓ : Span, in m, of the pillar

f : Coefficient, to be obtained from Tab 12.

6.2.3 Critical torsional buckling stress of built-up pillars

The critical torsional buckling stress of built-up pillars is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cT} = \sigma_{E2} \quad \text{for} \quad \sigma_{E2} \le \frac{R_{eH}}{2}$$

$$\sigma_{cT} = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_{E2}}\right) \quad \text{for} \quad \sigma_{E2} > \frac{R_{eH}}{2}$$

where:

σ_{E2} : Euler torsional buckling stress, to be obtained, in N/mm², from the following formula:

$$\sigma_{E2} = \frac{\pi^2 E I_w}{10^4 I_p \ell^2} + 0{,}41 E \frac{I_t}{I_p}$$

I_w : Net sectorial moment of inertia of the pillar, to be obtained, in cm⁶, from the following formula:

$$I_w = \frac{t_f b_f^3 h_w^2}{24} 10^{-6}$$

h_W : Web height of built-up section, in mm

t_W : Net web thickness of built-up section, in mm

b_F : Face plate width of built-up section, in mm

t_F : Net face plate thickness of built-up section, in mm

I_p : Net polar moment of inertia of the pillar, to be obtained, in cm⁴, from the following formula:

$$I_P = I_{XX} + I_{YY}$$

I_{XX} : Net moment of inertia about the XX axis of the pillar section (see Fig 4)

I_{YY} : Net moment of inertia about the YY axis of the pillar section (see Fig 4)

I_t : St. Venant's net moment of inertia of the pillar, to be obtained, in cm⁴, from the following formula:

$$I_t = \frac{1}{3}[h_w t_w^3 + 2 b_f t_f^3] 10^{-4}$$

Table 12 : Coefficient f

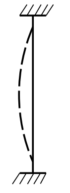
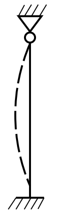
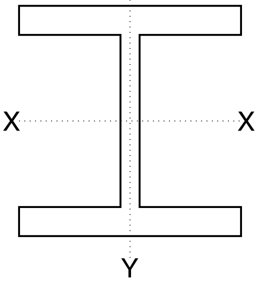
Boundary conditions of the pillar	f
Both ends fixed 	0,5
One end fixed, one end pinned 	$\frac{\sqrt{2}}{2}$
Both ends pinned 	1

Figure 4 : Reference axes for the calculation of the moments of inertia of a built-up section



6.2.4 Critical local buckling stress of built-up pillars

The critical local buckling stress of built-up pillars is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cL} = \sigma_{E3} \quad \text{for} \quad \sigma_{E3} \le \frac{R_{eH}}{2}$$

$$\sigma_{cL} = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_{E3}}\right) \quad \text{for} \quad \sigma_{E3} > \frac{R_{eH}}{2}$$

where:

σ_{E3} : Euler local buckling stress, to be taken equal to the lesser of the values obtained, in N/mm², from the following formulae:

- $\sigma_{E3} = 78\left(\frac{t_W}{h_W}\right)^2 10^4$
- $\sigma_{E3} = 32\left(\frac{t_F}{b_F}\right)^2 10^4$

t_W, h_W, t_F, b_F : Dimensions, in mm, of the built-up section, defined in [6.2.3].

6.2.5 Critical local buckling stress of pillars having hollow rectangular section

The critical local buckling stress of pillars having hollow rectangular section is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cL} = \sigma_{E4} \quad \text{for} \quad \sigma_{E4} \le \frac{R_{eH}}{2}$$

$$\sigma_{cL} = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_{E4}}\right) \quad \text{for} \quad \sigma_{E4} > \frac{R_{eH}}{2}$$

where:

σ_{E4} : Euler local buckling stress, to be taken equal to the lesser of the values obtained, in N/mm², from the following formulae:

- $\sigma_{E4} = 78\left(\frac{t_2}{b}\right)^2 10^4$
- $\sigma_{E4} = 78\left(\frac{t_1}{h}\right)^2 10^4$

b : Length, in mm, of the shorter side of the section

t_2 : Net web thickness, in mm, of the shorter side of the section

h : Length, in mm, of the longer side of the section

t_1 : Net web thickness, in mm, of the longer side of the section.

6.2.6 Checking criteria

The net scantlings of the pillar loaded by the compression axial stress F_A defined in [6.2.1] are to comply with the formulae in Tab 13.

6.3 Buckling of pillars subjected to compression axial load and bending moments

6.3.1 Checking criteria

In addition to the requirements in [6.2], the net scantlings of the pillar loaded by the compression axial load and bending moments are to comply with the following formula:

$$10F\left(\frac{1}{A} + \frac{\Phi e}{w_P}\right) + \left(10^3\frac{M_{max}}{w_P}\right) \le \frac{R_{eH}}{\gamma_R \gamma_m}$$

where:

F : Compression load, in kN, acting on the pillar

A : Net cross-sectional area, in cm², of the pillar

e : Eccentricity, in cm, of the compression load with respect to the centre of gravity of the cross-section

$$\Phi = \frac{1}{1 - \frac{10F}{\sigma_{E1}A}}$$

σ_{E1} : Euler column buckling stress, in N/mm², defined in [6.2.2]

w_P : Minimum net section modulus, in cm³, of the cross-section of the pillar

M_{max} : Max (M_1, M_2, M_0)

M_1 : Bending moment, in kN.m, at the upper end of the pillar

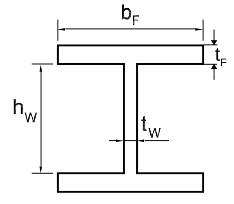
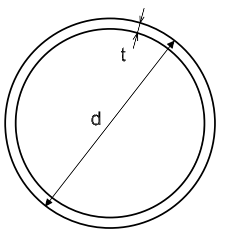
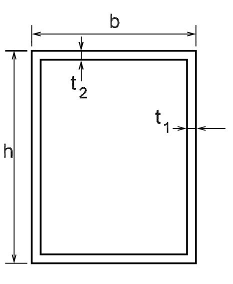
M_2 : Bending moment, in kN.m, at the lower end of the pillar

$$M_0 = \frac{0,5(\sqrt{1 + t^2})(M_1 + M_2)}{\cos(u)}$$

$$u = 0,5\pi\sqrt{\frac{10F}{\sigma_{E1}A}}$$

$$t = \frac{1}{\tan(u)}\left(\frac{M_2 - M_1}{M_2 + M_1}\right)$$

Table 13 : Buckling check of pillars subject to compression axial load *(1/1/2001)*

Pillar cross-section	Column buckling check	Torsional buckling check	Local buckling check	Geometric condition
Built-up 	$\frac{\sigma_{cB}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	$\frac{\sigma_{cT}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	$\frac{\sigma_{cL}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	$\frac{b_F}{t_F} \leq 40$
Hollow tubular 	$\frac{\sigma_{cB}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	Not required	Not required	$\frac{d}{t} \leq 55$ $t \geq 5,5$ mm
Hollow rectangular 	$\frac{\sigma_{cB}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	Not required	$\frac{\sigma_{cL}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	$\frac{b}{t_2} \leq 55$ $\frac{h}{t_1} \leq 55$ $t_1 \geq 5,5$ mm $t_2 \geq 5,5$ mm

Note 1:

- σ_{cB} : Critical column buckling stress, in N/mm², defined in [6.2.2]
- σ_{cT} : Critical torsional buckling stress, in N/mm², defined in [6.2.3]
- σ_{cL} : Critical local buckling stress, in N/mm², defined in [6.2.4] for built-up section or in [6.2.5] for hollow rectangular section
- γ_R : Resistance partial safety factor, to be taken equal to:
  - 1,50 for column buckling
  - 1,05 for torsional and local buckling
- F_A : compression axial load in the pillar, in kN, defined in [6.2.1]
- A : Net sectional area, in cm², of the pillar.

SECTION 4 FATIGUE CHECK OF STRUCTURAL DETAILS

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

p_W : Wave pressure, in kN/m^2, see [2.2]

s : Spacing, in m, of ordinary stiffeners

ℓ : Span, in m, of ordinary stiffeners, measured between the supporting members, see Ch 4, Sec 3, [3.2]

w : Net section modulus, in cm^3, of the stiffener, with an attached plating of width b_p , to be calculated as specified in Ch 4, Sec 3, [3.4]

K_h, K_ℓ : Stress concentration factors, defined in Ch 12, Sec 2 for the special structural details there specified

K_F : Fatigue notch factor, defined in [3.3.1]

K_m : Stress concentration factor, taking account of misalignment, defined in [3.3.1]

$\Delta\sigma_{P0}$: Allowable stress range, defined in [4].

1 General

1.1 Net scantlings

1.1.1 As specified in Ch 4, Sec 2, [1], all scantlings referred to in this Section are net, i.e. they do not include any margin for corrosion.

The gross scantlings are obtained as specified in Ch 4, Sec 2.

1.2 Application

1.2.1 Structural details to be checked

The requirements of this Section apply for the fatigue check of special structural details, according to Ch 12, Sec 2.

The Society may require other details to be checked, when deemed necessary on the basis of the detail geometry and stress level.

1.2.2 Categorisation of details

With respect to the method to be adopted to calculate the stresses acting on structural members, the details for which the fatigue check is to be carried out may be grouped as follows:

- details where the stresses are to be calculated through a three dimensional structural model (e.g. connections between primary supporting members)
- details located at ends of ordinary stiffeners, for which an isolated structural model can be adopted.

1.2.3 Details where the stresses are to be calculated through a three dimensional structural model

The requirements of App 1, [7] apply, in addition of those of [1] to [5] of this Section.

1.2.4 Details located at ends of ordinary stiffeners

The requirements of [1] to [6] of this Section apply.

1.2.5 Other details

In general, for details other than those in [1.2.2], the stresses are to be calculated through a method agreed by the Society on a case by case basis, using the load model defined in [2].

The checking criterion in [5] is generally to be applied.

1.3 Definitions

1.3.1 Hot spots

Hot spots are the locations where fatigue cracking may occur. They are indicated in the relevant figures of special structural details in Ch 12, Sec 2.

1.3.2 Nominal stress

Nominal stress is the stress in a structural component taking into account macro-geometric effects but disregarding the stress concentration due to structural discontinuities and to the presence of welds (see Fig 1).

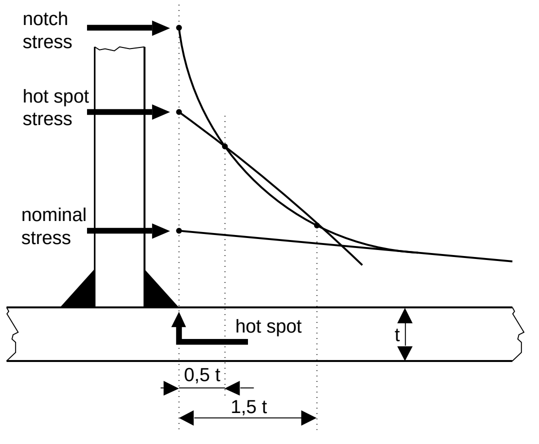
1.3.3 Hot spot stress

Hot spot stress is a local stress at the hot spot taking into account the influence of structural discontinuities due to the geometry of the detail, but excluding the effects of welds (see Fig 1).

1.3.4 Notch stress

Notch stress is a peak stress in a notch such as the root of a weld or the edge of a cut-out. This peak stress takes into account the stress concentrations due to the presence of notches (see Fig 1).

Figure 1 : Nominal, hot spot and notch stresses



1.3.5 Elementary stress range

Elementary stress range is the stress range determined for one of the load cases "a", "b", "c" or "d" (see Ch 5, Sec 4, [2]) and for either of the loading conditions (see Ch 5, Sec 1, [2.4] and Ch 5, Sec 1, [2.5]).

1.3.6 Equivalent stress range

Equivalent stress range is a stress range obtained from a combination of elementary stress ranges, as indicated in [3.3.2] for notch stress and [6.2.1] for hull girder nominal stress.

1.4 Partial safety factors

1.4.1 The partial safety factors to be considered for the fatigue check of structural details are specified in Tab 1.

Table 1 : Fatigue check - Partial safety factors

Partial safety factors covering uncertainties regarding:	Symbol	Value	
		General	Details at ends of ordinary stiffeners
Still water hull girder loads	γ_{S1}	1,00	1,00
Wave hull girder loads	γ_{W1}	1,05	1,15
Still water pressure	γ_{S2}	1,00	1,00
Wave pressure	γ_{W2}	1,10	1,20
Resistance	γ_R	1,02	1,10

2 Load model

2.1 General

2.1.1 Load point

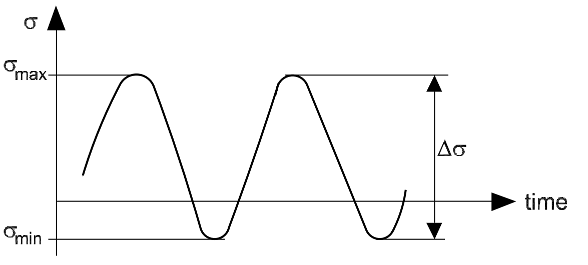
Unless otherwise specified, design loads are to be determined at points defined in:

- Sec 2, [1.3] for ordinary stiffeners
- Sec 3, [1] for primary supporting members.

2.1.2 Local and hull girder loads

The fatigue check is based on the stress range induced at the hot spot by the time variation of local and hull girder loads in each load case "a", "b", "c" and "d" defined in [2.2] for the loading conditions defined in [2.1.4] and [2.1.3] (see Fig 2).

Figure 2 : Stress range



2.1.3 Loading conditions for details where the stresses are to be calculated through a three dimensional structural model

The most severe full load and ballast conditions for the detail concerned are to be considered in accordance with Ch 5, Sec 1, [2.5].

2.1.4 Loading conditions for details located at ends of ordinary stiffeners

The cargo and ballast distribution is to be considered in accordance with Ch 5, Sec 1, [2.4].

2.1.5 Spectral fatigue analysis

For ships with non-conventional shapes or with restricted navigation, the Society may require a spectral fatigue analysis to be carried out.

In this analysis, the loads and stresses are to be evaluated through long-term stochastic analysis taking into account the characteristics of the ship and the navigation notation.

The load calculations and fatigue analysis are to be submitted to the Society for approval.

2.2 Lateral pressure

2.2.1 General

Lateral pressure is constituted by the wave pressure.

2.2.2 Upright ship conditions (Load cases "a" and "b")

Wave pressure (p_W) includes:

- maximum and minimum wave pressures obtained from Tab 2
- inertial pressures:
  - no inertial pressures are considered for load case "a"
  - maximum and minimum inertial pressures for load case "b" are to be obtained from Tab 3 for the various types of cargoes.

Table 2 : Load cases "a" and "b" - Maximum and minimum wave pressures for fatigue check

Case	Wave pressures, in kN/m²	
Load case "a"	p_{Wmax}	p_W defined in Ch 5, Sec 5, [2.1.1] for "load case a, crest"
	p_{Wmin}	p_W defined in Ch 5, Sec 5, [2.1.1] for "load case a, trough"
Load case "b"	p_{Wmax}	p_W defined in Ch 5, Sec 5, [2.1.1] for "load case b, crest"
	p_{Wmin}	p_W defined in Ch 5, Sec 5, [2.1.1] for "load case b, trough"

Table 3 : Load case "b" - Maximum and minimum inertial pressures for fatigue check

Cargo	Inertial pressures, in kN/m²	
	p_{Wmax}	p_{Wmin}
Liquids	p_W defined in Ch 5, Sec 6, Tab 1 for: • load case "b" • $a_{X1} > 0$ and $a_{Z1} > 0$	p_W defined in Ch 5, Sec 6, Tab 1 for: • load case "b" • $a_{X1} < 0$ and $a_{Z1} < 0$
Dry bulk cargoes	p_W defined in Ch 5, Sec 6, Tab 5 for: • load case "b" • $a_{Z1} > 0$	p_W defined in Ch 5, Sec 6, Tab 5 for: • load case "b" • $a_{Z1} < 0$
Dry uniform cargoes	p_W defined in Ch 5, Sec 6, Tab 6 for: • load case "b" • $a_{Z1} > 0$	p_W defined in Ch 5, Sec 6, Tab 6 for: • load case "b" • $a_{Z1} < 0$

2.2.3 Inclined ship conditions (Load cases "c" and "d")

Wave pressure (p_W) includes:

- maximum and minimum wave pressures obtained from Tab 4
- maximum and minimum inertial pressures obtained from Tab 5 for liquid cargoes.

  For dry bulk cargoes and dry uniform cargoes, no inertial pressures are to be considered.

2.3 Hull girder normal stresses

2.3.1 The hull girder normal stresses to be considered for the fatigue check are the following, multiplied by γ_{W1}:

$\sigma_{WV,H}$, $\sigma_{WV,S}$, σ_{WH}: Hull girder normal stresses, in N/mm², defined in Tab 6

$_{\Omega}\sigma$: Warping stresses, in N/mm², induced by the torque $0,625M_{WT}$ and obtained through direct calculation analyses based on a structural model in accordance with Ch 6, Sec 1, [2.6].

Table 4 : Load cases "c" and "d" - Maximum and minimum wave pressures for fatigue check

Case	Wave pressures, in kN/m²	
Load case "c"	p_{Wmax}	p_W defined in Ch 5, Sec 5, [2.2.1] for: • load case "c" • negative roll angle
	p_{Wmin}	p_W defined in Ch 5, Sec 5, [2.2.1] for: • load case "c" • positive roll angle
Load case "d"	p_{Wmax}	p_W defined in Ch 5, Sec 5, [2.2.1] for: • load case "d" • negative roll angle
	p_{Wmin}	p_W defined in Ch 5, Sec 5, [2.2.1] for: • load case "d" • positive roll angle

Table 5 : Load cases "c" and "d" - Maximum and minimum inertial pressures (liquid cargoes) for fatigue check

Load case	Inertial pressures, in kN/m²	
Load case "c"	p_{Wmax}	p_W defined in Ch 5, Sec 6, Tab 1 for: • load case "c" • negative roll angle
	p_{Wmin}	p_W defined in Ch 5, Sec 6, Tab 1 for: • load case "c" • positive roll angle
Load case "d"	p_{Wmax}	p_W defined in Ch 5, Sec 6, Tab 1 for: • load case "d" • negative roll angle
	p_{Wmin}	p_W defined in Ch 5, Sec 6, Tab 1 for: • load case "d" • positive roll angle

Table 6 : Hull girder normal stresses for fatigue check

Load condition	Symbol	Normal stress, in N/mm²
Vertical wave bending moment in hogging	$\sigma_{WV,H}$	$\left\lvert \frac{0,625 M_{WV,H}}{I_Y}(z-N) \right\rvert 10^{-3}$
Vertical wave bending moment in sagging	$\sigma_{WV,S}$	$\left\lvert \frac{0,625 M_{WV,S}}{I_Y}(z-N) \right\rvert 10^{-3}$
Horizontal wave bending moment	σ_{WH}	$\left\lvert \frac{0,625 M_{WH}}{I_Z} y \right\rvert 10^{-3}$

3 Stress range

3.1 General

3.1.1 Calculation point

Unless otherwise specified, stresses are to be determined at the hot spots indicated, for each detail, in the relevant figures in Ch 12, Sec 2.

3.1.2 Stress components

For the details in [1.2.2], the stresses to be used in the fatigue check are the normal stresses in the directions indicated, for each detail, in the relevant figures in Ch 12, Sec 2.

Where the fatigue check is required for details other than those in [1.2.2], the stresses to be used are the principal stresses at the hot spots which form the smallest angle with the crack rising surface.

3.2 Hot spot stress range

3.2.1 Elementary hot spot stress range

The elementary hot spot stress range $\Delta\sigma_{S,ij}$ is to be obtained, in N/mm², in accordance with:

- App 1, [7] for details where the stresses are to be calculated through a three dimensional structural models
- [6.2] for details located at ends of ordinary stiffeners.

3.3 Notch stress range

3.3.1 Elementary notch stress range

The elementary notch stress range is to be obtained, in N/mm², from the following formula:

$$\Delta\sigma_{N,ij} = 0{,}7 K_F K_m K_{C,ij} \Delta\sigma_{S,ij}$$

where:

i : Denotes the load case “a”; “b”, “c” or “d”

j : Denotes the loading condition “Full load” or “Ballast”

K_F : Fatigue notch factor, equal to:

$$K_F = \lambda\sqrt{\frac{\theta}{30}}$$

for flame-cut edges, K_F may be taken equal to 1,4

λ : Coefficient depending on the weld configuration, and given in Tab 7

θ : Mean weld toe angle, in degrees, without being taken less than 30°. Unless otherwise specified, θ may be taken equal to:

- 30° for butt joints
- 45° for T joints or cruciform joints

K_m : Additional stress concentration factor, taking account of misalignment, defined in Tab 9, and to be taken not less than 1

$\Delta\sigma_{S,ij}$: Elementary hot spot stress range, defined in [3.2.1]

$$K_{C,ij} = \frac{0{,}4R_y}{\Delta\sigma_{S,ij}} + 0{,}6 \quad \text{with} \quad 0{,}8 \le K_{C,ij} \le 1$$

Table 7 : Weld coefficient λ

Weld configuration	Coefficient λ	
	Grind welds	Other cases
Butt joints:		
• Stresses parallel to weld axis		
- full penetration	1,85	2,10
- partial penetration	1,85	2,10
• Stresses perpendicular to weld axis		
- full penetration	2,10	2,40
- partial penetration	3,95	4,50
T joints:		
• Stresses parallel to weld axis; fillet weld and partial penetration	1,60	1,80
• Stresses perpendicular to weld axis and in plane of continuous element **(1)**; fillet weld and partial penetration	1,90	2,15
• Stresses perpendicular to weld axis and in plane of welded element; fillet weld and partial penetration	3,95	4,50
Cruciform joints:		
• Full penetration	1,85	2.10
• Partial penetration	2,05	2,35

(1) This case includes the hot spots indicated in the sheets of special structural details in Ch 12, Sec 2 , relevant to the connections of longitudinal ordinary stiffeners with transverse primary supporting members.

3.3.2 Equivalent notch stress range

The equivalent notch stress range is to be obtained, in N/mm², from the following formula:

$$\Delta\sigma_{N,eq} = \left(\frac{\alpha}{2}\Sigma_{3N,F} + \frac{1-\alpha}{2}\Sigma_{3N,B}\right)^{1/3}$$

where:

α : Part of the ship’s life in full load condition, given in Tab 8 for various ship types.

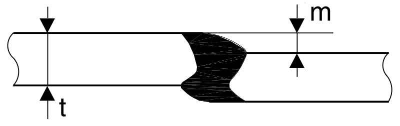
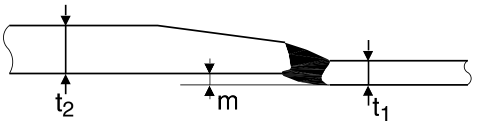
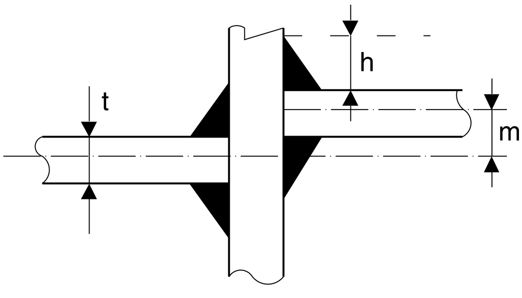
Table 8 : Part of the ship’s life in full load condition

Service notation	Coefficient α
oil tanker ESP **chemical tanker ESP** **liquefied gas carrier** **tanker**	0,5
bulk carrier ESP **ore carrier ESP** **combination carrier ESP**	0,6
Others	0,75

$$\Sigma_{3N,F} = \max(\mu_{aF}\Delta\sigma^3_{N,aF};\mu_{bF}\Delta\sigma^3_{N,bF}) + \max(\mu_{cF}\Delta\sigma^3_{N,cF};\mu_{dF}\Delta\sigma^3_{N,dF})$$

$$\Sigma_{3N,B} = \max(\mu_{aB}\Delta\sigma^3_{N,aB};\mu_{bB}\Delta\sigma^3_{N,bB}) + \max(\mu_{cB}\Delta\sigma^3_{N,cB};\mu_{dB}\Delta\sigma^3_{N,dB})$$

Table 9 : Stress concentration factor K_m for misalignment

Geometry	K_m
Axial misalignment between flat plates 	$1 + \frac{3(m - m_0)}{t}$
Axial misalignment between flat plates of different thicknesses 	$1 + \frac{6(m - m_0)}{t_1} \frac{t_1^{3/2}}{t_1^{3/2} + t_2^{3/2}}$
Axial misalignment in fillet welded cruciform joints 	$1 + \frac{m - m_0}{t + h}$
Note 1: m : Actual misalignment between two abutting members m_0 : Permissible misalignment for the detail considered, given in Ch 12, Sec 2.	

$\Delta\sigma_{N,aF}$, $\Delta\sigma_{N,bF}$, $\Delta\sigma_{N,cF}$, $\Delta\sigma_{N,dF}$: Elementary notch stress ranges for load cases "a", "b", "c" and "d", respectively, in "Full load" condition, defined in [3.3.1]

$\Delta\sigma_{N,aB}$, $\Delta\sigma_{N,bB}$, $\Delta\sigma_{N,cB}$, $\Delta\sigma_{N,dB}$: Elementary notch stress ranges for load cases "a", "b", "c" and "d", respectively, in "Ballast" condition, defined in [3.3.1]

$$\mu_{ij} = 1 - \frac{\Gamma_N\left[\frac{3}{\xi} + 1, \nu_{ij}\right] - \Gamma_N\left[\frac{5}{\xi} + 1, \nu_{ij}\right]\nu_{ij}^{-2/\xi}}{\Gamma_C\left[\frac{3}{\xi} + 1\right]}$$

$$\xi = \frac{73 - 0{,}07L}{60}$$ without being less than 0,85

$$\nu_{ij} = \left(\frac{S_q}{\Delta\sigma_{N,ij}}\right)^{\xi} \ln N_R$$

$$S_q = (K_p 10^{-7})^{1/3}$$

$$K_p = 5{,}802\left(\frac{16}{t}\right)^{0,9} 10^{12}$$

$$N_R = 10^5$$

t : Net thickness, in mm, of the element under consideration not being taken less than 16 mm

$\Gamma_N[X+1, \nu_{ij}]$: Incomplete Gamma function, calculated for X= 3/ξ or X= 5/ξ and equal to:

$$\Gamma_N[X + 1, \nu_{ij}] = \int_0^{\nu_{ij}} t^X e^{-t} dt$$

Values of $\Gamma_N[X+1,\nu_{ij}]$ are also indicated in Tab 10. For intermediate values of X and ν_{ij}, Γ_N may be obtained by linear interpolation

$\Gamma_C[X+1]$: Complete Gamma function, calculated for X=3/ξ, equal to:

$$\Gamma_C[X + 1] = \int_0^{\infty} t^X e^{-t} dt$$

Values of $\Gamma_C[X+1]$ are also indicated in Tab 11. For intermediate values of X, Γ_C may be obtained by linear interpolation.

Table 10 : Function Γ_N [X+1, ν_{ij}]

X	ν_{ij} = 1,5	ν_{ij} = 2	ν_{ij} = 2,5	ν_{ij} = 3	ν_{ij} = 3,5	ν_{ij} = 4	ν_{ij} = 4,5
2,6	0,38	0,75	1,19	1,63	2,04	2,41	2,71
2,7	0,39	0,78	1,25	1,73	2,20	2,62	2,97
2,8	0,39	0,80	1,31	1,85	2,38	2,85	3,26
2,9	0,39	0,83	1,38	1,98	2,57	3,11	3,58
3,0	0,39	0,86	1,45	2,12	2,78	3,40	3,95
3,1	0,40	0,89	1,54	2,27	3,01	3,72	4,35
3,2	0,40	0,92	1,62	2,43	3,27	4,08	4,81
3,3	0,41	0,95	1,72	2,61	3,56	4,48	5,32
3,4	0,41	0,99	1,82	2,81	3,87	4,92	5,90
3,5	0,42	1,03	1,93	3,03	4,22	5,42	6,55
3,6	0,42	1,07	2,04	3,26	4,60	5,97	7,27
3,7	0,43	1,12	2,17	3,52	5,03	6,59	8,09
3,8	0,43	1,16	2,31	3,80	5,50	7,28	9,02
3,9	0,44	1,21	2,45	4,10	6,02	8,05	10,06
4,0	0,45	1,26	2,61	4,43	6,59	8,91	11,23
4,1	0,45	1,32	2,78	4,80	7,22	9,87	12,55
4,2	0,46	1,38	2,96	5,20	7,93	10,95	14,05
4,3	0,47	1,44	3,16	5,63	8,70	12,15	15,73
4,4	0,48	1,51	3,37	6,11	9,56	13,50	17,64
4,5	0,49	1,57	3,60	6,63	10,52	15,01	19,79
4,6	0,49	1,65	3,85	7,20	11,57	16,70	22,23
4,7	0,50	1,73	4,12	7,82	12,75	18,59	24,98
4,8	0,52	1,81	4,40	8,50	14,04	20,72	28,11
4,9	0,52	1,90	4,71	9,25	15,49	23,11	31,64
5,0	0,53	1,99	5,04	10,07	17,09	25,78	35,65
5,1	0,55	2,09	5,40	10,97	18,86	28,79	40,19
5,2	0,56	2,19	5,79	11,95	20,84	32,17	45,34
5,3	0,57	2,30	6,21	13,03	23,03	35,96	51,19
5,4	0,58	2,41	6,66	14,21	25,46	40,23	57,83
5,5	0,59	2,54	7,14	15,50	28,17	45,03	65,37
5,6	0,61	2,67	7,67	16,92	31,18	50,42	73,93
5,7	0,62	2,80	8,23	18,48	34,53	56,49	83,66
5,8	0,64	2,95	8,84	20,19	38,25	63,33	94,73
5,9	0,65	3,10	9,50	22,07	42,39	71,02	107,32

4 Allowable stress range

4.1 General

4.1.1 The allowable notch stress range $\Delta\sigma_{p0}$ is to be obtained, in N/mm², from the following formula:

$$\Delta\sigma_{p0} = (\ln N_R)^{1/\xi}\left(\frac{K_p}{N_t\Gamma_C\left[\frac{3}{\xi}+1\right]}\right)^{1/3}$$

where:

N_R, K_p : Coefficients defined in [3.3.2]

N_t : Number of cycles, to be taken equal to:

$$N_t = \frac{536}{T_A}10^6$$

T_A : Average period, in seconds, to be taken equal to:

$$T_A = 4\log L$$

Γ_C[X+1] : Complete Gamma function, defined in [3.3.2] and calculated for X = 3/ξ .

Table 11 : Function Γ_C [X+1]

X	Γ_C [X+1]
2,6	3,717
2,7	4,171
2,8	4,694
2,9	5,299
3,0	6,000
3,1	6,813
3,2	7,757
3,3	8,855
3,4	10,136
3,5	11,632
3,6	13,381

5 Checking criteria

5.1 General

5.1.1 The equivalent notch stress range $\Delta\sigma_{N,eq}$, calculated according to [3.3.2], is to comply with the following formula:

$$\Delta\sigma_{N,eq} \le \frac{\Delta\sigma_{p0}}{\gamma_R^{1/3}}$$

6 Structural details located at ends of ordinary stiffeners

6.1 General

6.1.1 For the fatigue check of connections located at ends of ordinary stiffeners, an approach equivalent to the checking criteria indicated in [5] is given in [6.3] in terms of the net section modulus of the stiffener.

6.2 Determination of equivalent stress and pressure ranges

6.2.1 Hull girder equivalent stress range

The hull girder equivalent stress range is to be obtained, in N/mm², from the following formula:

$$\Delta\sigma_{h,eq} = \left(\frac{\max(\Delta\sigma_{h,a};\Delta\sigma_{h,b})^3}{2} + \frac{\max(\Delta\sigma_{h,c};\Delta\sigma_{h,d})^3}{2}\right)^{1/3}$$

where $\Delta\sigma_{h,a}$, $\Delta\sigma_{h,b}$, $\Delta\sigma_{h,c}$, $\Delta\sigma_{h,d}$ are the hull girder elementary stress ranges for load cases "a", "b", "c" and "d", respectively, obtained, in N/mm², from the following formulae:

- for members contributing to the hull girder longitudinal strength:

  $$\Delta\sigma_{h,i} = \{C_{FV}|\sigma_{WV,H}| + C_{FV}|\sigma_{WV,S}| + 2C_{FH}|\sigma_{WH}| + 2C_{F\Omega}|\sigma_\Omega|\}_i$$

- for members not contributing to the hull girder longitudinal strength:

  $$\Delta\sigma_{h,i} = 0$$

where:

$\sigma_{WV,H}$, $\sigma_{WV,S}$, σ_{WH}, σ_Ω:H
ull girder normal stresses defined in [2.3]

C_{FV}, C_{FH}, $C_{F\Omega}$: Combination factors defined in Tab 12.

Table 12 : Combination factors C_{FV}, C_{FH} and $C_{F\Omega}$

Load case	C_{FV}	C_{FH}	$C_{F\Omega}$
"a"	1,0	0	0
"b"	1,0	0	0
"c"	0,4	1,0	1,0
"d"	0,4	1,0	0

6.2.2 Equivalent pressure range

The equivalent pressure range is to be obtained, in kN/m², from the following formula:

$$\Delta P_{W,eq} = \left(\frac{\alpha}{2}\Sigma_{3P,F} + \frac{1-\alpha}{2}\Sigma_{3P,B}\right)^{1/3}$$

where:

α : Part of the ship's life in full load condition, given in Tab 8

$$\Sigma_{3P,F} = \max(\Delta P_{W,aF};\Delta P_{W,bF})^3 + \max(\Delta P_{W,cF};\Delta P_{W,dF})^3$$

$$\Sigma_{3P,B} = \max(\Delta P_{W,aB};\Delta P_{W,bB})^3 + \max(\Delta P_{W,cB};\Delta P_{W,dB})^3$$

$\Delta P_{W,ij}$: Elementary pressure range for load case "i" (i.e. "a" , "b", "c" or "d"), in "j" load condition (i.e. "Full load" condition or "Ballast" condition), obtained, in kN/m², from the following formula:

$$\Delta P_{W,ij} = \{|P_{Wmax} - P_{Wmin}|\}_{ij}$$

P_{Wmax}, P_{Wmin}:Maximum and minimum resultant wave or inertial pressures, in kN/m², defined in [2.2].

6.3 Net section modulus of ordinary stiffeners

6.3.1 Longitudinal ordinary stiffeners contributing to the hull girder longitudinal strength

It is to be checked that the equivalent range of hull girder equivalent stress $\Delta\sigma_{h,eq}$, calculated according to [6.2.1] complies with the following formula:

$$\Delta\sigma_{h,eq} < \frac{\Delta\sigma_{p0}}{0,287K_FK_mK_h\gamma_R^{1/3}}$$

Moreover, the stiffener net section modulus is to be not less than the value obtained, in cm³, from the following formula:

$$w = 0,7K_FK_mK_GK_\ell\frac{\beta_b\gamma_{W2}\Delta P_{W,eq}}{12\left(\frac{\Delta\sigma_{p0}}{0,41\gamma_R^{1/3}} - 0,7K_FK_mK_h\Delta\sigma_{h,eq}\right)}\left(1-\frac{s}{2\ell}\right)s\ell^2 10^3$$

where:

K_G : Coefficient taking account of the stiffener section geometry, equal to:

$$K_G = 1 + \left[\frac{t_f(a^2-b^2)}{2w_B}\right]\left[1-\frac{b}{a+b}\left(1+\frac{w_B}{w_A}\right)\right]10^{-3}$$

t_f : Face plate net thickness, in mm

a, b : Eccentricities of the stiffener, in mm, defined in Fig 3

w_A, w_B : Net section moduli of the stiffener, in cm^3, in A and B, respectively, about its vertical axis and without attached plating

β_b : Coefficient to be taken equal to:

$\beta_b = 1$ in the case of an ordinary stiffener without brackets at ends

$\beta_b = \beta_{b1}$ defined in Sec 2, [3.4.3], in the case of an ordinary stiffener with a bracket of length not greater than $0,2\ell$ at one end

$\beta_b = \beta_{b2}$ defined in Sec 2, [3.4.4], in the case of an ordinary stiffener with symmetrical brackets of length not greater than $0,2\ell$ at both ends.

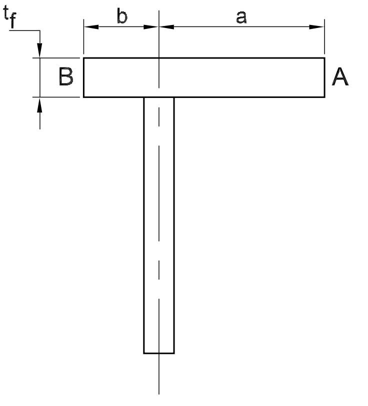
6.3.2 Longitudinal ordinary stiffeners not contributing to the hull girder longitudinal strength and transverse stiffeners

The stiffener net section modulus is to be not less than the value obtained, in cm^3, from the following formula:

$$w = 0,287 K_F K_m K_G K_\ell \frac{\beta_b \gamma_{W2} \gamma_R^{1/3} \Delta P_{W,eq}}{12 \Delta\sigma_{p0}} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

where K_G and β_b are the coefficients defined in [6.3.1].

Figure 3 : Geometry of a stiffener section



6.3.3 Vertical ordinary stiffeners

The stiffener net section modulus is to be not less than the value obtained, in cm^3, from the following formula:

$$w = 0,287 K_F K_m K_G K_\ell \frac{\beta_b \lambda_{bW} \gamma_{W2} \gamma_R^{1/3} \Delta P_{W,eq}}{12 \Delta\sigma_{p0}} \left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

where:

K_G, β_b : Coefficients defined in [6.3.1]

λ_{bW} : Coefficient defined in Sec 2, [3.4.5].

SECTION 5 BUCKLING STRENGTH ASSESSMENT OF SHIP STRUCTURAL ELEMENTS

1 Application And Definitions

1.1 Abbreviations

1.1.1 *(1/7/2024)*

EPP : Elementary Plate Panel, as defined in [1.3.3] a)

PSM : Primary Supporting Member

SP : Stiffened Panel, as defined in [1.3.3] c)

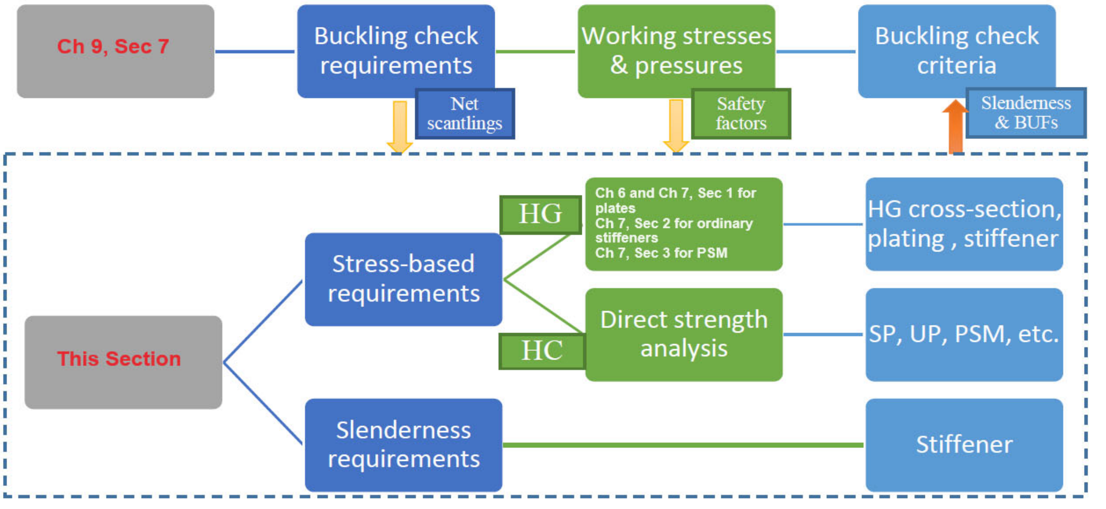
UP : Unstiffened Panel, as defined in [1.3.3] c)

1.2 Application

1.2.1 Relevant requirements concerning Strength of Ships *(1/7/2024)*

This Section establishes a general buckling assessment procedure as illustrated in Fig 1 and is to be applied in conjunction with Ch 9, Sec 7 for hatch cover structures.

Figure 1 : Overview of applying this Section in conjunction with Ch 9, Sec 7 *(1/7/2024)*



Note: BUF stands for Buckling Utilisation Factor, HC stands for Hatch Cover, and HG stands for Hull Girder.

1.2.2 Application of this Section *(1/7/2024)*

a) **Articles of this Section**

The buckling checks are to be performed according to:

- [1] for general definitions regarding buckling capacity, allowable buckling utilisation factors and buckling check criteria.
- [2] for the slenderness requirements of longitudinal and transverse stiffeners.
- [3] for the prescriptive buckling requirements of plates, longitudinal and transverse stiffeners, primary supporting members and other structures subject to hull girder stresses.
- [4] for direct strength analysis (usually by finite element method) buckling requirements of hatch cover structural members including plates, stiffeners and primary supporting members.
- [5] for the determination of buckling capacities of plate panels, stiffeners, primary supporting members and column structures.

b) **Buckling assessment with this Section**

For the buckling assessment of a ship hull girder, a hatch cover or some structural component, the slenderness requirements as defined in [2] and the buckling requirements as defined in [3] or [4] are to be checked as per the requirements of Ch 9, Sec 7.

c) **Alternative methods**

This Section contains the general methods for the determination of buckling capacities of plate panels, stiffeners, primary supporting members, and columns. For special cases not covered in this Section, such as a whole plate structure with stiffeners in two directions (i.e., a stiffened panel with both primary and secondary stiffeners), other more advanced methods, such as finite element analysis methods, can be used when found in compliance with the calculation methods used to develop the formulations in this Section. Acceptability of such methods is subject to a dedicated assessment of the Society.

1.3 Terminology and Assumptions

1.3.1 Buckling *(1/7/2024)*

a) **Buckling strength**

Buckling strength or capacity refers to the strength of a structure under in-plane compressions and/or shear and lateral load. Buckling strength with consideration of the buckling behaviour in [1.3.1] b) gives a lower bound estimate of ultimate capacity, or the maximum load a structural member can carry without suffering major permanent set.

For each structural member, its buckling strength is to be taken as corresponding to the most unfavourable or critical buckling mode.

b) **Buckling behaviour**

Buckling strength assessment takes into account both elastic buckling and post-buckling behaviours. Post-buckling can consider the internal redistribution of loads depending on the load situation, slenderness and type of structure. Such as for the buckling assessment of plates, generally its positive elastic post-buckling effect can be utilized.

As such, for slender structures, the calculated buckling strength is typically higher than the ideal elastic buckling stress (minimum eigenvalue). Accepting elastic buckling of slender plate panels implies that large elastic deflections and reduced in-plane stiffness may occur at higher buckling utilisation levels.

1.3.2 Net Scantling Approach *(1/7/2024)*

a) **General**

Unless otherwise specified, all the scantling requirements, including slenderness requirements, in this Section are based on net scantlings obtained by removing full corrosion addition t_c from the gross offered thicknesses.

b) **Corrosion addition**

Corrosion addition t_c referred to in this Section is defined in Ch 9, Sec 7.

c) **Stress calculation models**

The structural models used for the calculation of stresses to be applied for buckling assessment, which are usually based on net scantlings, are defined in Ch 9, Sec 7.

1.3.3 Structural Idealisation *(1/7/2024)*

a) **Elementary plate panel**

An elementary plate panel (EPP) is the unstiffened part of the plating between stiffeners and/or primary supporting members. The plate panel length, a, and breadth, b, of the EPP are defined respectively as the longest and shortest plate edges, as shown in Fig 2.

b) **Standard types of stiffeners**

Definitions of the cross-sectional dimensions of typical stiffener types are shown in Fig 3, which are flat bars, bulb flats, angles, L2 and T bars. If applicable, other types of stiffeners can be idealized to one of the typical types in Fig 3 for buckling check. For the U-type stiffener which is usually fitted in some hatch covers, the definition of its cross-sectional dimensions is shown in Fig 4.

Unless otherwise specified, the full span or full length *l*, in mm, of a stiffener is to be used for buckling check, which equals to the spacing between primary supporting members.

Symbolic dimensions of the cross-sections are as below:

b_1 : Width of the attached plate enclosed by the U-type stiffener, in mm, as shown in Fig 4.

b_2 : Width of the attached plate between adjacent U-type stiffeners, in mm, as shown in Fig 4.

b_f : Width of the flange or face plate of the stiffener, in mm, as shown in Fig 3 and Fig 4.

$b_{f\text{-}out}$: Maximum distance, in mm, from mid thickness of the web to the flange edge, in mm, as shown in Fig 3.

d_f : Breadth of the extended part of the flange for L2 profiles, in mm, as shown in Fig 3.

e_f : Distance from attached plating to centre of flange, in mm, as shown in Fig 3. For its detailed definition, refer to [5.1].

h_w : Depth of stiffener web, in mm, as shown in Fig 3 and Fig 4.

t_f : Net flange thickness, in mm.

t_p : Net thickness of plate, in mm.

t_w : Net web thickness, in mm.

c) **Stiffened panel (SP) and Unstiffened panel (UP)**

For a panel with relatively strong interactive effect between the stiffener and its attached plate, each stiffener with its attached plate as a whole is to be modelled as a stiffened panel (SP), so as to be able to consider both of its local and global buckling modes.

However, for an EPP, if its buckling strength can be checked without considering its interactive effect with stiffeners fitted along its edges, it's to be modelled as an unstiffened panel (UP).

1.3.4 Sign Convention *(1/7/2024)*

a) **Stresses**

In this Section, compressive and shear stresses are to be taken as positive, tension stresses are to be taken as negative.

Figure 2 : Elementary plate panel (EPP) definition *(1/7/2024)*

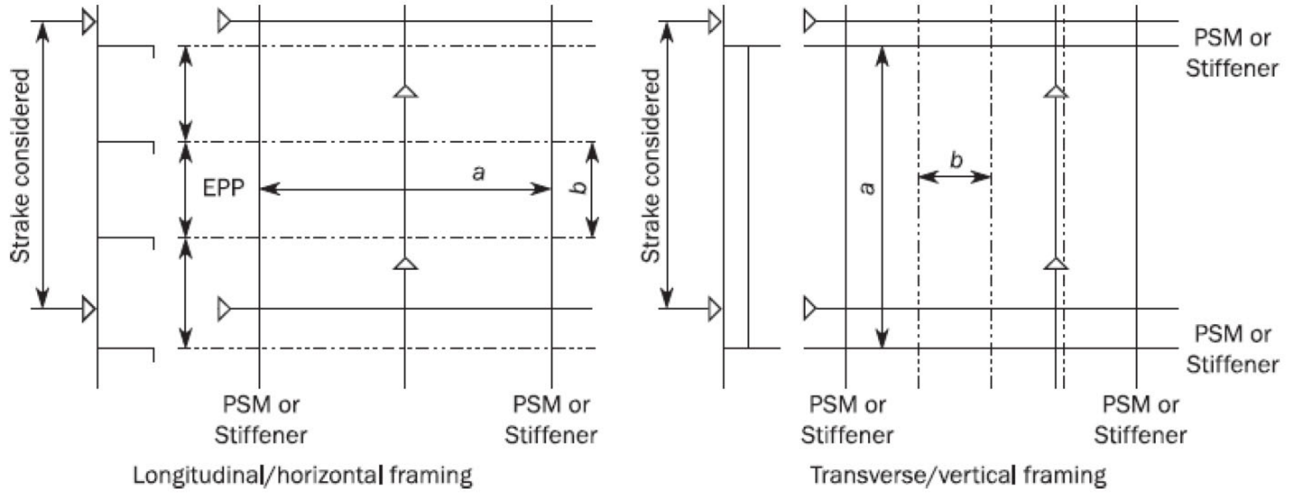


Figure 3 : Dimensions of typical stiffener cross sections *(1/7/2024)*

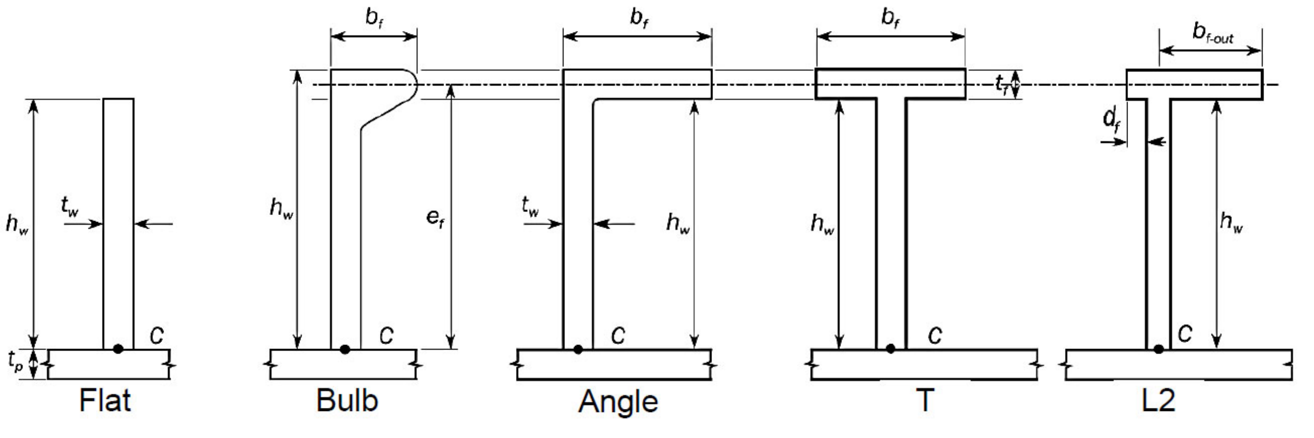
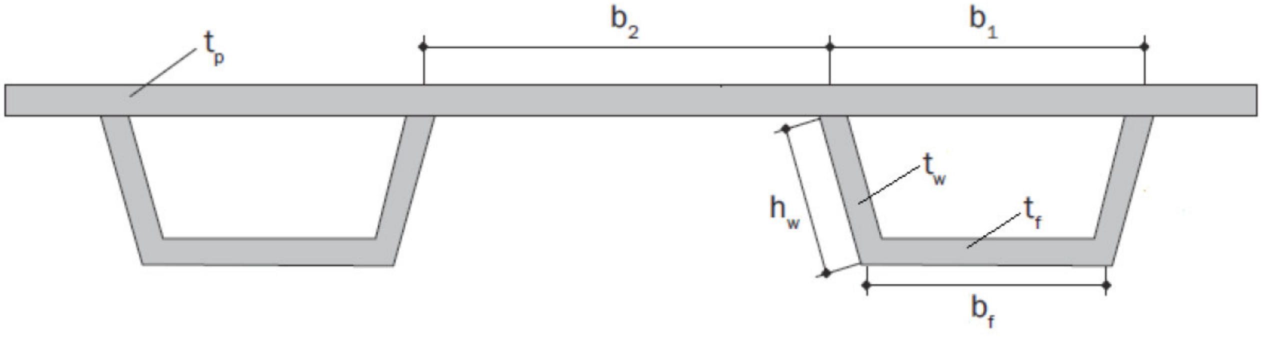


Figure 4 : Dimensions of a U-type stiffener cross section *(1/7/2024)*



1.4 Assessment Methods and Acceptance Criteria

1.4.1 Assessment Methods *(1/7/2024)*

a) **Method A and Method B**

The buckling assessment is to be carried out according to one of the following two methods taking into account different boundary condition types:

- Method A: All the edges of the EPP are forced to remain straight (but free to move in the in-plane directions) due to the surrounding structure/neighbouring plates.
- Method B: The edges of the EPP are not forced to remain straight due to low in-plane stiffness at the edges and/or no surrounding structure/neighbouring plates.

b) **SP-A, SP-B, UP-A and UP-B models**

For the buckling assessment of the stiffened panel (SP) and unstiffened panel (UP) structural models defined in [1.3.3] c), with application of either Method A or

Method B for the plate buckling assessment, the following four buckling assessment models are established:

- SP-A: a stiffened panel with application of Method A.
- SP-B: a stiffened panel with application of Method B.
- UP-A: an unstiffened panel with application of Method A.
- UP-B: an unstiffened panel with application of Method B.

1.4.2 Buckling Utilisation Factor *(1/7/2024)*

a) The utilisation factor, η , is defined as the ratio between the applied loads and the corresponding buckling capacity.

b) For combined loads, the utilisation factor, η_{act} , is to be defined as the ratio of the applied equivalent stress and the corresponding buckling capacity, as shown in Fig 5, and is to be taken as:

$$\eta_{act} = \frac{W_{act}}{W_u} = \frac{1}{\gamma_c}$$

where:

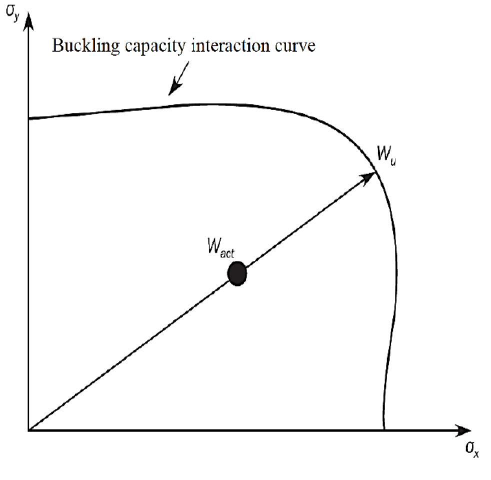
W_{act} : Equivalent applied stress. The actual applied stresses are given in [3] and [4] respectively for buckling assessment by prescriptive and direct strength analysis.

W_u : Equivalent buckling capacity. For plates and stiffeners, their respective buckling or ultimate capacities are given in [5].

γ_c : Stress multiplier factor at failure.

For each typical failure mode, the corresponding buckling capacity of the panel is calculated by applying the actual stress combination and then increasing or decreasing the stresses proportionally until collapse occurs, i.e., when the increased or decreased stresses are on a buckling strength interaction curve or surface. Fig 5 illustrates the buckling capacity and the buckling utilisation factor of a structural member subject to σ_x and σ_y stresses.

Figure 5 : Illustration of buckling capacity and buckling utilisation factor *(1/7/2024)*



1.4.3 Allowable Buckling Utilisation Factor *(1/7/2024)*

a) The allowable buckling utilisation factor η_{all} is to be taken according to Ch 9, Sec 7.

1.4.4 Buckling Acceptance Criteria *(1/7/2024)*

a) A structural member is considered to have an acceptable buckling strength if it satisfies the following criterion:

$$\eta_{act} \leq \eta_{all}$$

where:

η_{act} : Buckling utilisation factor based on the applied stress, defined in [1.4.2] b)

η_{all} : Allowable buckling utilisation factor as defined in [1.4.3] a).

2 Slenderness Requirements

2.1 Symbols

2.1.1 *(1/7/2024)*

For symbols not defined in this Article, refer to [1.3.3] b).

R_{eH} : Specified minimum yield stress of the structural member being considered, in N/mm^2.

2.2 General

2.2.1 *(1/7/2024)*

The stiffener elements except for U-type stiffeners are to comply with the applicable slenderness and proportion requirements given in [2.3].

2.3 Stiffeners

2.3.1 Proportions of Stiffeners *(1/7/2024)*

a) **Net thickness of all stiffener types**

The net thickness of stiffeners is to satisfy the following criteria:

1) Stiffener web plate:

$$t_w \geq \frac{h_w}{C_w} \cdot \sqrt{\frac{R_{eH}}{235}}$$

2) Flange:

$$t_f \geq \frac{b_{f-out}}{C_f} \cdot \sqrt{\frac{R_{eH}}{235}}$$

where:

C_w, C_f : Slenderness coefficients given in Tab 1.

If requirement 2) is not fulfilled, the effective free flange outstand, in mm, used in strength assessment including the calculation of actual net section modulus, is to be taken as:

$$b_{f-out-max} = C_f \cdot t_f \cdot \sqrt{\frac{235}{R_{eH}}}$$

For built-up profile where the relevant yielding strength for the web of built-up profile without the edge stiffener is acceptable, as an alternative the web can be assessed according to the web requirements of Angle and L2 bars in Tab 1, and the edge stiffener can be assessed as a flat bar stiffener according to [2.3.1] a). The requirement to flange in [2.3.1] b) is still to apply.

b) **Net dimensions of angle and T-bars**

The total flange breadth b_f, in mm, for angle and T-bars is to satisfy the following criterion:

$b_f \geq 0{,}2h_w$

Table 1 : Slenderness coefficients *(1/7/2024)*

Type of Stiffener	C_w	C_f
Angle and L2 bars	75	12
T-bars	75	12
Bulb flats	45	-
Flat bars	22	-

2.4 Primary Supporting Members

2.4.1 Proportions and Stiffness *(1/7/2024)*

a) **Proportions of web plate and flange**

The scantlings of webs and flanges of primary supporting members are to comply with Sec 3.

2.4.2 *(1/7/2024)*

The flange outstand of the primary supporting members is to be not greater than 15 times the flange thickness.

3 Buckling requirements for hull girder prescriptive analysis

3.1 Application

3.1.1 *(1/7/2024)*

The buckling requirements for hull girder strength prescriptive analysis to be complied with are:

- those in Chapter 6 and Sec 1 for plates;
- those in Sec 2 for ordinary stiffeners; and
- those in Sec 3 for primary supporting members.

The requirements of this Article, reflecting section 3 of new IACS UR S35 "Buckling Strength Assessment of Ship Structural Elements", are to be considered for information purposes only.

3.2 Symbols

3.2.1 *(1/7/2024)*

η_{all} : Allowable buckling utilisation factor, as defined in [1.4.3] a).

LCP : Load Calculation Point, as defined in [3.3.2] a).

3.3 General

3.3.1 Introduction *(1/7/2024)*

a) This Article applies to plate panels including plane and curved plate panels, stiffeners and corrugation of longitudinal corrugated bulkheads subject to hull girder compression and shear stresses.

b) The ship longitudinal extent where the buckling check is performed for structural elements subject to hull girder stresses is to be in accordance with IACS Unified Requirements concerning global strength of ships.

c) Design load sets: The buckling check is to be performed for all design load sets corresponding to the design loading conditions defined in IACS Unified Requirements concerning global strength of ships with the most unfavourable pressure combinations.

For each design load set, for all static and dynamic load cases, the lateral pressure is to be determined at the load calculation point defined in [3.3.2] a), and is to be applied together with the hull girder stress combinations defined in IACS Unified Requirements concerning global strength of ships.

3.3.2 Definitions *(1/7/2024)*

a) **Load calculation point**

The load calculation points (LCP) for both elementary plate panels (EPP) and stiffeners are defined as follows:

1) LCP for hull girder stresses of EPP

The hull girder stresses for EPP are to be calculated at the load calculation points defined in Tab 2.

2) LCP for hull girder stresses of longitudinal stiffeners

The hull girder stresses for longitudinal stiffeners are to be calculated at the following load calculation point:

- at the mid length of the considered stiffener.
- at the intersection point between the stiffener and its attached plate.

3) LCP for pressure of horizontal stiffeners

The load calculation point for the pressure is located at:

- Middle of the full length, ℓ, of the considered stiffener.
- The intersection point between the stiffener and its attached plate.

4) LCP for pressure of non-horizontal stiffeners

The lateral pressure, P is to be calculated as the maximum between the value obtained at middle of the full length, ℓ, and the value obtained from the following formulae:

$P=(p_u+p_L)/2$: when the upper end of the vertical stiffener is below the lowest zero pressure level.

$P=(\ell_1/\ell)\cdot(p_L/2)$: when the upper end of the vertical stiffener is at or above the lowest zero pressure level, see Fig 7.

where:

ℓ_1 : Distance, in m, between the lower end of vertical stiffener and the lowest zero pressure level.

p_u, p_L : Lateral pressures at the upper and lower end of the vertical stiffener span ℓ, respectively.

Table 2 : Load calculation points (LCP) coordinates for plate buckling assessment *(1/7/2024)*

LCP coordinates	Hull girder bending stress		Hull girder shear stress
	Non horizontal plating	**Horizontal plating**	
x coordinate	Mid-length of the EPP		
y coordinate	Both upper and lower ends of the EPP (points A1 and A2 in Fig 6)	Outboard and inboard ends of the EPP (points A1 and A2 in Fig 6)	Mid-point of EPP (point B in Fig 6)
z coordinate	Corresponding to x and y values		

Figure 6 : LCP for plate buckling assessment *(1/7/2024)*

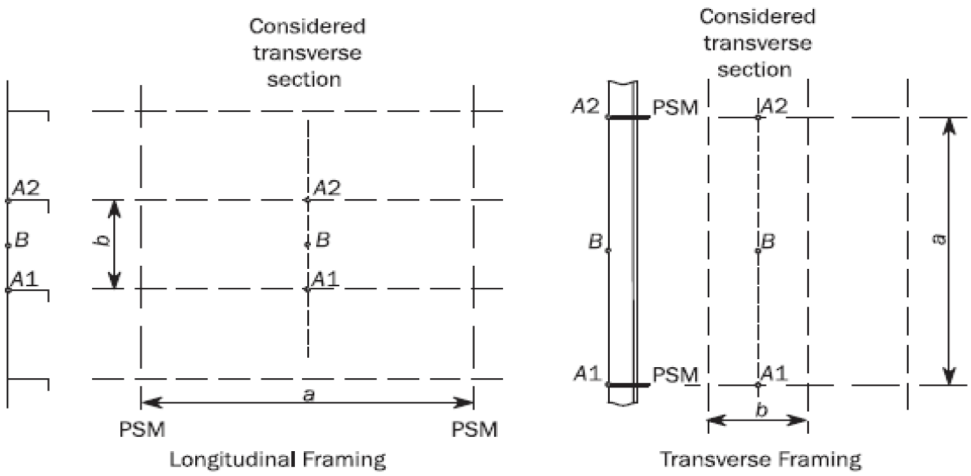
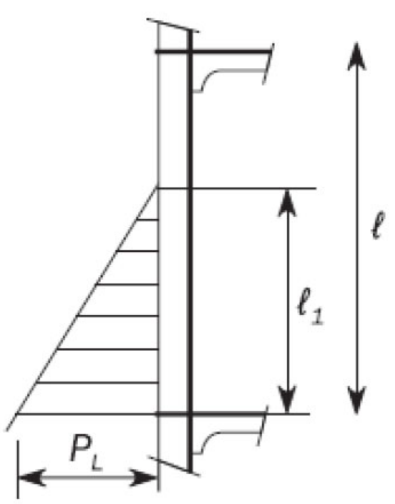


Figure 7 : Definition of pressure for vertical stiffeners *(1/7/2024)*



3.3.3 Assumptions for Equivalent Plate Panels *(1/7/2024)*

a) **Longitudinal stiffening with varying plate thickness**

In longitudinal stiffening arrangement, when the plate thickness varies over the width b, of a plate panel, the buckling check is to be performed for an equivalent plate panel width, combined with the smaller plate thickness, t_1. The width of this equivalent plate panel, b_{eq}, in mm, is defined by the following formula:

$$b_{eq} = \ell_1+\ell_2\cdot(t_1/t_2)^{1,5}$$

where:

ℓ_1 : Width of the part of the plate panel with the smaller plate thickness, t_1, in mm, as defined in Fig 8.

ℓ_2 : Width of the part of the plate panel with the greater plate thickness, t_2, in mm, as defined in Fig 8.

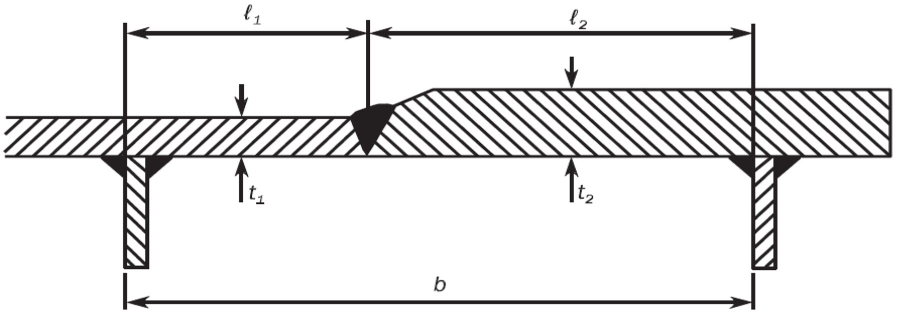
b) **Transverse stiffening with varying plate thickness**

In transverse stiffening arrangement, when an EPP is made with different thicknesses, the buckling check of the plate and stiffeners is to be made for each thickness considered constant on the EPP, the stresses and pressures being estimated for the EPP at the LCP.

c) **Plate panel with different materials**

When the plate panel is made of different materials, the minimum yield strength is to be used for the buckling assessment.

Figure 8 : Plate thickness change over the width *(1/7/2024)*



3.4 Buckling Criteria

3.4.1 Overall Stiffened Panel *(1/7/2024)*

a) The buckling strength of overall stiffened panels is to satisfy the following criterion:

$\eta_{overall} \leq \eta_{all}$

where:

$\eta_{overall}$: Maximum overall buckling utilisation factor as defined in [5.3.1].

3.4.2 Plates *(1/7/2024)*

a) The buckling strength of elementary plate panels is to satisfy the following criterion:

$\eta_{plate} \leq \eta_{all}$

where:

η_{plate} : Maximum plate buckling utilisation factor as defined in [5.3.2] where SP-A model is to be used.

For the determination of η_{plate} of the vertically stiffened side shell plating of single side skin bulk carrier between hopper and topside tanks, the cases 12 and 16 of Tab 4 corresponding to the shorter edge of the plate panel clamped are to be considered together with a mean σ_y stress and ψ_y =1.

3.4.3 Stiffeners *(1/7/2024)*

a) The buckling strength of stiffeners or of side frames of single side skin bulk carriers is to satisfy the following criterion:

$\eta_{stiffener} \leq \eta_{all}$

where:

$\eta_{stiffener}$: Maximum stiffener buckling utilisation factor as defined in [5.3.3].

Note 1: This buckling check can only be fulfilled when the overall stiffened panel buckling check, as defined in [3.4.1], is satisfied.

Note 2: The buckling check of the stiffeners is only applicable to the stiffeners fitted along the long edge of the buckling panel.

3.4.4 Vertically Corrugated Longitudinal Bulkheads *(1/7/2024)*

a) The shear buckling strength of vertically corrugated longitudinal bulkheads is to satisfy the following criterion:

$\eta_{shear} \leq \eta_{all}$

where:

η_{shear} : Maximum shear buckling utilisation factor, defined as:

$\eta_{shear} = \tau_{bhd} / \tau_c$

τ_{bhd} : Shear stress, in N/mm^2, in the bulkhead taken as the hull girder shear stress defined in IACS Unified Requirements concerning global strength of ships

τ_c : Shear critical stress, in N/mm^2, as defined in [5.3.2] c).

3.4.5 Horizontally Corrugated Longitudinal Bulkheads *(1/7/2024)*

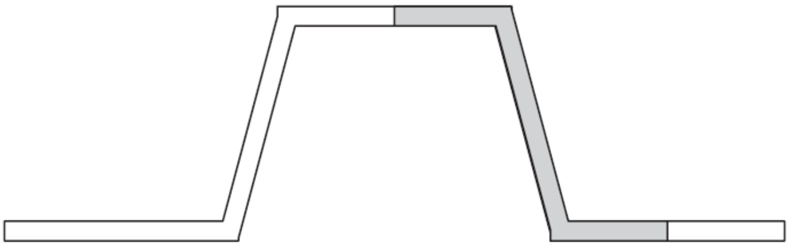
a) Each corrugation unit within the extension of half flange, web and half flange (i.e. single corrugation as shown in grey in Fig 9) is to satisfy the following criterion:

$\eta_{column} \leq \eta_{all}$

where:

η_{column} : Overall column buckling utilisation factor, as defined in [5.4.1].

Figure 9 : Single corrugation *(1/7/2024)*



4 Buckling requirements for direct strength analysis of hatch covers

4.1 Symbols

4.1.1 *(1/7/2024)*

R_{eh_P} : Yield stress of the plate panel, as defined in [4.3.1] c).

R_{eh_S} : Yield stress of the stiffener, as defined in [4.3.1] c).

α : Aspect ratio of the plate panel, as defined in the Symbol list of [3].

η_{all} : Allowable buckling utilisation factor, as defined in [1.4.3] a).

4.2 General

4.2.1 Introduction *(1/7/2024)*

a) The requirements of this Article apply to the buckling assessment of hatch cover structural members based on direct strength analysis (usually by finite element method) and subjected to normal stress, shear stress and lateral pressure.

b) All structural elements in the direct strength analysis carried out according to Ch 9, Sec 7 are to be assessed individually. The buckling checks are to be performed for the following structural elements:

- Stiffened and unstiffened panels
- Web plate in way of openings.

4.3 Stiffened and Unstiffened Panels

4.3.1 General *(1/7/2024)*

a) The plate panel of a hatch cover structure is to be modelled as stiffened panel (SP) or unstiffened panel (UP), with either Method A or Method B as defined in Sec 1, [3.1.1] to be used for the calculation of the plate buckling capacity, which in combination is also equivalent to use the buckling assessment models defined in [1.4.1] b).

b) **Average thickness of plate panel**

For FE analysis, where the plate thickness along a plate panel is not constant, the panel used for the buckling assessment is to be modelled with a weighted average thickness taken as:

$$t_{avr} = \frac{\sum_1^n A_i \cdot t_i}{\sum_1^n A_i}$$

where:

A_i : Area of the i-th plate element.

t_i : Net thickness of the i-th plate element.

n : Number of finite elements defining the buckling plate panel.

c) **Yield stress of the plate panel and stiffener**

The panel yield stress R_{eh_P} is taken as the minimum value of the specified yield stresses of the elements within the plate panel.

The stiffener yield stress R_{eh_S} is taken as the minimum value of the specified yield stresses of the elements within the stiffener.

4.3.2 Stiffened Panels *(1/7/2024)*

a) For a stiffened panel (SP), each stiffener with attached plate is to be idealized as a stiffened panel model of the extent defined in the Ch 9, Sec 7.

b) If the stiffener properties or stiffener spacing varies within the stiffened panel, the calculations are to be performed separately for all configurations of the panels, i.e. for each stiffener and plate between the stiffeners. Plate thickness, stiffener properties and stiffener spacing at the considered location are to be assumed for the whole panel.

c) The buckling check of the stiffeners of stiffened panels is only applicable to the stiffeners fitted along the longer side edges of the buckling panel.

4.3.3 Unstiffened Panels *(1/7/2024)*

a) **Irregular plate panel**

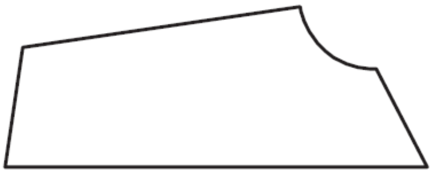
In way of web frames and brackets, the geometry of the panel (i.e. plate bounded by web stiffeners/face plate) may not have a rectangular shape. In this case, for FE analysis, an equivalent rectangular panel is to be defined according to [4.3.3] b) for irregular geometry and [4.3.3] c) for triangular geometry and to comply with buckling assessment.

b) **Equivalent EPP of an unstiffened panel with irregular geometry**

Unstiffened panels with irregular geometry are to be idealised to equivalent panels for plate buckling assessment according to the following procedure:

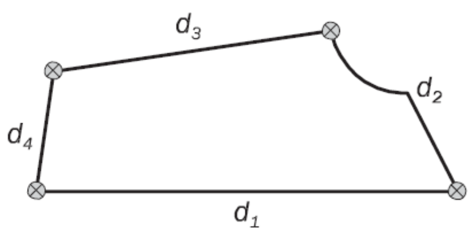
1) The four corners closest to a right angle, 90 deg, in the bounding polygon for the plate are identified.

Figure 10 *(1/7/2024)*



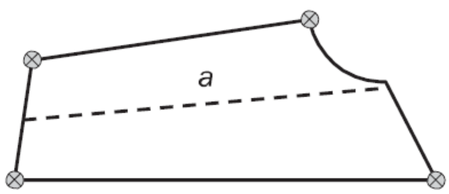
2) The distances along the plate bounding polygon between the corners are calculated, i.e. the sum of all the straight-line segments between the end points.

Figure 11 *(1/7/2024)*



3) The pair of opposite edges with the smallest total length is identified, i.e. minimum of $d_1 + d_3$ and $d_2 + d_4$.

Figure 12 *(1/7/2024)*



4) A line joins the middle points of the chosen opposite edges (i.e. a mid-point is defined as the point at half the distance from one end). This line defines the longitudinal direction for the capacity model. The length of the line defines the length of the capacity model, a, measured from one end point.
5) The length of shorter side, b, in mm, is to be taken as:

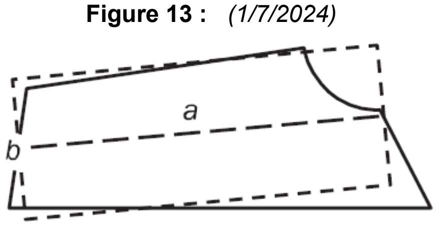
   $b = A/a$

   where:

   A : Area of the plate, in mm²

   a : Length defined in 4), in mm.

Figure 13 : *(1/7/2024)*



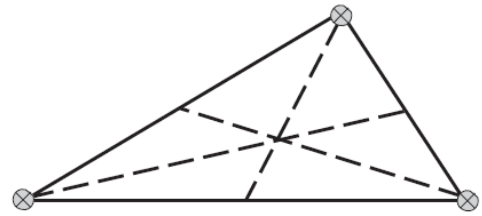
6) The stresses from the direct strength analysis are to be transformed into the local coordinate system of the equivalent rectangular panel. These stresses are to be used for the buckling assessment.

c) **Modelling of an unstiffened plate panel with triangular geometry**

Unstiffened panels with triangular geometry are to be idealised to equivalent panels for plate buckling assessment according to the following procedure:

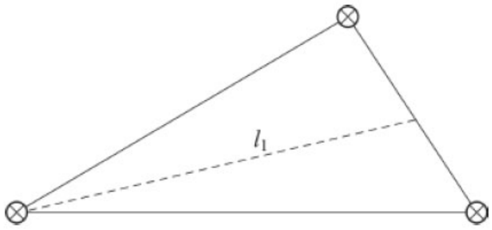
1) Medians are constructed as shown below.

Figure 14 *(1/7/2024)*



2) The longest median is identified. This median the length of which is ℓ_1, in mm, defines the longitudinal direction for the capacity model.

Figure 15 *(1/7/2024)*



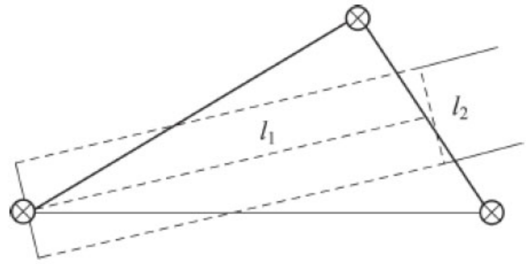
3) The width of the model, ℓ_2, in mm, is to be taken as:

   $\ell_2 = A / \ell_1$

   where:

   A : Area of the plate, in mm²

Figure 16 *(1/7/2024)*



4) The lengths of shorter side, b, and of the longer side, a, in mm, of the equivalent rectangular plate panel are to be taken as:

   $b = \ell_2 / C_{tri}$

   $a = \ell_1 / C_{tri}$

   where:

   $C_{tri} = 0,4 \cdot (\ell_2 / \ell_1) + 0,6$

5) The stresses from the direct strength analysis are to be transformed into the local coordinate system of the equivalent rectangular panel and are to be used

for the buckling assessment of the equivalent rectangular panel.

4.3.4 Reference Stress *(1/7/2024)*

a) The stress distribution is to be taken from the direct strength analysis according to Ch 9, Sec 7 and applied to the buckling model.

b) For FE analysis, the reference stresses are to be calculated using the stress-based reference stresses as defined in [6].

4.3.5 Lateral Pressure *(1/7/2024)*

a) The lateral pressure applied to the direct strength analysis is also to be applied to the buckling assessment.

For FE analysis, where the lateral pressure is not constant over a buckling panel defined by a number of finite plate elements, an average lateral pressure, N/mm^2, is calculated using the following formula:

$$P_{avr} = \frac{\sum_1^n A_i \cdot P_i}{\sum_1^n A_i}$$

where:

A_i : Area of the i-th plate element, in mm^2.

P_i : Lateral pressure of the i-th plate element, in N/mm^2.

n : Number of finite elements in the buckling panel.

4.3.6 Buckling Criteria *(1/7/2024)*

a) **UP-A**

The compressive buckling strength of UP-A is to satisfy the following criterion:

$\eta_{UP-A} \leq \eta_{all}$

where:

η_{UP-A} : Plate buckling utilisation factor, equal to η_{plate} as defined in [5.3.2] where UP-A model is to be used.

b) **UP-B**

The compressive buckling strength of UP-B is to satisfy the following criterion:

$\eta_{UP-B} \leq \eta_{all}$

where:

η_{UP-B} : Plate buckling utilisation factor, equal to η_{plate} as defined in [5.3.2] where UP-B model is to be used.

c) **SP-A**

The compressive buckling strength of SP-A is to satisfy the following criterion:

$\eta_{SP-A} \leq \eta_{all}$

where:

η_{SP-A} : Buckling utilisation factor of the stiffened panel, taken as the maximum of the buckling utilisation factors calculated as below:

- The overall stiffened panel buckling utilisation factor $\eta_{overall}$ as defined in [5.3.1].
- The plate buckling utilisation factor η_{plate} as defined in [5.3.2] where SP-A model is to be used.
- The stiffener buckling utilisation factor $\eta_{stiffener}$ as defined in [5.3.3] considering separately the properties (thickness, dimensions), the pressures defined in [4.3.5] and the reference stresses of each EPP at both sides of the stiffener.

Note 1: The stiffener buckling strength check can only be fulfilled when the overall stiffened panel capacity check, as defined in [5.3.1], is satisfied.

d) **SP-B**

The compressive buckling strength of SP-B is to satisfy the following criterion:

$\eta_{SP-B} \leq \eta_{all}$

where:

η_{SP-B} : Buckling utilisation factor of the stiffened panel, taken as the maximum of the buckling utilisation factors calculated as below:

- The overall stiffened panel buckling utilisation factor $\eta_{overall}$ as defined in [5.3.1].
- The plate buckling utilisation factor η_{plate} as defined in [5.3.2] where SP-B model is to be used.
- The stiffener buckling utilisation factor $\eta_{stiffener}$ as defined in [5.3.3] considering separately the properties (thickness, dimensions), the pressures defined in [4.3.5] and the reference stresses of each EPP at both sides of the stiffener.

Note 2: The stiffener buckling strength check can only be fulfilled when the overall stiffened panel capacity check, as defined in [5.3.1], is satisfied.

e) **Web plate in way of openings**

The web plate of primary supporting members with openings is to satisfy the following criterion:

$\eta_{opening} \leq \eta_{all}$

where:

$\eta_{opening}$: Maximum web plate utilisation factor in way of openings, calculated with the definition in [1.4.2] b) and the stress multiplier factor at failure γ_c which can be calculated following the requirements in [5.3.4].

5 Buckling Capacity

5.1 Symbols

5.1.1 *(1/7/2024)*

A_P : Net sectional area of the stiffener attached plating, in mm^2, taken as:

$A_P = s \cdot t_p$

A_S : Net sectional area of the stiffener without attached plating, in mm^2

a : Length of the longer side of the plate panel, in mm

b : Length of the shorter side of the plate panel, in mm

b_{eff} : Effective width of the attached plating of a stiffener, in mm, as defined in [5.3.3] e)

b_{eff1} : Effective width of the attached plating of a stiffener, in mm, without the shear lag effect taken as:

- For $\sigma_x > 0$
  - For prescriptive assessment:

    $b_{eff1} = (C_{x1} \cdot b_1 + C_{x2} \cdot b_2)/2$
  - For FE analysis:

    $b_{eff1} = C_x \cdot b$
- For $\sigma_x \leq 0$

  $b_{eff1} = b$

b_f : Breadth of the stiffener flange, in mm

b_1, b_2 : Width of plate panel on each side of the considered stiffener, in mm. For stiffened panels fitted with U-type stiffeners, b_1 and b_2 are as defined in Fig 4.

C_{x1}, C_{x2} : Reduction factor defined in Tab 4 calculated for the EPP1 and EPP2 on each side of the considered stiffener according to case 1

d : Length of the side parallel to the cylindrical axis of the cylinder corresponding to the curved plate panel as shown in Tab 5, in mm

d_f : Breadth of the extended part of the flange for L2 profiles, in mm, as shown in Fig 3

e_f : Distance from attached plating to centre of flange, in mm, as shown in Fig 3 to be taken as:

$e_f = h_w$ for flat bar profile

$e_f = h_w - 0{,}5 \cdot t_f$ for bulb profile

$e_f = h_w + 0{,}5 \cdot t_f$ for angle, L2 and T profiles

F_{long} : Coefficient defined in [5.3.2] d)

F_{tran} : Coefficient defined in [5.3.2] e)

h_w : Depth of stiffener web, in mm, as shown in Fig 3

ℓ : Span, in mm, of stiffener equal to spacing between primary supporting members or span of side frame equal to the distance between the hopper tank and top wing tank in way of the side shell

R : Radius of curved plate panel, in mm

R_{eH_P} : Specified minimum yield stress of the plate in N/mm^2

R_{eH_S} : Specified minimum yield stress of the stiffener in N/mm^2

S : Partial safety factor, unless otherwise specified in Ch 9, Sec 7, to be taken as 1,0

s : Stiffener spacing, in mm

t_p : Net thickness of plate panel, in mm

t_w : Net stiffener web thickness, in mm

t_f : Net flange thickness, in mm

x-axis : Local axis of a rectangular buckling panel parallel to its long edge

y-axis : Local axis of a rectangular buckling panel perpendicular to its long edge

α : Aspect ratio of the plate panel, defined in Tab 4 to be taken as: $\alpha = a/b$

β : Coefficient taken as: $\beta = (1-\psi)/\alpha$

ω : Coefficient taken as: $\omega = \min(3,\alpha)$

σ_x : Normal stress applied on the edge along x-axis of the buckling panel, in N/mm^2

σ_y : Normal stress applied on the edge along y-axis of the buckling panel, in N/mm^2

σ_1 : Maximum normal stress along a panel edge, in N/mm^2

σ_2 : Minimum normal stress along a panel edge, in N/mm^2

σ_E : Elastic buckling reference stress, in N/mm^2 to be taken as:

- For the application of the limit state of plane plate panels according to [5.3.2] a):

$$\sigma_E = \frac{\pi^2 \cdot E}{12 \cdot (1-\nu^2)} \cdot \left(\frac{t_p}{b}\right)^2$$

- For the application of the limit state of curved plate panels according to [5.3.2] f):

$$\sigma_E = \frac{\pi^2 \cdot E}{12 \cdot (1-\nu^2)} \cdot \left(\frac{t_p}{d}\right)^2$$

τ : Applied shear stress, in N/mm^2

τ_c : Buckling strength in shear, in N/mm^2, as defined in [5.3.2] c)

ψ : Edge stress ratio to be taken as: $\psi = \sigma_2 / \sigma_1$

γ : Stress multiplier factor acting on loads. When the factor is such that the loads reach the interaction formulae, $\gamma = \gamma_c$

γ_c : Stress multiplier factor at failure

γ_{GEB} : Stress multiplier factor of global elastic buckling capacity.

5.2 General

5.2.1 Introduction *(1/7/2024)*

a) This Article contains the methods for determination of the buckling capacities of plate panels, stiffeners, primary supporting members and columns.

b) For the application of this Article, the stresses σ_x, σ_y and τ applied on the structural members are defined in:

- [3] for hull girder prescriptive buckling requirements
- [4] for direct strength analysis buckling requirements of hatch covers.

c) **Buckling capacity**

The buckling capacity is calculated by applying the actual stress combination and then increasing or decreasing the stresses proportionally until the interaction formulae defined in [5.3.1] a), [5.3.2] a) and [5.3.3] d) are equal to 1,0, respectively.

d) **Buckling utilisation factor**

The buckling utilisation factor of the structural member is equal to the highest utilisation factor obtained for the different buckling modes.

e) **Lateral pressure**

The lateral pressure is to be applied and considered as constant for the calculation of buckling capacities as defined in [5.2.1] c).

5.3 Buckling Capacity of Plate Panels

5.3.1 Overall Stiffened Panels *(1/7/2024)*

a) The elastic stiffened panel limit state is based on the following interaction formula, which sets a precondition for the buckling check of stiffeners in accordance with [5.3.3] d):

$\gamma_c / \gamma_{GEB} = 1$

with the corresponding buckling utilization factor defined as:

$\eta_{overall} = 1 / \gamma_c$

where the stress multiplier factors of global elastic buckling capacity, γ_{GEB} , are to be calculated based on the following formulae:

$\gamma_{GEB} = \gamma_{GEB,bi+\tau}$ for $\tau \neq 0$ and ($\sigma_x > 0$ or $\sigma_y > 0$)

$\gamma_{GEB} = \gamma_{GEB,bi}$ for $\tau = 0$ and ($\sigma_x > 0$ or $\sigma_y > 0$)

$\gamma_{GEB} = \gamma_{GEB,\tau}$ for $\tau \neq 0$ and ($\sigma_x \leq 0$ and $\sigma_y \leq 0$)

where $\gamma_{GEB,bi+\tau}$, $\gamma_{GEB,bi}$ and $\gamma_{GEB,\tau}$ are stress multiplier factors of the global elastic buckling capacity for different load combinations as defined in [5.3.1] b), [5.3.1] c) and [5.3.1] d), respectively. For the calculation of $\gamma_{GEB,bi+\tau}$, $\gamma_{GEB,bi}$ and $\gamma_{GEB,\tau}$, neither σ_x nor σ_y are to be taken less than 0.

σ_x , σ_y : Applied normal stress to the plate panel, in N/mm^2, to be taken as defined in [5.3.2] g)

τ : Applied shear stress, in N/mm^2, to be taken as defined in [5.3.2] g).

b) The stress multiplier factor $\gamma_{GEB,bi}$ for the stiffened panel subjected to biaxial loads is taken as:

$$\gamma_{GEB,bi} = \frac{\pi^2}{L^2_{B1} \cdot L^2_{B2}} \cdot \frac{[D_{11} \cdot L^4_{B2} + 2 \cdot (D_{12} + D_{33}) \cdot n^2 \cdot L^2_{B1} \cdot L^2_{B2} + n^4 \cdot D_{22} \cdot L^4_{B1}]}{L^2_{B2} \cdot N_x + n^2 \cdot L^2_{B1} \cdot N_Y}$$

where:

N_x : Load per unit length applied on the edge along x-axis of the stiffened panel, in N/mm, taken as:

$N_x = \sigma_{x,av} . (A_p+A_s) / s$

For stiffened panels fitted with U-type stiffeners, stiffener spacing s is taken as:

$s = b_1 + b_2$

where b_1 and b_2 are as defined in Fig 4.

N_y : Load per unit length applied on the edge along y axis of the stiffened panel, in N/mm, taken as $N_y = c \cdot \sigma_y \cdot t_p$

L_{B1} : Stiffener span, in mm, distance between primary supporting members, i.e. LB1 = ℓ. Specially, for vertically stiffened side shell of single side skin bulk carriers, LB1=0,8ℓ.

L_{B2} : Total width of stiffened panel between lateral supports, in mm, taken as 6 times of the stiffener spacing, i.e. 6s.

n : Number of half waves along the direction perpendicular to the stiffener axis. The factor $\gamma_{GEB,bi}$ is to be minimized with respect to the wave parameters n, i.e. to be taken as the smallest value larger than zero.

c : Factor taking into account the normal stress distribution in the attached plating acting perpendicular to the stiffener's axis:

$c = 0,5 \cdot (1+\psi)$ for $0 \leq \psi \leq 1$

$c = 0,5 \cdot (1-\psi)$ for $\psi < 0$

y : Edge stress ratio for case 2 according to Tab 4.

$\sigma_{x,av}$: Average stress for both plate and stiffener, taken as:

for $\sigma_x > 0$ and $\sigma_y > 0$:

$\sigma_{x,av} = \sigma_x - v \cdot c \cdot \sigma_y \cdot A_s / (A_p+A_s) \geq 0$

for $\sigma_x \leq 0$ or $\sigma_y \leq 0$:

$\sigma_{x,av} = \sigma_x$

D_{11}, D_{12}, D_{22}, D_{33} : Bending stiffness coefficients, in Nmm, of the stiffened panel, defined in general as:

$$\left.\begin{aligned} D_{11} &= \frac{E \cdot I_{eff} \cdot 10^4}{s} \\ D_{12} &= \frac{E \cdot t_p^3 \cdot \nu}{12 \cdot (1-\nu^2)} \\ D_{22} &= \frac{E \cdot t_p^3}{12 \cdot (1-\nu^2)} \\ D_{33} &= \frac{E \cdot t_p^3}{12 \cdot (1+\nu)} \end{aligned}\right\}$$

For stiffened panels fitted with U-type stiffeners, D_{12} and D_{22} are defined as:

$$D_{22} = \frac{E \cdot t_p^3}{12 \cdot (1-\nu^2)} \cdot \left[1,2 + 4,8 \cdot \mathrm{Min}\left(1,0, \frac{b_1^2}{h_w \cdot (b_1 + b_2)}\right) \cdot \mathrm{Min}\left(1,0, \left(\frac{t_w}{t_p}\right)^3\right)\right]$$

$D_{12} = \nu \cdot D_{22}$

h_w is the breadth of U-type stiffener web as defined in Fig 4.

I_{eff} : Moment of inertia, in cm^4, of the stiffener including the effective width of the attached plating, same as I defined in [5.3.3] d).

c) The stress multiplier factor $\gamma_{GEB,\tau}$ for the stiffened panel subjected to pure shear load is taken as:

for $D_{11} \cdot D_{22} \geq (D_{12}+D_{33})^2$

$$\gamma_{GEB,\tau} = \frac{\sqrt[4]{D_{11}^3 \cdot D_{22}}}{\left(\frac{L_{B1}}{2}\right)^2 \cdot N_{xy}} \cdot \left[8,125 + 5,64 \cdot \sqrt{\frac{(D_{12}+D_{33})^2}{D_{11} \cdot D_{22}}} - 0,6 \cdot \frac{(D_{12}+D_{33})^2}{D_{11} \cdot D_{22}}\right]$$

for $D_{11} \cdot D_{22} < (D_{12}+D_{33})^2$

$$\gamma_{GEB,\tau} = \frac{\sqrt{2 \cdot D_{11} \cdot (D_{12}+D_{33})}}{\left(\frac{L_{B1}}{2}\right)^2 \cdot N_{xy}} \cdot \left[8,3 + 1,525 \cdot \frac{D_{11} \cdot D_{22}}{(D_{12}+D_{33})^2} - 0,493 \cdot \frac{D_{11}^2 \cdot D_{22}^2}{(D_{12}+D_{33})^4}\right]$$

where:

$N_{xy} = \tau \cdot t_p$

d) The stress multiplier factor $\gamma_{GEB,bi+\tau}$ for the stiffened panel subjected to combined loads is taken as:

$$\gamma_{GEB,bi+\tau} = \frac{\gamma_{GEB,\tau}^2}{2} \cdot \left[-\frac{1}{\gamma_{GEB,bi}} + \sqrt{\frac{1}{\gamma_{GEB,bi}^2} + 4 \cdot \frac{1}{\gamma_{GEB,\tau}^2}}\right]$$

where $\gamma_{GEB,bi}$ and $\gamma_{GEB,\tau}$ are as defined in [5.3.1] b) and [5.3.1] c), respectively.

5.3.2 Plates *(1/7/2024)*

a) **Plate limit state**

The plate limit state is based on the following interaction formulae:

$$\left(\frac{\gamma_{c1} \cdot \sigma_x \cdot S}{\sigma_{cx}}\right)^{e_0} - B \cdot \left(\frac{\gamma_{c1} \cdot \sigma_x \cdot S}{\sigma_{cx}}\right)^{\frac{e_0}{2}} \cdot \left(\frac{\gamma_{c1} \cdot \sigma_y \cdot S}{\sigma_{cy}}\right)^{\frac{e_0}{2}} + \left(\frac{\gamma_{c1} \cdot \sigma_y \cdot S}{\sigma_{cy}}\right)^{e_0} + \left(\frac{\gamma_{c1} \cdot |\tau| \cdot S}{\tau_c}\right)^{e_0} = 1$$

$$\left(\frac{\gamma_{c2} \cdot \sigma_x \cdot S}{\sigma_{cx}}\right)^{\frac{2}{\beta_p^{0,25}}} + \left(\frac{\gamma_{c2} \cdot |\tau| \cdot S}{\tau_c}\right)^{\frac{2}{\beta_p^{0,25}}} = 1 \qquad \text{for } \sigma_x \geq 0$$

$$\left(\frac{\gamma_{c3} \cdot \sigma_y \cdot S}{\sigma_{cy}}\right)^{\frac{2}{\beta_p^{0,25}}} + \left(\frac{\gamma_{c3} \cdot |\tau| \cdot S}{\tau_c}\right)^{\frac{2}{\beta_p^{0,25}}} = 1 \qquad \text{for } \sigma_y \geq 0$$

$$\frac{\gamma_{c4} \cdot |\tau| \cdot S}{\tau_c} = 1$$

with:

$\gamma_c = \text{Min}(\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4})$

and the corresponding buckling utilization factor defined as:

$\eta_{plate} = 1 / \gamma_c$

where:

- σ_x, σ_y : Applied normal stress to the plate panel, in N/mm^2, to be taken as defined in [5.3.2] g)
- τ : Applied shear stress to the plate panel, in N/mm^2
- σ_{cx} : Ultimate buckling stress, in N/mm^2, in direction parallel to the longer edge of the buckling panel as defined in [5.3.2] c)
- σ_{cy} : Ultimate buckling stress, in N/mm^2, in direction parallel to the shorter edge of the buckling panel as defined in [5.3.2] c)
- τ_c : Ultimate buckling shear stress, in N/mm^2, as defined in [5.3.2] c)
- $\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4}$: Stress multiplier factors at failure for each of the above different limit states. γ_{c2} and γ_{c3} are only to be considered when $\sigma_x \geq 0$ and $\sigma_y \geq 0$ respectively
- B : Coefficient given in Tab 2
- e_0 : Coefficient given in Tab 2
- β_p : Plate slenderness parameter taken as:

$$\beta_p = \frac{b}{t_p} \cdot \sqrt{\frac{R_{eH\_P}}{E}}$$

b) **Reference degree of slenderness**

The reference degree of slenderness is to be taken as:

$\lambda = (R_{eH\_P} / K\sigma_E)^{1/2}$

where:

- K : Buckling factor, as defined in Tab 4 and Tab 5.

c) **Ultimate buckling stresses**

The ultimate buckling stresses of plate panels, in N/mm^2, are to be taken as:

$\sigma_{cx} = C_x \cdot R_{eH\_P}$

$\sigma_{cy} = C_y \cdot R_{eH\_P}$

The ultimate buckling stress of plate panels subject to shear, in N/mm^2, is to be taken as:

$\tau_c = C_\tau \cdot (R_{eH\_P} / 3^{0,5})$

where:

C_x, C_y, C_τ : Reduction factors, as defined in Tab 4

- For the 1st Equation of [5.3.2] a), when $\sigma_x < 0$ or $\sigma_y < 0$, the reduction factors are to be taken as:
  $C_x = C_y = C_\tau = 1$
- For other cases:
  - For SP-A and UP-A, C_y is calculated according to Tab 5 by using:
    $c_1 = (1-1/\alpha) \geq 0$
  - For SP-B and UP-B, C_y is calculated according to Tab 5 by using:
    $c_1 = 1$
  - For vertically stiffened single side skin of bulk carrier, C_y is calculated according to Tab 4 by using:
    $c_1 = (1-1/\alpha) \geq 0$
  - For corrugation of corrugated bulkheads, C_y is calculated according to Tab 4 by using:
    $c_1 = (1-1/\alpha) \geq 0$

The boundary conditions for plates are to be considered as simply supported, see cases 1, 2 and 15 of Tab 4. If the boundary conditions differ significantly from simple support, a more appropriate boundary condition can be applied according to the different cases of Tab 4 subject to the agreement of the Society.

d) **Correction factor F_{long}**

The correction factor F_{long} depending on the edge stiffener types on the longer side of the buckling panel is defined in Tab 3. An average value of F_{long} is to be used for plate panels having different edge stiffeners. For stiffener types other than those mentioned in Tab 3, the value of c is to be agreed by the Society. In such a case, value of c higher than those mentioned in Tab 3 can be used, provided it is verified by buckling strength check of panel using non-linear FE analysis and deemed appropriate by the Society.

e) **Correction factor F_{tran}**

The correction factor F_{tran} is to be taken as:

- For transversely framed EPP of single side skin bulk carrier, between the hopper and top wing tank:
  - F_{tran} = 1,25 when the two adjacent frames are supported by one tripping bracket fitted in way of the adjacent plate panels
  - F_{tran} = 1,33 when the two adjacent frames are supported by two tripping brackets each fitted in way of the adjacent plate panels
  - F_{tran} = 1,15 elsewhere.

- For the attached plate of a U-type stiffener fitted on a hatch cover:

  $F_{tran} = Max(3-0{,}08 \cdot (F_{tran0} - 6)^2 , 1{,}0) \leq 2{,}25$

  where:

$$F_{tran0} = Min\left(\frac{b_2}{b_1} + \frac{6 \cdot b_2^2}{\pi \cdot h_w \cdot (b_1 + b_2)} \cdot \left(\frac{t_w}{t_p}\right)^3, 6\right) \quad \text{for EPP } b_2$$

$$F_{tran0} = Min\left(\frac{b_1}{b_2} + \frac{6 \cdot b_1^2}{\pi \cdot h_w \cdot (b_2 + b_1)} \cdot \left(\frac{t_w}{t_p}\right)^3, 6\right) \quad \text{for EPP } b_1$$

  with b_1, b_2 and h_w as defined in Fig 4.

  Coefficient F defined in Case 2 of Tab 4 is to be replaced by the following formula:

$$F = \left[1 - \left(\frac{K_y}{0{,}91 \cdot F_{tran}} - 1\right) / \lambda_p^2\right] \cdot c_1 \geq 0$$

- For other cases: $F_{tran} = 1$.

f) **Curved plate panels**

This requirement for curved plate limit state is applicable when $R/t_p \leq 2500$. Otherwise, the requirement for plate limit state given in [5.3.2] a) is applicable.

The curved plate limit state is based on the following interaction formula:

$$\left(\frac{\gamma_c \cdot \sigma_{ax} \cdot S}{C_{ax} \cdot R_{eH\_P}}\right)^{1,25} - 0,5 \cdot \left(\frac{\gamma_c \cdot \sigma_{ax} \cdot S}{C_{ax} \cdot R_{eH\_P}}\right) \cdot \left(\frac{\gamma_c \cdot \sigma_{tg} \cdot S}{C_{tg} \cdot R_{eH\_P}}\right) + \left(\frac{\gamma_c \cdot \sigma_{tg} \cdot S}{C_{tg} \cdot R_{eH\_P}}\right)^{1,25} + \left(\frac{\gamma_c \cdot \tau \cdot \sqrt{3} \cdot S}{C_\tau \cdot R_{eH\_P}}\right)^2 = 1$$

with the corresponding buckling utilization factor defined as:

$\eta_{curved\_plate} = 1 / \gamma_c$

where:

σ_{ax} : Applied axial stress to the cylinder corresponding to the curved plate panel, in N/mm^2. In case of tensile axial stresses, $\sigma_{ax} = 0$

σ_{tg} : Applied tangential stress to the cylinder corresponding to the curved plate panel, in N/mm^2. In case of tensile tangential stresses, $\sigma_{tg} = 0$

C_{ax}, C_{tg}, C_τ : Buckling reduction factor of the curved plate panel, as defined in Tab 5.

The stress multiplier factor, γ_c , of the curved plate panel need not be taken less than the stress multiplier factor, γ_c , for the expanded plane panel according to [5.3.2] a).

g) **Applied normal and shear stresses to plate panels**

The normal stress, σ_x and σ_y, in N/mm^2, to be applied for the overall stiffened panel capacity and the plate panel capacity calculations as given in [5.3.1] a) and [5.3.2] a) respectively, are to be taken as follows:

- For FE analysis, the reference stresses as defined in [4.3.4]
- For prescriptive assessment of the overall stiffened panel capacity and the plate panel capacity, the axial or transverse compressive stresses calculated according to [3], at load calculation points of the considered stiffener or the considered elementary plate panel, as defined in item 1) and item 2) of [3.3.2] a) respectively. However, in case of transverse stiffening arrangement, the transverse compressive stress used for the assessment of the overall stiffened panel capacity is to be taken as the compressive stress calculated at load calculation points of the stiffener attached plating, as defined in [3.3.2] a), 1)
- For grillage analysis where the stresses are obtained based on beam theory, the stresses taken as:

$$\sigma_x = \frac{\sigma_{xb} + \nu \cdot \sigma_{yb}}{1 - \nu^2}$$

$$\sigma_y = \frac{\sigma_{yb} + \nu \cdot \sigma_{xb}}{1 - \nu^2}$$

where:

σ_{xb}, σ_{yb} : Stress, in N/mm^2, from grillage beam analysis respectively along x or y axis of the plate attached to the PSM web.

The shear stress τ, in N/mm^2, to be applied for the overall stiffened panel capacity and the plate panel capacity calculations as given in [5.3.1] a) and [5.3.2] a) respectively, are to be taken as follows:

- For FE analysis, the reference shear stresses as defined in Sec 4, [2.3]
- For prescriptive assessment of the plate panel capacity, the shear stresses calculated according to [3], at load calculation points of the considered elementary plate panel, as defined in [3.3.2] a), 1)
- For prescriptive assessment of the overall stiffened panel capacity, the shear stresses calculated according to [3], at the following load calculation point:
  - At the middle of the full span, ℓ, of the considered stiffener
  - At the intersection point between the stiffener and its attached plating.
- For grillage beam analysis, $\tau = 0$ in the plate attached to the PSM web.

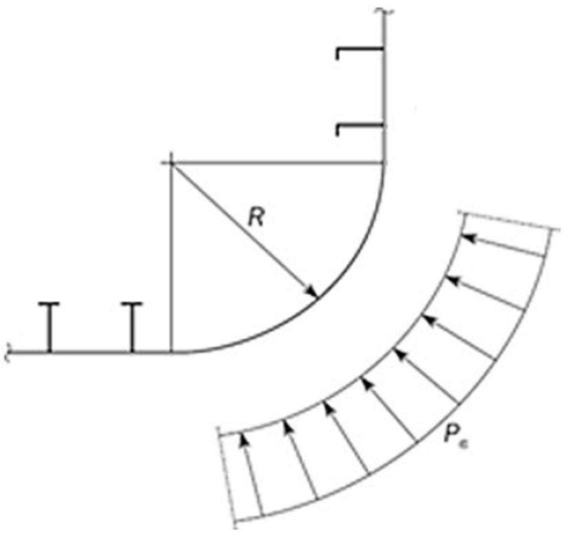


Figure 17 : Transverse stiffened bilge plating *(1/7/2024)*

Table 3 : Definition of coefficients B and e0 *(1/7/2024)*

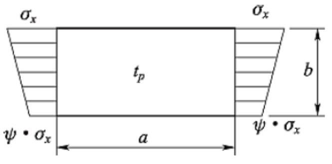
Applied stress	B	e_0
$\sigma_x \geq 0$ and $\sigma_y \geq 0$	$0,7-0,3 \cdot \beta_p / \alpha^2$	$2 \cdot \beta_p^{0,25}$
$\sigma_x < 0$ or $\sigma_y < 0$	1,0	2,0

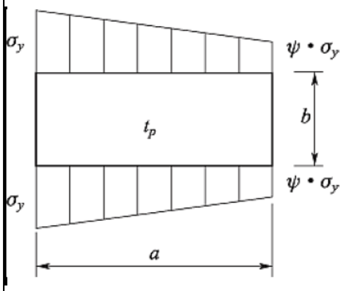
Table 4 : Correction factor F_{long} *(1/7/2024)*

Structural element types			F_{long}	c
Unstiffened Panel			1,0	N/A
Stiffened Panel	Stiffener not fixed at both ends		1,0	N/A
	Stiffener fixed at both ends	Flat bar (1)	$F_{long} = c+1$ for $t_w / t_p > 1$ $F_{long} = c \cdot (t_w / t_p)^3$ for $t_w / t_p \leq 1$	0,10
		Bulb profile		0,30
		Angle and L2 profiles		0,40
		T profile		0,30
		Girder of high rigidity (e.g. bottom transverse)	1,4	N/A
		U-type profile fitted on hatch cover (2)	• Plate on which the U-type profile is fitted, including EPP b_1 and EPP b_2 - $F_{long} = 1$ for $b_2 < b_1$ - $F_{long} = (1,55-0,55 \cdot b_1 / b_2) \cdot [1+c \cdot (t_w / t_p)^3]$ • Other plates of the U-type profile: $F_{long} = 1$	0,2

(1) t_w is the net web thickness, in mm, without the correction defined in [5.3.3] b).
(2) b_1, b_2 and t_w are defined in Fig 4.

Table 5 : Buckling factor and reduction factor for plane plate panels *(1/7/2024)*

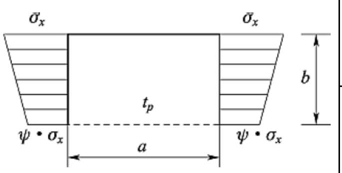
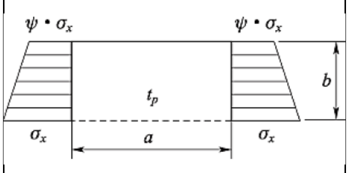
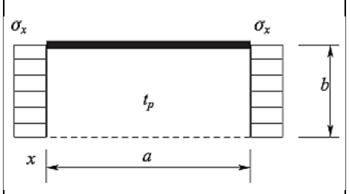
Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
1 	$1 \geq \psi \geq 0$		$k_x = F_{long} \cdot 8,4 / (\psi + 1,1)$	When $\sigma_x \leq 0$, $C_x = 1$ When $\sigma_x > 0$, $C_x = 1$ for $\lambda \leq \lambda_c$ $C_x = c\,[(1/\lambda) - (0,22/\lambda^2)]$ for $\lambda > \lambda_c$ where: $c = (1,25 - 0,12\,\psi) \leq 1,25$ $\lambda_c = \frac{c}{2}\left(1 + \sqrt{1 - \frac{0,88}{c}}\right)$
	$0 > \psi > -1$		$k_x = F_{long} \cdot [7,63 - \psi(6,26 - 10\psi)]$	
	$\psi \leq -1$		$k_x = F_{long} \cdot [5,975 \cdot (1 - \psi)^2]$	
Edge boundary conditions: Plate edge free Plate edge simply supported Plate edge clamped Note 1: Cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.				

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
2 	$1 \geq \psi \geq 0$		$K_y = \dfrac{F_{tran} \cdot 2 \cdot \left(1+\frac{1}{\alpha^2}\right)^2}{1+\psi+\frac{(1-\psi)}{100} \cdot \left(\frac{2{,}4}{\alpha^2}+6{,}9 \cdot f_1\right)}$	when $\sigma_y \leq 0$, $C_y = 1$ when $\sigma_y > 0$ $C_y = c\left(\frac{1}{\lambda}-\frac{R+F^2(H-R)}{\lambda^2}\right)$
		$\alpha \leq 6$	$f_1 = (1-\psi)\cdot(\alpha - 1)$	where: $c = (1{,}25 - 0{,}12\,\psi) \leq 1{,}25$
		$\alpha > 6$	$f_1 = 0{,}6\cdot(1-6\cdot\psi/\alpha)\cdot(\alpha + 14/\alpha)$ but not grater than $14{,}5-0{,}35/\alpha^2$	
	$1-4\cdot a/3 \leq \psi < 0$		$K_y = \dfrac{200 \cdot F_{tran} \cdot (1+\beta^2)^2}{(1-f_3)\cdot(100+2{,}4\cdot\beta^2+6{,}9\cdot f_1+23\cdot f_2)}$	$R = \lambda\left(1-\frac{\lambda}{c}\right)$ for $\lambda < \lambda_C$
		$\alpha > 6\cdot(1-\psi)$	$f_1 = 0{,}6\cdot(1/\beta+14\cdot\beta)$ but not grater than $14{,}5-0{,}35/\beta^2$ $f_2 = f_3 = 0$	$R = 0{,}22$ for $\lambda \geq \lambda_C$
		$3\cdot(1-\psi) \leq \alpha \leq 6\cdot(1-\psi)$	$f_1 = 1/\beta - 1$ $f_2 = f_3 = 0$	$\lambda_C = \frac{c}{2}\left(1+\sqrt{1-\frac{0{,}88}{c}}\right)$
		$1{,}5\cdot(1-\psi) \leq \alpha < 3\cdot(1-\psi)$	$f_1 = 1/\beta -(2-\omega\beta)^4-9\cdot(\omega\beta-1)\cdot(2/3-\beta)$ $f_2 = f_3 = 0$	$F = \left[1-\left(\frac{k}{0{,}91}-1\right)/\lambda_p^2\right]\cdot c_1 \geq 0$
		$1-\psi \leq \alpha < 1{,}5\cdot(1-\psi)$	For $\alpha > 1{,}5$ $f_1 = 2\cdot(1/\beta - 16\cdot(1-\omega/3)^4)\cdot(1/\beta-1)$ $f_2 = 3\cdot\beta-2$ $f_3 = 0$ For $\alpha \leq 1{,}5$ $f_1 = 2\cdot(1{,}5/(1-\psi)-1)\cdot(1/\beta-1)$ $f_2 = \psi\cdot(1-16\cdot f_4^2)\cdot(1-\alpha)$ $f_3 = 0$ $f_4 = (1{,}5-\text{Min}(1{,}5,\alpha))^2$	$\lambda_p^2 = \lambda^2 - 0{,}5$ for $1 \geq \lambda_p^2 \geq 3$ c_1 as defined in [5.3.2], c) $H = \lambda - \frac{2\lambda}{c\cdot(T+\sqrt{T^2-4})} \geq R$
		$0{,}75\cdot(1-\psi) \leq \alpha < 1-\psi$	$f_1 = 0$ $f_2 = 1+2{,}31\cdot(\beta-1)-48\cdot(4/3-\beta)\cdot f_4^2$ $f_3 = 3\cdot f_4\cdot(\beta-1)-(f_4/1{,}81-(\alpha-1)/1{,}31)$ $f_4 = (1{,}5-\text{Min}(1{,}5,\alpha))^2$	$T = \lambda + \frac{14}{15\lambda}+\frac{1}{3}$
	$\psi < 1-4\cdot a/3$		$K_y = \dfrac{5{,}972 \cdot F_{tran} \cdot \beta^2}{1-f_3}$ where: $f_3 = f_5\cdot(f_5/1{,}81+(1+3\psi)/5{,}24)$ $f_5 = (9/16)\cdot(1+\text{Max}(-1,\psi))^2$	

Edge boundary conditions:

- Plate edge free
- Plate edge simply supported
- Plate edge clamped

Note 1: Cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
3 	$1 \geq \psi \geq 0$		$K_x = \dfrac{4\left(0,425 + \dfrac{1}{\alpha^2}\right)}{3\psi + 1}$	For UP-A: $C_x = 1$ for $\lambda \leq 0,75$ $C_x = \dfrac{0,75}{\lambda}$ for $\lambda > 0,75$ For UP-B: $C_x = 1$ for $\lambda \leq 0,7$ $C_x = \dfrac{1}{\lambda^2 + 0,51}$ for $\lambda > 0,7$
	$0 > \psi > -1$		$K_x = 4\left(0,425 + \dfrac{1}{\alpha^2}\right)(1+\psi) - 5\psi(1 - 3,42\psi)$	
4 	$1 \geq \psi \geq -1$		$K_x = \left(0,425 + \dfrac{1}{\alpha^2}\right)\dfrac{3 - \psi}{2}$	
5 	-	$\alpha \geq$ 1,64	$K_\tau = 1,28$	
		$\alpha < 1,64$	$K_\tau = \dfrac{1}{\alpha^2} + 0,56 + 0,13 \cdot \alpha^2$	

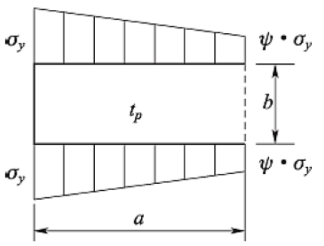
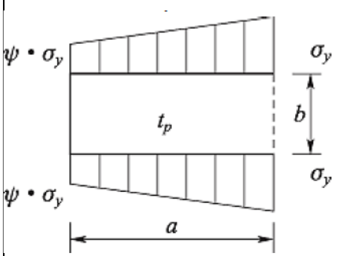
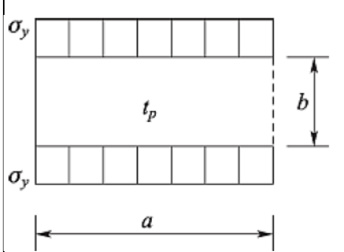
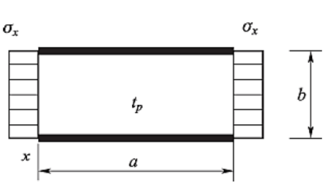
Edge boundary conditions:

Plate edge free

Plate edge simply supported

Plate edge clamped

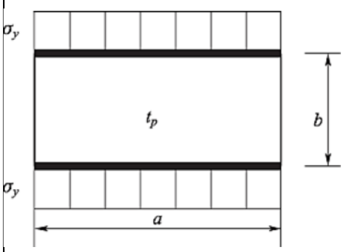
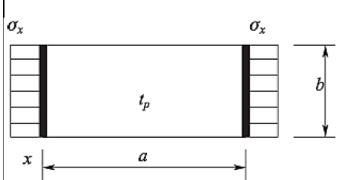
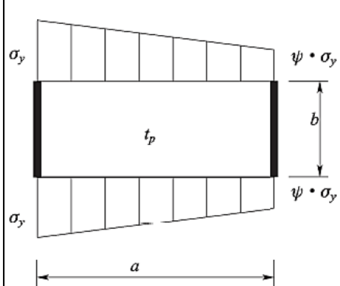
Note 1: Cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
6 	$1 \geq \psi \geq 0$		$K_y = \frac{4(0,425 + \alpha^2)}{(3\psi + 1) \cdot \alpha^2}$	For UP-A: $C_y = 1$ for $\lambda \leq 0,75$; $C_y = \frac{0,75}{\lambda}$ for $\lambda > 0,75$. For UP-B: $C_y = 1$ for $\lambda \leq 0,7$; $C_y = \frac{1}{\lambda^2 + 0,51}$ for $\lambda > 0,7$
	$0 > \psi > -1$		$K_y = 4(0,425 + \alpha^2)(1 + \psi)\frac{1}{\alpha^2} - 5\psi(1 - 3,42\psi)\frac{1}{\alpha^2}$	
7 	$1 \geq \psi \geq -1$		$K_y = (0,425 + \alpha^2)\frac{3 - \psi}{2 \cdot \alpha^2}$	
8 	-		$K_y = 1 + \frac{0,56}{\alpha^2} + \frac{0,13}{\alpha^4}$	
9 	-		$K_x = 6,97$	$C_x = 1$ for $\lambda \leq 0,83$; $C_x = 1,13 \cdot \left(\frac{1}{\lambda} - \frac{0,22}{\lambda^2}\right)$ for $\lambda > 0,83$

Edge boundary conditions:

- - - - - - Plate edge free
——— Plate edge simply supported
▬▬▬ Plate edge clamped

Note 1: Cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
10 	-		$K_y = 4 + \frac{2,07}{\alpha^2} + \frac{0,67}{\alpha^4}$	$C_y = 1$ for $\lambda \le 0,83$ $C_y =$ $1,13 \cdot \left(\frac{1}{\lambda} - \frac{0,22}{\lambda^2}\right)$ for $\lambda > 0,83$
11 	-	$\alpha \ge 4$	$K_x = 4$	$C_x = 1$ for $\lambda \le 0,83$ $C_x =$ $1,13 \cdot \left(\frac{1}{\lambda} - \frac{0,22}{\lambda^2}\right)$ for $\lambda > 0,83$
		$\alpha < 4$	$K_x = 4 + 2,74 \cdot \left(\frac{4-\alpha}{3}\right)^4$	
12 	-		Ky = Ky determined as per case 2	For $\alpha < 2$ $C_y = C_{y2}$ For $\alpha \ge 2$ $C_y = \left(1,06 + \frac{1}{10 \cdot \alpha}\right) \cdot C_{y2}$ where: C_{y2} : C_y determined as per case 2

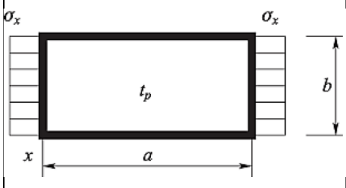
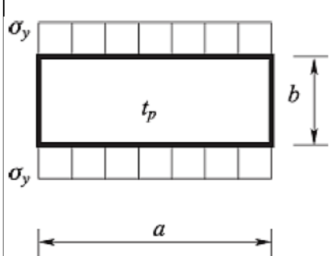
Edge boundary conditions:

- - - - - Plate edge free

——— Plate edge simply supported

▬▬▬ Plate edge clamped

Note 1: Cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
13 	-	$\alpha \geq 4$	$K_x = 6,97$	$C_x = 1$ for $\lambda \leq 0,83$
		$\alpha < 4$	$K_x = 6,97 + 3,1 \cdot \left(\frac{4-\alpha}{3}\right)^4$	$C_x =$ $1,13 \cdot \left(\frac{1}{\lambda} - \frac{0,22}{\lambda^2}\right)$ for $\lambda > 0,83$
14 	-		$K_y = \frac{6,97}{\alpha^2} + \frac{3,1}{\alpha^2} \cdot \left(\frac{4 - \frac{1}{\alpha}}{3}\right)^4$	$C_y = 1$ for $\lambda \leq 0,83$ $C_y =$ $1,13 \cdot \left(\frac{1}{\lambda} - \frac{0,22}{\lambda^2}\right)$ for $\lambda > 0,83$

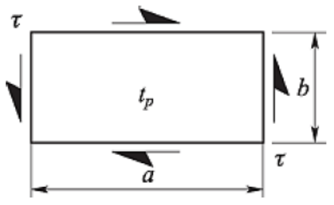
Edge boundary conditions:

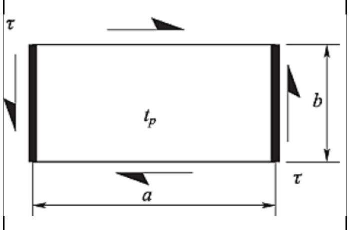
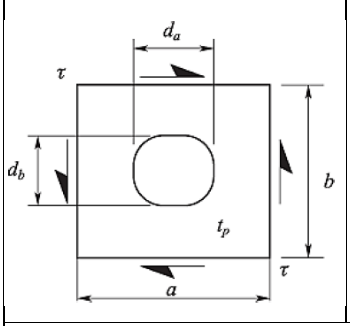
- - - - - - Plate edge free

——— Plate edge simply supported

▬▬▬ Plate edge clamped

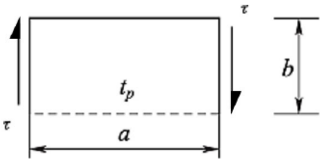
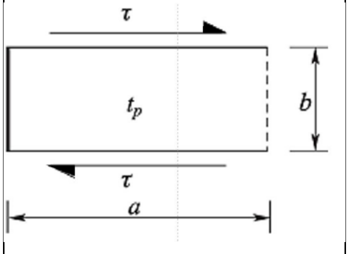
Note 1: Cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.

<table>
<tr><th>Case</th><th>Stress ratio ψ</th><th>Aspect ratio α</th><th>Buckling factor K</th><th>Reduction factor C</th></tr>
<tr><td>15
</td><td>-</td><td></td><td>$K_\tau = \sqrt{3} \cdot \left(5,34 + \frac{4}{\alpha^2}\right)$</td><td rowspan="3">$C_\tau = 1 \quad \text{for } \lambda \le 0,84$

$C_\tau = \frac{0,84}{\lambda} \quad \text{for } \lambda > 0,84$</td></tr>
<tr><td>16
</td><td>-</td><td></td><td>$K_\tau = \sqrt{3} \cdot \left[5,34 + \text{Max}\left(\frac{4}{\alpha^2}, \frac{7,15}{\alpha^{2,5}}\right)\right]$</td></tr>
<tr><td>17
</td><td>-</td><td></td><td>$K_\tau = K_{\tau case15} \cdot \Upsilon$
$K_{\tau case15}$: K_τ according to case 15
Υ : Opening reduction factor taken as
$\Upsilon = (1 - d_a/a) \cdot (1 - d_b/b)$
with:
$d_a/a \le 0,7$ and $d_b/b \le 0,7$</td></tr>
<tr><td colspan="5">Edge boundary conditions:

- - - - - - Plate edge free
——— Plate edge simply supported
▬▬▬ Plate edge clamped

Note 1: Cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.</td></tr>
</table>

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
18 	-		$K_\tau = \sqrt{3} \cdot \left(0,6 + \frac{4}{a^2}\right)$	$C_\tau = 1$ for $\lambda \leq 0,84$ $C_\tau = \frac{0,84}{\lambda}$ for $\lambda > 0,84$
19 	-		$K_\tau = 8$	

Edge boundary conditions:

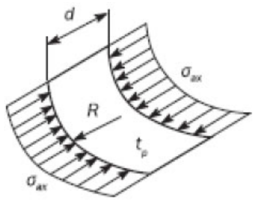
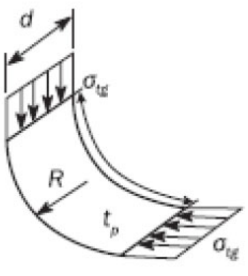
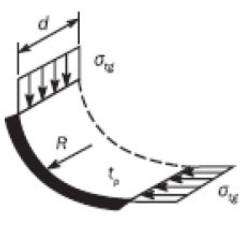
- - - - - - Plate edge free

——— Plate edge simply supported

▬▬▬ Plate edge clamped

Note 1: Cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.

Table 6 : Buckling factor and reduction factor for curved plate panels with $R/t_p \le 2500$ *(1/7/2024)*

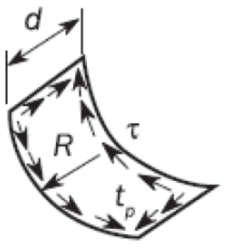
Case	Aspect ratio	**Buckling factor K**	**Reduction factor C**
1 	$\frac{d}{R} \le 0,5 \cdot \sqrt{\frac{R}{t_p}}$	$K = 1 + \frac{2}{3} \cdot \frac{d^2}{R \cdot t_p}$	For general application: $C_{ax} = 1$ for $\lambda \le 0,25$ $C_{ax} = 1,233-0,933 \cdot \lambda$ for $0,25<\lambda \le 1$ $C_{ax} = 0,3 \cdot \lambda^3$ for $1<\lambda \le 1,5$ $C_{ax} = 0,2 \cdot \lambda^2$ for $\lambda > 1,5$ For curved single fields, e.g. bilge strake, which are bounded by plane panels as shown in Fig 17: $C_{ax} = 0,65/\lambda^2 \le 1,0$
	$\frac{d}{R} > 0,5 \cdot \sqrt{\frac{R}{t_p}}$	$K = 0,267 \cdot \frac{d^2}{R \cdot t_p} \cdot \left[3 - \frac{d}{R} \cdot \sqrt{\frac{t_p}{R}}\right] \ge 0,4 \cdot \frac{d^2}{R \cdot t_p}$	
2 	$\frac{d}{R} \le 1,63 \cdot \sqrt{\frac{R}{t_p}}$	$K = \frac{d}{\sqrt{R \cdot t_p}} + 3 \cdot \frac{(R \cdot t_p)^{0,175}}{d^{0,35}}$	For general application: $C_{tg} = 1$ for $\lambda \le 0,4$ $C_{tg} = 1,274-0,686 \cdot \lambda$ for $0,4<\lambda \le 1,2$ $C_{tg} = 0,65/\lambda^2$ for $\lambda > 1,2$ For curved single fields, e.g. bilge strake, which are bounded by plane panels as shown in Fig 17: $C_{tg} = 0,8/\lambda^2 \le 1,0$
	$\frac{d}{R} > 1,63 \cdot \sqrt{\frac{R}{t_p}}$	$K = 0,3 \cdot \frac{d^2}{R^2} + 2,25 \cdot \left(\frac{R^2}{d \cdot t_p}\right)^2$	
3 	$\frac{d}{R} \le \sqrt{\frac{R}{t_p}}$	$K = \frac{0,6 \cdot d}{\sqrt{R \cdot t_p}} + \frac{\sqrt{R \cdot t_p}}{d} - 0,3 \cdot \frac{R \cdot t_p}{d^2}$	As in load case 2
	$\frac{d}{R} > \sqrt{\frac{R}{t_p}}$	$K = 0,3 \cdot \frac{d^2}{R^2} + 0,291 \cdot \left(\frac{R^2}{d \cdot t_p}\right)^2$	

Edge boundary conditions:

- - - - - - Plate edge free

——— Plate edge simply supported

▬▬▬ Plate edge clamped

Case	Aspect ratio	Buckling factor K	Reduction factor C
4 	$\frac{d}{R} \le 8,7 \cdot \sqrt{\frac{R}{t_p}}$	$K = \sqrt{3} \cdot \sqrt{28,3 + \frac{0,67 \cdot d^3}{R^{1,5} \cdot t_p^{1,5}}}$	$C_\tau = 1$ for $\lambda \le 0,4$ $C_\tau = 1,274 - 0,686 \cdot \lambda$ for $0,4 < \lambda \le 1,2$ $C_\tau = 0,65/\lambda^2$ for $\lambda > 1,2$
	$\frac{d}{R} > 8,7 \cdot \sqrt{\frac{R}{t_p}}$	$K = \sqrt{3} \cdot \frac{0,28 \cdot d^2}{R \cdot \sqrt{R \cdot t_p}}$	

Edge boundary conditions:

Plate edge free

Plate edge simply supported

Plate edge clamped

5.3.3 Stiffeners *(1/7/2024)*

a) **Buckling modes**

The following buckling modes are to be checked:

- Stiffener induced failure (SI)
- Associated plate induced failure (PI).

b) **Web thickness of flat bar**

For accounting the decrease of the stiffness due to local lateral deformation, the effective web thickness of flat bar stiffener, in mm, is to be used in [5.3.1] and [5.3.3] d) for the calculation of the net sectional area, A_s, the net section modulus, Z, and the moment of inertia, *I*, of the stiffener and is taken as:

$$t_{w\_red} = t_w \cdot \left(1 - \frac{2 \cdot \pi^2}{3} \cdot \left(\frac{h_w}{s}\right)^2 \cdot \left(1 - \frac{b_{eff1}}{s}\right)\right)$$

c) **Idealisation of bulb profile**

Bulb profiles are to be considered as equivalent angle profiles. The net dimensions of the equivalent built-up section are to be obtained, in mm, from the following formulae.

$$h_w = h'_w - \frac{h'_w}{9,2} + 2$$

$$b_f = \alpha \cdot \left(t'_w + \frac{h'_w}{6,7} - 2\right)$$

$t_f = h'_w/9,2 - 2$

$t_w = t'_w$

where:

h'_w, t'_w : Net height and thickness of a bulb section, in mm, as shown in Fig 18

α : Coefficient equal to:

$$\alpha = 1,1 + \frac{(120 - h'_w)^2}{3000} \quad \text{for } h'_w \le 120$$

$$\alpha = 1,0 \quad \text{for } h'_w > 120$$

d) **Ultimate buckling capacity**

When $\sigma_a + \sigma_b + \sigma_w > 0$ while initially setting $\gamma = 1$, the ultimate buckling capacity for stiffeners is to be checked according to the following interaction formula:

$$\frac{\gamma_c \cdot \sigma_a + \sigma_b + \sigma_w}{R_{eH}} \cdot S = 1$$

with the corresponding buckling utilization factor defined as:

$\eta_{stiffener} = 1 / \gamma_c$

where:

σ_a : Effective axial stress, in N/mm^2, at mid span of the stiffener, acting on the stiffener with its attached plating.

$$\sigma_a = \sigma_x \cdot \frac{s \cdot t_p + A_s}{b_{eff1} \cdot t_p + A_s}$$

σ_x : Nominal axial stress, in N/mm^2, acting on the stiffener with its attached plating.

- For FE analysis, σ_x is the FE corrected stress as defined in [5.3.3] f) in the attached plating in the direction of the stiffener axis
- For prescriptive assessment, σ_x is the axial stress calculated according to [3.4.2] a) at load calculation point of the stiffener, as defined in [3.3.2] a)

- For grillage beam analysis, σ_x is the stress acting along the x-axis of the attached buckling panel.

R_{eH} : Specified minimum yield stress of the material, in N/mm^2
- $R_{eH} = R_{eH\_S}$ for stiffener induced failure (SI).
- $R_{eH} = R_{eH\_P}$ for plate induced failure (PI).

σ_b : Bending stress in the stiffener, in N/mm^2:

$\sigma_b = (M_0+M_1+M_2)/1000 \cdot Z$

Z : Net section modulus of stiffener, in cm^3, including effective width of plating according to [5.3.3], e), to be taken as:
- The section modulus calculated at the top of stiffener flange for stiffener induced failure (SI)
- The section modulus calculated at the attached plating for plate induced failure (PI).

M_2 : Bending moment, in Nmm, due to eccentricity of sniped stiffeners, to be taken as:
- M_2=0 for continuous stiffeners
- $M_2 = C_{snip} \cdot w_{na} \cdot \gamma \cdot \sigma_x \cdot (A_p+A_s)$ for stiffeners sniped at one or both ends.

C_{snip} : Coefficient to account for the end effect of the stiffener sniped at one or both ends, to be taken as:
- C_{snip} = -1,2 for stiffener induced failure (SI)
- C_{snip} = 1,2 for plate induced failure (PI).

M_1 : Bending moment, in Nmm, due to the lateral load P:

for continuous stiffener:

$$M_1 = C_i \cdot \frac{|P| \cdot s \cdot l^2}{24 \cdot 10^3}$$

for sniped stiffener:

$$M_1 = C_i \cdot \frac{|P| \cdot s \cdot l^2}{8 \cdot 10^3}$$

for stiffener sniped at one end and continuous at the other end

$$M_1 = C_i \cdot \frac{|P| \cdot s \cdot l^2}{14,2 \cdot 10^3}$$

P : Lateral load, in kN/m^2.
- For FE analysis, P is the average pressure as defined in [4.3.5] in the attached plating
- For prescriptive assessment, P is the pressure calculated at load calculation point of the stiffener, as defined in [3.3.2] a).

C_i : Pressure coefficient:
- $C_i = C_{SI}$ for stiffener induced failure (SI)
- $C_i = C_{PI}$ for plate induced failure (PI).

C_{PI} : Plate induced failure pressure coefficient:
- C_{PI} = 1 if the lateral pressure is applied on the side opposite to the stiffener
- C_{PI} = -1 if the lateral pressure is applied on the same side as the stiffener.

C_{SI} : Stiffener induced failure pressure coefficient:
- C_{SI} = -1 if the lateral pressure is applied on the side opposite to the stiffener
- C_{SI} = 1 if the lateral pressure is applied on the same side as the stiffener.

M_0 : Bending moment, in Nmm, due to the lateral deformation w of stiffener:

$$M_0 = F_E \cdot C_{sl} \cdot \frac{\gamma}{\gamma_{GEB} - \gamma} \cdot w_0 \quad \text{with precondition } \gamma_{GEB} - \gamma > 0$$

γ_{GEB} : Stress multiplier factor of global elastic buckling capacity as defined in [5.3.1].

F_E : Ideal elastic buckling force of the stiffener, in N:

$F_E = (\pi/\ell)^2 \cdot E \cdot I \cdot 10^4$

I : Moment of inertia, in cm^4, of the stiffener including effective width of attached plating according to [5.3.3] e). I is to comply with the following requirement:

$I \geq s \cdot t_p^3 / 12 \cdot 10^4$

t_p : Net thickness of plate, in mm, to be taken as:
- For prescriptive requirements: the mean thickness of the two attached plating panels
- For FE analysis: the thickness of the considered EPP on one side of the stiffener.

C_{sl} : Deformation reduction factor to account for global slenderness, to be taken as:
- $C_{sl} = 1-(1/12)\lambda_G^4$ for $\lambda_G \leq 1,56$
- $C_{sl} = 3/\lambda_G^4$ for $\lambda_G > 1,56$

λ_G : The reference degree of global slenderness of the stiffened panel, to be taken as:

$$\lambda_G = \sqrt{\frac{\gamma_{ReH}}{\gamma_{GEB}}}$$

with

$$\gamma_{ReH} = \frac{Min(R_{eH\_P}, R_{eH\_S})}{\sqrt{\sigma_{x,av}^2 + \sigma_y^2 - \sigma_{x,av} \cdot \sigma_y + 3 \cdot \tau^2}}$$

$\sigma_{x,av}$: Average stress for both plate and stiffener as defined in [5.3.1] b)

σ_y : Applied transverse stress to the plate panel as defined in [5.3.1] a)

τ : Applied shear stress to the plate panel as defined in [5.3.1] a)

w_0 : Assumed imperfection, in mm, to be taken as:

$w_0 = \ell/1000$

σ_w : Stress due to torsional deformation, in N/mm^2, to be taken as:

- For stiffener induced failure (SI)
  - For $\sigma_a > 0$

$$\sigma_w = E \cdot y_w \cdot e_f \cdot \Phi_0 \cdot \left(\frac{m_{tor} \cdot \pi}{\ell_{tor}}\right)^2 \cdot \left(\frac{1}{1 - \frac{\gamma \cdot \sigma_a}{\sigma_{ET}}} - 1\right)$$

with precondition $\sigma_{ET} - \gamma \cdot \sigma_a > 0$

  - For $\sigma_a \leq 0$

    $\sigma_w = 0$

- For plate induced failure (PI)

  $\sigma_w = 0$

y_w : Distance, in mm, from centroid of stiffener cross section to the free edge of stiffener flange, to be taken as:

- $y_w = t_w / 2$ for flat bar
- for angle and bulb profiles:

$$y_w = b_f - \frac{h_w \cdot t_w^2 + t_f \cdot b_f^2}{2 \cdot A_s}$$

- for L2 profile:

$$y_w = b_{f-out} + 0,5 \cdot t_w - \frac{h_w \cdot t_w^2 + t_f \cdot (b_f^2 - 2 \cdot b_f \cdot d_f)}{2 \cdot A_s}$$

- $y_w = b_f / 2$ for T profile.

Φ_0 : Coefficient taken as:

$$\Phi_0 = \frac{\ell_{tor}}{m_{tor} \cdot h_w} \cdot 10^{-4}$$

σ_{ET} : Reference stress for torsional buckling, in N/mm^2, to be taken as:

$$\sigma_{ET} = \frac{E}{I_p} \cdot \left[\left(\frac{m_{tor} \cdot \pi}{\ell_{tor}}\right) \cdot I_\omega \cdot 10^2 + \frac{1}{2 \cdot (1 + \nu)} \cdot I_T + \left(\frac{\ell_{tor}}{m_{tor} \cdot \pi}\right)^2 \cdot \varepsilon \cdot 10^{-4}\right]$$

I_p : Net polar moment of inertia of the stiffener, in cm^4, about point C as shown in Fig 3, as defined in Tab 7

I_T : Net St. Venant's moment of inertia of the stiffener, in cm^4, as defined in Tab 7

I_ω : Net sectorial moment of inertia of the stiffener, in cm^6, about point C as shown in Fig 3, as defined in Tab 7

ℓ_{tor} : Stiffener span, distance equal to spacing between primary supporting members, i.e. $\ell_{tor} = \ell$ .When the stiffener is supported by tripping brackets, ℓ_{tor} should be taken as the maximum spacing between the adjacent primary supporting members and fitted tripping brackets

m_{tor} : Number of half waves, taken as a positive integer so as to give smallest reference stress for torsional buckling

ε : Degree of fixation, in mm^2, to be taken as:

- for bulb, angle, L2 and T profiles:

$$\varepsilon = \left(\frac{3 \cdot b}{t_p^3} + \frac{2 \cdot h_w}{t_w^3}\right)$$

- for flat bars:

$$\varepsilon = \left(\frac{t_p^3}{3b}\right)$$

A_w : Net web area, in mm^2

A_f : Net flange area, in mm^2

e) **Effective width of attached plating**

The effective width of attached plating of stiffeners, b_{eff}, in mm, is to be taken as:

- For $\sigma_x > 0$
  - For FE analysis

    $b_{eff} = Min(C_x \cdot b, \chi_s \cdot s)$
  - For prescriptive assessment

$$b_{eff} = Min\left(\frac{C_{x1} \cdot b_1 + C_{x2} \cdot b_2}{2}, \chi_s \cdot s\right)$$

- For $\sigma_x \leq 0$

  $b_{eff} = \chi_s \cdot s$

where:

χ_s : Effective width coefficient to be taken as:

$$\chi_s = \frac{1,12}{1 + \frac{1,75}{\left(\frac{\ell_{eff}}{s}\right)^{1,6}}} \leq 1,0 \quad \text{for } \frac{\ell_{eff}}{s} \geq 1$$

$$\chi_s = 0,407 \cdot \frac{\ell_{eff}}{s} \quad \text{for } \frac{\ell_{eff}}{s} < 1$$

ℓ_{eff} : Effective length of the stiffener, in mm, taken as:

$\ell_{eff} = \ell / 3^{0,5}$ for stiffener fixed at both ends

$\ell_{eff} = 0,75 \cdot \ell$ for stiffener simply supported at one end and fixed at the other

$\ell_{eff} = \ell$ for stiffener simply supported at both ends.

f) **FE corrected stresses for stiffener capacity**

When the reference stresses σ_x and σ_y obtained by FE analysis according to Sec 4, [2.3] are both compressive, σ_x is to be corrected according to the following formulae:

- If $\sigma_x < \nu \cdot \sigma_y$

  $\sigma_{xcor} = 0$

- If $\sigma_x \geq \nu \cdot \sigma_y$

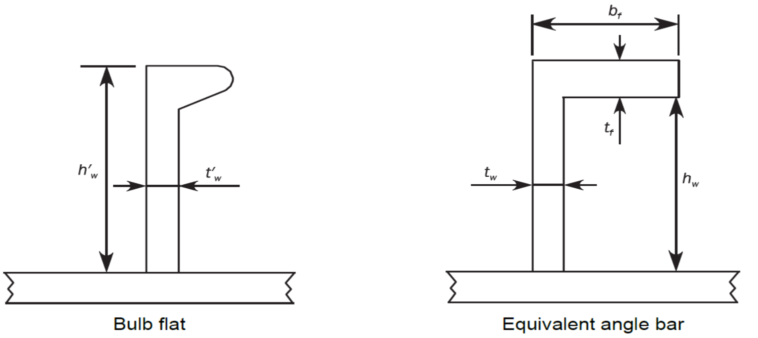
  $\sigma_{xcor} = \sigma_x - \nu \cdot \sigma_y$

Table 7 : Moments of inertia *(1/7/2024)*

	Flat bars (1)	Bulb, angle, L2 and T profiles
I_p	$\dfrac{h_w^3 \cdot t_w}{3 \cdot 10^4}$	$\left(\dfrac{A_w \cdot (e_f - 0,5 \cdot t_f)^2}{3} + A_f \cdot e_f\right) \cdot 10^{-4}$
I_T	$\dfrac{h_w \cdot t_w^3}{3 \cdot 10^4} \cdot \left(1 - 0,63 \cdot \dfrac{t_w}{h_w}\right)$	$\dfrac{(e_f - 0,5 \cdot t_f) \cdot t_w^3}{3 \cdot 10^4} \cdot \left(1 - 0,63 \cdot \dfrac{t_w}{e_f - 0,5 \cdot t_f}\right) + \dfrac{b_f \cdot t_f^3}{3 \cdot 10^4} \cdot \left(1 - 0,63 \cdot \dfrac{t_f}{b_f}\right)$
I_ω	$\dfrac{h_w^3 \cdot t_w^3}{36 \cdot 10^6}$	For bulb, angle and L2 profiles **(2)**: $\dfrac{A_f^3 + A_w^3}{36 \cdot 10^6} + \dfrac{e_f^2}{10^6} \cdot \left(\dfrac{A_f \cdot b_f^2 + A_w \cdot t_w^2}{3} - \dfrac{(A_f \cdot (b_f - 2 \cdot d_f) + A_w \cdot t_w)^2}{4 \cdot (A_f + A_w)} - A_f \cdot d_f \cdot (b_f - d_f)\right)$ For T profile: $\dfrac{b_f^3 \cdot t_f \cdot e_f^2}{12 \cdot 10^6}$

(1) t_w is the net web thickness, in mm
t_{w_red} as defined in [5.3.3] b) is not to be used in this table.
(2) d_f is to be taken as 0 for bulb and angle profiles.

Figure 18 : Idealisation of bulb stiffener *(1/7/2024)*



5.3.4 Primary Supporting Members *(1/7/2024)*

a) **Web plate in way of openings**

The web plate of primary supporting members with openings is to be assessed for buckling based on the combined axial compressive and shear stresses.

The web plate adjacent to the opening on both sides is to be considered as individual unstiffened plate panels as shown in Tab 8.

The interaction formulae of [5.3.2] a) are to be used with:

$\sigma_x = \sigma_{av}$

$\sigma_y = 0$

$\tau = \tau_{av}$

where:

σ_{av} : Weighted average compressive stress, in N/mm^2, in the area of web plate being considered, i.e. P1, P2, or P3 as shown in Tab 8.

For the application of Tab 8, the weighted average shear stress is to be taken as:

- Opening modelled in primary supporting members:

  τ_{av} : Weighted average shear stress, in N/mm^2, in the area of web plate being considered, i.e. P1, P2, or P3 as shown in Tab 8.

- Opening not modelled in primary supporting members:

τ_{av} : Weighted average shear stress, in N/mm^2, given in Tab 8.

b) **Reduction factors of web plate in way of openings**

The reduction factors, C_x or C_y in combination with, C_τ of the plate panel(s) of the web adjacent to the opening is to be taken as shown in Tab 8.

c) The equivalent plate panel of web plate of primary supporting members crossed by perpendicular stiffeners is to be idealised as shown in Fig 19.

The correction of panel breadth is applicable also for other slot configurations provided that the web or collar plate is attached to at least one side of the passing stiffener.

Figure 19 : Web plate idealization *(1/7/2024)*

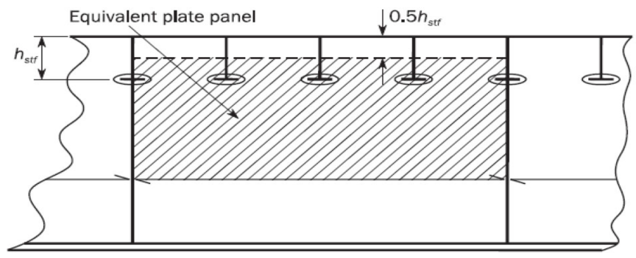
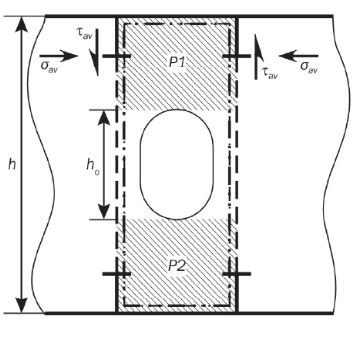
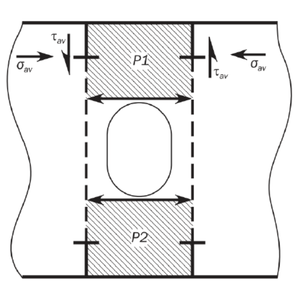
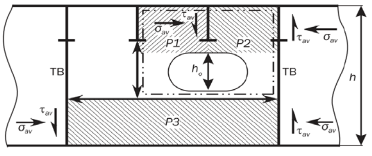


Table 8 : Reduction factors *(1/7/2024)*

<table>
<tr><th rowspan="2">Configuration (1)</th><th rowspan="2">C_x, C_y</th><th colspan="2">C_τ</th></tr>
<tr><th>Opening modelled in PSM</th><th>Opening not modelled in PSM</th></tr>
<tr><td rowspan="2">(a) Without edge reinforcements: (2)
</td><td rowspan="2">Separate reduction factors are to be applied to areas P1 and P2 using case 3 or case 6 in Tab 4, with edge stress ratio:
$\psi = 1,0$</td><td rowspan="2">Separate reduction factors are to be applied to areas P1 and P2 using case 18 or case 19 in Tab 5.</td><td>When case 17 of Tab 4 is applicable:
A common reduction factor is to be applied to areas P1 and P2 using case 17 in Tab 4 with:
$\tau_{av} = \tau_{av}$ (web)</td></tr>
<tr><td>When case 17 of Tab 4 is not applicable:
Separate reduction factors are to be applied to areas P1 and P2 using case 18 or case 19 in Tab 5 with:
$\tau_{av} = \tau_{av}$ (web)·h/ (h-h_0)</td></tr>
<tr><td>(b) With edge reinforcements:
</td><td>Separate reduction factors are to be applied for areas P1 and P2 using C_x for case 1 or C_y for case 2 in Tab 4 with stress ratio:
$\psi = 1,0$</td><td>Separate reduction factors are to be applied for areas P1 and P2 using case 15 in Tab 4.</td><td>Separate reduction factors are to be applied to areas P1 and P2 using case 15 in Tab 4 with:
$\tau_{av} = \tau_{av}$ (web)·h/ (h-h_0)</td></tr>
<tr><td colspan="4">Where:
h : Height, in m, of the web of the primary supporting member in way of the opening
h_0 : Height in m, of the opening measured in the depth of the web
τ_{av}(web) : Weighted average shear stress, in N/mm^2, over the web height h of the primary supporting member.
(1) Web panels to be considered for buckling in way of openings are shown shaded and numbered P1, P2, etc.
(2) For a PSM web panel with opening and without edge reinforcements as shown in configuration (a), the applicable buckling assessment method depends on its specific boundary conditions. If one of the long edges along the face plate or along the attached plating is not subject to "inline support", i.e. the edge is free to pull in, Method B should be applied. In other cases, typically such as when the short plate edge is attached to the plate flanges, Method A is applicable.</td></tr>
</table>

Configuration (1)	C_x, C_y	C_τ	
		Opening modelled in PSM	Opening not modelled in PSM
(c) Example of hole in web: 	Panels P1 and P2 are to be evaluated in accordance with (a). Panel P3 is to be evaluated in accordance with (b).		

Where:

h : Height, in m, of the web of the primary supporting member in way of the opening

h_0 : Height in m, of the opening measured in the depth of the web

τ_{av}(web) : Weighted average shear stress, in N/mm^2, over the web height h of the primary supporting member.

(1) Web panels to be considered for buckling in way of openings are shown shaded and numbered P1, P2, etc.

(2) For a PSM web panel with opening and without edge reinforcements as shown in configuration (a), the applicable buckling assessment method depends on its specific boundary conditions. If one of the long edges along the face plate or along the attached plating is not subject to "inline support", i.e. the edge is free to pull in, Method B should be applied. In other cases, typically such as when the short plate edge is attached to the plate flanges, Method A is applicable.

5.3.5 Stiffened Panels with U-type Stiffeners *(1/7/2024)*

a) **Local plate buckling**

For stiffened panels with U-type stiffeners, local plate buckling is to be checked for each of the plate panels EPP b_1, b_2, b_f and h_w (see Fig 4) separately as follows:

- The attached plate panels EPP b_1 and b_2 are to be assessed using SP-A model, where in the calculation of buckling factors K_x as defined in Case 1 of Tab 4, the correction factor F_{long} for U-type stiffeners as defined in Tab 3 is to be used; and in the calculation of K_y as defined in Case 2 of Tab 4, the F_{tran} for U-type stiffeners as defined in [5.3.2] e) is to be used.
- The face plate and web plate panels b_f and h_w are to be assessed using UP-B model with F_{long} =1 and F_{tran} =1.

b) **Overall stiffened panel buckling and stiffener buckling**

For a stiffened panel with U-type stiffeners, the overall buckling capacity and ultimate capacity of the stiffeners are to be checked with warping stress σ_w = 0, and with bending moment of inertia including effective width of attached plating being calculated based on the following assumptions:

- The two web panels of a U-type stiffener are to be taken as perpendicular to the attached plate with thickness equal to t_w and height equal to the distance between the attached plate and the face plate of the stiffener
- Effective width of the attached plating, b_{eff} , taken as the sum of the b_{eff} calculated for the EPP b_1 and b_2 respectively according to SP-A model
- Effective width of the attached plating of a stiffener without shear lag effect, b_{eff1} , taken as the sum of the b_{eff1} calculated for the EPP b_1 and b_2 respectively.

5.4 Buckling Capacity of column structures

5.4.1 Column Buckling of Corrugations *(1/7/2024)*

a) **Buckling utilisation factor**

The column buckling utilisation factor, η, for axially compressed corrugations is to be taken as:

$$\eta_{column} = \sigma_{av} / \sigma_{cr}$$

where:

σ_{av} : Average axial compressive stress in the member, in N/mm^2.

σ_{cr} : Minimum critical buckling stress, in N/mm^2, taken as:

- $\sigma_{cr} = \sigma_E$ for $\sigma_E \le 0{,}5 \cdot R_{eH\_S}$
- for $\sigma_E > 0{,}5 \cdot R_{eH\_S}$:

$$\sigma_{cr} = \left(1 - \frac{R_{eH\_S}}{4 \cdot \sigma_E}\right) \cdot R_{eH\_S}$$

σ_E : Elastic column compressive buckling stress, in N/mm^2, according to [5.4.1] b).

R_{eH_S} : Specified minimum yield stress of the considered member, in N/mm^2. For built-up members, the lowest specified minimum yield stress is to be used.

b) **Elastic column buckling stress**

The elastic compressive column buckling stress, σ_E in N/mm^2 of members subject to axial compression is to be taken as:

$$\sigma_E = \pi^2 \cdot E \cdot f_{end} \cdot \frac{I}{A \cdot \ell_{pill}^2} \cdot 10^{-4}$$

where:

- I : Net moment of inertia about the weakest axis of the cross section, in cm^4
- A : Net cross-sectional area of the member, in cm^2
- ℓ_{pill} : Unsupported length of the member, in m
- f_{end} : End constraint factor, corresponding to simply supported ends is to be applied except for fixed end support to be used in way of stool with width exceeding 2 times the depth of the corrugation, taken as:
  - f_{end} = 1,0 where both ends are simply supported
  - f_{end} = 2,0 where one end is simply supported and the other end is fixed
  - f_{end} = 4,0 where both ends are fixed.

6 Stress based reference stresses

6.1 Symbols

6.1.1 *(1/7/2024)*

- a : Length, in mm, of the longer side of the plate panel as defined in [5]
- b : Length, in mm, of the shorter side of the plate panel as defined in [5]
- A_i : Area, in mm^2, of the i-th plate element of the buckling panel
- n : Number of plate elements in the buckling panel
- σ_{xi} : Actual stress, in N/mm^2, at the centroid of the i-th plate element in x direction, applied along the shorter edge of the buckling panel
- σ_{yi} : Actual stress, in N/mm^2, at the centroid of the i-th plate element in y direction, applied along the longer edge of the buckling panel
- ψ : Edge stress ratio as defined in [5]
- σ_{yi} : Actual membrane shear stress, in N/mm^2, at the centroid of the i-th plate element of the buckling panel.

6.2 Stress Based Method

6.2.1 Introduction *(1/7/2024)*

a) This Section provides a method to determine stress distribution along edges of the considered buckling panel by second-order polynomial curve, by linear distribution using least square method and by weighted average approach. This method is called Stress based Method. The reference stress is the stress components at centre of plate element transferred into the local system of the considered buckling panel.

b) **Definition**: A regular panel is a plate panel of rectangular shape. An irregular panel is plate panel which is not regular, as detailed in [4.3.3] a).

6.2.2 Stress Application *(1/7/2024)*

a) **Regular panel**

The reference stresses are to be taken as defined in [6.3.1] for a regular panel when the following conditions are satisfied:

- At least, one plate element centre is located in each third part of the long edge a of a regular panel and
- This element centre is located at a distance in the panel local x direction not less than $\alpha/4$ to at least one of the element centres in the adjacent third part of the panel.

Otherwise, the reference stresses are to be taken as defined in [6.3.2] for an irregular panel.

b) **Irregular panel and curved panel**

The reference stresses of an irregular panel or of a curved panel are to be taken as defined in [6.3.2].

6.3 Reference Stresses

6.3.1 Regular Panel *(1/7/2024)*

a) **Longitudinal stress**

The longitudinal stress σ_x applied on the shorter edge of the buckling panel is to be calculated as follows:

- For plate buckling assessment, the distribution of $\sigma_x(x)$ is assumed as second order polynomial curve as:

  $\sigma_x = Cx^2 + Dx + E$

  The best fitting curve $\sigma_x(x)$ is to be obtained by minimising the square error Π considering the area of each element as a weighting factor.

  $$\Pi = \sum_{i=1}^{n} A_i \cdot [\sigma_{xi} - (Cx_i^2 + Dx_i + E)]^2$$

  The unknown coefficients C, D and E must yield zero first derivatives, $\partial\Pi$ with respect to C, D and E, respectively.

  The unknown coefficients C, D and E can be obtained by solving the 3 above equations.

$$\begin{cases} \dfrac{\partial\Pi}{\partial C} = 2 \cdot \sum_{i=1}^{n} A_i \cdot x_i^2 \cdot [\sigma_{xi} - (Cx_i^2 + Dx_i + E)] = 0 \\ \dfrac{\partial\Pi}{\partial D} = 2 \cdot \sum_{i=1}^{n} A_i \cdot x_i \cdot [\sigma_{xi} - (Cx_i^2 + Dx_i + E)] = 0 \\ \dfrac{\partial\Pi}{\partial E} = 2 \cdot \sum_{i=1}^{n} A_i \cdot [\sigma_{xi} - (Cx_i^2 + Dx_i + E)] = 0 \end{cases}$$

$$\sigma_{x1} = \frac{1}{b} \cdot \int_0^b \sigma_x(x)dx = \frac{b^2}{3} \cdot C + \frac{b}{2} \cdot D + E$$

$$\sigma_{x2} = \frac{1}{b} \cdot \int_{a-b}^{a} \sigma_x(x)dx = \left(a^2 - a \cdot b + \frac{b^2}{3}\right) \cdot C + \left(a - \frac{b}{2}\right) \cdot D + E$$

if -D/2C < b/2 or -D/2C > a-b/2 , σ_{x3} is to be ignored. Otherwise, σ_{x3} is taken as:

$$\sigma_{x3} = \frac{1}{b} \cdot \int_{xmin}^{xmax} \sigma_x(x)dx = \frac{b^2}{12} \cdot C - \frac{D^2}{4 \cdot C} + E$$

where:

x_{min} = -b/2 - D/2C

x_{max} = b/2 - D/2C

The longitudinal stress is to be taken as:

$\sigma_x = Max(\sigma_{x1}, \sigma_{x2}, \sigma_{x3})$

The edge stress ratio is to be taken as:

$\psi_x = 1$

- For overall stiffened panel buckling and stiffener buckling assessments, the longitudinal stress σ_x applied on the shorter edge of the attached plate is to be taken as:

$$\sigma_x = \frac{\sum_{i=1}^{n} A_i \cdot \sigma_{xi}}{\sum_{i=1}^{n} A_i}$$

The edge stress ratio ψ_x for the stress σ_x is equal to 1,0.

b) **Transverse stress**

The transverse stress σ_y applied along the longer edges of the buckling panel is to be calculated by extrapolation of the transverse stresses of all elements up to the shorter edges of the considered buckling panel.

The distribution of $\sigma_y(x)$ is assumed as straight line. Therefore: $\sigma_y(x) = A+Bx$

The best fitting curve $\sigma_y(x)$ is to be obtained by the least square method minimising the square error Π considering area of each element as a weighting factor.

$$\Pi = \sum_{i=1}^{n} A_i \cdot [\sigma_{yi} - (A + Bx_i)]^2$$

The unknown coefficients C and D must yield zero first partial derivatives, $\partial\Pi$ with respect to C and D, respectively.

$$\frac{\partial\Pi}{\partial A} = 2 \cdot \sum_{i=1}^{n} A_i \cdot [\sigma_{yi} - (A + Bx_i)] = 0$$

$$\frac{\partial\Pi}{\partial B} = 2 \cdot \sum_{i=1}^{n} A_i \cdot x_i \cdot [\sigma_{yi} - (A + Bx_i)] = 0$$

The unknown coefficients A and B are obtained by solving the 2 above equations and are given as follow:

$$A = \frac{\left(\sum_{i=1}^{n} A_i \cdot \sigma_{yi}\right) \cdot \left(\sum_{i=1}^{n} A_i \cdot x_i^2\right) - \left(\sum_{i=1}^{n} A_i \cdot x_i\right) \cdot \left(\sum_{i=1}^{n} A_i \cdot x_i \cdot \sigma_{yi}\right)}{\left(\sum_{i=1}^{n} A_i\right) \cdot \left(\sum_{i=1}^{n} A_i \cdot x_i^2\right) - \left(\sum_{i=1}^{n} A_i \cdot x_i\right)^2}$$

$$B = \frac{\left(\sum_{i=1}^{n} A_i\right) \cdot \left(\sum_{i=1}^{n} A_i \cdot x_i \cdot \sigma_{yi}\right) - \left(\sum_{i=1}^{n} A_i \cdot x_i\right) \cdot \left(\sum_{i=1}^{n} A_i \cdot \sigma_{yi}\right)}{\left(\sum_{i=1}^{n} A_i\right) \cdot \left(\sum_{i=1}^{n} A_i \cdot x_i^2\right) - \left(\sum_{i=1}^{n} A_i \cdot x_i\right)^2}$$

The transverse stress is to be taken as:

$\sigma_y = max(A, A+Ba)$

The edge stress ratio is to be taken as:

$$\psi = \frac{min(A, A + B \cdot a)}{max(A, A + B \cdot a)} \quad \text{for} \quad \sigma_y > 0$$

$\psi_y = 1$ for $\sigma_y \le 0$

c) **Shear stress**

The shear stress τ is to be calculated using a weighted average approach, and is to be taken as:

$$\tau = \frac{\sum_{i=1} A_i \cdot \tau_i}{\sum_{i=1}^{n} A_i}$$

6.3.2 Irregular Panel and Curved Panel *(1/7/2024)*

a) **Reference stresses**

The longitudinal, transverse and shear stresses are to be calculated using a weighted average approach. They are to be taken as:

$$\sigma_x = \frac{\sum_{i=1}^{n} A_i \cdot \sigma_{xi}}{\sum_{i=1}^{n} A_i}$$

$$\sigma_y = \frac{\sum_{i=1}^{n} A_i \cdot \sigma_{yi}}{\sum_{i=1}^{n} A_i}$$

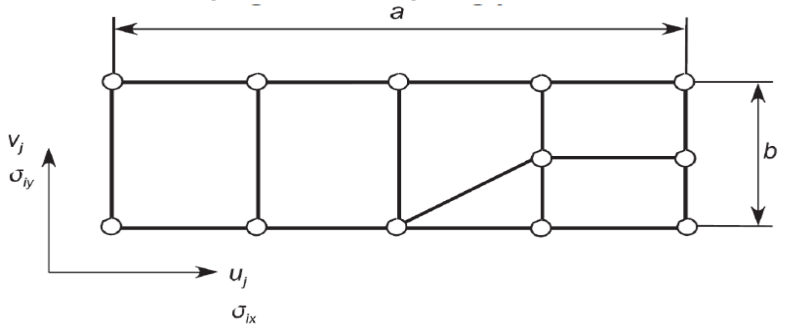
$$\tau = \frac{\sum_{i=1}^{n} A_i \cdot \tau_i}{\sum_{i=1}^{n} A_i}$$

The edge stress ratios are to be taken as

$\psi_x = 1$

$\psi_y = 1$

Figure 20 : Buckling panel *(1/7/2024)*



APPENDIX 1 ANALYSES BASED ON THREE DIMENSIONAL MODELS

Symbols

For symbols not defined in this Appendix, refer to the list at the beginning of this Chapter.

ρ : Sea water density, taken equal to 1,025 t/m³

g : Gravity acceleration, in m/s²:

$g = 9,81$ m/s²

h_1 : Reference values of the ship relative motions in the upright ship condition, defined in Ch 5, Sec 3, [3.3]

h_2 : Reference values of the ship relative motions in the inclined ship conditions, defined in Ch 5, Sec 3, [3.3]

$\alpha = \frac{T_1}{T}$

T_1 : draught, in m, corresponding to the loading condition considered

M_{SW} : Still water bending moment, in kN.m, at the hull transverse section considered

M_{WV} : Vertical wave bending moment, in kN.m, at the hull transverse section considered, defined in Ch 5, Sec 2, [3.1], having the same sign as M_{SW}

Q_{SW} : Still water shear force, in kN, at the hull transverse section considered

Q_{WV} : Vertical wave shear force, in kN, at the hull transverse section considered, defined in Ch 5, Sec 2, [3.4], having sign:

- where M_{WV} is positive (hogging condition):
  - positive for $x < 0,5L$
  - negative for $x \geq 0,5L$
- where M_{WV} is negative (sagging condition):
  - negative for $x < 0,5L$
  - positive for $x \geq 0,5L$

γ_{S1}, γ_{W1} : Partial safety factors, defined in Sec 3.

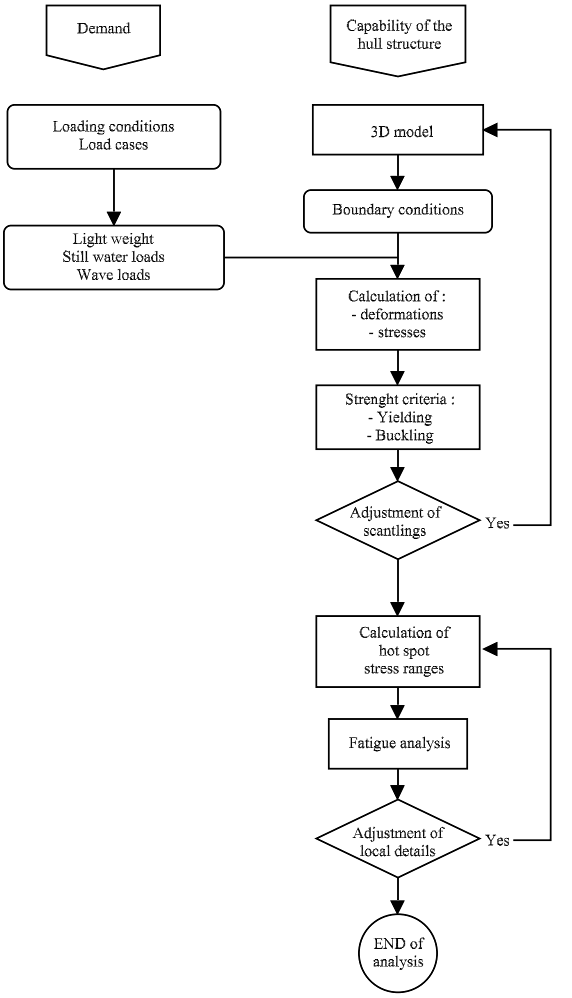
1 General

1.1 Application

1.1.1 The requirements of this Appendix apply for the analysis criteria, structural modelling, load modelling and stress calculation of primary supporting members which are to be analysed through three dimensional structural models, according to Sec 3.

The analysis application procedure is shown graphically in Fig 1.

Figure 1 : Application procedure of the analyses based on three dimensional models



1.1.2 This Appendix deals with that part of the structural analysis which aims at:

- calculating the stresses in the primary supporting members in the midship area and, when necessary, in other areas, which are to be used in the yielding and buckling checks
- calculating the hot spot stress ranges in the structural details which are to be used in the fatigue check.

1.1.3 The yielding and buckling checks of primary supporting members are to be carried out according to Sec 3.

The fatigue check of structural details is to be carried out according to Sec 4.

1.2 Information required

1.2.1 The following information is necessary to perform these structural analyses:

- general arrangement
- capacity plan
- structural plans of the areas involved in the analysis
- longitudinal sections and decks.

2 Analysis criteria

2.1 General

2.1.1 All primary supporting members in the midship regions are normally to be included in the three dimensional model, with the purpose of calculating their stress level and verifying their scantlings.

When the primary supporting member arrangement is such that the Society can accept that the results obtained for the midship region are extrapolated to other regions, no additional analyses are required. Otherwise, analyses of the other regions are to be carried out.

2.2 Finite element model analyses

2.2.1 For ships more than 150 m in length, finite element models, built according to [3.2] and [3.4], are generally to be adopted.

The analysis of primary supporting members is to be carried out on fine mesh models, as defined in [3.4.3].

2.2.2 Areas which appear, from the primary supporting member analysis, to be highly stressed may be required to be further analysed through appropriately meshed structural models, as defined in [3.4.4].

2.3 Beam model analyses

2.3.1 For ships less than 150 m in length, beam models built according to [3.5] may be adopted in lieu of the finite element models in [2.2.1], provided that:

- primary supporting members are not so stout that the beam theory is deemed inapplicable by the Society
- their behaviour is not substantially influenced by the transmission of shear stresses through the shell plating.

In any case, finite element models may need to be adopted when deemed necessary by the Society on the basis of the ship's structural arrangement.

2.4 Structural detail analysis

2.4.1 Structural details in Sec 4, [1.2.3], for which a fatigue analysis is to be carried out, are to be modelled as specified in [7].

3 Primary supporting members structural modelling

3.1 Model construction

3.1.1 Elements

The structural model is to represent the primary supporting members with the plating to which they are connected.

Ordinary stiffeners are also to be represented in the model in order to reproduce the stiffness and inertia of the actual hull girder structure. The way ordinary stiffeners are represented in the model depends on the type of model (beam or finite element), as specified in [3.4] and [3.5].

3.1.2 Net scantlings

All the elements in [3.1.1] are to be modelled with their net scantlings according to Ch 4, Sec 2, [1]. Therefore, also the hull girder stiffness and inertia to be reproduced by the model are those obtained by considering the net scantlings of the hull structures.

3.2 Model extension

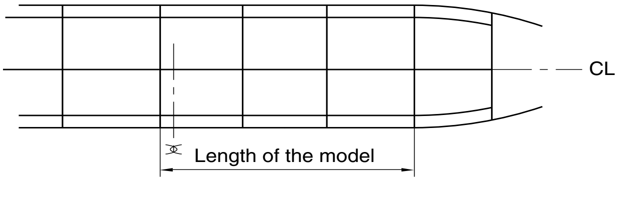
3.2.1 The longitudinal extension of the structural model is to be such that:

- the hull girder stresses in the area to be analysed are properly taken into account in the structural analysis
- the results in the areas to be analysed are not influenced by the unavoidable inaccuracy in the modelling of the boundary conditions.

3.2.2 In general, for multitank/hold ships more than 150 m in length, the conditions in [3.2.1] are considered as being satisfied when the model is extended over at least three cargo tank/hold lengths.

For the analysis of the midship area, this model is to be such that its aft end corresponds to the first transverse bulkhead aft of the midship, as shown in Fig 2. The structure of the fore and aft transverse bulkheads located within the model, including the bulkhead plating, is to be modelled.

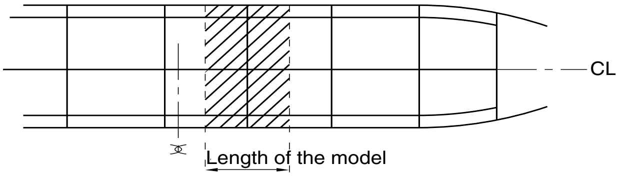
Figure 2 : Model longitudinal extension Ships more than 150 m in length



3.2.3 For ships less than 150 m in length, the model may be limited to one cargo tank/hold length (one half cargo tank/hold length on either side of the transverse bulkhead; see Fig 3).

However, larger models may need to be adopted when deemed necessary by the Society on the basis of the ship's structural arrangement.

Figure 3 : Model longitudinal extension Ships less than 150 m in length



3.2.4 In the case of structural symmetry with respect to the ship's centreline longitudinal plane, the hull structures may be modelled over half the ship's breadth.

3.3 Finite element modelling criteria

3.3.1 Modelling of primary supporting members

The analysis of primary supporting members based on fine mesh models, as defined in [3.4.3], is to be carried out by applying one of the following procedures (see Fig 4), depending on the computer resources:

- an analysis of the whole three dimensional model based on a fine mesh
- an analysis of the whole three dimensional model based on a coarse mesh, as defined in [3.4.2], from which the nodal displacements or forces are obtained to be used as boundary conditions for analyses based on fine mesh models of primary supporting members, e.g.:
  - transverse rings
  - double bottom girders
  - side girders
  - deck girders
  - primary supporting members of transverse bulkheads
  - primary supporting members which appear from the analysis of the whole model to be highly stressed.

3.3.2 Modelling of the most highly stressed areas

The areas which appear from the analyses based on fine mesh models to be highly stressed may be required to be further analysed, using the mesh accuracy specified in [3.4.4].

3.4 Finite element models

3.4.1 General

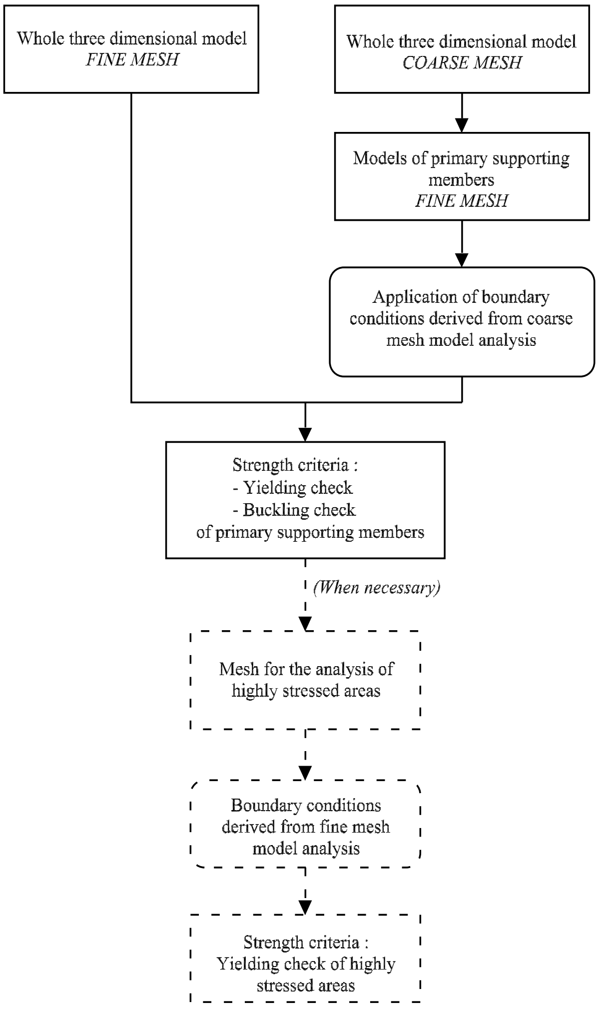
Finite element models are generally to be based on linear assumptions. The mesh is to be executed using membrane or shell elements, with or without mid-side nodes.

Meshing is to be carried out following uniformity criteria among the different elements.

In general, for some of the most common elements, the quadrilateral elements are to be such that the ratio between the longer side length and the shorter side length does not exceed 4 and, in any case, is less than 2 for most elements. Their angles are to be greater than 60° and less than 120°. The triangular element angles are to be greater than 30° and less than 120°.

Further modelling criteria depend on the accuracy level of the mesh, as specified in [3.4.2] to [3.4.4].

Figure 4 : Finite element modelling criteria



3.4.2 Coarse mesh

The number of nodes and elements is to be such that the stiffness and inertia of the model properly represent those of the actual hull girder structure, and the distribution of loads among the various load carrying members is correctly taken into account.

To this end, the structural model is to be built on the basis of the following criteria:

- ordinary stiffeners contributing to the hull girder longitudinal strength and which are not individually represented in the model are to be modelled by rod elements and grouped at regular intervals
- webs of primary supporting members may be modelled with only one element on their height
- face plates may be simulated with bars having the same cross-section
- the plating between two primary supporting members may be modelled with one element stripe
- holes for the passage of ordinary stiffeners or small pipes may be disregarded

- manholes (and similar discontinuities) in the webs of primary supporting members may be disregarded, but the element thickness is to be reduced in proportion to the hole height and the web height ratio.

In some specific cases, some of the above simplifications may not be deemed acceptable by the Society in relation to the type of structural model and the analysis performed.

3.4.3 Fine mesh

The ship's structure may be considered as finely meshed when each longitudinal ordinary stiffener is modelled; as a consequence, the standard size of finite elements used is based on the spacing of ordinary stiffeners.

The structural model is to be built on the basis of the following criteria:

- webs of primary members are to be modelled with at least three elements on their height
- the plating between two primary supporting members is to be modelled with at least two element stripes
- the ratio between the longer side and the shorter side of elements is to be less than 3 in the areas expected to be highly stressed
- holes for the passage of ordinary stiffeners may be disregarded.

In some specific cases, some of the above simplifications may not be deemed acceptable by the Society in relation to the type of structural model and the analysis performed.

3.4.4 Refined local mesh for the analysis of structural details *(1/7/2018)*

The structural modelling is to be as accurate as to enable a faithful representation of the stress gradients at structural detail level. The refined structural model is to be built on the basis of the following criteria:

- the size of elements in the area of interest is not to be greater than 50 mm x 50 mm
- the extent of the refined area is to be at least of 10 elements in any direction around its centre
- the element mesh size used in the way of rounded edges (openings corners, rounded brackets, etc.) should be such that to ensure at least 12 elements in a 90 degree arc of the edge of the plate
- the use of membrane elements is only allowed when significant bending effects are not present; in the other cases, elements with general behaviour are to be used
- the use of linear triangular elements is to be avoided as much as possible in high stress area; quadrilateral elements are to have 90° angles as much as possible, or angles between 60° and 120°; the aspect ratio is to be close to 1; when the use of a linear triangular element cannot be avoided, its edges are to have the same length
- in general, it may be convenient to carry out separate analyses of the areas concerned, where the boundary conditions are constituted by the nodal displacements and rotations obtained from the fine mesh model analysis. In these cases, it is recommended that nodal displacements and rotations to be assigned to refined local mesh models are based on finely mesh modelled parts, in such a way to better represent the local hull stiffness. However, it is also acceptable refined local mesh models being incorporated in the fine mesh models and assessed at same time. In these cases, transition zones should be properly arranged avoiding too rapid element refinements.

3.5 Beam models

3.5.1 Beams representing primary supporting members

Primary supporting members are to be modelled by beam elements with shear strain, positioned on their neutral axes, whose inertia characteristics are to be calculated as specified in Ch 4, Sec 3, [4].

3.5.2 Torsional moments of inertia

Whenever the torsional effects of the modelling beams are to be taken into account (e.g. for modelling the double bottom, hopper tanks and lower stools), their net torsional moments of inertia are obtained, in cm^4, from the following formulae:

- for open section beams (see Fig 5):

$$I_T = \frac{1}{3}\sum_i (t_i^3 \ell_i) 10^{-4}$$

- for box-type section beams, e.g. those with which hopper tanks and lower stools are modelled (see Fig 6):

$$I_T = \frac{4\Omega^2}{\sum_i \frac{\ell_i}{t_i}} 10^{-4}$$

- for beams of double skin structures (see Fig 7):

$$I_T = \frac{t_1 t_2 (b_1 + b_2) H_D^2}{2(t_1 + t_2)} 10^{-4}$$

where:

Σi : Sum of all the profile segments that constitute the beam section

t_i, ℓ_i : Net thickness and length, respectively, in mm, of the i-th profile segment of the beam section (see Fig 5 and Fig 6)

Ω : Area, in mm^2, of the section enclosed by the beam box profile (see Fig 6)

t_1, t_2 : Net thickness, in mm, of the inner and outer plating, respectively, (see Fig 7)

b_1, b_2 : Distances, in mm, from the beam considered to the two adjacent beams (see Fig 7)

H_D : Height, in mm, of the double skin (see Fig 7).

Figure 5 : Open section beams

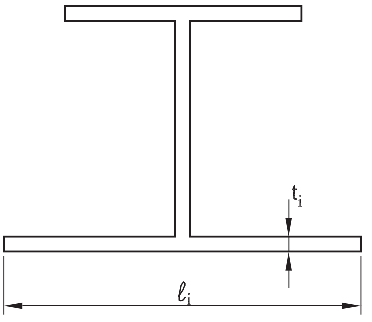


Figure 6 : Box-type section beams

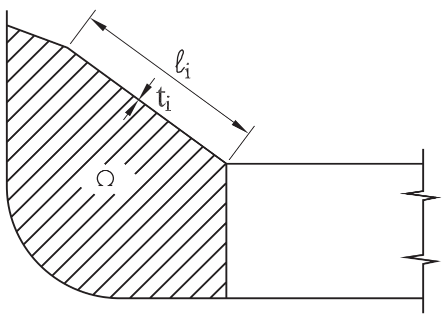
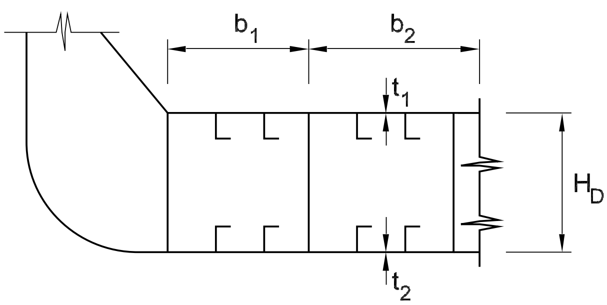


Figure 7 : Beams of double skin structures



3.5.3 Variable cross-section primary supporting members

In the case of variable cross-section primary supporting members, the inertia characteristics of the modelling beams may be assumed as a constant and equal to their average value along the length of the elements themselves.

3.5.4 Modelling of primary supporting members ends

The presence of end brackets may be disregarded; in such case their presence is also to be neglected for the evaluation of the beam inertia characteristics.

Rigid end beams are generally to be used to connect ends of the various primary supporting members, such as:

- floors and side vertical primary supporting members
- bottom girders and vertical primary supporting members of transverse bulkheads
- cross ties and side/longitudinal bulkhead primary supporting members.

3.5.5 Beams representing hull girder characteristics

The stiffness and inertia of the hull girder are to be taken into account by longitudinal beams positioned as follows:

- on deck and bottom in way of side shell and longitudinal bulkheads, if any, for modelling the hull girder bending strength
- on deck, side shell, longitudinal bulkheads, if any, and bottom for modelling the hull girder shear strength.

3.6 Boundary conditions of the whole three dimensional model

3.6.1 Structural model extended over at least three cargo tank/hold lengths

The whole three dimensional model is assumed to be fixed at its aft end, while shear forces and bending moments are applied at its fore end to ensure equilibrium (see [4]).

At the fore end section, rigid constraint conditions are to be applied to all nodes located on longitudinal members, in such a way that the transverse section remains plane after deformation.

When the hull structure is modelled over half the ship's breadth (see [3.2.4]), in way of the ship's centreline longitudinal plane, symmetry or anti-symmetry boundary conditions as specified in Tab 1 are to be applied, depending on the loads applied to the model (symmetrical or anti-symmetrical, respectively).

Table 1 : Symmetry and anti-symmetry conditions in way of the ship's centreline longitudinal plane

Boundary conditions	DISPLACEMENTS in directions **(1)**		
	X	Y	Z
Symmetry	free	fixed	free
Anti-symmetry	fixed	free	fixed

Boundary conditions	ROTATION around axes **(1)**		
	X	Y	Z
Symmetry	fixed	free	fixed
Anti-symmetry	free	fixed	free

(1) X, Y and Z directions and axes are defined with respect to the reference co-ordinate system in Ch 1, Sec 2, [4].

3.6.2 Structural models extended over one cargo tank/hold length

Symmetry conditions are to be applied at the fore and aft ends of the model, as specified in Tab 2.

Table 2 : Symmetry conditions at the model fore and aft ends

DISPLACEMENTS in directions **(1)**:			ROTATION around axes **(1)**:		
X	Y	Z	X	Y	Z
fixed	free	free	free	fixed	fixed

(1) X, Y and Z directions and axes are defined with respect to the reference co-ordinate system in Ch 1, Sec 2, [4].

When the hull structure is modelled over half the ship's breadth (see [3.2.4]), in way of the ship's centreline longitudinal plane, symmetry or anti-symmetry boundary conditions as specified in Tab 1 are to be applied, depending on the loads applied to the model (symmetrical or anti-symmetrical, respectively).

Vertical supports are to be fitted at the nodes positioned in way of the connection of the transverse bulkhead with longitudinal bulkheads, if any, and with sides.

4 Primary supporting members load model

4.1 General

4.1.1 Loading conditions and load cases in intact conditions *(1/7/2016)*

The still water and wave loads are to be calculated for the most severe loading conditions as given in the loading manual, with a view to maximising the stresses in the longitudinal structure and primary supporting members.

The following loading conditions are generally to be considered:

- homogeneous loading conditions at draught T
- non-homogeneous loading conditions at draught T, when applicable
- partial loading conditions at the relevant draught
- ballast conditions at the relevant draught.

The wave local and hull girder loads are to be calculated in the mutually exclusive load cases “a”, “b”, “c” and “d” in Ch 5, Sec 4.

For ships with the service notation **container ship**, the loading conditions specified in Tab 3 are to be considered in addition to those specified above.

Table 3 : Loading conditions to be considered for ships with the service notation container ship *(1/7/2016)*

Loading condition	Draught	Container weight	Ballast and fuel oil tanks	Still water hull girder moment
Full load condition	Scantling draught	Heavy cargo weight **(1)** (40' containers)	Empty	Permissible hogging
Full load condition	Scantling draught	Light cargo weight **(2)** (40' containers)	Empty	Permissible hogging
Full load condition	Reduced draught **(3)**	Heavy cargo weight **(1)** (20' containers)	Empty	Permissible hogging (minimum hogging)
One bay empty condition **(4)**	Scantling draught	Heavy cargo weight **(1)** (40' containers)	Empty	Permissible hogging

(1) Heavy cargo weight of a container unit is to be calculated as the permissible stacking weight divided by the maximum number of tiers planned.

(2) Light cargo weight corresponds to the expected cargo weight when light cargo is loaded in the considered holds.
- Light cargo weight of a container unit in hold is not to be taken more than 55% of its related heavy cargo weight (see **(1)**)
- Light cargo weight of a container unit on deck is not to be taken more than 90% of its related heavy cargo weight (see **(1)**) or 17 metric tons, whichever is the lesser.

(3) Reduced draught corresponds to the expected draught amidships when heavy cargo is loaded in the considered holds while lighter cargo is loaded in other holds. Reduced draught is not to be taken more than 90% of scantling draught.

(4) For one bay empty condition, if the cargo hold consists of two or more bays, then each bay is to be considered entirely empty in hold and on deck (other bays full) in turn as separate load cases.

4.1.2 Loading conditions and load cases in flooding conditions

When applicable, the pressures in flooding conditions are to be calculated according to Ch 5, Sec 6, [9].

4.1.3 Lightweight

The lightweight of the modelled portion of the hull is to be uniformly distributed over the length of the model in order to obtain the actual longitudinal distribution of the still water bending moment.

4.1.4 Models extended over half ship’s breadth

When the ship is symmetrical with respect to her centreline longitudinal plane and the hull structure is modelled over half the ship's breadth, non-symmetrical loads are to be broken down into symmetrical and anti-symmetrical loads and applied separately to the model with symmetry and anti-symmetry boundary conditions in way of the ship's centreline longitudinal plane (see [3.6]).

4.2 Local loads

4.2.1 General

Still water loads include:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal loads, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave loads include:

- the wave pressure, defined in [4.2.2] for each load case "a", "b", "c" and "d"
- the inertial loads, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast, and for each load case "a", "b", "c" and "d".

4.2.2 Wave loads

The wave pressure at any point of the model is obtained from the formulae in Tab 4 for upright ship conditions (load cases "a" and "b") and in Tab 5 for inclined ship conditions (load cases "c" and "d").

4.2.3 Distributed loads

Distributed loads are to be applied to the plating panels.

In the analyses carried out on the basis of membrane finite element models or beam models, the loads distributed perpendicularly to the plating panels are to be applied on the ordinary stiffeners proportionally to their areas of influence. When ordinary stiffeners are not modelled or are modelled with rod elements (see [3.4]), the distributed loads are to be applied to the primary supporting members actually supporting the ordinary stiffeners.

4.2.4 Concentrated loads

When the elements directly supporting the concentrated loads are not represented in the structural model, the loads are to be distributed on the adjacent structures according to the actual stiffness of the structures which transmit them.

In the analyses carried out on the basis of coarse mesh finite element models or beam models, concentrated loads applied in 5 or more points almost equally spaced inside the same span may be applied as equivalent linearly distributed loads.

4.2.5 Cargo in sacks, bales and similar packages

The vertical loads are comparable to distributed loads. The loads on vertical walls may be disregarded.

Table 4 : Wave pressure in upright ship conditions (load cases "a" and "b")

Location	Wave pressure p_W, in kN/m²	C_1	
		crest	trough **(1)**
Bottom and sides below the waterline with: $z \le T_1 - h$	$C_1 \rho g h e^{\frac{-2\pi(T_1 - z)}{\alpha L}}$	1,0	-1,0
Sides below the waterline with: $T_1 - h < z \le T_1$	$C_1 \rho g h e^{\frac{-2\pi(T_1 - z)}{\alpha L}}$	1,0	$\frac{z - T_1}{h}$
Sides above the waterline: $z > T_1$	$C_1 \rho g (T_1 + h - z)$	1,0	0,0

(1) The wave pressure for load case "b, trough" is to be used only for the fatigue check of structural details.

Note 1:

$h = \alpha^{1/4} C_{F1} h_1$

C_{F1} : Combination factor, to be taken equal to:

- C_{F1} = 1,0 for load case "a"
- C_{F1} = 0,5 for load case "b".

Table 5 : Wave pressure in inclined ship conditions (load cases “c” and “d”)

Location	Wave pressure p_W, in kN/m²	C_2 (negative roll angle)	
		$y \geq 0$	$y < 0$
Bottom and sides below the waterline with: $z \leq T_1 - h$	$C_2 C_{F2} \alpha^{1/4} \rho g \left[\frac{y}{B_W} h_1 e^{\frac{-2\pi(T_1 - z)}{\alpha L}} + A_R y e^{\frac{-\pi(T_1 - z)}{\alpha L}}\right]$	1,0	1,0
Sides below the waterline with: $T_1 - h < z \leq T_1$	$C_2 C_{F2} \alpha^{1/4} \rho g \left[\frac{y}{B_W} h_1 e^{\frac{-2\pi(T_1 - z)}{\alpha L}} + A_R y e^{\frac{-\pi(T_1 - z)}{\alpha L}}\right]$	1,0	$\frac{T_1 - z}{h}$
Sides above the waterline: $z > T_1$	$C_2 \rho g \left[T_1 + C_{F2} \alpha^{1/4} \left(\frac{y}{B_W} h_1 + A_R y\right) - z\right]$	1,0	0,0

Note 1:
$h = \alpha^{1/4} C_{F2} h_2$
C_{F2} : Combination factor, to be taken equal to:
- C_{F2} = 1,0 for load case “c”
- C_{F2} = 0,5 for load case “d”

B_W : Moulded breadth, in m, measured at the waterline at draught T_1, at the hull transverse section considered
A_R : Roll amplitude, defined in Ch 5, Sec 3, [2.4.1].

Table 6 : Hull girder loads - Maximal bending moments at the middle of the central tank/hold *(1/7/2016)*

Ship condition	Load case	Vertical bending moments at the middle of the central tank/hold		Horizontal wave bending moment at the middle of the central tank/hold	Vertical shear forces at the middle of the central tank/hold	
		Still water	Wave		Still water	Wave
Upright	“a” crest	$\gamma_{S1} M_{SW}$	0,625 $\gamma_{W1} M_{WV,H}$ **(1)**	0	0	0
	“a” trough	$\gamma_{S1} M_{SW}$	0,625 $\gamma_{W1} M_{WV,S}$ **(1)**	0	0	0
	“b”	$\gamma_{S1} M_{SW}$	0,625 $\gamma_{W1} M_{WV,S}$ **(1)**	0	0	0
Inclined	“c”	$\gamma_{S1} M_{SW}$	0,25 $\gamma_{W1} M_{WV}$ **(1)**	0,625 $\gamma_{W1} M_{WH}$	$\gamma_{S1} Q_{SW}$	0,25 $\gamma_{W1} Q_{WV}$ **(2)**
	“d”	$\gamma_{S1} M_{SW}$	0,25 $\gamma_{W1} M_{WV}$ **(1)**	0,625 $\gamma_{W1} M_{WH}$	$\gamma_{S1} Q_{SW}$	0,25 $\gamma_{W1} Q_{WV}$ **(2)**

(1) For ships with the service notation **container ship** the vertical wave bending moment M_{WH} is to be taken as defined in Pt E, Ch 2, App 1
(2) For ships with the service notation **container ship** the vertical wave shear force Q_{WH} is to be taken as defined in Pt E, Ch 2, App 1
Note 1: Hull girder loads are to be calculated at the middle of the central tank/hold.

4.2.6 Other cargoes

The modelling of cargoes other than those mentioned under [4.2.3] to [4.2.5] will be considered by the Society on a case by case basis.

4.3 Hull girder loads

4.3.1 Structural model extended over at least three cargo tank/hold lengths

The hull girder loads are constituted by:

- the still water and wave vertical bending moments
- the horizontal wave bending moment
- the still water and wave vertical shear forces

and are to be applied at the model fore end section. The shear forces are to be distributed on the plating according to the theory of bidimensional flow of shear stresses.

These loads are to be applied separately for the following two conditions:

- maximal bending moments at the middle of the central tank/hold: the hull girder loads applied at the fore end section are to be such that the values of the hull girder loads in Tab 6 are obtained
- maximal shear forces in way of the aft transverse bulkhead of the central tank/hold: the hull girder loads applied at the fore end section are to be such that the values of the hull girder loads in Tab 7 are obtained.

4.3.2 Structural model extended over one cargo tank/hold length

The normal and shear stresses induced by the hull girder loads in Tab 8 are to be added to the stresses induced in the primary supporting members by local loads.

4.4 Additional requirements for the load assignment to beam models

4.4.1 Vertical and transverse concentrated loads are to be applied to the model, as shown in Fig 8, to compensate the portion of distributed loads which, due to the positioning of beams on their neutral axes, are not modelled.

In this figure, F_Y and F_Z represent concentrated loads equivalent to the dashed portion of the distributed loads which is not directly modelled.

Table 7 : Hull girder loads - Maximal shear forces in way of the aft bulkhead of the central tank/hold *(1/7/2018)*

Ship condition	Load case	Vertical bending moments in way of the aft bulkhead of the central tank/hold		Vertical shear forces in way of the aft bulkhead of the central tank/hold	
		Still water	Wave	Still water	Wave
Upright	"a" crest	$\gamma_{S1}\, M_{SW}$	$0{,}4\ \gamma_{W1}\, M_{WV}$ **(1)**	$\gamma_{S1}\, Q_{SW}$	$0{,}625\ \gamma_{W1}\, Q_{WV}$ **(2)**
	"a" trough	$\gamma_{S1}\, M_{SW}$	$0{,}4\ \gamma_{W1}\, M_{WV}$ **(1)**	$\gamma_{S1}\, Q_{SW}$	$0{,}625\ \gamma_{W1}\, Q_{WV}$ **(2)**
	"b"	$\gamma_{S1}\, M_{SW}$	$0{,}4\ \gamma_{W1}\, M_{WV}$ **(1)**	$\gamma_{S1}\, Q_{SW}$	$0{,}625\ \gamma_{W1}\, Q_{WV}$ **(2)**
Inclined	"c"	$\gamma_{S1}\, M_{SW}$	$0{,}25\ \gamma_{W1}\, M_{WV}$ **(1)**	$\gamma_{S1}\, Q_{SW}$	$0{,}25\ \gamma_{W1}\, Q_{WV}$ **(2)**
	"d"	$\gamma_{S1}\, M_{SW}$	$0{,}25\ \gamma_{W1}\, M_{WV}$ **(1)**	$\gamma_{S1}\, Q_{SW}$	$0{,}25\ \gamma_{W1}\, Q_{WV}$ **(2)**

(1) For ships with the service notation **container ship** the vertical wave bending moment M_{WH} is to be taken as defined in Pt E, Ch 2, App 1

(2) For ships with the service notation **container ship** the vertical wave shear force Q_{WH} is to be taken as defined in Pt E, Ch 2, App 1

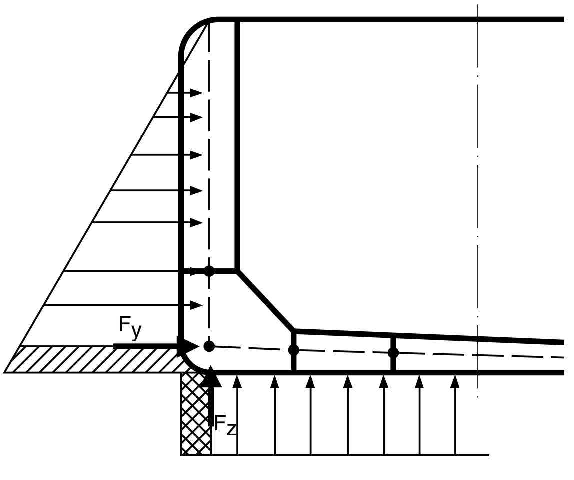
Note 1: Hull girder loads are to be calculated in way of the aft bulkhead of the central tank/hold.

Table 8 : Hull girder loads for a structural model extended over one cargo tank/hold length

Ship condition	Load case	Vertical bending moments at the middle of the model		Horizontal wave bending moment at the middle of the model	Vertical shear forces at the middle of the model	
		Still water	Wave		Still water	Wave
Upright	"a" crest	$\gamma_{S1}\, M_{SW}$	$0{,}625\ \gamma_{W1}\, M_{WV,H}$	0	$\gamma_{S1}\, Q_{SW}$	$0{,}625\ \gamma_{W1}\, Q_{WV}$
	"a" trough	$\gamma_{S1}\, M_{SW}$	$0{,}625\ \gamma_{W1}\, M_{WV,S}$	0	$\gamma_{S1}\, Q_{SW}$	$0{,}625\ \gamma_{W1}\, Q_{WV}$
	"b"	$\gamma_{S1}\, M_{SW}$	$0{,}625\ \gamma_{W1}\, M_{WV,S}$	0	$\gamma_{S1}\, Q_{SW}$	$0{,}625\ \gamma_{W1}\, Q_{WV}$
Inclined	"c"	$\gamma_{S1}\, M_{SW}$	$0{,}25\ \gamma_{W1}\, M_{WV}$	$0{,}625\ \gamma_{W1}\, M_{WH}$	$\gamma_{S1}\, Q_{SW}$	$0{,}25\ \gamma_{W1}\, Q_{WV}$
	"d"	$\gamma_{S1}\, M_{SW}$	$0{,}25\ \gamma_{W1}\, M_{WV}$	$0{,}625\ \gamma_{W1}\, M_{WH}$	$\gamma_{S1}\, Q_{SW}$	$0{,}25\ \gamma_{W1}\, Q_{WV}$

Note 1: Hull girder loads are to be calculated at the middle of the model.

Figure 8 : Concentrated loads equivalent to non-modelled distributed loads



5 Stress calculation

5.1 Analyses based on finite element models

5.1.1 Stresses induced by local and hull girder loads

When finite element models extend over at least three cargo tank/hold lengths, both local and hull girder loads are to be directly applied to the model, as specified in [4.3.1]. In this case, the stresses calculated by the finite element program include the contribution of both local and hull girder loads.

When finite element models extend over one cargo tank/hold length, only local loads are directly applied to the structural model, as specified in [4.3.2]. In this case, the stresses calculated by the finite element program include the contribution of local loads only. Hull girder stresses are to be calculated separately and added to the stresses induced by local loads.

5.1.2 Stress components

Stress components are generally identified with respect to the element co-ordinate system, as shown, by way of example, in Fig 9. The orientation of the element co-ordinate system may or may not coincide with that of the reference co-ordinate system in Ch 1, Sec 2, [4].

The following stress components are to be calculated at the centroid of each element:

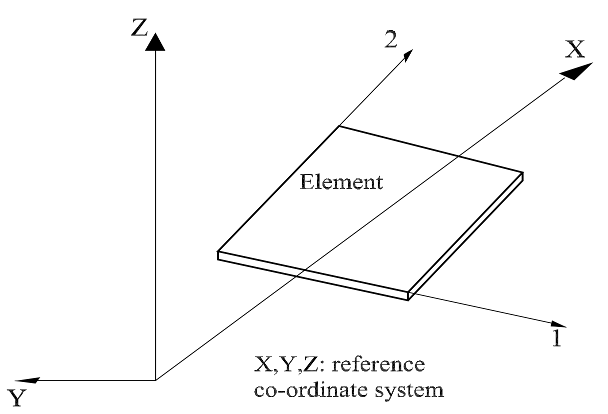
- the normal stresses σ_1 and σ_2 in the directions of the element co-ordinate system axes
- the shear stress τ_{12} with respect to the element co-ordinate system axes
- the Von Mises equivalent stress, obtained from the following formula:

$$\sigma_{VM} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2 + 3\tau_{12}^2}$$

5.1.3 Stress calculation points

Stresses are generally calculated by the computer programs for each element. The values of these stresses are to be used for carrying out the checks required.

Figure 9 : Reference and element co-ordinate systems



5.2 Analyses based on beam models

5.2.1 Stresses induced by local and hull girder loads

Since beam models generally extend over one cargo tank/hold length (see [2.3.1] and [3.2.3]), only local loads are directly applied to the structural model, as specified in [4.3.2]. Therefore, the stresses calculated by the beam program include the contribution of local loads only. Hull girder stresses are to be calculated separately and added to the stresses induced by local loads.

5.2.2 Stress components

The following stress components are to be calculated:

- the normal stress σ_1 in the direction of the beam axis
- the shear stress τ_{12} in the direction of the local loads applied to the beam
- the Von Mises equivalent stress, obtained from the following formula:

$$\sigma_{VM} = \sqrt{\sigma_1^2 + 3\tau_{12}^2}$$

5.2.3 Stress calculation points

Stresses are to be calculated at least in the following points of each primary supporting member:

- in the primary supporting member span where the maximum bending moment occurs
- at the connection of the primary supporting member with other structures, assuming as resistant section that formed by the member, the bracket (if any and if represented in the model) and the attached plating
- at the toe of the bracket (if any and if represented in the model) assuming as resistant section that formed by the member and the attached plating.

The values of the stresses are to be used for carrying out the checks required.

6 Buckling analysis based on fine mesh model

6.1 Buckling panel definition

6.1.1 *(1/7/2018)*

Buckling panel is the representative entity adopted such as to identify an elementary plate panel along its spacing and span; this can be composed by one or more plate elements of the fine mesh model.

6.1.2 Thickness of buckling panel *(1/7/2018)*

Net thickness is to be used in buckling checks of the buckling panel.

When the buckling panel consists of a number of finite plate elements then the weighted-by-area average thickness, in mm, is to be used, defined as follows:

$$t^* = \frac{\sum A_j \cdot t_j}{\sum A_j}$$

where:

A_j : Area of the j[th] plate element making up the panel, in mm^2

t_j : Net thickness of the j[th] plate element making up the panel, in mm.

6.1.3 Yield stress of buckling panel *(1/7/2018)*

When the buckling panel consists of a number of finite plate elements having different material yield strength, the lowest value is to be adopted.

6.2 Reference stresses on buckling panel

6.2.1 *(1/7/2018)*

The reference stresses on buckling panels consisting of a number of finite plate elements may be obtained by means of the weighted-by-area of elemental stresses, in N/mm², as follow:

$$\sigma_x^* = \frac{\sum_{I=1}^{n} A_i \cdot \sigma_{x_i}}{\sum_{I}^{n} A_i} \geq 0$$

$$\sigma_y^* = \frac{\sum_{I=1}^{n} A_i \cdot \sigma_{y_i}}{\sum_{I}^{n} A_i} \geq 0$$

$$\tau_{xy}^* = \frac{\sum_{I=1}^{n} A_i \cdot |\tau_{xy_i}|}{\sum_{I}^{n} A_i} \geq 0$$

where:

Compression is positive, tensile is negative.

x,y : co-ordinates in elemental reference-system,

σ_{xi} : membrane stress in x-direction at the centroid of the ith plate element of the panel, in mm²,

σ_{yi} : membrane stress in y-direction at the centroid of the ith plate element of the panel, in mm²,

τ_{xyi} : membrane shear stress at the centroid of the ith plate element of the panel, in mm²,

A_i : Area of the jth plate element making up the panel, in mm² ,

n : number of elements in the buckling panel.

When σ_{xi} or σ_{yi} are in tension, then the respective value is to be taken as zero.

6.2.2 *(1/7/2018)*

The bending stress ratios ψ are taken as 1.

6.3 Checking criteria

6.3.1 *(1/7/2018)*

Buckling checks of the buckling panels are to be performed according to Sec 1, [5.4].

7 Fatigue analysis

7.1 Elementary hot spot stress range calculation

7.1.1 General

The requirements of this Article apply for calculating the elementary hot spot stress range for the fatigue check of structural details at the connections of primary supporting members analysed through a three dimensional structural model. The fatigue check of these details is to be carried out in accordance with the general requirements of Sec 4, [1] to Sec 4, [5].

The definitions in Sec 4, [1.3] apply.

7.1.2 Net scantlings

The three dimensional structural model is to be built considering all the structures with their net scantlings according to Ch 4, Sec 2, [1].

7.1.3 Hot spot stresses directly obtained through finite element analyses

Where the structural detail is analysed through a finite element analysis based on a very fine mesh, the elementary hot spot stress range may be obtained as the difference between the maximum and minimum stresses induced by the wave loads in the hot spot considered.

The requirements for:

- the finite element modelling, and
- the calculation of the hot spot stresses and the hot spot stress range

are specified in [7.2].

7.1.4 Hot spot stresses directly obtained through the calculation of nominal stresses

Where the structural detail is analysed through a finite element analysis based on a mesh less fine than that in [7.1.3], the elementary hot spot stress range may be obtained by multiplying the nominal stress range, obtained as the difference between the maximum and minimum nominal stresses induced by the wave loads in the vicinity of the hot spot considered, by the appropriate stress concentration factors.

The requirements for:

- the finite element modelling
- the calculation of the nominal stresses and the nominal stress range
- the stress concentration factors
- the calculation of the hot spot stresses and the hot spot stress range

are specified in [7.3].

7.2 Hot spot stresses directly obtained through finite element analyses

7.2.1 Finite element model

In general, the determination of hot spot stresses necessitates carrying out a very fine mesh finite element analysis, further to a coarser mesh finite element analysis. The boundary nodal displacements or forces obtained from the coarser mesh model are applied to the very fine mesh model as boundary conditions.

The model extension is to be such as to enable a faithful representation of the stress gradient in the vicinity of the hot spot and to avoid it being incorrectly affected by the application of the boundary conditions.

7.2.2 Finite element modelling criteria *(1/7/2018)*

The finite element model is to be built according to the following requirements:

- the detail may be considered as being realised with no misalignment
- the size of finite elements located in the vicinity of the hot spot is to be about once to twice the thickness of the

structural member. Where the details is the connection between two or more members of different thickness, the thickness to be considered is that of the thinnest member

- a "t x t" mesh scheme has to be applied in the proximity of the hot spot, with the centres of the first and second elements adjacent to a weld toe to be located at respectively 0,5 and 1,5 times the thickness "t" of the thinnest structural member connected by the weld
- plating, webs and face plates of primary and secondary members are to be modelled by 4-node thin shell or 8-node solid elements. In the case of a steep stress gradient, 8-node thin shell elements or 20-node solid elements are recommended
- when thin shell elements are used, the structure is to be modelled at mid-face of the plates
- the aspect ratio of elements is to be not greater than 3

7.2.3 Calculation of hot spot stresses *(1/7/2018)*

The hot spot stresses are to be based on the stresses at the centroids of the elements adjacent to the hot spot.

The linear extrapolation of element centroidal stresses to the hot spot location is generally deemed sufficient.

The stress components to be considered are those specified in Sec 4, [3.1.2]. They are to be calculated at the surface of the plate in order to take into account the plate bending moment, where relevant.

Where the detail is the free edge of an opening (e.g. a cut-out for the passage of an ordinary stiffener through a primary supporting member), fictitious truss elements with minimal stiffness may needed to be fitted along the edge to calculate the hot spot stresses.

7.2.4 Calculation of the elementary hot spot stress range

The elementary hot spot stress range is to be obtained, in N/mm², from the following formula:

$$\Delta\sigma_{S,ij} = |\sigma_{S,ij,max} - \sigma_{S,ij,min}|$$

where:

$\sigma_{S,ij,max}$, $\sigma_{S,ij,min}$: Maximum and minimum values of the hot spot stress, induced by the maximum and minimum loads, defined in Sec 4, [2.2] and Sec 4, [2.3]

i : Denotes the load case

j : Denotes the loading condition.

7.3 Hot spot stresses obtained through the calculation of nominal stresses

7.3.1 Finite element model

A finite element is to be adopted, to be built according to the requirements in [3.3] and [3.4]. The areas in the vicinity of the structural details are to be modelled with fine mesh models, as defined in [3.4.3].

7.3.2 Calculation of the elementary nominal stress range

The elementary nominal stress range is to be obtained, in N/mm², from the following formula:

$$\Delta\sigma_{n,ij} = |\sigma_{n,ij,max} - \sigma_{n,ij,min}|$$

where:

$\sigma_{n,ij,max}$, $\sigma_{n,ij,min}$: Maximum and minimum values of the nominal stress, induced by the maximum and minimum loads, defined in Sec 4, [2.2] and Sec 4, [2.3]

i : Denotes the load case

j : Denotes the loading condition.

7.3.3 Calculation of the elementary hot spot stress range

The elementary hot spot stress range is to be obtained, in N/mm², from the following formula:

$$\Delta\sigma_{S,ij} = K_S \Delta\sigma_{n,ij}$$

where:

K_S : Stress concentration factor, defined in Ch 12, Sec 2, [2], for the relevant detail configuration

$\Delta\sigma_{n,ij}$: Elementary nominal stress range, defined in [7.3.2].

APPENDIX 2 ANALYSES OF PRIMARY SUPPORTING MEMBERS SUBJECTED TO WHEELED LOADS

1 General

1.1 Scope

1.1.1 The requirements of this Appendix apply for the analysis criteria, structural modelling, load modelling and stress calculation of primary supporting members subjected to wheeled loads which are to be analysed through three dimensional structural models, according to Sec 3.

1.1.2 The purpose of these structural analyses is to determine:

- the distribution of the forces induced by the vertical acceleration acting on wheeled cargoes, among the various primary supporting members of decks, sides and possible bulkheads
- the behaviour of the above primary supporting members under the racking effects due to the transverse forces induced by the transverse acceleration acting on wheeled cargoes, when the number or location of transverse bulkheads are not sufficient to avoid such effects

and to calculate the stresses in primary supporting members.

The above calculated stresses are to be used in the yielding and buckling checks.

In addition, the results of these analyses may be used, where deemed necessary by the Society, to determine the boundary conditions for finer mesh analyses of the most highly stressed areas.

1.1.3 When the behaviour of primary supporting members under the racking effects, due to the transverse forces induced by the transverse acceleration, is not to be determined, the stresses in deck primary supporting members may be calculated according to the simplified analysis in [6], provided that the conditions for its application are fulfilled (see [6.1]).

1.1.4 The yielding and buckling checks of primary supporting members are to be carried out according to Sec 3, [4.3].

1.2 Application

1.2.1 The requirements of this Appendix apply to ships whose structural arrangement is such that the following assumptions may be considered as being applicable:

- primary supporting members of side and possible bulkheads may be considered fixed in way of the double bottom (this is generally the case when the stiffness of floors is at least three times that of the side primary supporting members)
- under transverse inertial forces, decks behave as beams loaded in their plane and supported at the ship ends; their effect on the ship transverse rings (side primary supporting members and deck beams) may therefore be simulated by means of elastic supports in the transverse direction or transverse displacements assigned at the central point of each deck beam.

1.2.2 When the assumptions in [1.2.1] are considered by the Society as not being applicable, the analysis criteria are defined on a case by case basis, taking into account the ship's structural arrangement and loading conditions. In such cases, the analysis is generally to be carried out on the basis of a finite element model of the whole ship, built according to the requirements in App 1, as far as applicable.

1.3 Information required

1.3.1 The following information is necessary to perform these structural analyses:

- general arrangement
- structural plans of the areas involved in the analysis
- longitudinal sections and decks
- characteristics of vehicles loaded: load per axles, arrangement of wheels on axles, tyre dimensions.

1.4 Lashing of vehicles

1.4.1 The presence of lashing for vehicles is generally to be disregarded, but may be given consideration by the Society, on a case by case basis, at the request of the interested parties.

2 Analysis criteria

2.1 Finite element model analyses

2.1.1 For ships greater than 200 m in length, finite element models, built according to App 1, [3.4], are generally to be adopted.

The analysis of primary supporting members is to be carried out on fine mesh models, as defined in App 1, [3.4.3].

2.1.2 Areas which appear, from the primary supporting member analysis, to be highly stressed may be required to be further analysed through appropriately meshed structural models, as defined in App 1, [3.4.4].

2.2 Beam model analyses

2.2.1 For ships less than 200 m in length, beam models, built according to App 1, [3.5], may be adopted in lieu of the finite element models in [2.1], provided that:

- primary supporting members are not so stout that the beam theory is deemed inapplicable by the Society
- their behaviour is not substantially influenced by the transmission of shear stresses through the shell plating.

2.2.2 In any case, finite element models may need to be adopted when deemed necessary by the Society on the basis of the ship's structural arrangement.

3 Primary supporting members structural modelling

3.1 Model construction

3.1.1 Elements

The structural model is to represent the primary supporting members with the plating to which they are connected. In particular, the following primary supporting members are to be included in the model:

- deck beams
- side primary supporting members
- primary supporting members of longitudinal and transverse bulkheads, if any
- pillars
- deck beams, deck girders and pillars supporting ramps and deck openings, if any.

3.1.2 Net scantlings

All the elements in [3.1.1] are to be modelled with their net scantlings according to Ch 4, Sec 2, [1].

3.2 Model extension

3.2.1 The structural model is to represent a hull portion which includes the zone under examination and which is repeated along the hull. The non-modelled hull parts are to be considered through boundary conditions as specified in [3.3].

In addition, the longitudinal extension of the structural model is to be such that the results in the areas to be analysed are not influenced by the unavoidable inaccuracy in the modelling of the boundary conditions.

3.2.2 Double bottom structures are not required to be included in the model, based on the assumptions in [1.2.1].

3.3 Boundary conditions of the three dimensional model

3.3.1 Boundary conditions at the lower ends of the model

The lower ends of the model (i.e. the lower ends of primary supporting members of side and possible bulkheads) are to be considered as being clamped in way of the inner bottom.

3.3.2 Boundary conditions at the fore and aft ends of the model

Symmetry conditions are to be applied at the fore and aft ends of the model, as specified in Tab 1.

Table 1 : Symmetry conditions at the model fore and aft ends

DISPLACEMENTS in directions **(1)**:			ROTATION around axes **(1)**:		
X	Y	Z	X	Y	Z
fixed	free	free	free	fixed	fixed
(1) X, Y and Z directions and axes are defined with respect to the reference co-ordinate system in Ch 1, Sec 2, [4].					

3.3.3 Additional boundary conditions at the fore and aft ends of models subjected to transverse loads

When the model is subjected to transverse loads, i.e. when the loads in inclined ship conditions (as defined in Ch 5, Sec 4) are applied to the model, the transverse displacements of the deck beams are to be obtained by means of a racking analysis and applied at the fore and aft ends of the model, in way of each deck beam.

For ships with a traditional arrangement of fore and aft parts, a simplified approximation may be adopted, when deemed acceptable by the Society, defining the boundary conditions without taking into account the racking calculation and introducing springs, acting in the transverse direction, at the fore and aft ends of the model, in way of each deck beam (see Fig 1). Each spring, which simulates the effects of the deck in way of which it is modelled, has a stiffness obtained, in kN/m, from the following formula:

$$R_D = \frac{48EJ_D s_a 10^3}{2x^4 - 4L_D x^3 + L_D^2\left(x^2 + 15,6\dfrac{J_D}{A_D}\right) + L_D^3 x}$$

where:

J_D : Net moment of inertia, in m^4, of the average cross-section of the deck, with the attached side shell plating

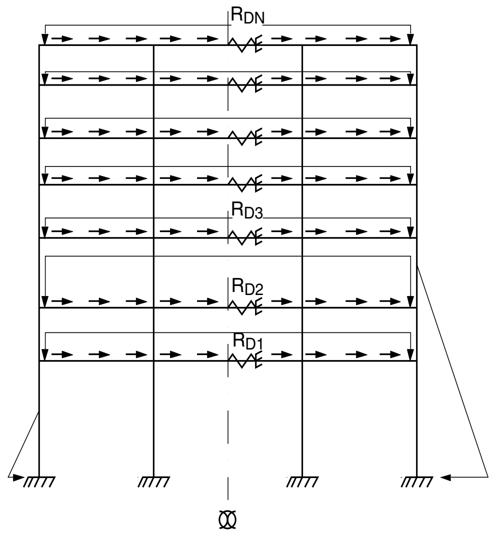
A_D : Net area, in m^2, of the average cross-section of deck plating.

s_a : Spacing of side vertical primary supporting members, in m

x : Longitudinal distance, in m, measured from the transverse section at mid-length of the model to any deck end

L_D : Length of the deck, in m, to be taken equal to the ship's length. Special cases in which such value may be reduced will be considered by the Society on a case by case basis.

Figure 1 : Springs at the fore and aft ends of models subjected to transverse loads



4 Load model

4.1 General

4.1.1 Hull girder and local loads

Only local loads are to be directly applied to the structural model.

The stresses induced by hull girder loads are to be calculated separately and added to the stresses induced by local loads.

4.1.2 Loading conditions and load cases: wheeled cargoes

The still water and wave loads are to be calculated for the most severe loading conditions as given in the loading manual, with a view to maximising the stresses in primary supporting members.

The loads transmitted by vehicles are to be applied taking into account the most severe axle positions for the ship structures.

The wave local loads and hull girder loads are to be calculated in the mutually exclusive load cases “b” and “d” in Ch 5, Sec 4. Load cases “a” and “c” may be disregarded for the purposes of the structural analyses dealt with in this Appendix.

4.1.3 Loading conditions and load cases: dry uniform cargoes

When the ship’s decks are also designed to carry dry uniform cargoes, the loading conditions which envisage the transportation of such cargoes are also to be considered. The still water and wave loads induced by these cargoes are to be calculated for the most severe loading conditions, with a view to maximising the stresses in primary supporting members.

The wave local loads and hull girder loads are to be calculated in the mutually exclusive load cases “b” and “d” in Ch 5, Sec 4. Load cases “a” and “c” may be disregarded for the purposes of the structural analyses dealt with in this Appendix.

4.2 Local loads

4.2.1 General

Still water loads include:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water forces induced by wheeled cargoes, defined in Ch 5, Sec 6, Tab 8.

Wave induced loads include:

- the wave pressure, defined in Ch 5, Sec 5, [2] for load cases “b” and “d”
- the inertial forces defined in Ch 5, Sec 6, Tab 8 for load cases “b” and “d”.

When the ship’s decks are also designed to carry dry uniform cargoes, local loads also include the still water and inertial pressures defined in Ch 5, Sec 6, [4]. Inertial pressures are to be calculated for load cases “b” and “d”.

4.2.2 Tyred vehicles

For the purpose of primary supporting members analyses, the forces transmitted through the tyres may be considered as concentrated loads in the tyre print centre.

The forces acting on primary supporting members are to be determined taking into account the area of influence of each member and the way ordinary stiffeners transfer the forces transmitted through the tyres.

4.2.3 Non-tyred vehicles

The requirements in [4.2.2] also apply to tracked vehicles. In this case, the print to be considered is that below each wheel or wheelwork.

For vehicles on rails, the loads transmitted are to be applied as concentrated loads.

4.2.4 Distributed loads

In the analyses carried out on the basis of beam models or membrane finite element models, the loads distributed perpendicularly to the plating panels are to be applied on the primary supporting members proportionally to their areas of influence.

4.3 Hull girder loads

4.3.1 The normal stresses induced by the hull girder loads in Tab 2 are to be added to the stresses induced in the primary supporting members by local loads.

Table 2 : Hull girder loads

Ship condition	Load case	Vertical bending moments at the middle of the model		Horizontal wave bending moment at the middle of the model
		Still water	Wave	
Upright	"b"	M_{SW}	0,625 $M_{WV,S}$	0
Inclined	"d"	M_{SW}	0,25 M_{WV}	0,625 M_{WH}

Note 1:
M_{SW} : Still water bending moment at the middle of the model, for the loading condition considered
$M_{WV,S}$: Sagging wave bending moments at the middle of the model, defined in Ch 5, Sec 2
M_{WV} : Wave bending moment at the middle of the model, defined in Ch 5, Sec 2, having the same sign as M_{SW}
M_{WH} : Horizontal wave bending moment at the middle of the model, defined in Ch 5, Sec 2.

5 Stress calculation

5.1 Stresses induced by local and hull girder loads

5.1.1 Only local loads are directly applied to the structural model, as specified in [4.1.1]. Therefore, the stresses calculated by the program include the contribution of local loads only. Hull girder stresses are to be calculated separately and added to the stresses induced by local loads.

5.2 Analyses based on finite element models

5.2.1 Stress components

Stress components are generally identified with respect to the element co-ordinate system, as shown, by way of example, in Fig 2. The orientation of the element co-ordinate system may or may not coincide with that of the reference co-ordinate system in Ch 1, Sec 2, [4].

The following stress components are to be calculated at the centroid of each element:

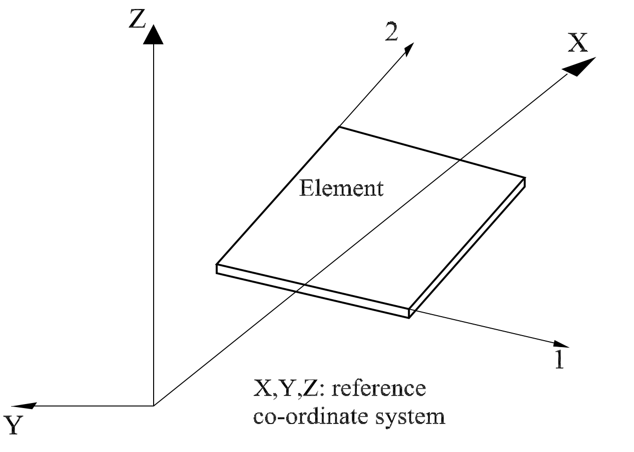
- the normal stresses σ_1 and σ_2 in the directions of element co-ordinate system axes
- the shear stress τ_{12} with respect to the element co-ordinate system axes
- the Von Mises equivalent stress, obtained from the following formula:

$$\sigma_{VM} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2 + 3\tau_{12}^2}$$

5.2.2 Stress calculation points

Stresses are generally calculated by the computer programs for each element. The values of these stresses are to be used for carrying out the checks required.

Figure 2 : Reference and element co-ordinate systems



5.3 Analyses based on beam models

5.3.1 Stress components

The following stress components are to be calculated:

- the normal stress σ_1 in the direction of the beam axis
- the shear stress τ_{12} in the direction of the local loads applied to the beam
- the Von Mises equivalent stress, obtained from the following formula:

$$\sigma_{VM} = \sqrt{\sigma_1^2 + 3\tau_{12}^2}$$

5.3.2 Stress calculation points

Stresses are to be calculated at least in the following points of each primary supporting member:

- in the primary supporting member span where the maximum bending moment occurs
- at the connection of the primary supporting member with other structures, assuming as resistant section that formed by the member, the bracket (if any and if represented in the model) and the attached plating
- at the toe of the bracket (if any and if represented in the model) assuming as resistant section that formed by the member and the attached plating.

The values of the stresses calculated in the above points are to be used for carrying out the checks required.

6 Grillage analysis of primary supporting members of decks

6.1 Application

6.1.1 For the sole purpose of calculating the stresses in deck primary supporting members, due to the forces induced by the vertical accelerations acting on wheeled cargoes, these members may be subjected to the simplified two dimensional analysis described in [6.2].

This analysis is generally considered as being acceptable for usual structural typology, where there are neither pillar lines, nor longitudinal bulkheads.

6.2 Analysis criteria

6.2.1 Structural model

The structural model used to represent the deck primary supporting members is a beam grillage model.

6.2.2 Model extension

The structural model is to represent a hull portion which includes the zone under examination and which is repeated along the hull. The non-modelled hull parts are to be considered through boundary conditions as specified in [3.3].

6.3 Boundary conditions

6.3.1 Boundary conditions at the fore and aft ends of the model

Symmetry conditions are to be applied at the fore and aft ends of the model, as specified in Tab 1.

6.3.2 Boundary conditions at the connections of deck beams with side vertical primary supporting members

Vertical supports are to be fitted at the nodes positioned in way of the connection of deck beams with side primary supporting members.

The contribution of flexural stiffness supplied by the side primary supporting members to the deck beams is to be simulated by springs, applied at their connections, having rotational stiffness, in the plane of the deck beam webs, obtained, in kN.m/rad, from the following formulae:

- for intermediate decks:

$$R_F = \frac{3E(J_1 + J_2)(\ell_1 + \ell_2)}{\ell_1^2 + \ell_2^2 - \ell_1 \ell_2} 10^{-5}$$

- for the uppermost deck:

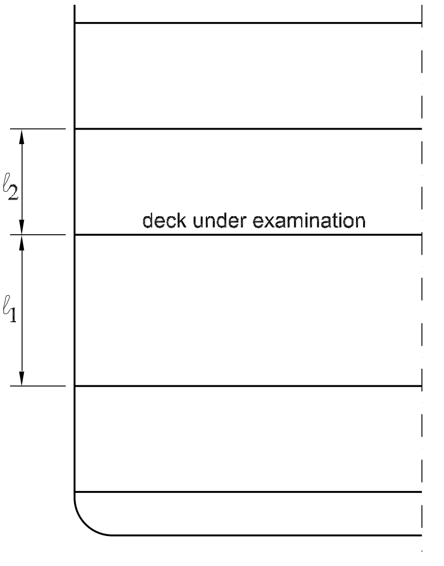
$$R_F = \frac{6EJ_1}{\ell_1} 10^{-5}$$

where:

ℓ_1, ℓ_2 : Height, in m, of the 'tweendecks, respectively below and above the deck under examination (see Fig 3)

J_1, J_2 : Net moments of inertia, in cm^4, of side primary supporting members with attached shell plating, relevant to the 'tweendecks, respectively below and above the deck under examination.

Figure 3 : Heights of tween-decks for grillage analysis of deck primary supporting members



6.4 Load model

6.4.1 Hull girder and local loads are to be calculated and applied to the model according to [4].

Wave loads are to be calculated considering load case "b" only.

6.5 Stress calculation

6.5.1 Stress components are to be calculated according to [5.1] and [5.3].

APPENDIX 3 ANALYSES BASED ON COMPLETE SHIP MODELS

Symbols

$\gamma_{S1}, \gamma_{W1}, \gamma_{S2}, \gamma_{W2}$: Partial safety factors defined in Sec 3

λ : Wave length, in m.

1 General

1.1 Application

1.1.1 The requirements of this Appendix apply for the analysis criteria, structural modelling, load modelling and stress calculation of primary supporting members which are to be analysed through a complete ship model, according to Sec 3.

1.1.2 This Appendix deals with that part of the structural analysis which aims at calculating the stresses in the primary supporting members and more generally in the hull plating, to be used for yielding and buckling checks.

1.1.3 The yielding and buckling checks of primary supporting members are to be carried out according to Sec 3.

1.2 Information required

1.2.1 The following information is necessary to perform these structural analyses:

- general arrangement
- capacity plan
- lines plan
- structural plans
- longitudinal sections and decks
- loading manual.

2 Structural modelling

2.1 Model construction

2.1.1 Elements

The structural model is to represent the primary supporting members with the plating to which they are connected.

Ordinary stiffeners are also to be represented in the model in order to reproduce the stiffness and the inertia of the actual hull girder structure.

2.1.2 Net scantlings

All the elements in [2.1.1] are to be modelled with their net scantlings according to Ch 4, Sec 2. Therefore, also the hull girder stiffness and inertia to be reproduced by the model are those obtained by considering the net scantlings of the hull structures.

2.2 Model extension

2.2.1 The complete ship is to be modelled so that the coupling between torsion and horizontal bending is properly taken into account in the structural analysis.

Superstructures are to be modelled in order to reproduce the correct lightweight distribution.

Long superstructures of ships with one of the service notations **passenger ship** and **ro-ro passenger ship** are to be modelled in order to also reproduce the correct hull global strength, in particular the contribution of each superstructure deck to the hull girder longitudinal strength.

2.2.2 In the case of structural symmetry with respect to the ship's centreline longitudinal plane, the hull structures may be modelled over half the ship's breadth.

2.3 Finite element modelling criteria

2.3.1 Modelling of primary supporting members

The analyses of primary supporting members are to be based on fine mesh models, as defined in App 1, [3.4.3].

Such analyses may be carried out deriving the nodal displacements or forces, to be used as boundary conditions, from analyses of the complete ships based on coarse meshes, as defined in App 1, [3.4.2].

The areas for which analyses based on fine mesh models are to be carried out are listed in Tab 1 for various types of ships.

Other areas may be required to be analysed through fine mesh models, where deemed necessary by the Society, depending on the ship's structural arrangement and loading conditions as well as the results of the coarse mesh analysis.

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2.3.2 Modelling of the most highly stressed areas

The areas which appear from the analyses based on fine mesh models to be highly stressed may be required to be further analysed, using the mesh accuracy specified in App 1, [3.4.4].

Table 1 : Areas to be analysed through fine mesh models

Service notation	Areas
container ship	• typical transverse reinforced frames • hatch corners and hatch coamings of the strength deck • connection of the cross-deck box beams to the longitudinal bulkheads and hatch coamings • connection of the longitudinal deck girders to the transverse bulkheads • end connections of hatch coamings including connection with the fore front of the superstructures, if any • cut-outs in the longitudinal bulkheads, longitudinal deck girders, hatch coamings, and cross-deck box beams.
ro-ro cargo ship	• typical reinforced transverse rings • typical deck girders • areas of structural discontinuity (e.g. ramp areas).
passenger ship	• areas in way of typical side and deck openings • areas of significant discontinuity in primary supporting member arrangements (e.g. in way of lounges, large public spaces, theatres).
ro-ro passenger ship	• typical reinforced transverse rings • typical deck girders • areas of structural discontinuity (e.g. ramp areas) • areas in way of typical side and deck openings • areas of significant discontinuity in primary supporting member arrangements (e.g. in way of lounges, large public spaces).

2.4 Finite element models

2.4.1 General

Finite element models are generally to be based on linear assumptions. The mesh is to be executed using membrane or shell elements, with or without mid-side nodes.

Meshing is to be carried out following uniformity criteria among the different elements.

In general, for some of the most common elements, the quadrilateral elements are to be such that the ratio between the longer side length and the shorter side length does not exceed 4 and, in any case, is less than 2 for most elements. Their angles are to be greater than 60° and less than 120°. The triangular element angles are to be greater than 30° and less than 120°.

Further modelling criteria depend on the accuracy level of the mesh, as specified in [2.4.2] to [2.4.4].

2.4.2 Coarse mesh

The number of nodes and elements is to be such that the stiffness and the inertia of the model represent properly those of the actual hull girder structure, and the distribution of loads among the various load carrying members is correctly taken into account.

To this end, the structural model is to be built on the basis of the following criteria:

- ordinary stiffeners contributing to the hull girder longitudinal strength and which are not individually represented in the model are to be modelled by rod elements and grouped at regular intervals
- webs of primary supporting members may be modelled with only one element on their height
- face plates may be simulated with bars having the same cross-section
- the plating between two primary supporting members may be modelled with one element stripe
- holes for the passage of ordinary stiffeners or small pipes may be disregarded
- manholes (and similar discontinuities) in the webs of primary supporting members may be disregarded, but the element thickness is to be reduced in proportion to the hole height and the web height ratio.

In some specific cases, some of the above simplifications may not be deemed acceptable by the Society in relation to the type of structural model and the analysis performed.

2.4.3 Fine mesh

The ship’s structure may be considered as finely meshed when each longitudinal secondary stiffener is modelled; as a consequence, the standard size of finite elements used is based on the spacing of ordinary stiffeners.

The structural model is to be built on the basis of the following criteria:

- webs of primary members are to be modelled with at least three elements on their height
- the plating between two primary supporting members is to be modelled with at least two element stripes
- the ratio between the longer side and the shorter side of elements is to be less than 3 in the areas expected to be highly stressed
- holes for the passage of ordinary stiffeners may be disregarded.

In some specific cases, some of the above simplifications may not be deemed acceptable by the Society in relation to the type of structural model and the analysis performed.

2.4.4 Mesh for the analysis of structural details

The structural modelling is to be accurate; the mesh dimensions are to be such as to enable a faithful representation of the stress gradients. The use of membrane elements is only allowed when significant bending effects are not present; in other cases, elements with general behaviour are to be used.

2.5 Boundary conditions of the model

2.5.1 In order to prevent rigid body motions of the overall model, the constraints specified in Tab 2 are to be applied.

2.5.2 When the hull structure is modelled over half the ship's breadth (see [2.2.2]), in way of the ship's centreline longitudinal plane, symmetry or anti-symmetry boundary conditions as specified in Tab 3 are to be applied, depending on the loads applied to the model (respectively symmetrical or anti-symmetrical).

Table 2 : Boundary conditions to prevent rigid body motion of the model

Boundary conditions	DISPLACEMENTS in directions **(1)**		
	X	Y	Z
One node on the fore end of the ship	free	fixed	fixed
One node on the port side shell at aft end of the ship **(2)**	fixed	free	fixed
One node on the starboard side shell at aft end of the ship **(2)**	free	fixed	fixed

Boundary conditions	ROTATION around axes **(1)**		
	X	Y	Z
One node on the fore end of the ship	free	free	free
One node on the port side shell at aft end of the ship **(2)**	free	free	free
One node on the starboard side shell at aft end of the ship **(2)**	free	free	free

(1) X, Y and Z directions and axes are defined with respect to the reference co-ordinate system in Ch 1, Sec 2, [4].
(2) The nodes on the port side shell and that on the starboard side shell are to be symmetrical with respect to the ship's longitudinal plane of symmetry.

Table 3 : Symmetry and anti-symmetry conditions in way of the ship's centreline longitudinal plane

Boundary conditions	DISPLACEMENTS in directions **(1)**		
	X	Y	Z
Symmetry	free	fixed	free
Anti-symmetry	fixed	free	fixed

Boundary conditions	ROTATION around axes **(1)**		
	X	Y	Z
Symmetry	fixed	free	fixed
Anti-symmetry	free	fixed	free

(1) X, Y and Z directions and axes are defined with respect to the reference co-ordinate system in Ch 1, Sec 2, [4].

3 Load model

3.1 General

3.1.1 Local loads

Still water loads include:

- the still water sea pressure, defined in Ch 5, Sec 5, [1]
- the still water internal loads, defined in Ch 5, Sec 6 for the various types of cargoes and for ballast.

Wave loads, determined by mean of hydrodynamic calculations according to [3.2], include:

- the wave pressure
- the inertial loads.

3.1.2 Hull girder loads

The hull girder loads are constituted by:

- still water hull girder loads
- wave hull girder loads, to be calculated according to [3.2].

3.1.3 Lightweight

The lightweight of the ship is to be uniformly distributed over the model length, in order to obtain the actual longitudinal distribution of the still water bending moment.

3.1.4 Models extended over half ship's breadth

When the ship is symmetrical with respect to her centreline longitudinal plane and the hull structure is modelled over half the ship's breadth, non-symmetrical loads are to be broken down into symmetrical and anti-symmetrical loads and applied separately to the model with symmetry and anti-symmetry boundary conditions in way of the ship's centreline longitudinal plane (see [2.5.2]).

3.2 Load cases

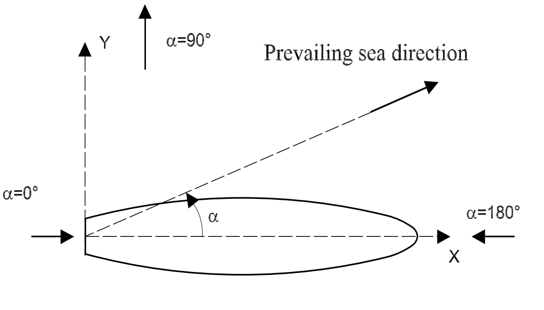
3.2.1 Equivalent waves

Wave loads are to be calculated for different load cases.

For each load case, the ship is considered to encounter a regular wave, defined by its parameters:

- wave length
- heading angle (see Fig 1)
- wave height
- phase.

Figure 1 : Wave heading



3.2.2 Load effects

The parameters listed in [3.2.1] are to be such that they maximise, and make equal to the target values specified in [3.2.3], the following load effects (one for each load case):

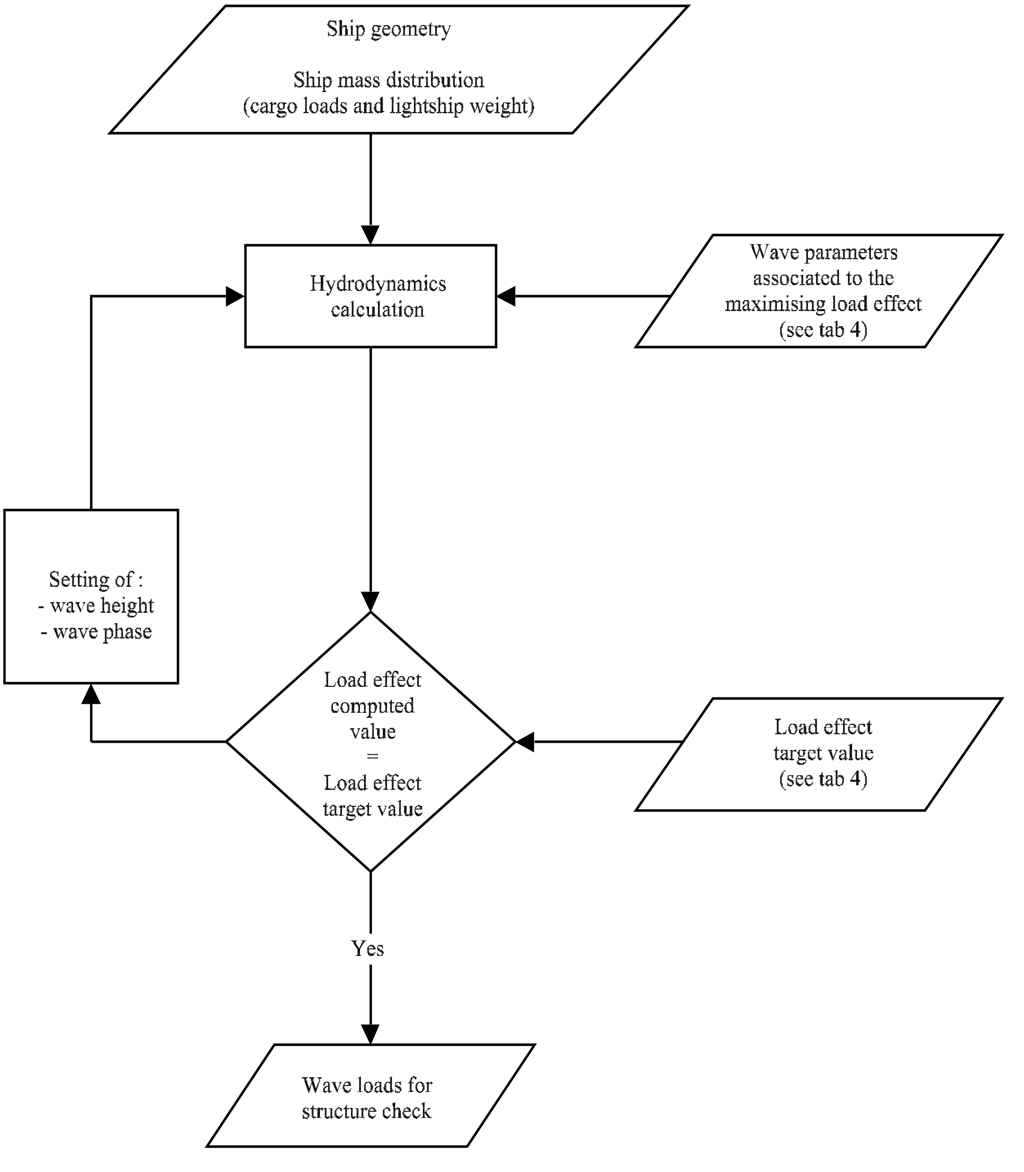
- vertical wave bending moment in hogging condition at midship section
- vertical wave bending moment in sagging condition at midship section
- vertical wave shear force on transverse bulkheads
- wave torque for ships with large deck openings at midship section
- transverse acceleration and roll angle
- vertical relative motion at sides in upright ship condition, at midship section.
- vertical relative motion at sides in inclined ship condition, at midship section

3.2.3 Value of loads effects

The wave lengths and headings which maximise each load effect are specified in Tab 4.

The wave amplitudes and phases are to be defined so that the target values in Tab 4 are attained by the maximised load effect, according to the procedure shown in Fig 2.

Figure 2 : Wave parameter calculations



4 Stress calculation

4.1 Stress components

4.1.1 Stress components are generally identified with respect to the element co-ordinate system, as shown, by way of example, in Fig 3. The orientation of the element co-ordinate system may or may not coincide with that of the reference co-ordinate system in Ch 1, Sec 2, [4].

The following stress components are to be calculated at the centroid of each element:

- the normal stresses σ_1 and σ_2 in the directions of element co-ordinate system axes
- the shear stress τ_{12} with respect to the element co-ordinate system axes
- the Von Mises equivalent stress, obtained from the following formula:

$$\sigma_{VM} = \sqrt{\sigma_1^2 + \sigma_2^2 - \sigma_1\sigma_2 + 3\tau_{12}^2}$$

Figure 3 : Reference and element co-ordinate systems

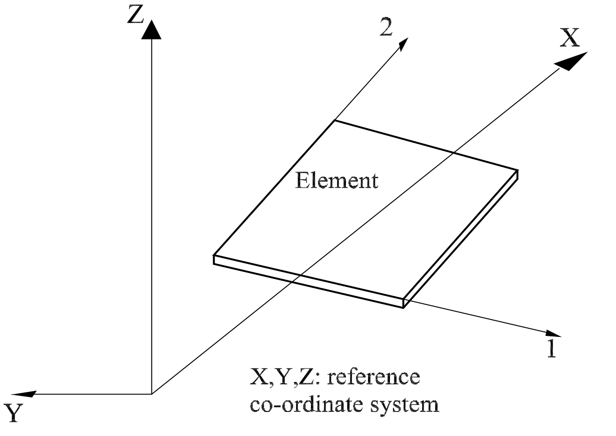


Table 4 : Load cases and load effect values *(1/7/2016)*

Load case	Maximised effect	Wave parameters **(2)**		Target		References
		λ/L	Heading angle	Value	Location(s)	
1	Vertical wave bending moment in hogging condition	1,0	180°	$0{,}625\gamma_{W1}M_{WV,H}$	Midship section	$M_{WV,H}$ defined in Ch 5, Sec 2, [3.1.1] **(3)**
2	Vertical wave bending moment in sagging condition and vertical acceleration	1,0	180°	$0{,}625\gamma_{W1}M_{WV,S}$	Midship section	$M_{WV,S}$ defined in Ch 5, Sec 2, [3.1.1] **(3)**
3	Vertical wave shear force	1,0	0° or 180°	$0{,}625\gamma_{W1}Q_{WV}$	Each transverse bulkhead	Q_{WV} defined in Ch 5, Sec 2, [3.4] **(4)**
4	Wave torque **(1)**	0,5	60°	$0{,}625\gamma_{W1}M_{WT}$	Midship section	M_T defined in Ch 5, Sec 2, [3.3]
5	Transverse acceleration and roll angle	3,0	90°	$\gamma_{W2}A_{TY}$		A_{TY} defined in Ch 5, Sec 6, [1.2.2]
6	Vertical relative motion at sides in upright ship condition, at midship section	1,0	180°	$\gamma_{W2}h_1$	Midship section	h_1 defined in Ch 5, Sec 3, [3.3.1]
7	Vertical relative motion at sides in inclined ship condition, at midship section	0,7	90°	$\gamma_{W2}h_2$	Midship section	h_2 defined in Ch 5, Sec 3, [3.3.2]

(1) This load case is to be considered for ships with large deck openings only.
(2) The forward ship speed is to be taken equal to 0,6V.
(3) For ships with the service notation **container ship** the vertical wave bending moment M_{WH} is to be taken as defined in Pt E, Ch 2, App 1
(4) For ships with the service notation **container ship** the vertical wave shear force Q_{WH} is to be taken as defined in Pt E, Ch 2, App 1

Part B
Hull and Stability

Chapter 8
SHIPS LESS THAN 90 M IN LENGTH

Symbols used in chapter 8

E : Young's modulus, in N/mm^2, to be taken equal to:
- for steels in general: $E = 2,06 \cdot 10^5$ N/mm^2
- for stainless steels: $E = 1,95 \cdot 10^5$ N/mm^2
- for aluminium alloys: $E = 7,0 \cdot 10^4$ N/mm^2

ν : Poisson's ratio. Unless otherwise specified, a value of 0,3 is to be taken into account,

k : material factor, defined in:
- Pt B, Ch 4, Sec 1, [2.3], for steel,
- Pt B, Ch 4, Sec 1, [4.4], for aluminium alloys,

R_y : Minimum yield stress, in N/mm^2, of the material, to be taken equal to 235/k N/mm^2, unless otherwise specified,

t_c : corrosion addition, in mm, defined in Pt B, Ch 4, Sec 2, Tab 2,

$M_{SW,H}$: Design still water bending moment, in kN.m, in hogging condition, at the hull transverse section considered, defined in Pt B, Ch 8, Sec 1, [2.2],

$M_{SW,S}$: Design still water bending moment, in kN.m, in sagging condition, at the hull transverse section considered, defined in Pt B, Ch 8, Sec 1, [2.2],

$M_{SW,Hmin}$: Minimum still water bending moment, in kN.m, in hogging condition, at the hull transverse section considered, without being taken greater than $0,3M_{WV,S}$,

$M_{WV,H}$: Vertical wave bending moment, in kN.m, in hogging condition, at the hull transverse section considered, defined in Pt B, Ch 8, Sec 1, [2.3],

$M_{WV,S}$: Vertical wave bending moment, in kN.m, in sagging condition, at the hull transverse section considered, defined in Pt B, Ch 8, Sec 1, [2.3],

g : Gravity acceleration, in m/s^2: $g = 9,81$ m/s^2,

x, y, z : X, Y and Z co-ordinates, in m, of the calculation point with respect to the reference co-ordinate system defined in Pt B, Ch 1, Sec 2, [4].

SECTION 1 DESIGN LOADS

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

n, n_1 : Navigation coefficients, defined in [1.5]

C : Wave parameter:

$$C = (118 - 0,36L)\frac{L}{1000}$$

F : Froude's number:

$$F = 0,164\frac{V}{\sqrt{L}}$$

V : Contractual service speed, in knots

a_B : Motion and acceleration parameter:

$$a_B = n\left(0,76F + 1,875\frac{h_W}{L}\right)$$

h_W : Wave parameter, in m:

$$h_W = 11,44 - \left|\frac{L-250}{110}\right|^3$$

h_1 : Reference value of the ship relative motion, in m, defined in [3.3.1]

a_{X1}, a_{Z1} : Reference values of the accelerations, in m/s^2, defined in [3.3.2].

1 General

1.1 Definitions

1.1.1 Still water loads

Still water loads are those acting on the ship at rest in calm water.

1.1.2 Wave loads

Wave loads are those due to wave pressures and ship motions, which can be assumed to have the same period as the inducing waves.

1.1.3 Local loads

Local loads are pressures and forces which are directly applied to the individual structural members: plating panels, ordinary stiffeners and primary supporting members.

- Still water local loads are constituted by the hydrostatic external sea pressures and the static pressures and forces induced by the weights carried in the ship spaces.
- Wave local loads are constituted by the external sea pressures due to waves and the inertial pressures and forces induced by the ship accelerations applied to the weights carried in the ship spaces.

For the structures which form the boundary of spaces not intended to carry liquids and which do not belong to the outer shell, the still water and wave pressures in flooding conditions are also to be considered.

1.1.4 Hull girder loads

Hull girder loads are still water and wave bending moments which result as effects of local loads acting on the ship as a whole and considered as a girder.

1.1.5 Loading condition

A loading condition is a distribution of weights carried in the ship spaces arranged for their storage.

1.1.6 Load case

A load case is a state of the ship structures subjected to a combination of hull girder and local loads.

1.2 Application criteria

1.2.1 Requirements applicable to all types of ships

The still water and wave loads defined in this Section are to be used for the determination of the hull girder strength and structural scantlings in the central part (see Ch 1, Sec 1) of ships less than 90 m in length, according to the requirements in Sec 2, Sec 3, Sec 4 and Sec 5.

1.2.2 Requirements applicable to specific ship types

The design loads applicable to specific ship types are to be defined in accordance with the requirements in Part E.

1.3 Hull girder loads

1.3.1 The still water and wave bending moment to be used for the determination of:

- the hull girder strength, according to the requirements of Sec 2
- the structural scantling of plating, ordinary stiffeners and primary supporting members contributing to the hull girder strength, in combination with the local loads given in [4] and [5], according to the requirements in Sec 3, Sec 4 and Sec 5,

are specified in [2].

1.4 Local loads

1.4.1 General

The local loads defined in [1.1.3] are to be calculated as specified in [1.4.2] for the elements of the outer shell and in [1.4.3] for the other elements.

1.4.2 Local loads for the elements of the outer shell

The local loads are to be calculated considering separately:

- the still water and wave external sea pressures, defined in [4]
- the still water and wave internal pressure, defined in [5], considering the compartment adjacent to the outer shell as being loaded.

1.4.3 Local loads for elements other than those of the outer shell

The local loads are to be calculated considering the still water and wave internal pressure, defined in [5].

When calculating the local loads for the structural scantling of an element which separates two adjacent compartments, the latter may not be considered simultaneously loaded. The local loads to be used are those obtained considering the two compartments individually loaded.

1.4.4 Flooding conditions

The still water and wave pressures in flooding conditions are specified in [5.8].

1.5 Navigation coefficients

1.5.1 The navigation coefficients, which appear in the formulae of this Section for the definition of wave hull girder and local loads, are defined in Tab 1 depending on the assigned navigation notation.

Table 1 : Navigation coefficients

Navigation notation	Navigation coefficient n	Navigation coefficient n_1
Unrestricted navigation	1,00	1,00
Summer zone	0,90	0,95
Tropical zone	0,80	0,90
Coastal area	0,80	0,90
Sheltered area	0,65	0,80

2 Hull girder loads

2.1 General

2.1.1 Application

The requirements of this Article apply to ships having the following characteristics:

- L < 90 m
- L / B > 5
- B / D < 2,5
- $C_B \geq 0,6$

Ships not having one or more of the following characteristics, ships intended for the carriage of heated cargoes and ships of unusual type or design are considered by the Society on a case by case basis.

2.1.2 Hull girder load components

Hull girder loads include the still water and wave vertical bending moments.

In the case of ships with large openings in the strength deck, the Society may require longitudinal strength calculations to take into account also wave horizontal bending moments and torques, when deemed necessary on the basis of the ship's characteristics and intended service.

2.1.3 Sign conventions of bending moments

The hull girder bending moment is positive when it induces tensile stresses in the strength deck (hogging bending moment); it is negative in the opposite case (sagging bending moment).

2.2 Still water bending moments

2.2.1 For all ships, the longitudinal distributions of still water bending moment are to be calculated, for all the design loading conditions on which the approval of hull structural scantlings is based, on the basis of realistic data related to the amount of cargo, ballast, fuel, lubricating oil and fresh water. Except for docking condition afloat, departure and arrival conditions are to be considered. For conventional ships, these calculations may not be required when they are considered unnecessary by the Society on the basis of the ship's length and loading conditions.

The actual hull lines and lightweight distribution are to be taken into account in the calculations. The lightweight distribution may be replaced, if the actual values are not available, by a statistical distribution of weights accepted by the Society.

The Designer is to supply the data necessary to verify the calculations of still water loads.

2.2.2 The design still water bending moments $M_{SW,H}$ and $M_{SW,S}$ at any hull transverse section are the maximum still water bending moments calculated, in hogging and sagging conditions, respectively, at that hull transverse section for the loading conditions specified in [2.2.1].

Where no sagging bending moments act in the hull section considered, the value of $M_{SW,S}$ is to be taken as specified in Sec 3, Sec 4 and Sec 5.

2.2.3 If the design still water bending moments are not defined, at a preliminary design stage, their absolute values amidships are to be taken not less than the values obtained, in kN.m, from the following formulae:

- in hogging conditions:

$$M_{SWM,H} = 175 n_1 C L^2 B (C_B + 0,7) 10^{-3} - M_{WV,H}$$

- in sagging conditions:

$$M_{SWM,S} = 175 n_1 C L^2 B (C_B + 0,7) 10^{-3} + M_{WV,S}$$

where $M_{WV,H}$ and $M_{WV,S}$ are the vertical wave bending moments, in kN.m, defined in [2.3].

2.3 Vertical wave bending moments

2.3.1 The vertical wave bending moments at any hull transverse section are obtained, in kN.m, from the following formulae:

- hogging conditions

$$M_{WV,H} = 190 F_M n C L^2 B C_B 10^{-3}$$

- sagging conditions

$$M_{WV,S} = -110 F_M n C L^2 B (C_B + 0,7) 10^{-3}$$

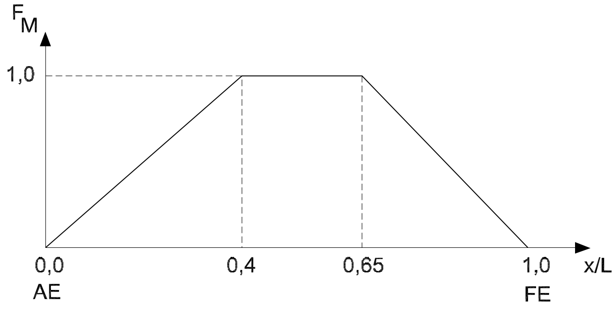
where:

F_M : Distribution factor defined in Tab 2 (see also Fig 1).

Table 2 : Distribution factor F_M

Hull transverse section location	Distribution factor F_M
$0 \le x < 0,4L$	$2,5\frac{x}{L}$
$0,4L \le x \le 0,65L$	1
$0,65L < x \le L$	$2,86\left(1 - \frac{x}{L}\right)$

Figure 1 : Distribution factor F_M



3 Ship motions and accelerations

3.1 General

3.1.1 Ship motions and accelerations are defined, with their sign, according to the reference co-ordinate system in Ch 1, Sec 2, [4].

3.1.2 Ship motions and accelerations are assumed to be periodic. The motion amplitudes, defined by the formulae of this Article, are half of the crest to through amplitudes.

3.2 Ship absolute motions and accelerations

3.2.1 Surge

The surge acceleration a_{SU} is to be taken equal to 0,5 m/s².

3.2.2 Heave

The heave acceleration is obtained, in m/s², from the following formula:

$$a_H = a_B g$$

3.2.3 Pitch

The pitch amplitude and acceleration are obtained from the formulae in Tab 3.

Table 3 : Pitch amplitude and acceleration

Amplitude A_P, in rad	Acceleration α_P, in rad/s²
$0,328 a_B \left(1,32 - \frac{h_W}{L}\right)\left(\frac{0,6}{C_B}\right)^{0,75}$	$A_p\left(\frac{2\pi}{0,575\sqrt{L}}\right)^2$

Table 4 : Reference values of the ship relative motion

Location	Reference value of the relative motion h_1, in m
x = 0	$0,7\left(\frac{4,35}{\sqrt{C_B}} - 3,25\right)h_{1,M}$ if $C_B < 0,875$ $h_{1,M}$ if $C_B \ge 0,875$
0 < x < 0,3L	$h_{1,AE} - \frac{h_{1,AE} - h_{1,M}}{0,3}\frac{x}{L}$
0,3L ≤ x ≤ 0,7L	$0,42 n C (C_B + 0,7)$ without being taken greater than D - 0,9T
0,7L < x < L	$h_{1,M} + \frac{h_{1,FE} - h_{1,M}}{0,3}\left(\frac{x}{L} - 0,7\right)$
x = L	$\left(\frac{4,35}{\sqrt{C_B}} - 3,25\right) h_{1,M}$
Note 1: $h_{1,AE}$: Reference value h_1 calculated for x = 0 $h_{1,M}$: Reference value h_1 calculated for x = 0,5L $h_{1,FE}$: Reference value h_1 calculated for x = L	

Table 5 : Reference value of the accelerations a_{X1} and a_{Z1}

Direction	Accelerations, in m/s²
X - Longitudinal	$a_{X1} = \sqrt{a_{SU}^2 + [A_P g + \alpha_p (z - T_1)]^2}$
Z - Vertical	$a_{Z1} = \sqrt{a_H^2 + \alpha_p^2 K_X L^2}$
Note 1: a_{SU} : Surge acceleration, in m/s², defined in [3.2.1] a_H : Heave acceleration, in m/s², defined in [3.2.2] A_P, α_P : Pitch amplitude, in rad, and acceleration, in rad/s², defined in [3.2.3] $K_X = 1,2\left(\frac{x}{L}\right)^2 - 1,1\frac{x}{L} + 0,2$ without being taken less than 0,018.	

3.3 Ship relative motion and accelerations

3.3.1 Ship relative motion

The ship relative motion is the vertical oscillating translation of the sea waterline on the ship side. It is measured, with its sign, from the waterline at draught T and can be assumed as being symmetrical on the ship sides.

The reference value of the relative motion is obtained, at any hull transverse section, from the formulae in Tab 4.

3.3.2 Accelerations

The accelerations in X and Z direction are the acceleration components which result from the ship motions defined in [3.2]. Their reference values at any point are obtained from the formulae in Tab 5.

4 Sea pressures

4.1 Still water and wave pressures

4.1.1 The still water and wave pressures are obtained, in kN/m², as specified in Tab 6 (see also Fig 2).

4.2 Exposed decks

4.2.1 Application *(1/1/2023)*

The still water and wave sea pressures defined in Tab 6 for exposed decks are to be considered independently of the pressures due to dry uniform cargoes, dry unit cargoes or wheeled cargoes, if any, as defined in [5.3], [5.4] and [5.5] respectively.

5 Internal pressures and forces

5.1 Liquids

5.1.1 Still water and inertial pressures

The still water and inertial pressures are obtained, in kN/m², as specified in Tab 7.

Table 6 : Still water and wave pressures *(1/1/2023)*

Location	Still water pressure p_S, in kN/m²	Wave pressure p_W, in kN/m²
Bottom and side below the waterline $z \le T$	$\rho g(T-z)$	$\rho g h_1 e^{\frac{-2\pi(T-z)}{L}}$
Side above the waterline $z > T$	0	$\rho g(T+h_1-z)$ without being taken less than 0,15L
Exposed decks	10φ kN/m²	$17{,}5n\varphi$ for $0 \le x \le 0{,}5L$ $\left\{17{,}5+\left[\frac{19{,}6\sqrt{H_F}-17{,}5}{0{,}25}\right]\left(\frac{x}{L}-0{,}5\right)\right\}n\varphi$ for $0{,}5L < x < 0{,}75L$ $19{,}6n\varphi\sqrt{H}$ for $0{,}75L \le x \le L$

Note 1:

ρ : Sea water density, in t/m³: ρ = 1,025 t/m³,

H_F : Value of H calculated at x = 0,75L

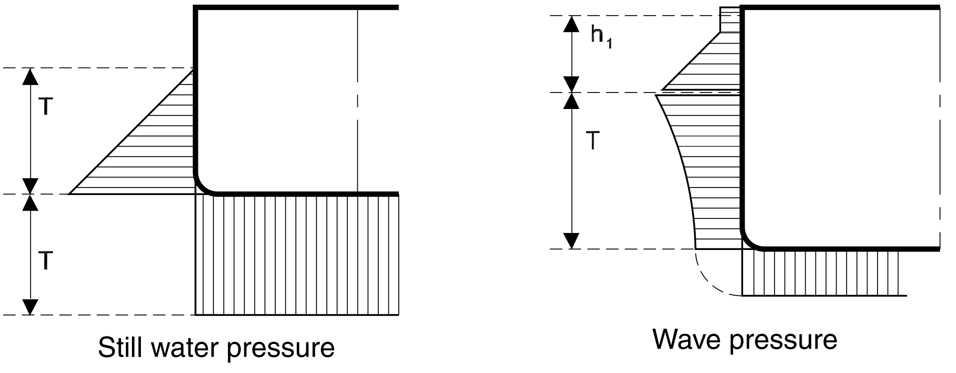
V : Contractual service speed, in knots, to be taken not less than 13 knots

φ : Defined in Ch 5, Sec 5, Tab 2.

$$H = \left[2{,}66\left(\frac{x}{L}-0{,}7\right)^2+0{,}14\right]\sqrt{\frac{VL}{C_B}}-(z-T)$$

without being taken less than 0,8,

Figure 2 : Still water and wave pressures



5.2 Dry bulk cargoes

5.2.1 Still water and inertial pressures

The still water and inertial pressures (excluding those acting on the sloping plates of wing tanks, which may be taken equal to zero) are obtained, in kN/m², as specified in Tab 8.

5.3 Dry uniform cargoes

5.3.1 Still water and inertial pressures

In ships with two or more decks, the pressure transmitted to the deck structures by the dry uniform cargoes in cargo compartments is to be considered.

The still water and inertial pressures transmitted to the deck structures are obtained, in kN/m², as specified in Tab 9.

Table 7 : Liquids
Still water and wave pressures

Still water pressure p_S , in kN/m²	Inertial pressure p_W , in kN/m²
The greater of the values obtained from the following formulae: $\rho_L g(z_L - z)$ $\rho_L g(z_{TOP} - z) + 100 p_{PV}$ to be taken not less than: $\rho_L g\left(\frac{0,8L_1}{420 - L_1}\right)$	$\rho_L\left[a_{X1}\frac{\ell_C}{2} + a_{Z1}(z_{TOP} - z)\right]$

Note 1:

ρ_L : Density, in t/m³, of the liquid cargo carried

z_{TOP} : Z co-ordinate, in m, of the highest point of the tank in the z direction

z_L : Z co-ordinate, in m, of the highest point of the liquid:

$$z_L = z_{TOP} + 0,5(z_{AP} - z_{TOP})$$

z_{AP} : Z co-ordinate, in m, of the moulded deck line of the deck to which the air pipes extend, to be taken not less than z_{TOP}

p_{PV} : Setting pressure, in bar, of safety valves

ℓ_C : Longitudinal distance, in m, between the transverse tank boundaries.

Table 8 : Dry bulk cargoes - Still water and inertial pressures

Still water pressure p_S , in kN/m²	Inertial pressure p_W , in kN/m²
$\rho_B g(z_B - z)\left\{(\sin\alpha)^2\left[\tan\left(45^\circ - \frac{\varphi}{2}\right)\right]^2 + (\cos\alpha)^2\right\}$	$\rho_B a_{Z1}(z_B - z)\left\{(\sin\alpha)^2\left[\tan\left(45^\circ - \frac{\varphi}{2}\right)\right]^2 + (\cos\alpha)^2\right\}$

Note 1:

ρ_B : Density, in t/m³, of the dry bulk cargo carried, to be taken equal to:

$$\rho_B = \frac{p_{DB}}{g(z_B - h_{DB})}$$

p_{DB} : Design pressure, in kN/m², on the double bottom

z_B : Z co-ordinate, in m, of the rated upper surface of the bulk cargo (horizontal ideal plane of the volume filled by the cargo), to be taken equal to:

$$z_B = 0{,}9(D - h_{DB}) + h_{DB}$$

h_{DB} : Height, in m, of the double bottom, to be taken as the vertical distance from the baseline to the inner bottom

α : Angle, in degrees, between the horizontal plane and the surface of the hull structure to which the calculation point belongs

φ : Angle of repose, in degrees, of the dry bulk cargo carried (considered drained and removed); in the absence of more precise evaluation, the following values may be taken:

- $\varphi = 30^\circ$ in general
- $\varphi = 35^\circ$ for iron ore
- $\varphi = 25^\circ$ for cement.

Table 9 : Dry uniform cargoes Still water and inertial pressures

Still water pressure p_S , in kN/m²	Inertial pressure p_W , in kN/m²
The value of p_S is in general defined by the designer; in any case, it may not be taken less than 10 kN/m². When the value of p_S is not defined by the designer, it may be taken, in kN/m² equal to 6,9 h_{TD} , where h_{TD} is the compartment 'tweendeck height at side, in m	$p_S \frac{a_{Z1}}{g}$

5.4 Dry unit cargoes

5.4.1 Still water and inertial forces

The still water and inertial forces transmitted to the hull structures are to be determined on the basis of the forces obtained, in kN, as specified in Tab 10, taking into account the elastic characteristics of the lashing arrangement and/or the structure which contains the cargo.

Table 10 : Dry unit cargoes Still water and inertial forces

Still water forces F_S , in kN	Inertial forces F_W , in kN
$F_S = Mg$	$F_{W,X} = Ma_{X1}$ in x direction $F_{W,Z} = Ma_{Z1}$ in z direction

Note 1:

M : Mass, in t, of a dry unit cargo carried.

5.5 Wheeled cargoes

5.5.1 Still water and inertial forces

Caterpillar trucks and unusual vehicles are considered by the Society on a case by case basis.

The load supported by the crutches of semi-trailers, handling machines and platforms is considered by the Society on a case by case basis.

The forces transmitted through the tyres are comparable to pressure uniformly distributed on the tyre print, whose dimensions are to be indicated by the Designer together with information concerning the arrangement of wheels on axles, the load per axles and the tyre pressures.

With the exception of dimensioning of plating, such forces may be considered as concentrated in the tyre print centre.

The still water and inertial forces transmitted to the hull structures are to be determined on the basis of the forces obtained, in kN, as specified in Tab 11.

In the case of tracked vehicles, the print to be considered is that below each wheel.

For vehicles on rails, all the forces transmitted are to be considered as concentrated.

5.6 Accommodation

5.6.1 Still water and inertial pressures

The still water and inertial pressures transmitted to the deck structures are obtained, in kN/m², as specified in Tab 12.

Table 11 : Wheeled cargoes Still water and inertial forces

Still water forces F_S, in kN	Inertial forces F_W, in kN
$F_S = Mg$	$F_{W,Z} = Ma_{Z1}$ in z direction

Note 1:
M : Force applied by one wheel, obtained, in t, from the following formula:

$$M = \frac{Q_A}{n_W}$$

Q_A : Axle load, in t. For fork-lift trucks, the value of Q_A is to be taken equal to the total mass of the vehicle, including that of the cargo handled, applied to one axle only.
n_W : Number of wheels for the axle considered.

Table 12 : Accommodation Still water and inertial pressures

Still water pressure p_S, in kN/m²	Inertial pressure p_W, in kN/m²
The value of p_S is defined in Tab 13 depending on the type of the accommodation compartment	$p_S \frac{a_{Z1}}{g}$

Table 13 : Still water deck pressure in accommodation compartments

Type of accommodation compartment	p_S, in kN/m²
Large public spaces, such as: restaurants, halls, cinemas, lounges	5,0
Large rooms, such as: games and hobbies rooms, hospitals	3,0
Cabins	3,0
Other compartments	2,5

5.7 Machinery

5.7.1 Still water and inertial pressures

The still water and inertial pressures transmitted to the deck structures are obtained, in kN/m², from the formulae in Tab 14.

Table 14 : Machinery Still water and inertial pressures

Still water pressure p_S, in kN/m²	Inertial pressure p_W, in kN/m²
10	$p_S \frac{a_{Z1}}{g}$

5.8 Flooding

5.8.1 Still water and inertial pressures

The still water and inertial pressures to be considered as acting on bulkheads or inner sides which constitute boundaries of compartments not intended to carry liquids are obtained, in kN/m², from the formulae in Tab 15.

Table 15 : Flooding - Still water and inertial pressures *(1/7/2022)*

Still water pressure p_{SF}, in kN/m²	Inertial pressure p_{WF}, in kN/m²
$\rho_L g(z_F - z)$ without being taken less than 0,4 g d_0	$0{,}6\rho_L a_{Z1}(z_F - z)$ without being taken less than 0,4 g d_0

Note 1:
z_F : Z co-ordinate, in m, of the deepest equilibrium waterline, taking into account the transient conditions. The deepest equilibrium waterlines are to be provided by the Designer under his own responsibility.
In case the deepest equilibrium waterline is not known, e.g. at the preliminary design stage, the Z co-ordinate, in m, of the freeboard deck at side in way of the transverse section considered may be used in lieu.
d_0 : Distance, in m, to be taken equal to:
$d_0 = 0{,}02L$

SECTION 2 HULL GIRDER STRENGTH

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

M_{SW} : Still water bending moment, in kN.m:
- in hogging conditions:
  $M_{SW} = M_{SW,H}$
- in sagging conditions:
  $M_{SW} = M_{SW,S}$

M_{WV} : Vertical wave bending moment, in kN.m:
- in hogging conditions:
  $M_{WV} = M_{WV,H}$
- in sagging conditions:
  $M_{WV} = M_{WV,S}$

I_Y : Moment of inertia, in m^4, of the hull transverse section defined in [1.1] about its horizontal neutral axis

Z_A : Section modulus, in cm^3, at any point of the hull transverse section, to be calculated according to [1.3.1]

Z_{AB}, Z_{AD} : Section moduli, in cm^3, at bottom and deck, respectively, to be calculated according to [1.3.2]

n_1 : Navigation coefficient defined in Sec 1, Tab 1

C : Wave parameter, defined in Sec 1.

1 Basic criteria

1.1 Hull girder transverse sections

1.1.1 General

Hull girder transverse sections are constituted by the members contributing to the hull girder longitudinal strength, i.e. all continuous longitudinal members below the strength deck defined in [1.2], taking into account the requirements in [1.1.2] to [1.1.9].

These members are to be considered as having (see also Ch 4, Sec 2):

- gross scantlings, when the hull girder strength characteristics to be calculated are used for the yielding checks in [2]
- net scantlings, when the hull girder strength characteristics to be calculated are used for calculating the hull girder stresses for the strength checks of plating, ordinary stiffeners and primary supporting members in Sec 3, Sec 4 and Sec 5.

1.1.2 Continuous trunks and continuous longitudinal hatch coamings

Continuous trunks and continuous longitudinal hatch coamings may be included in the hull girder transverse sections, provided they are effectively supported by longitudinal bulkheads or primary supporting members.

1.1.3 Longitudinal ordinary stiffeners or girders welded above the decks

Longitudinal ordinary stiffeners or girders welded above the decks (including the deck of any trunk fitted as specified in [1.1.2]) may be included in the hull girder transverse sections.

1.1.4 Longitudinal girders between hatchways

Where longitudinal girders are fitted between hatchways, the sectional area that can be included in the hull girder transverse sections is obtained, in m^2, from the following formula:

$A_{EFF} = A_{LG}\, a$

where:

A_{LG} : Sectional area, in m^2, of longitudinal girders

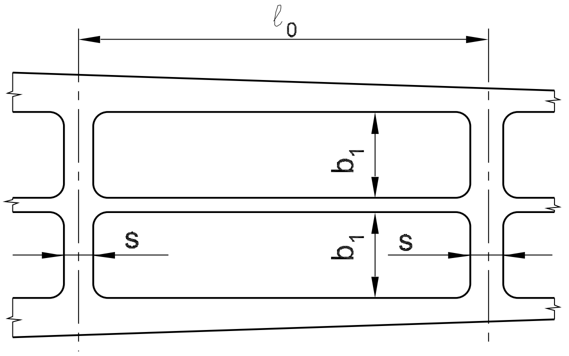
a : Coefficient:
- for longitudinal girders effectively supported by longitudinal bulkheads or primary supporting members:
  a = 1
- for longitudinal girders not effectively supported by longitudinal bulkheads or primary supporting members and having dimensions and scantlings such that $\ell_0/r \le 60$:
  $$a = 0{,}6\left(\frac{s}{b_1}+0{,}15\right)^{0{,}5}$$
- for longitudinal girders not effectively supported by longitudinal bulkheads or primary supporting members and having dimensions and scantlings such that $\ell_0/r > 60$:
  a = 0

ℓ_0 : Span, in m, of longitudinal girders, to be taken as shown in Fig 1

r : Minimum radius of gyration, in m, of the longitudinal girder transverse section

s, b_1 : Dimensions, in m, defined in Fig 1.

Figure 1 : Longitudinal girders between hatchways



1.1.5 Longitudinal bulkheads with vertical corrugations

Longitudinal bulkheads with vertical corrugations may not be included in the hull girder transverse sections.

1.1.6 Members in materials other than steel

Where a member contributing to the longitudinal strength is made in material other than steel with a Young's modulus E equal to 2,06 10^5 N/mm², the steel equivalent sectional area that may be included in the hull girder transverse sections is obtained, in m², from the following formula:

$$A_{SE} = \frac{E}{2,06 \cdot 10^5} A_M$$

where:

A_M : Sectional area, in m², of the member under consideration.

1.1.7 Large openings

Large openings are:

- elliptical openings exceeding 2,5 m in length or 1,2 m in breadth
- circular openings exceeding 0,9 m in diameter.

Large openings and scallops, where scallop welding is applied, are always to be deducted from the sectional areas included in the hull girder transverse sections.

1.1.8 Small openings

Smaller openings than those in [1.1.7] in one transverse section in the strength deck or bottom area need not be deducted from the sectional areas included in the hull girder transverse sections, provided that:

$$\Sigma b_S \leq 0,06 (B - \Sigma b)$$

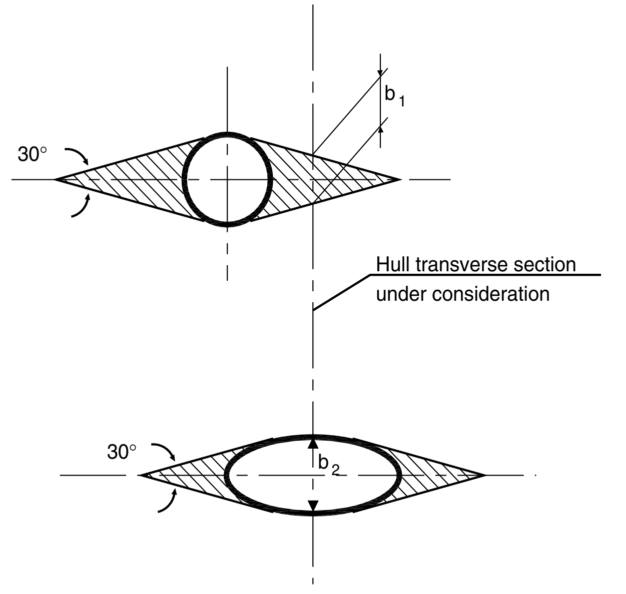
where:

Σb_S : Total breadth of small openings, in m, in the strength deck or bottom area at the transverse section considered, determined as indicated in Fig 2

Σb : Total breadth of large openings, in m, at the transverse section considered, determined as indicated in Fig 2

Where the total breadth of small openings Σb_S does not fulfil the above criteria, only the excess of breadth is to be deducted from the sectional areas included in the hull girder transverse sections.

Figure 2 : Calculation of Σb and Σb$_S$



b_1 and b_2 included in Σ b and Σ bs

1.1.9 Lightening holes, draining holes and single scallops

Lightening holes, draining holes and single scallops in longitudinals need not be deducted if their height is less than 0,25 h_W, without being greater than 75 mm, where h_W is the web height, in mm, defined in Ch 4, Sec 3.

Otherwise, the excess is to be deducted from the sectional area or compensated.

1.2 Strength deck

1.2.1 The strength deck is, in general, the uppermost continuous deck.

In the case of a superstructure or deckhouses contributing to the longitudinal strength, the strength deck is the deck of the superstructure or the deck of the uppermost deckhouse.

1.2.2 A superstructure extending at least 0,15L within 0,4L amidships may generally be considered as contributing to the longitudinal strength. For other superstructures and for deckhouses, their contribution to the longitudinal strength is to be assessed on a case by case basis, through a finite element analysis of the whole ship, which takes into account the general arrangement of the longitudinal elements (side, decks, bulkheads).

The presence of openings in the side shell and longitudinal bulkheads is to be taken into account in the analysis. This may be done in two ways:

- by including these openings in the finite element model
- by assigning to the plate panel between the side frames beside each opening an equivalent thickness, in mm, obtained from the following formula:

$$t_{EQ} = 10^3 \left[\ell_P \left(\frac{Gh^2}{12EI_J} + \frac{1}{A_J} \right) \right]^{-1}$$

where (see Fig 3):

ℓ_P : Longitudinal distance, in m, between the frames beside the opening

h : Height, in m, of openings

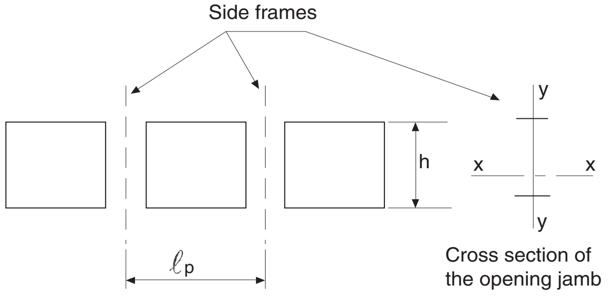
I_J : Moment of inertia, in m^4, of the opening jamb about the transverse axis y-y

A_J : Shear area, in m^2, of the opening jamb in the direction of the longitudinal axis x-x

G : Coulomb's modulus, in N/mm^2, of the material used for the opening jamb, to be taken equal to:

- for steels:
  G = 8,0.10^4 N/mm^2,
- for aluminium alloys:
  G = 2,7.10^4 N/mm^2.

Figure 3 : Side openings



1.3 Section modulus

1.3.1 The section modulus at any point of a hull transverse section is obtained, in m^3, from the following formula:

$$Z_A = \frac{I_Y}{|z - N|}$$

where:

z : Z co-ordinate, in m, of the calculation point with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]

N : Z co-ordinate, in m, of the centre of gravity of the hull transverse section defined in [1.1], with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4].

1.3.2 The section moduli at bottom and at deck are obtained, in m^3, from the following formulae:

- at bottom:

$$Z_{AB} = \frac{I_Y}{N}$$

- at deck:

$$Z_{AD} = \frac{I_Y}{V_D}$$

where:

N : Defined in [1.3.1]

V_D : Vertical distance, in m:

- in general:
  $V_D = z_D - N$

  where:

  z_D : Z co-ordinate, in m, of strength deck, defined in [1.2] with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]

- if continuous trunks or hatch coamings are taken into account in the calculation of I_Y, as specified in [1.1.2]:

$$V_D = (z_T - N)\left(0,9 + 0,2\frac{y_T}{B}\right) \geq z_D - N$$

  where:

  y_T, z_T : Y and Z co-ordinates, in m, of the top of continuous trunk or hatch coaming with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]; y_T and z_T are to be measured for the point which maximises the value of V_D

- if longitudinal ordinary stiffeners or girders welded above the strength deck are taken into account in the calculation of I_Y, as specified in [1.1.3], V_D is to be obtained from the formula given above for continuous trunks or hatch coamings. In this case, y_T and z_T are the Y and Z co-ordinates, in m, of the top of the longitudinal ordinary stiffeners or girders with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4].

2 Yielding check

2.1 Normal stresses induced by vertical bending moments

2.1.1 The normal stresses induced by vertical bending moments are obtained, in N/mm^2, from the following formulae:

- at any point of the hull transverse section:

$$\sigma_1 = \frac{M_{SW} + M_{WV}}{Z_A}$$

- at bottom:

$$\sigma_1 = \frac{M_{SW} + M_{WV}}{Z_{AB}}$$

- at deck:

$$\sigma_1 = \frac{M_{SW} + M_{WV}}{Z_{AD}}$$

2.1.2 The normal stresses in a member made in material other than han steel with a Young's modulus E equal to 2,06 10^5 N/mm^2, and included in the hull girder transverse sections as specified in [1.1.6], are obtained from the following formula:

$$\sigma_1 = \frac{E}{2,06{,}10^5}\sigma_{1S}$$

where:

σ_{1S} : Normal stress, in N/mm², in the member under consideration, calculated according to [2.1.1] considering this member as having the steel equivalent sectional area A_{SE} defined in [1.1.6].

2.2 Checking criteria

2.2.1 It is to be checked that the normal stresses σ_1 calculated according to [2.1] are in compliance with the following formula:

$$\sigma_1 \le \sigma_{1,ALL}$$

where:

$\sigma_{1,ALL}$: Allowable normal stress, in N/mm²:

$\sigma_{1,ALL} = 175 / k$

3 Section modulus and moment of inertia

3.1 General

3.1.1 The requirements in [3.2] to [3.4] provide the minimum hull girder section modulus, complying with the checking criteria indicated in [2.2], and the midship section moment of inertia required to ensure sufficient hull girder rigidity.

3.2 Section modulus

3.2.1 For ships with C_B greater than 0,8,the gross section moduli Z_{AB} and Z_{AD} within 0,4L amidships are to be not less than the greater value obtained, in m³, from the following formulae:

- $Z_{R,MIN} = n_1 C L^2 B (C_B + 0,7) k 10^{-6}$
- $Z_R = \dfrac{M_{SW} + M_{WV}}{175/k} 10^{-3}$

3.2.2 For ships with C_B less than or equal to 0,8, the gross section moduli Z_{AB} and Z_{AD} at the midship section are to be not less than the value obtained, in m³, from the following formula:

$$Z_{R,MIN} = n_1 C L^2 B (C_B + 0,7) k 10^{-6}$$

In addition, the gross section moduli Z_{AB} and Z_{AD} within 0,4L amidships are to be not less than the value obtained, in m³, from the following formula:

$$Z_R = \frac{M_{SW} + M_{WV}}{175/k} 10^{-3}$$

3.2.3 The k material factors are to be defined with respect to the materials used for the bottom and deck members contributing to the hull girder longitudinal strength according to [1]. When factors for higher strength steels are used, the requirements in [3.4] apply.

3.2.4 Where the total breadth Σb_S of small openings, as defined in [1.1.8], is deducted from the sectional areas included in the hull girder transverse sections, the values Z_R and $Z_{R,MIN}$ defined in [4.2.1] may be reduced by 3%.

3.2.5 Scantlings of members contributing to the longitudinal strength (see [1]) are to be maintained within 0,4L amidships.

3.2.6 Scantlings of members contributing to the hull girder longitudinal strength (see [1]) may be gradually reduced, outside 0,4L amidships, to the minimum required for local strength purposes at fore and aft parts, as specified in Chapter 9.

3.3 Midship section moment of inertia

3.3.1 The gross midship section moment of inertia about its horizontal neutral axis is to be not less than the value obtained, in m⁴, from the following formula:

$$I_{YR} = 3 Z'_{R,MIN} L 10^{-2}$$

where $Z'_{R,MIN}$ is the required midship section modulus $Z_{R,MIN}$, in m³, calculated as specified in [3.2.1], but assuming k = 1.

3.4 Extent of higher strength steel

3.4.1 When a factor for higher strength steel is used in calculating the required section modulus at bottom or deck according to [3.2.1], the relevant higher strength steel is to be adopted for all members contributing to the longitudinal strength (see [1]), at least up to a vertical distance, in m, obtained from the following formulae:

- above the baseline (for section modulus at bottom):

  $$V_{HB} = \frac{\sigma_{1B} - 175}{\sigma_{1B} + \sigma_{1D}} z_D$$

- below a horizontal line located at a distance V_D (see [1.3.2]) above the neutral axis of the hull transverse section (for section modulus at deck):

  $$V_{HD} = \frac{\sigma_{1D} - 175}{\sigma_{1B} + \sigma_{1D}} (N + V_D)$$

  where:

  σ_{1B}, σ_{1D} : Normal stresses, in N/mm², at bottom and deck, respectively, calculated according to [2.1.1]

  z_D : Z co-ordinate, in m, of the strength deck, defined in [1.2], with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]

  N : Z co-ordinate, in m, of the centre of gravity of the hull transverse section, defined in [1.1], with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]

  V_D : Vertical distance, in m, defined in [1.3.2]

3.4.2 When a higher strength steel is adopted at deck, members not contributing to the longitudinal strength and welded on the strength deck (e.g. hatch coamings, strengthening of deck openings) are also generally to be made of the same higher strength steel.

3.4.3 The higher strength steel is to extend in length at least throughout the whole midship area where it is required for strength purposes according to the requirements of Part B.

4 Permissible still water bending moment

4.1 Permissible still water bending moment during navigation

4.1.1 The permissible still water bending moment at any hull transverse section during navigation, in hogging or sagging conditions, is the value M_{SW} considered in the hull girder section modulus calculation according to [3].

In the case of structural discontinuities in the hull transverse sections, the distribution of permissible still water bending moments is considered on a case by case basis.

4.2 Permissible still water bending moment in harbour conditions

4.2.1 The permissible still water bending moment at any hull transverse section in harbour conditions, in hogging or sagging conditions, is obtained, in kN.m, from the following formula:

$$M_{P,H} = \frac{130}{k} Z_{A,M} 10^3$$

where $Z_{A,M}$ is the lesser of Z_{AB} and Z_{AD} defined in [3.2.1].

SECTION 3 PLATING

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

p_S : Still water pressure, in kN/m², see [3.2.2]

p_W : Wave pressure, in kN/m², see [3.2.2]

p_{SF}, p_{WF} : Still water and wave pressure, in kN/m², in flooding conditions, defined in Sec 1, [5.8]

F_S : Still water wheeled force, in kN, see [4.2.2]

$F_{W,Z}$: Inertial wheeled force, in kN, see [4.2.2]

σ_{X1} : In-plane hull girder normal stress, in N/mm², defined in:

- [3.2.4] for the strength check of plating subjected to lateral pressure
- [5.2.2] for the buckling check of plating for ships equal to or greater than 65 m in length

R_{eH} : Minimum yield stress, in N/mm², of the plating material, defined in Ch 4, Sec 1, [2]

I_Y : Net moment of inertia, in m⁴, of the hull transverse section around its horizontal neutral axis, to be calculated according to Sec 2 considering the members contributing to the hull girder longitudinal strength as having their net scantlings

N : Z co-ordinate, in m, with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4], of the centre of gravity of the hull transverse section constituted by members contributing to the hull girder longitudinal strength considered as having their net scantlings (see Sec 1, [1])

ℓ : Length, in m, of the longer side of the plate panel

s : Length, in m, of the shorter side of the plate panel

s : Lengths, in m, of the sides of the plate panel, as shown in Fig 3

c_a : Aspect ratio of the plate panel, equal to:

$$c_a = 1{,}21\sqrt{1 + 0{,}33\left(\frac{s}{\ell}\right)^2} - 0{,}69\frac{s}{\ell}$$

to be taken not greater than 1,0

c_r : Coefficient of curvature of the panel, equal to:

$$c_r = 1 - 0{,}5s/r$$

to be taken not less than 0,75

r : Radius of curvature, in m

t_{net} : Net thickness, in mm, of a plate panel

1 General

1.1 Application

1.1.1 *(1/7/2003)*

For ships less than 65 m in length, the criteria in App 1 may be used for the strength check of plating, as an alternative to those contained in this Section.

1.2 Net thicknesses

1.2.1 As specified in Ch 4, Sec 2, [1], all thicknesses referred to in this Section are net, i.e. they do not include any margin for corrosion.

The gross thicknesses are obtained as specified in Ch 4, Sec 2.

1.3 Partial safety factors

1.3.1 The partial safety factors to be considered for the checking of the plating are specified in Tab 1.

Table 1 : Plating - Partial safety factors

Partial safety factors covering uncertainties regarding:	Symbol	Strength check of plating subjected to lateral pressure		Buckling check for L ≥ 65 m (see [5])
		General (see [3.2], [3.3.1], [3.4.1], [3.5.1] and [4])	Watertight bulkhead plating **(1)** (see [3.3.2], [3.4.2] and [3.5.2])	
Still water hull girder loads	γ_{S1}	Not applicable	Not applicable	1,00
Wave hull girder loads	γ_{W1}	Not applicable	Not applicable	1,15
Still water pressure	γ_{S2}	1,00	1,00	Not applicable
Wave pressure	γ_{W2}	1,20	1,20	Not applicable
Material	γ_m	1,02	1,02	1,02
Resistance	γ_R	1,20	1,05 **(2)**	1,10

(1) Applies also to plating of bulkheads or inner side which constitute boundary of compartments not intended to carry liquids.
(2) For plating of the collision bulkhead, γ_R =1,25.

1.4 Elementary plate panel

1.4.1 The elementary plate panel is the smallest unstiffened part of plating.

1.5 Load point

1.5.1 Unless otherwise specified, lateral pressure and hull girder stresses are to be calculated:

- for longitudinal framing, at the lower edge of the elementary plate panel or, in the case of horizontal plating, at the point of minimum y-value among those of the elementary plate panel considered
- for transverse framing, at the lower edge of the strake.

2 General requirements

2.1 General

2.1.1 The requirements in [2.2] and [2.3] are to be applied to plating in addition of those in [3] to [5].

2.2 Minimum net thicknesses

2.2.1 The net thickness of plating is to be not less than the values given in Tab 2.

2.3 Bilge plating

2.3.1 The bilge plating net thickness is to be not less than the net thickness obtained from:

- [3.3.1] for longitudinally framed bilges
- [3.4.1] for transversely framed bilges.

The net thickness of longitudinally framed bilge plating is to be not less than that required for the adjacent bottom or side plating, whichever is the greater.

The net thickness of transversely framed bilge plating may be taken not greater than that required for the adjacent bottom or side plating, whichever is the greater.

2.4 Inner bottom of cargo holds intended to carry dry cargo

2.4.1 For ships with one of the following service notations:

- **general cargo ship**, intended to carry dry bulk cargo in holds
- **bulk carrier ESP**
- **ore carrier ESP**
- **combination carrier ESP**

the inner bottom and sloping plating net thickness is to be increased by 2 mm unless they are protected by a continuous wooden ceiling.

2.5 Sheerstrake

2.5.1 Welded sheerstrake

The net thickness of a welded sheerstrake is to be not less than that of the adjacent side plating, taking into account higher strength steel corrections if needed.

In general, the required net thickness of the adjacent side plating is to be taken as a reference. In specific case, depending on its actual net thickness, this latter may be required to be considered when deemed necessary by the Society.

Table 2 : Minimum net thickness of plating

Plating	Minimum net thickness, in mm
Keel	$5,1 + 0,026Lk^{1/2} + 4,5s$
Bottom	
• longitudinal framing	$3,2 + 0,018Lk^{1/2} + 4,5s$
• transverse framing	$4,1 + 0,018Lk^{1/2} + 4,5s$
Inner bottom	
• outside the engine room **(1)**	$1,9 + 0,024Lk^{1/2} + 4,5s$
• engine room	$3,0 + 0,024Lk^{1/2} + 4,5s$
Side	
• below freeboard deck **(1)**	$3,1 + 0,017Lk^{1/2} + 4,5s$
• between freeboard deck and strength deck	$3,0 + 0,004Lk^{1/2} + 4,5s$
Inner side	$1,7 + 0,013Lk^{1/2} + 4,5s$
Weather strength deck and trunk deck, if any **(2)**	
• area within 0,4L amidships	
- longitudinal framing	$2,1 + 0,032Lk^{1/2} + 4,5s$
- transverse framing	$2,1 + 0,040Lk^{1/2} + 4,5s$
• area outside 0,4 L amidships	**(3)**
• between hatchways	$2,1 + 0,013Lk^{1/2} + 4,5s$
• at fore and aft part	$2,1 + 0,013Lk^{1/2} + 4,5s$
Cargo deck	
• general	$9,7sk^{1/2}$
• wheeled load only	4,5
Accommodation deck	$1,3 + 0,004Lk^{1/2} + 4,5s$
Platform in engine room	$1,7 + 0,013Lk^{1/2} + 4,5s$
Transverse watertight bulkhead	$1,3 + 0,004Lk^{1/2} + 4,5s$
Longitudinal watertight bulkhead	$1,7 + 0,013Lk^{1/2} + 4,5s$
Tank and wash bulkhead	$1,7 + 0,013Lk^{1/2} + 4,5s$

(1) Not applicable to ships with one of the service notations **passenger ship** and **ro-ro passenger ship**. For such ships, refer to the applicable requirements of Part E.

(2) Not applicable to ships with the following service notations:
- **ro-ro cargo ship**
- **liquefied gas carrier**
- **passenger ship**
- **ro-ro passenger ship**.

For such ships, refer to the applicable requirements of Part E.

(3) The minimum net thickness is to be obtained by linearly interpolating between that required for the area within 0,4 L amidships and that at the fore and aft part.

2.5.2 Rounded sheerstrake

The net thickness of a rounded sheerstrake is to be not less than the actual net thickness of the adjacent deck plating.

2.5.3 Net thickness of the sheerstrake in way of breaks of long superstructures

The net thickness of the sheerstrake is to be increased in way of breaks of long superstructures occurring within 0,5L amidships, over a length of about one sixth of the ship's breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 40%, without exceeding 4,5 mm.

Where the breaks of superstructures occur outside 0,5L amidships, the increase in net thickness may be reduced to 30%, without exceeding 2,5 mm.

2.5.4 Net thickness of the sheerstrake in way of breaks of short superstructures

The net thickness of the sheerstrake is to be increased in way of breaks of short superstructures occurring within 0,6L amidships, over a length of about one sixth of the ship's breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 15%, without exceeding 4,5 mm.

2.6 Stringer plate

2.6.1 General

The net thickness of the stringer plate is to be not less than the actual net thickness of the adjacent deck plating.

2.6.2 Net thickness of the stringer plate in way of breaks of long superstructures

The net thickness of the stringer plate is to be increased in way of breaks of long superstructures occurring within 0,5L amidships, over a length of about one sixth of the ship's breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 40%, without exceeding 4,5 mm.

Where the breaks of superstructures occur outside 0,5L amidships, the increase in net thickness may be reduced to 30%, without exceeding 2,5 mm.

2.6.3 Net thickness of the stringer plate in way of breaks of short superstructures

The net thickness of the stringer plate is to be increased in way of breaks of short superstructures occurring within 0,6L amidships, over a length of about one sixth of the ship's breadth on each side of the superstructure end.

This increase in net thickness is to be equal to 15%, without exceeding 4,5 mm.

3 Strength check of plating subjected to lateral pressure

3.1 General

3.1.1 The requirements of this Article apply for the strength check of plating subjected to lateral pressure and, for plating contributing to the longitudinal strength, to in-plane hull girder normal stresses.

3.2 Load model

3.2.1 General

The still water and wave lateral pressures induced by the sea and the various types of cargoes and ballast in intact conditions are to be considered, depending on the location of the plating under consideration and the type of the compartments adjacent to it, in accordance with Sec 1, [1.4].

The plating of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids is to be subjected to lateral pressure in flooding conditions.

3.2.2 Lateral pressure in intact conditions

The lateral pressure in intact conditions is constituted by still water pressure and wave pressure.

Still water pressure (p_S) includes:

- the still water sea pressure, defined in Sec 1, [4]
- the still water internal pressure, defined in Sec 1, [5.1] to Sec 1, [5.7] for the various types of cargoes and for ballast.

Wave pressure (p_W) includes:

- the wave pressure, defined in Sec 1, [4]
- the inertial pressure, defined in Sec 1, [5.1] to Sec 1, [5.7] for the various types of cargoes and for ballast.

3.2.3 Lateral pressure in flooding conditions

The lateral pressure in flooding conditions is constituted by the still water pressure p_{SF} and wave pressure p_{WF} defined in Sec 1, [5.8].

3.2.4 In-plane hull girder normal stresses

The in-plane hull girder normal stresses to be considered for the strength check of plating are obtained, at any hull transverse section, from the formulae in Tab 3.

3.3 Longitudinally framed plating contributing to the hull girder longitudinal strength

3.3.1 General

The net thickness of laterally loaded plate panels subjected to in-plane normal stress acting on the shorter sides is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{\lambda_L R_y}}$$

where:

$$\lambda_L = \sqrt{1 - 0{,}95\left(\gamma_m \frac{\sigma_{x1}}{R_y}\right)^2} - 0{,}225 \gamma_m \frac{\sigma_{x1}}{R_y}$$

3.3.2 Flooding conditions

The plating of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids is to be checked in flooding conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{\lambda_L R_y}}$$

where λ_L is defined in [3.3.1].

Table 3 : Hull girder normal stresses

Condition		Hull girder normal stresses σ_{X1}, in N/mm²
Plating contributing to the hull girder longitudinal strength	z = 0	$\frac{[100+1,2(L_M-65)]}{k_B}\frac{Z_{REQ}}{Z_{AB}}F_S$
	0 < z < 0,25D	$\sigma_{X1,B}-\frac{\sigma_{X1,B}-\sigma_{X1,N}}{0,25D}z$
	0,25D ≤ z ≤ 0,75D	$\frac{[50+0,6(L_M-65)]}{k_N}F_S$
	0,75D < z < D	$\sigma_{X1,N}+\frac{\sigma_{X1,D}-\sigma_{X1,N}}{0,25D}(z-0,75D)$
	z ≥ D	$\frac{[100+1,2(L_M-65)]}{k_D}\frac{Z_{REQ}}{Z_{AD}}F_S$
Plating not contributing to the hull girder longitudinal strength		0

Note 1:

- L_M : Ship's length, in m, defined in Ch 1, Sec 2, [3.1], but to be taken not less than 65 m
- Z_{REQ} : the greater of Z_R and $Z_{R,MIN}$, in m³, defined in Sec 2, [3.2]
- Z_{AB}, Z_{AD} : Section moduli at bottom and deck, respectively, in m³, defined in Sec 2, [1.3], but to be taken not greater than $2Z_{REQ}$
- k_B, k_N, k_D : Material factor k for bottom, neutral axis area and deck, respectively
- F_S : Distribution factor defined in Tab 4 (see also Fig 1)
- $\sigma_{X1,B}$: Reference value σ_{X1} calculated for z = 0
- $\sigma_{X1,N}$: Reference value σ_{X1} calculated for z = 0,5D
- $\sigma_{X1,D}$: Reference value σ_{X1} calculated for z = D

Table 4 : Distribution factor F_S

Hull transverse section location	Distribution factor F_S
0 ≤ x ≤ 0,1 L	0
0,1 L < x < 0,3 L	$5\frac{x}{L}-0,5$
0,3 L ≤ x ≤ 0,7 L	1
0,7 L < x < 0,9 L	$4,5-5\frac{x}{L}$
0,9 L ≤ x ≤ L	0

3.4 Transversely framed plating contributing to the hull girder longitudinal strength

3.4.1 General

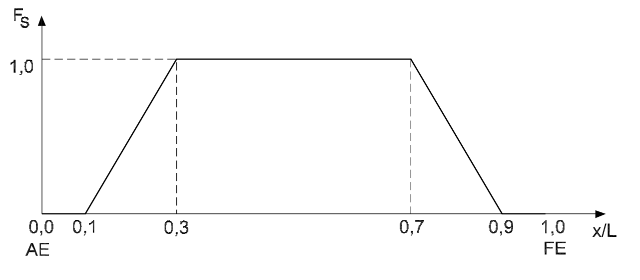
The net thickness of laterally loaded plate panels subjected to in-plane normal stress acting on the longer sides is to be not less than the value obtained, in mm, from the following formula:

$$t = 17,2c_ac_rs\sqrt{\gamma_R\gamma_m\frac{\gamma_{S2}p_S+\gamma_{W2}p_W}{\lambda_TR_y}}$$

where:

$$\lambda_T = 1-0,89\gamma_m\frac{\sigma_{x1}}{R_y}$$

Figure 1 : Distribution factor F_S



3.4.2 Flooding conditions

The plating of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids is to be checked in flooding conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 17,2c_ac_rs\sqrt{\gamma_R\gamma_m\frac{\gamma_{S2}p_{SF}+\gamma_{W2}p_{WF}}{\lambda_TR_y}}$$

where λ_T is defined in [3.4.1].

3.5 Plating not contributing to the hull girder longitudinal strength

3.5.1 General

The net thickness of plate panels subjected to lateral pressure is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{R_y}}$$

3.5.2 Flooding conditions

The plating of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids is to be checked in flooding conditions. To this end, its net thickness is to be not less than the value obtained, in mm, from the following formula:

$$t = 14{,}9 c_a c_r s \sqrt{\gamma_R \gamma_m \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{R_y}}$$

4 Strength check of plating subjected to wheeled loads

4.1 General

4.1.1 The requirements of this Article apply for the strength check of plating subjected to wheeled loads.

4.2 Load model

4.2.1 General

The still water and inertial forces induced by the sea and the various types of wheeled vehicles are to be considered, depending on the location of the plating.

4.2.2 Wheeled forces

The wheeled force applied by one wheel is constituted by still water force and inertial force.

Still water force is the vertical force (F_S) defined in Sec 1, Tab 11.

Inertial force is the vertical force ($F_{W,Z}$) defined in Sec 1, Tab 11, for load case "b", with the acceleration a_{Z1} calculated at x = 0,5L.

4.3 Plating

4.3.1 *(1/7/2009)*

The net thickness of plate panels subjected to wheeled loads is to be not less than the value obtained, in mm, from the following formula:

$$t = C_{WL}(nP_0k)^{0,5} - t_c$$

where:

C_{WL} : Coefficient to be taken equal to:

$$C_{WL} = 2,15 - \frac{0,05\ell}{s} + 0,02\left(4 - \frac{\ell}{s}\right)\alpha^{0,5} - 1,75\alpha^{0,25}$$

where ℓ/s is to be taken not greater than 3

$$\alpha = \frac{A_T}{\ell s}$$ where ℓ is to be taken not greater than 5s

A_T : Tyre print area, in m² (see Fig 2). In the case of double or triple wheels, the area is that corresponding to the group of wheels.

n : Number of wheels on the plate panel, taken equal to:
- 1 in the case of a single wheel
- the number of wheels in a group of wheels in the case of double or triple wheels

P_0 : Wheeled force, in kN, taken equal to:

$$P_0 = \gamma_{S2}F_S + 0,4\gamma_{W2}F_{W,Z}$$

4.3.2 When the tyre print area is not known, it may be taken equal to:

$$A_T = 9,81\frac{nQ_A}{n_W p_T}$$

where:

n : Number of wheels on the plate panel, defined in [4.3.1]

Q_A : Axle load, in t

n_W : Number of wheels for the axle considered

p_T : Tyre pressure, in kN/m². When the tyre pressure is not indicated by the designer, it may be taken as defined in Tab 5.

Table 5 : Tyre pressures p_T for vehicles

Vehicle type	Tyre pressure p_T, in kN/m²	
	Pneumatic tyres	Solid rubber tyres
Private cars	250	Not applicable
Vans	600	Not applicable
Trucks and trailers	800	Not applicable
Handling machines	1100	1600

4.3.3 For vehicles with the four wheels of the axle located on a plate panel as shown in Fig 2, the net thickness of deck plating is to be not less than the greater of the values obtained, in mm, from the following formulae:

$$t = t_1$$

$$t = t_2(1 + \beta_2 + \beta_3 + \beta_4)^{0,5}$$

where:

t_1 : Net thickness obtained from [4.3.1] for n = 2, considering one group of two wheels located on the plate panel

t_2 : Net thickness obtained from [4.3.1] for n = 1, considering one wheel located on the plate panel

$\beta_2, \beta_3, \beta_4$: Coefficients obtained from the following formula, by replacing i by 2, 3 and 4, respectively (see Fig 2):
- for $x_i/b < 2$:

$$\beta_i = 0,8(1,2 - 2,02\alpha_i + 1,17\alpha_i^2 - 0,23\alpha_i^3)$$

- for $x_i/b \geq 2$:

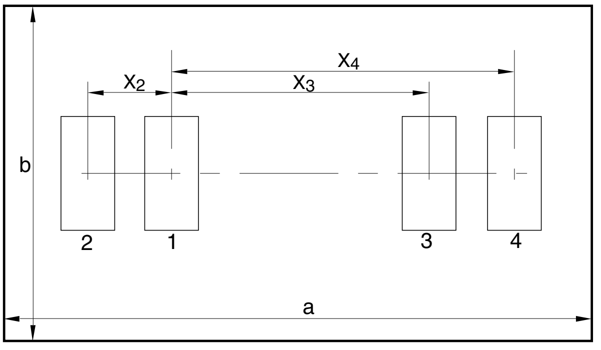
$$\beta_i = 0$$

x_i : Distance, in m, from the wheel considered to the reference wheel (see Fig 2)

b : Dimension, in m, of the plate panel side perpendicular to the axle

$$\alpha_i = \frac{x_i}{b}$$

Figure 2 : Four wheel axle located on a plate panel



5 Buckling check for ships equal to or greater than 65 m in length

5.1 General

5.1.1 Application

The requirements of this Article apply for the buckling check of plating subjected to in-plane hull girder compression stresses, in ships equal to or greater than 65m in length.

Rectangular plate panels are considered as being simply supported. For specific designs, other boundary conditions may be considered, at the Society's discretion, provided that the necessary information is submitted for review.

5.1.2 Compression and bending

For plate panels subjected to compression and bending along one side, as shown in Fig 3, side "b" is to be taken as the loaded side. In such case, the compression stress varies linearly from σ_1 to $\sigma_2 = \psi\ \sigma_1$ ($\psi \leq 1$) along edge "b".

5.2 Load model

5.2.1 Sign convention for normal stresses

The sign convention for normal stresses is as follows:

- tension: positive
- compression: negative.

5.2.2 In-plane hull girder compression normal stresses

The in-plane hull girder compression normal stresses to be considered for the buckling check of plating contributing to the longitudinal strength are obtained, in N/mm², from the following formula:

$$\sigma_{X1} = \gamma_{S1}\sigma_{S1} + \gamma_{W1}\sigma_{WV1}$$

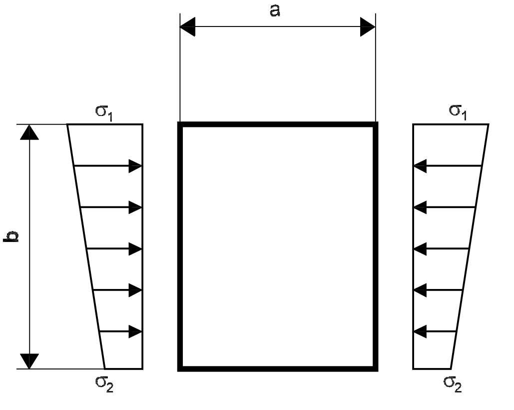
where σ_{S1} and σ_{WV1} are the hull girder normal stresses, in N/mm², defined in Tab 6.

σ_{X1} is to be taken as the maximum compression stress on the plate panel considered.

In no case may σ_{X1} be taken less than 30/k N/mm².

When the ship in still water is always in hogging condition, σ_{X1} may be evaluated by means of direct calculations when justified on the basis of the ship's characteristics and intended service. The calculations are to be submitted to the Society for approval.

Figure 3 : Buckling of a simply supported rectangular plate panel subjected to compression and bending



5.3 Critical stresses

5.3.1 Compression and bending for plane panel

The critical buckling stress is to be obtained, in N/mm², from the following formulae:

$$\sigma_c = \sigma_E \qquad \text{for} \qquad \sigma_E \leq \frac{R_{eH}}{2}$$

$$\sigma_c = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_E}\right) \qquad \text{for} \qquad \sigma_E > \frac{R_{eH}}{2}$$

where:

σ_E : Euler buckling stress, to be obtained, in N/mm², from the following formula:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_{net}}{b}\right)^2 K_1 \varepsilon \cdot 10^{-6}$$

K_1 : Buckling factor defined in Tab 7

ε : Coefficient to be taken equal to:

- ε = 1,00 for $\alpha \geq 1$
- ε = 1,05 for $\alpha < 1$ and side "b" stiffened by flat bar
- ε = 1,10 for $\alpha < 1$ and side "b" stiffened by bulb section
- ε = 1,21 for $\alpha < 1$ and side "b" stiffened by angle or T-section
- ε = 1,30 for $\alpha < 1$ and side "b" stiffened by primary supporting members.

α = a/b

Table 6 : Hull girder normal compression stresses

Condition	σ_{S1} , in N/mm² **(1)**	σ_{WV1} , in N/mm²
$z \geq N$	$\frac{M_{SW,S}}{I_Y}(z-N)10^{-3}$	$\frac{0{,}625 M_{WV,S}}{I_Y}(z-N)10^{-3}$
$z < N$	$\frac{M_{SW,H}}{I_Y}(z-N)10^{-3}$	$\frac{0{,}625 M_{WV,H}}{I_Y}(z-N)10^{-3}$

(1) When the ship in still water is always in hogging condition, σ_{S1} for $z \geq N$ is to be obtained, in N/mm², from the following formula, unless σ_{X1} is evaluated by means of direct calculations (see [5.2.2]):

$$\sigma_{S1} = \frac{M_{SW,Hmin}}{I_Y}(z-N)10^{-3}$$

5.3.2 Compression for corrugation flanges

The critical buckling stress is to be obtained, in N/mm², from the following formulae:

$$\sigma_c = \sigma_E \quad \text{for} \quad \sigma_E \leq \frac{R_{eH}}{2}$$

$$\sigma_c = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_E}\right) \quad \text{for} \quad \sigma_E > \frac{R_{eH}}{2}$$

where:

σ_E : Euler buckling stress, to be obtained, in N/mm², from the following formula:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_f}{V}\right)^2 (K_5 \cdot 10^{-6})$$

K_5 : Buckling factor to be taken equal to:

$$K_5 = \left(1 + \frac{t_w}{t_f}\right)\left\{3 + 0{,}5\frac{V'}{V} - 0{,}33\left(\frac{V'}{V}\right)^2\right\}$$

t_f : Net thickness, in mm, of the corrugation flange

t_w : Net thickness, in mm, of the corrugation web

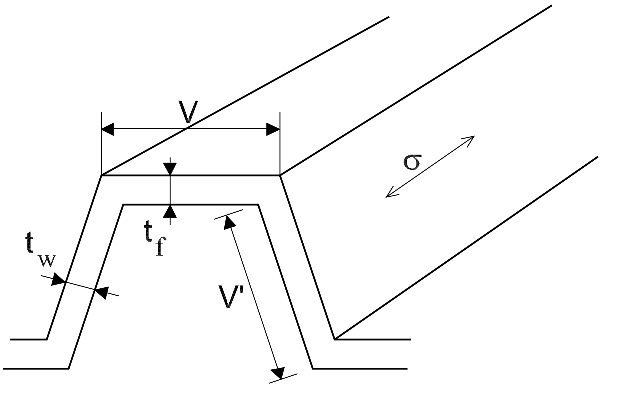
V, V’ : Dimensions of a corrugation, in m, as shown in Fig 4.

5.4 Checking criteria

5.4.1 Acceptance of results

The net thickness of plate panels is to be such as to satisfy the buckling check, as indicated in [5.4.2]. When the buckling criteria is exceeded by less than 15 %, the scantlings may still be considered as acceptable, provided that the stiffeners located on the plate panel satisfy the buckling checks as specified in Sec 4, [4].

Figure 4 : Dimensions of a corrugation



5.4.2 Compression and bending

For plate panels subjected to compression and bending on one side, the critical buckling stress is to comply with the following formula:

$$\frac{\sigma_c}{\gamma_R \gamma_m} \geq |\sigma_b|$$

where:

σ_c : Critical buckling stress, in N/mm², defined in [5.3.1] or [5.3.2], as the case may be

σ_b : Compression stress, in N/mm², acting on side “b” of the plate panel, to be calculated as specified in [5.2.2].

Table 7 : Buckling factor K_1 for plate panels

Load pattern	Aspect ratio	Buckling factor K_1
$0 \le \psi \le 1$	$\alpha \ge 1$	$\dfrac{8,4}{\psi + 1,1}$
	$\alpha < 1$	$\left(\alpha + \dfrac{1}{\alpha}\right)^2 \dfrac{2,1}{\psi + 1,1}$
$-1 < \psi < 0$		$(1 + \psi)K_1' - \psi K_1'' + 10\psi(1 + \psi)$
$\psi \le -1$	$\alpha \dfrac{1-\psi}{2} \ge \dfrac{2}{3}$	$23,9\left(\dfrac{1-\psi}{2}\right)^2$
	$\alpha \dfrac{1-\psi}{2} < \dfrac{2}{3}$	$\left(15,87 + \dfrac{1,87}{\left(\alpha\dfrac{1-\psi}{2}\right)^2} + 8,6\left(\alpha\dfrac{1-\psi}{2}\right)^2\right)\left(\dfrac{1-\psi}{2}\right)^2$

Note 1:

$\psi = \dfrac{\sigma_2}{\sigma_1}$

K_1' : Value of K_1 calculated for $\psi = 0$

K_1'' : Value of K_1 calculated for $\psi = -1$

SECTION 4 ORDINARY STIFFENERS

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

p_S : Still water pressure, in kN/m², see [3.3.2]

p_W : Wave pressure, in kN/m², see [3.3.2]

p_{SF}, p_{WF} : Still water and wave pressure, in kN/m², in flooding conditions, defined in Sec 1, [5.8]

F_S : Still water wheeled force, in kN, see [3.3.4]

$F_{W,Z}$: Inertial wheeled force, in kN, see [3.3.4]

σ_{X1} : Hull girder normal stress, in N/mm², defined in:

- [3.3.5] for the yielding check of ordinary stiffeners
- [4.2.2] for the buckling check of ordinary stiffeners for ships equal to or greater than 65 m in length

R_{eH} : Minimum yield stress, in N/mm², of the stiffener material, defined in Ch 4, Sec 1, [2]

s : Spacing, in m, of ordinary stiffeners

ℓ : Span, in m, of ordinary stiffeners, measured between the supporting members, see Ch 4, Sec 3, [3.2]

h_w : Stiffener web height, in mm

t_w : Net web thickness, in mm

b_f : Face plate width, in mm

t_f : Net face plate thickness, in mm

b_p : Width, in m, of the plating attached to the stiffener, for the yielding check, defined in Ch 4, Sec 3, [3.3.1]

b_e : Width, in m, of the plating attached to the stiffener, for the buckling check, defined in [4.1]

t_p : Net thickness, in mm, of the attached plating

w : Net section modulus, in cm³, of the stiffener, with an attached plating of width b_p, to be calculated as specified in Ch 4, Sec 3, [3.4]

A_e : Net sectional area, in cm², of the stiffener with attached plating of width b_e

A_{Sh} : Net shear sectional area, in cm², of the stiffener, to be calculated as specified in Ch 4, Sec 3, [3.4]

I_e : Net moment of inertia, in cm⁴, of the stiffener with attached shell plating of width b_e about its neutral axis parallel to the plating

$$\chi = \left(1 + 50\frac{\ell}{h_W}\right)^3$$

1 General

1.1 Application

1.1.1 *(1/7/2003)*

For ships less than 65 m in length, the criteria in App 1 may be used for the strength check of ordinary stiffeners as an alternative to those contained in this Section.

1.2 Net scantlings

1.2.1 As specified in Ch 4, Sec 2, [1], all scantlings referred to in this section are net, i.e. they do not include any margin for corrosion.

The gross scantlings are obtained as specified in Ch 4, Sec 2.

1.3 Partial safety factors

1.3.1 The partial safety factors to be considered for the checking of the ordinary stiffeners are specified in Tab 1.

1.4 Load point

1.4.1 Lateral pressure

Unless otherwise specified, lateral pressure is to be calculated at mid-span of the ordinary stiffener considered.

1.4.2 Hull girder stresses

For longitudinal ordinary stiffeners contributing to the hull girder longitudinal strength, the hull girder bending stresses are to be calculated in way of the neutral axis of the stiffener considered.

1.5 Net dimensions of ordinary stiffeners

1.5.1 Flat bar

The net dimensions of a flat bar ordinary stiffener (see Fig 1) are to comply with the following requirements:

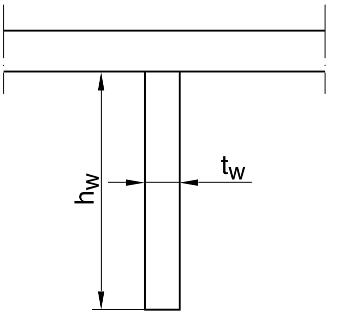
$$\frac{h_w}{t_w} \le 20\sqrt{k}$$

Table 1 : Ordinary stiffeners - Partial safety factors

Partial safety factors covering uncertainties regarding:	Symbol	Yielding check		Buckling check for L ≥ 65 m (see [4])
		General (see [3.3] to [3.5])	Watertight bulkhead ordinary stiffeners **(1)** (see [3.6])	
Still water hull girder loads	γ_{S1}	Not applicable	Not applicable	1,00
Wave hull girder loads	γ_{W1}	Not applicable	Not applicable	1,15
Still water pressure	γ_{S2}	1,00	1,00	Not applicable
Wave pressure	γ_{W2}	1,20	1,05	Not applicable
Material	γ_m	1,02	1,02	1,02
Resistance	γ_R	1,02	1,02 **(2)**	1,10

(1) Applies also to ordinary stiffeners of bulkheads or inner side which constitute boundary of compartments not intended to carry liquids.
(2) For ordinary stiffeners of the collision bulkhead, γ_R =1,25.

Figure 1 : Net dimensions of a flat bar



1.5.2 T-section

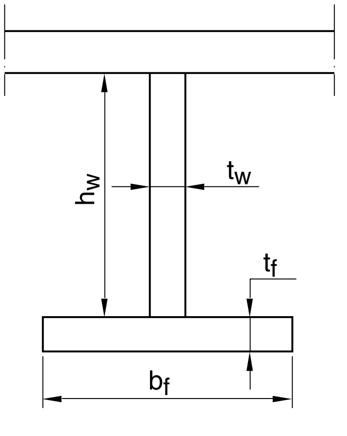
The net dimensions of a T-section ordinary stiffener (see Fig 2) are to comply with the following two requirements:

$$\frac{h_w}{t_w} \le 55\sqrt{k}$$

$$\frac{b_f}{t_f} \le 33\sqrt{k}$$

$$b_f t_f \ge \frac{h_w t_w}{6}$$

Figure 2 : Net dimensions of a T-section



1.5.3 Angle

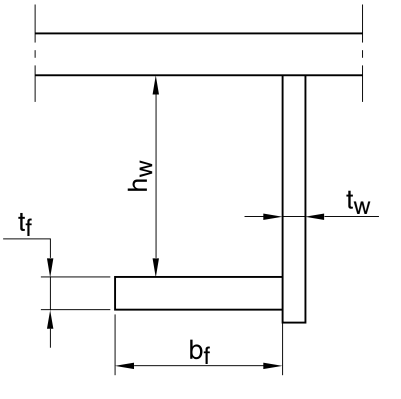
The net dimensions of an angle ordinary stiffener (see Fig 3) are to comply with the two following requirements:

$$\frac{h_w}{t_w} \le 55\sqrt{k}$$

$$\frac{b_f}{t_f} \le 16{,}5\sqrt{k}$$

$$b_f t_f \ge \frac{h_w t_w}{6}$$

Figure 3 : Net dimensions of an angle



2 General requirements

2.1 General

2.1.1 The requirements in [2.2] and [2.4] are to be applied to ordinary stiffeners in addition of those in [3] and [4].

2.2 Minimum net thicknesses

2.2.1 The net thickness of the web of ordinary stiffeners is to be not less than the lesser of:

- the value obtained, in mm, from the following formula:
  $t_{MIN} = (0,8 + 0,004Lk^{1/2} + 4,5s)\ c_T$
- the net as built thickness of the attached plating

where c_T is a coefficient equal to:

$$c_T = 0{,}7 + \frac{3T}{L} \quad \text{for} \quad L \le 25\,m$$

$$c_T = 0{,}85 + \frac{2T}{L} \quad \text{for} \quad 25\,m < L \le 40\,m$$

$$c_T = 1{,}0 \quad \text{for} \quad L > 40\,m$$

c_T may be taken not greater than 1,0.

2.3 Minimum net section modulus of side vertical ordinary stiffeners

2.3.1 The net section modulus of side vertical ordinary stiffeners is to be not less than the value obtained, in cm^3, from the following formula:

$$W_{MIN} = \alpha \cdot s \cdot \ell \cdot B^{1,5}$$

where:

α : Coefficient to be taken equal to:

- α = 0,75 for side vertical ordinary stiffeners located below the freeboard deck
- α = 0,65 for side vertical ordinary stiffeners located above the freeboard deck

In the area between 0,8 L from the aft end and the collision bulkhead, α is to be increased by 10%.

B : Breadth of the ship, in m, with:

- 6 m < B < 9 m for ships less than or equal to 50 m in length
- L/7 < B < L/6 for ships greater than 50 m in length.

2.4 Struts of open floors

2.4.1 The sectional area A_{ST}, in cm^2, and the moment of inertia I_{ST} about the main axes, in cm^4, of struts of open floors are to be not less than the values obtained from the following formulae:

$$A_{ST} = \frac{p_{ST} s \ell}{20}$$

$$I_{ST} = \frac{0{,}75 s \ell (p_{STB} + p_{STU}) A_{AST} \ell^2_{ST}}{47{,}2 A_{AST} - s \ell (p_{STB} + p_{STU})}$$

where:

p_{ST} : Pressure to be taken equal to the greater of the values obtained, in kN/m^2, from the following formulae:

$p_{ST} = 0{,}5\,(p_{STB} + p_{STU})$

$p_{ST} = p_{STD}$

p_{STB} : Sea pressure, in kN/m^2, acting on the bottom in way of the strut equal to:

$p_{STB} = \gamma_{S2} p_S + \gamma_{W2} p_W$

p_{STU} : Pressure, in kN/m^2, acting on the inner bottom in way of the strut due to the load in the tank or hold above, equal to:

$p_{STU} = \gamma_{S2} p_S + \gamma_{W2} p_W$

p_{STD} : Pressure, in kN/m^2, in double bottom at mid-span of the strut equal to:

$p_{STD} = \gamma_{S2} p_S + \gamma_{W2} p_W$

ℓ : Span, in m, of transverse ordinary stiffeners constituting the open floor (see Ch 4, Sec 3, [3.2.2])

ℓ_{ST} : Length, in m, of the strut

A_{AST} : Actual net sectional area, in cm^2, of the strut.

3 Yielding check

3.1 General

3.1.1 The requirements of this Article apply for the yielding check of ordinary stiffeners subjected to lateral pressure or wheeled loads and, for ordinary stiffeners contributing to the hull girder longitudinal strength, to hull girder normal stresses.

3.1.2 The yielding check is also to be carried out for ordinary stiffeners subjected to specific loads, such as concentrated loads.

3.2 Structural model

3.2.1 Boundary conditions

The requirements in [3.4] and [3.6] apply to stiffeners considered as clamped at both ends, whose end connections comply with the requirements in [3.2.2].

The requirements in [3.5] apply to stiffeners considered as simply supported at both ends. Other boundary conditions may be considered by the Society on a case by case basis, depending on the distribution of wheeled loads.

For other boundary conditions, the yielding check will be considered on a case by case basis.

3.2.2 Bracket arrangement

The requirements of this Article apply to ordinary stiffeners without end brackets, with a 45° bracket at one end or with two 45° equal end brackets, where the bracket length is not less than $0{,}1\ell$.

In the case of ordinary stiffeners with two 45° end brackets of different length (in no case less than $0{,}1\ell$), the minimum section modulus and shear sectional area are considered by the Society on a case by case basis. In general, an acceptable solution consists in applying the criteria for equal brackets, considering both brackets as having length equal to $0{,}1\ell$.

In the case of significantly different bracket arrangement, the minimum section modulus and shear sectional area are considered by the Society on a case by case basis.

3.3 Load model

3.3.1 General

The still water and wave lateral loads induced by the sea and the various types of cargoes and ballast in intact conditions are to be considered, depending on the location of the ordinary stiffener under consideration and the type of the compartments adjacent to it, in accordance with Sec 1, [1.4].

Ordinary stiffeners of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids are to be subjected to the lateral pressure in flooding conditions.

3.3.2 Lateral pressure in intact conditions

Lateral pressure in intact conditions is constituted by still water pressure and wave pressure.

Still water pressure (p_S) includes:

- the still water sea pressure, defined in Sec 1, [4]
- the still water internal pressure, defined in Sec 1, [5.1] to Sec 1, [5.7] for the various types of cargoes and for ballast.

Wave pressure (p_W) includes:

- the wave pressure, defined in Sec 1, [4]
- the inertial pressure, defined in Sec 1, [5.1] to Sec 1, [5.7] for the various types of cargoes and for ballast.

3.3.3 Lateral pressure in flooding conditions

The lateral pressure in flooding conditions is constituted by the still water pressure p_{SF} and wave pressure p_{WF} defined in Sec 1, [5.8].

3.3.4 Wheeled forces

The wheeled force applied by one wheel is constituted by still water force and inertial force.

Still water force is the vertical force (F_S) defined in Sec 1, Tab 11.

Inertial force is the vertical force ($F_{W,Z}$) defined in Sec 1, Tab 11.

3.3.5 Hull girder normal stresses

The hull girder normal stresses to be considered for the yielding check of ordinary stiffeners are obtained, at any hull transverse section, from the formulae in Tab 2.

Table 2 : Hull girder normal stresses

Condition		Hull girder normal stresses σ_{X1}, in N/mm²
Longitudinal ordinary stiffeners contributing to the hull girder longitudinal strength	$z = 0$	$\frac{[100+1,2(L_M-65)]}{k_B}\frac{Z_{REQ}}{Z_{AB}}F_S$
	$0 < z < 0,25D$	$\sigma_{X1,B}-\frac{\sigma_{X1,B}-\sigma_{X1,N}}{0,25D}z$
	$0,25D \le z \le 0,75D$	$\frac{[50+0,6(L_M-65)]}{k_N}F_S$
	$0,75D < z < D$	$\sigma_{X1,N}+\frac{\sigma_{X1,D}-\sigma_{X1,N}}{0,25D}(z-0,75D)$
	$z \ge D$	$\frac{[100+1,2(L_M-65)]}{k_D}\frac{Z_{REQ}}{Z_{AD}}F_S$
Longitudinal ordinary stiffeners not contributing to the hull girder longitudinal strength		0
Transverse ordinary stiffeners		0

Note 1:

L_M : Ship's length, in m, defined in Ch 1, Sec 2, [3.1], but to be taken not less than 65 m

Z_{REQ} : the greater of Z_R and $Z_{R,MIN}$, in m³, defined in Sec 2, [3.2]

Z_{AB}, Z_{AD} : Section moduli at bottom and deck, respectively, in m³, defined in Sec 2, [1.3], but to be taken not greater than $2Z_{REQ}$

k_B, k_N, k_D : Material factor k for bottom, neutral axis area and deck, respectively

F_S : Distribution factor defined in Tab 3 (see also Fig 4)

$\sigma_{X1,B}$: Reference value σ_{X1} calculated for z = 0

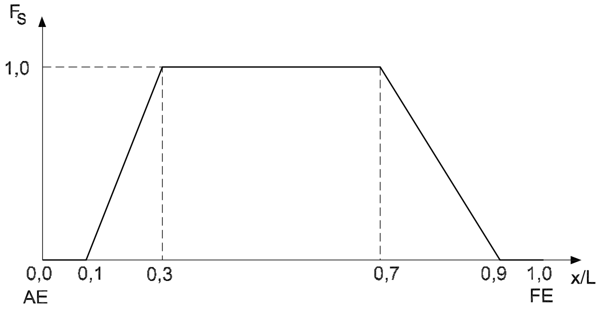
$\sigma_{X1,N}$: Reference value σ_{X1} calculated for z = 0,5D

$\sigma_{X1,D}$: Reference value σ_{X1} calculated for z = D

Table 3 : Distribution factor F_S

Hull transverse section location	Distribution factor F_S
$0 \le x \le 0,1\ L$	0
$0,1\ L < x < 0,3\ L$	$5\frac{x}{L} - 0,5$
$0,3\ L \le x \le 0,7\ L$	1
$0,7\ L < x < 0,9\ L$	$4,5 - 5\frac{x}{L}$
$0,9\ L \le x \le L$	0

Figure 4 : Distribution factor F_S



3.4 Net section modulus and net shear sectional area of ordinary stiffeners subjected to lateral pressure in intact condition

3.4.1 General

The requirements in [3.4.3] and [3.4.4] provide the required net section modulus and net shear sectional area of an ordinary stiffener subjected to lateral pressure in intact conditions.

3.4.2 Groups of equal ordinary stiffeners

Where a group of equal ordinary stiffeners is fitted, it is acceptable that the minimum net section modulus in [3.4.1] is calculated as the average of the values required for all the stiffeners of the same group, but this average is to be taken not less than 90% of the maximum required value.

The same applies for the minimum net shear sectional area.

3.4.3 Longitudinal and transverse ordinary stiffeners *(1/1/2021)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of longitudinal or transverse ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{12(R_y - \gamma_R \gamma_m \sigma_{X1})}\left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{R_y}\left(1 - \frac{s}{2\ell}\right) s \ell$$

where β_b and β_s are the coefficients defined in Tab 4.

Table 4 : Coefficients β_b and β_s

End bracket arrangement	β_b	β_s
No bracket at ends	1,0	1,0
45° bracket of length not less than $0,1\ell$ at one end	$\frac{0,53\chi + 0,47}{0,65\chi + 0,34}$	$\frac{0,59\chi + 0,41}{0,65\chi + 0,34}$
45° equal brackets of length not less than $0,1\ell$ at both ends	$\frac{0,51\chi - 0,05}{0,8\chi + 0,2}$	0,8

3.4.4 Vertical ordinary stiffeners

The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of vertical ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} \lambda_{bS} p_S + \gamma_{W2} \lambda_{bW} p_W}{12 R_y}\left(1 - \frac{s}{2\ell}\right) s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} \lambda_{sS} p_S + \gamma_{W2} \lambda_{sW} p_W}{R_y}\left(1 - \frac{s}{2\ell}\right) s \ell$$

where:

β_b, β_s : Coefficients defined in Tab 4

$$\lambda_{bS} = 1 + 0,2\frac{p_{Sd} - p_{Su}}{p_{Sd} + p_{Su}}$$

$$\lambda_{bW} = 1 + 0,2\frac{p_{Wd} - p_{Wu}}{p_{Wd} + p_{Wu}}$$

$$\lambda_{sS} = 1 + 0,4\frac{p_{Sd} - p_{Su}}{p_{Sd} + p_{Su}}$$

$$\lambda_{sW} = 1 + 0,4\frac{p_{Wd} - p_{Wu}}{p_{Wd} + p_{Wu}}$$

p_{Sd} : Still water pressure, in kN/m², at the lower end of the ordinary stiffener considered

p_{Su} : Still water pressure, in kN/m², at the upper end of the ordinary stiffener considered

p_{Wd} : Wave induced pressure, in kN/m², at the lower end of the ordinary stiffener considered.

p_{Wu} : Wave induced pressure, in kN/m², at the upper end of the ordinary stiffener considered

3.5 Net section modulus and net shear sectional area of ordinary stiffeners subjected to wheeled loads

3.5.1 The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of ordinary stiffeners subjected to wheeled loads are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \frac{\alpha_S P_0 \ell}{6(R_y - \gamma_R \gamma_m \sigma_{X1})} 10^3$$

$$A_{Sh} = 20 \gamma_R \gamma_m \frac{\alpha_T P_0}{R_y}$$

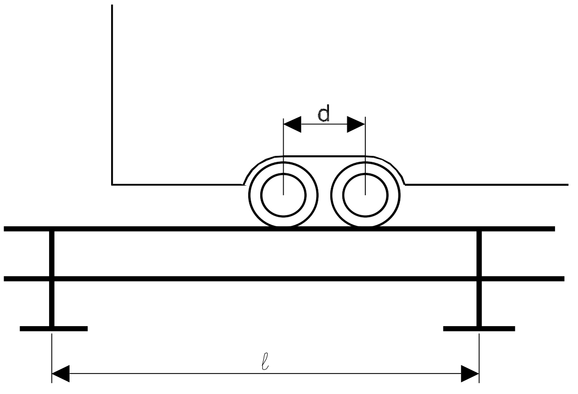
where:

P_0 : Wheeled force, in kN, taken equal to:

$$P_0 = \gamma_{S2} F_S + 0,4 \gamma_{W2} F_{W,Z}$$

α_S, α_T : Coefficients taking account of the number of axles and wheels per axle considered as acting on the stiffener, defined in Tab 5 (see Fig 5).

Figure 5 : Wheeled load on stiffeners - Double axles



3.6 Net section modulus and net shear sectional area of ordinary stiffeners subjected to lateral pressure in flooding conditions

3.6.1 General

The requirements in [3.6.1] to [3.6.4] apply to ordinary stiffeners of bulkheads or inner side which constitute boundary of compartments not intended to carry liquids.

These ordinary stiffeners are to be checked in flooding conditions as specified in [3.6.3] and [3.6.4], depending on the type of stiffener.

3.6.2 Groups of equal ordinary stiffeners

Where a group of equal ordinary stiffeners is fitted, it is acceptable that the minimum net section modulus in [3.6.1] is calculated as the average of the values required for all the stiffeners of the same group, but this average is to be taken not less than 90% of the maximum required value.

The same applies for the minimum net shear sectional area.

3.6.3 Longitudinal and transverse ordinary stiffeners *(1/7/2022)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh} , in cm², of longitudinal or transverse ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R\gamma_m\beta_b\frac{\gamma_{S2}p_{SF}+\gamma_{W2}p_{WF}}{12c_P(R_y-\gamma_R\gamma_m\sigma_{X1})}\left(1-\frac{s}{2\ell}\right)s\ell^2 10^3$$

$$A_{Sh} = 10\gamma_R\gamma_m\beta_s\frac{\gamma_{S2}p_{SF}+\gamma_{W2}p_{WF}}{R_y}\left(1-\frac{s}{2\ell}\right)s\ell$$

where:

β_b, β_s : Coefficients defined in [3.4.3]

c_P : Ratio of the plastic section modulus to the elastic section modulus of the ordinary stiffeners with an attached shell plating b_p , to be taken equal to 1,16 in the absence of more precise evaluation.

3.6.4 Vertical ordinary stiffeners *(1/7/2022)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh} , in cm², of vertical ordinary stiffeners are to be not less than the values obtained from the following formulae:

$$w = \gamma_R\gamma_m\beta_b\frac{\gamma_{S2}\lambda_{bS}p_{SF}+\gamma_{W2}\lambda_{bW}p_{WF}}{12c_PR_y}\left(1-\frac{s}{2\ell}\right)s\ell^2 10^3$$

$$A_{Sh} = 10\gamma_R\gamma_m\beta_s\frac{\gamma_{S2}\lambda_{sS}p_{SF}+\gamma_{W2}\lambda_{sW}p_{WF}}{R_y}\left(1-\frac{s}{2\ell}\right)s\ell$$

where:

β_b, β_s : Coefficients defined in [3.4.3]

c_P : Ratio defined in [3.6.3]

$$\lambda_{bS} = 1+0,2\frac{p_{SFd}-p_{SFu}}{p_{SFd}+p_{SFu}}$$

$$\lambda_{bW} = 1+0,2\frac{p_{WFd}-p_{WFu}}{p_{WFd}+p_{WFu}}$$

$$\lambda_{sS} = 1+0,4\frac{p_{SFd}-p_{SFu}}{p_{SFd}+p_{SFu}}$$

$$\lambda_{sW} = 1+0,4\frac{p_{WFd}-p_{WFu}}{p_{WFd}+p_{WFu}}$$

p_{SFd} : Still water pressure, in kN/m², in flooding conditions, at the lower end of the ordinary stiffener considered

p_{SFu} : Still water pressure, in kN/m², in flooding conditions, at the upper end of the ordinary stiffener considered

p_{WFd} : Wave pressure, in kN/m², in flooding conditions, at the lower end of the ordinary stiffener considered.

p_{WFu} : Wave pressure, in kN/m², in flooding conditions, at the upper end of the ordinary stiffener considered

4 Buckling check for ships equal to or greater than 65 m in length

4.1 Width of attached plating

4.1.1 The width of the attached plating to be considered for the buckling check of the ordinary stiffeners is to be obtained, in m, from the following formulae:

- where no local buckling occurs on the attached plating (see Sec 3, [5.4.1]):

  $b_e = s$

- where local buckling occurs on the attached plating (see Sec 3, [5.4.1]):

  $$b_e = \left(\frac{2,25}{\beta_e}-\frac{1,25}{\beta_e^2}\right)s$$

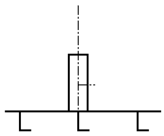
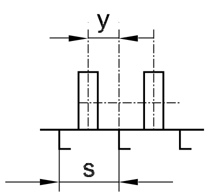
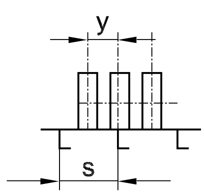
  to be taken not greater than s,

  where:

  $$\beta_e = \frac{s}{t_p}\sqrt{\frac{\sigma_b}{E}}10^3$$

  σ_b : Compression stress σ_{X1}, in N/mm², acting on the plate panel, defined in Sec 3, [5.2.2].

Table 5 : Wheeled load on stiffeners - Coefficients α_S and α_T

Configuration	Single axle		Double axles	
	α_S	α_T	α_S	α_T
Single wheel 	1	1	$0{,}5\left(2-\frac{d}{\ell}\right)^2$	$2+\frac{d}{\ell}$
Double wheels 	$2\left(1-\frac{y}{s}\right)$	$2\left(1-\frac{y}{s}\right)$	$\left(1-\frac{y}{s}\right)\left(2-\frac{d}{\ell}\right)^2$	$2\left(1-\frac{y}{s}\right)\left(2+\frac{d}{\ell}\right)$
Triple wheels 	$3-2\frac{y}{s}$	$3-2\frac{y}{s}$	$0{,}5\left(3-2\frac{y}{s}\right)\left(2-\frac{d}{\ell}\right)^2$	$\left(3-2\frac{y}{s}\right)\left(2+\frac{d}{\ell}\right)$

Note 1:
d : Distance, in m, between two axles (see Fig 5)
y : Distance, in m, from the external wheel of a group of wheels to the stiffener under consideration, to be taken equal to the distance from the external wheel to the centre of the group of wheels.

4.2 Load model

4.2.1 Sign convention for normal stresses

The sign convention for normal stresses is as follows:

- tension: positive
- compression: negative.

4.2.2 Hull girder compression normal stresses

The hull girder compression normal stresses to be considered for the buckling check of ordinary stiffeners contributing to the hull girder longitudinal strength are obtained, in N/mm², from the following formula:

$$\sigma_{X1} = \gamma_{S1}\sigma_{S1} + \gamma_{W1}\sigma_{WV1}$$

where σ_{S1} and σ_{WV1} are the hull girder normal stresses, in N/mm², defined in Tab 6.

For longitudinal stiffeners, σ_{X1} is to be taken as the maximum compression stress on the stiffener considered.

In no case may σ_{X1} be taken less than 30/k N/mm².

When the ship in still water is always in hogging condition, σ_{X1} may be evaluated by means of direct calculations when justified on the basis of the ship's characteristics and intended service. The calculations are to be submitted to the Society for approval.

4.3 Critical stress

4.3.1 General

The critical buckling stress σ_c is to be obtained, in N/mm², from the following formulae:

$$\sigma_c = \sigma_E \qquad \text{for} \quad \sigma_E \le \frac{R_{eH}}{2}$$

$$\sigma_c = R_{eH}\left(1-\frac{R_{eH}}{4\sigma_E}\right) \qquad \text{for} \quad \sigma_E > \frac{R_{eH}}{2}$$

where:

$\sigma_E = \min(\sigma_{E1}, \sigma_{E2})$

σ_{E1} : Euler column buckling stress, in N/mm², given in [4.3.2]

σ_{E2} : Euler web buckling stress, in N/mm², given in [4.3.3].

4.3.2 Column buckling of axially loaded stiffeners

The Euler column buckling stress is obtained, in N/mm², from the following formula:

$$\sigma_E = \pi^2 E \frac{I_e}{A_e \ell^2} 10^{-4}$$

4.3.3 Web buckling of axially loaded stiffeners

The Euler buckling stress of the stiffener web is obtained, in N/mm², from the following formulae:

- for flat bars:

$$\sigma_E = 16\left(\frac{t_W}{h_W}\right)^2 10^4$$

- for stiffeners with face plate:

$$\sigma_E = 78\left(\frac{t_W}{h_W}\right)^2 10^4$$

4.4 Checking criteria

4.4.1 Stiffeners parallel to the direction of compression

The critical buckling stress of the ordinary stiffener is to comply with the following formula:

$$\frac{\sigma_c}{\gamma_R \gamma_m} \geq |\sigma_b|$$

where:

σ_c : Critical buckling stress, in N/mm², as calculated in [4.3.1]

σ_b : Compression stress σ_{xb} or σ_{yb}, in N/mm², in the stiffener, as calculated in [4.2.2].

4.4.2 Stiffeners perpendicular to the direction of compression

The net moment of inertia of stiffeners, in cm⁴, is to be not less than $400\ell^2$.

Table 6 : Hull girder normal compression stresses

Condition	σ_{S1} in N/mm² **(1)**	σ_{WV1} in N/mm²
$z \geq N$	$\frac{M_{SW,S}}{I_Y}(z-N)10^{-3}$	$\frac{0{,}625 M_{WV,S}}{I_Y}(z-N)10^{-3}$
$z < N$	$\frac{M_{SW,H}}{I_Y}(z-N)10^{-3}$	$\frac{0{,}625 M_{WV,H}}{I_Y}(z-N)10^{-3}$

(1) When the ship in still water is always in hogging condition, σ_{S1} for $z \geq N$ is to be obtained, in N/mm², from the following formula, unless σ_{X1} is evaluated by means of direct calculations (see [4.2.2]):

$$\sigma_{S1} = \frac{M_{SW,Hmin}}{I_Y}(z-N)10^{-3}$$

Figure 6 : Buckling of stiffeners perpendicular to the direction of compression

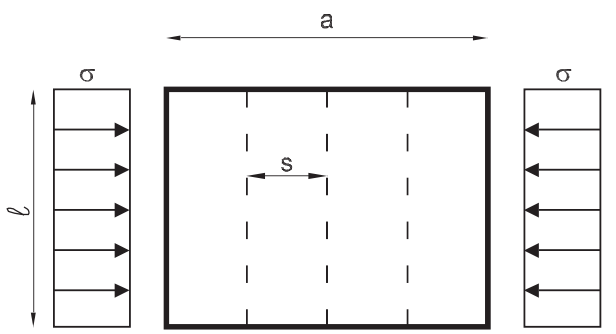
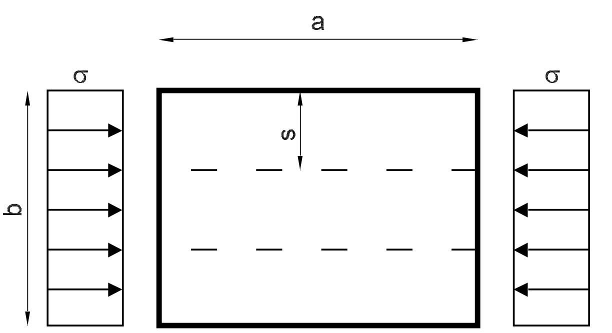


Figure 7 : Buckling of stiffeners parallel to the direction of compression



SECTION 5 PRIMARY SUPPORTING MEMBERS

Symbols

For symbols not defined in this Section, refer to the list at the beginning of this Chapter.

p_S : Still water pressure, in kN/m², see [3.4.2] and [3.4.4]

p_W : Wave pressure, in kN/m², see [3.4.2] and [3.4.4]

p_{SF}, p_{WF} : Still water and wave pressures, in kN/m², in flooding conditions, defined in Ch 8, Sec 1, [5.8]

σ_{X1} : Hull girder normal stress, in N/mm², defined in [3.4.5]

s : Spacing, in m, of primary supporting members

ℓ : Span, in m, of primary supporting members, measured between the supporting members, see Ch 4, Sec 3, [4.1]

h_W : Primary supporting member web height, in mm

b_p : Width, in m, of the plating attached to the primary supporting member, for the yielding check, as defined in Ch 4, Sec 3, [4.2]

w : Net section modulus, in cm³, of the primary supporting member, with an attached plating of width b_p, to be calculated as specified in Ch 4, Sec 3, [4.3]

A_{Sh} : Net shear sectional area, in cm², of the primary supporting member, to be calculated as specified in Ch 4, Sec 3, [4.3]

m : Boundary coefficient, to be taken equal to:

- m = 10 in general
- m = 12 for bottom and side girders

$$\chi = \left(1 + 50\frac{\ell}{h_W}\right)^3$$

1 General

1.1 Application

1.1.1 Ships less than 65 m in length *(1/7/2003)*

For ships less than 65 m in length, the criteria in App 1 may be used for the strength check of primary supporting members, as an alternative to those contained in this Section.

1.1.2 Analysis criteria

The requirements of this Section apply for the yielding and buckling checks of primary supporting members and analysed through an isolated beam structural model.

1.1.3 Direct calculations

Direct calculations may be required by the Society when deemed necessary on the basis of the ship's structural arrangement and load conditions. When required, these analyses are to be carried out according to the applicable requirements in Ch 7, Sec 3, Ch 7, App 1 or Ch 7, App 2.

1.2 Net scantlings

1.2.1 As specified in Ch 4, Sec 2, [1], all scantlings referred to in this section are net, i.e. they do not include any margin for corrosion.

The gross scantlings are obtained as specified in Ch 4, Sec 2.

1.3 Partial safety factors

1.3.1 The partial safety factors to be considered for checking primary supporting members are specified in Tab 1.

2 Minimum net thicknesses

2.1 General

2.1.1 The net thickness of plating which forms the webs of primary supporting members, with the exception of double bottom girders and floors for which specific requirements are given in [2.2], is to be not less than the lesser of:

- the value obtained, in mm, from the following formula:

  $t_{MIN} = (3,7 + 0,015Lk^{1/2})\, c_T$
- the thickness of the attached plating

where c_T is a coefficient equal to:

$$c_T = 0,7 + \frac{3T}{L} \quad \text{for } L \le 25\,m$$

$$c_T = 0,85 + \frac{2T}{L} \quad \text{for } 25\,m < L \le 40\,m$$

$$c_T = 1,0 \quad \text{for } L > 40\,m$$

c_T may not be taken greater than 1,0.

Table 1 : Primary supporting members - Partial safety factors *(1/7/2011)*

Partial safety factors covering uncertainties regarding:	Symbol	Yielding check		Buckling check of pillars (see [4.1])
		General (see [3.4] and [3.5])	Watertight bulkhead primary supporting members **(1)** (see [3.6])	
Still water hull girder loads	γ_{S1}	Not applicable	Not applicable	1,00
Wave hull girder loads	γ_{W1}	Not applicable	Not applicable	1,15
Still water pressure	γ_{S2}	1,00	1,00	Not applicable
Wave pressure	γ_{W2}	1,20	1,05	Not applicable
Material	γ_m	1,02	1,02	1,02
Resistance	γ_R	1,02 in general 1,15 for bottom and side girders	1,02 **(2)**	1,50

(1) Applies also to primary supporting members of bulkheads or inner side which constitute boundary of compartments not intended to carry liquids.
(2) For primary supporting members of the collision bulkhead, γ_R =1,25

2.2 Double bottom

2.2.1 The net thickness of plating which forms primary supporting members of the double bottom is to be not less than the values given in Tab 2.

3 Yielding check

3.1 General

3.1.1 The requirements of this Article apply for the yielding check of primary supporting members subjected to lateral pressure or to wheeled loads and, for those contributing to the hull girder longitudinal strength, to hull girder normal stresses.

3.1.2 The yielding check is also to be carried out for primary supporting members subjected to specific loads, such as concentrated loads.

3.2 Bracket arrangement

3.2.1 The requirements of this Article apply to primary supporting members with 45° brackets at both ends of length not less than $0,1\ell$.

In the case of a significantly different bracket arrangement, the section modulus and shear sectional area are considered by the Society on a case by case basis.

3.3 Load point

3.3.1 Lateral pressure

Unless otherwise specified, lateral pressure is to be calculated at mid-span of the primary supporting member considered.

3.3.2 Hull girder normal stresses

For longitudinal primary supporting members contributing to the hull girder longitudinal strength, the hull girder normal stresses are to be calculated in way of the face plate of the primary supporting member considered.

For bottom and deck girders, it may generally be assumed that the hull girder normal stresses in the face plate are equal to 0,75 times those in the relevant plating.

3.4 Load model

3.4.1 General

The still water and wave lateral loads induced by the sea and the various types of cargoes and ballast in intact conditions are to be considered, depending on the location of the primary supporting member under consideration and the type of compartments adjacent to it, in accordance with Sec 1, [1.4].

Primary supporting members of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids are to be subjected to the lateral pressure in flooding conditions.

3.4.2 Lateral pressure in intact conditions

Lateral pressure in intact conditions is constituted by still water pressure and wave pressure.

Still water pressure (p_S) includes:

- the still water sea pressure, defined in Sec 1, [4]
- the still water internal pressure, defined in Sec 1, [5.1] to Sec 1, [5.7] for the various types of cargoes and for ballast.

Wave pressure (p_W) includes:

- the wave pressure, defined in Sec 1, [4]
- the inertial pressure, defined in Sec 1, [5.1] to Sec 1, [5.7] for the various types of cargoes and for ballast.

Table 2 : Minimum net thicknesses of double bottom primary supporting members

Primary supporting member	Minimum net thickness, in mm	
	Area within 0,4L amidships	Area outside 0,4L amidships
Centre girder	$2{,}1\ L^{1/3}\ k^{1/6}$	$1{,}7\ L^{1/3}\ k^{1/6}$
Side girders	$1{,}4\ L^{1/3}\ k^{1/6}$	$1{,}4\ L^{1/3}\ k^{1/6}$
Floors	$1{,}4\ L^{1/3}\ k^{1/6}$	$1{,}4\ L^{1/3}\ k^{1/6}$

3.4.3 Lateral pressure in flooding conditions

The lateral pressure in flooding conditions is constituted by the still water pressure p_{SF} and the wave pressure p_{WF} defined in Sec 1, [5.8].

3.4.4 Wheeled loads

For primary supporting members subjected to wheeled loads, the yielding check may be carried out according to [3.5] considering uniform pressures equivalent to the distribution of vertical concentrated forces, when such forces are closely located.

For the determination of the equivalent uniform pressures, the most unfavourable case, i.e. where the maximum number of axles are located on the same primary supporting member, according to Fig 1 to Fig 3, is to be considered.

The equivalent still water pressure and inertial pressure are indicated in Tab 3.

3.4.5 Hull girder normal stresses

The hull girder normal stresses to be considered for the yielding check of primary supporting members are obtained, at any hull transverse section, from the formulae in Tab 4.

Figure 1 : Wheeled loads - Distribution of vehicles on a primary supporting member

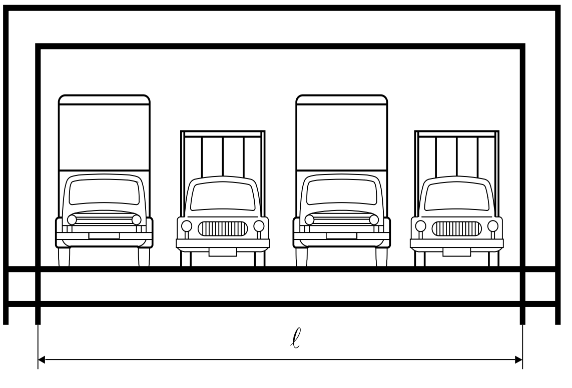


Figure 2 : Wheeled loads Distance between two consecutive axles

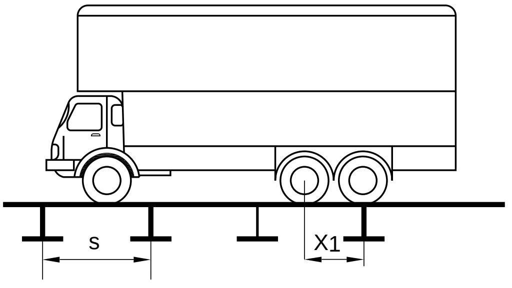


Figure 3 : Wheeled loads - Distance between axles of two consecutive vehicles

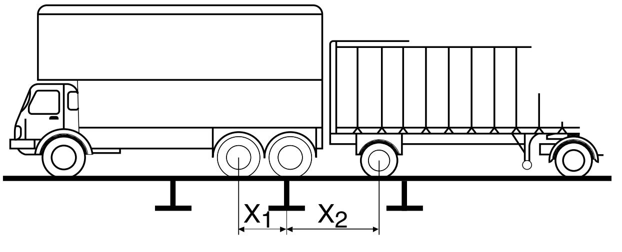


Table 3 : Wheeled loads Equivalent uniform still water and inertial pressures

Still water pressure p_S , in kN/m²	Inertial pressure p_W , in kN/m²
$10\ p_{eq}$	$p_{eq}\ a_{Z1}$

Note 1:

$$p_{eq} = \frac{n_V Q_A}{\ell s}\left(3 - \frac{X_1 + X_2}{s}\right)$$

- n_V : Maximum number of vehicles possible located on the primary supporting member
- Q_A : Maximum axle load, in t, as defined in Sec 1, [5.5]
- X_1 : Minimum distance, in m, between 2 consecutive axles (see Fig 2 and Fig 3
- X_2 : Minimum distance, in m, between axles of 2 consecutive vehicles (see Fig 3).

Table 4 : Hull girder normal stresses

Condition		Hull girder normal stresses σ_{X1}, in N/mm²
Longitudinal primary supporting members contributing to the hull girder longitudinal strength	z = 0	$\frac{[100 + 1,2(L_M - 65)]}{k_B} \frac{Z_{REQ}}{Z_{AB}} F_S$
	0 < z < 0,25D	$\sigma_{X1,B} - \frac{\sigma_{X1,B} - \sigma_{X1,N}}{0,25D} z$
	0,25D ≤ z ≤ 0,75D	$\frac{[50 + 0,6(L_M - 65)]}{k_N} F_S$
	0,75D < z < D	$\sigma_{X1,N} + \frac{\sigma_{X1,D} - \sigma_{X1,N}}{0,25D}(z - 0,75D)$
	z ≥ D	$\frac{[100 + 1,2(L_M - 65)]}{k_D} \frac{Z_{REQ}}{Z_{AD}} F_S$
Longitudinal primary supporting members not contributing to the hull girder longitudinal strength		0
Transverse primary supporting members		0

Note 1:

L_M : Ship's length, in m, as defined in Ch 1, Sec 2, [3.1], but to be taken not less than 65 m

Z_{REQ} : the greater of Z_R and $Z_{R,MIN}$, in m³, defined in Sec 2, [3.2]

Z_{AB},Z_{AD} : Section moduli at bottom and deck, respectively, in m³, defined in Sec 2, [1.3], but to be taken not less than $2Z_{REQ}$

k_B, k_N, k_D : Material factor k for bottom, neutral axis area and deck, respectively

F_S : Distribution factor defined in Tab 5 (see also Fig 4)

$\sigma_{X1,B}$: Reference value σ_{X1} calculated for z = 0

$\sigma_{X1,N}$: Reference value σ_{X1} calculated for z = 0,5D

$\sigma_{X1,D}$: Reference value σ_{X1} calculated for z = D

Table 5 : Distribution factor F_S

Hull transverse section location	Distribution factor F_S
0 ≤ x ≤ 0,1 L	0
0,1 L < x < 0,3 L	$5\frac{x}{L} - 0,5$
0,3 L ≤ x ≤ 0,7 L	1
0,7 L < x < 0,9 L	$4,5 - 5\frac{x}{L}$
0,9 L ≤ x ≤ L	0

3.5 Net section modulus and net sectional shear area of primary supporting members subjected to lateral pressure in intact conditions

3.5.1 General

The requirements in [3.5.2] and [3.5.3] provide the minimum net section modulus and net shear sectional area of primary supporting members subjected to lateral pressure in intact conditions.

3.5.2 Longitudinal and transverse primary supporting members

The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of longitudinal or transverse primary supporting members are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{m(R_y - \gamma_R \gamma_m \sigma_{X1})} s \ell^2 10^3$$

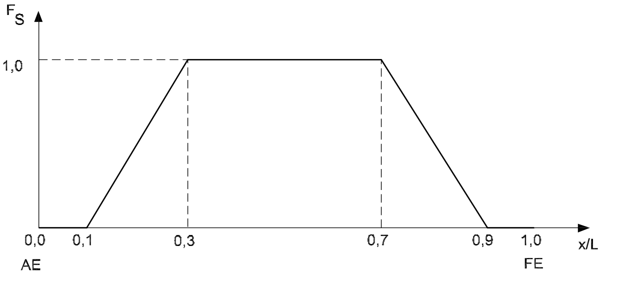
$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} p_S + \gamma_{W2} p_W}{R_y} s \ell$$

where:

$$\beta_b = \frac{0,51\chi - 0,05}{0,8\chi + 0,2}$$

$$\beta_s = 0,8$$

Figure 4 : Distribution factor F_S



3.5.3 Vertical primary supporting members

The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of vertical primary supporting members are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2}\lambda_{bS} p_S + \gamma_{W2}\lambda_{bW} p_W}{m(R_y - \gamma_R \gamma_m \sigma_A)} s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2}\lambda_{sS} p_S + \gamma_{W2}\lambda_{sW} p_W}{R_y} s \ell$$

where:

β_b, β_s : Coefficients defined in [3.5.2]

$$\lambda_{bS} = 1 + 0,2\frac{p_{Sd} - p_{Su}}{p_{Sd} + p_{Su}}$$

$$\lambda_{bW} = 1 + 0,2\frac{p_{Wd} - p_{Wu}}{p_{Wd} + p_{Wu}}$$

$$\lambda_{sS} = 1 + 0,4\frac{p_{Sd} - p_{Su}}{p_{Sd} + p_{Su}}$$

$$\lambda_{sW} = 1 + 0,4\frac{p_{Wd} - p_{Wu}}{p_{Wd} + p_{Wu}}$$

p_{Sd} : Still water pressure, in kN/m², at the lower end of the primary supporting member considered

p_{Su} : Still water pressure, in kN/m², at the upper end of the primary supporting member considered

p_{Wd} : Wave pressure, in kN/m², at the lower end of the primary supporting member considered

p_{Wu} : Wave pressure, in kN/m², at the upper end of the primary supporting member considered

σ_A : Axial stress, to be obtained, in N/mm², from the following formula:

$$\sigma_A = 10\frac{F_A}{A}$$

F_A : Axial load (still water and wave) transmitted to the vertical primary supporting members by the structures above. For multideck ships, the criteria in [4.1.1] for pillars are to be adopted.

A : Net sectional area, in cm², of the vertical primary supporting members with attached plating of width b_P.

3.6 Net section modulus and net shear sectional area of primary supporting members subjected to lateral pressure in flooding conditions

3.6.1 General

The requirements in [3.6.1] to [3.6.3] apply to primary supporting members of bulkheads or inner side which constitute the boundary of compartments not intended to carry liquids.

These primary supporting members are to be checked in flooding conditions as specified in [3.6.2] and [3.6.3], depending on the type of member.

3.6.2 Longitudinal and transverse primary supporting members *(1/7/2021)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of longitudinal or transverse primary supporting members are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{12 c_P (R_y - \gamma_m \sigma_{X1})} s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2} p_{SF} + \gamma_{W2} p_{WF}}{R_y} s \ell$$

where:

β_b, β_s : Coefficients defined in [3.5.2]

c_P : Ratio of the plastic section modulus to the elastic section modulus of the primary supporting members with an attached shell plating b_p, to be taken equal to 1,16 in the absence of more precise evaluation.

3.6.3 Vertical primary supporting members *(1/7/2021)*

The net section modulus w, in cm³, and the net shear sectional area A_{Sh}, in cm², of vertical primary supporting members are to be not less than the values obtained from the following formulae:

$$w = \gamma_R \gamma_m \beta_b \frac{\gamma_{S2}\lambda_{bS} p_{SF} + \gamma_{W2}\lambda_{bW} p_{WF}}{12 c_P R_y} s \ell^2 10^3$$

$$A_{Sh} = 10 \gamma_R \gamma_m \beta_s \frac{\gamma_{S2}\lambda_{sS} p_{SF} + \gamma_{W2}\lambda_{sW} p_{WF}}{R_y} s \ell$$

where:

β_b, β_s : Coefficients defined in [3.5.2]

c_P : Ratio defined in [3.6.2]

$$\lambda_{bS} = 1 + 0,2\frac{p_{SFd} - p_{SFu}}{p_{SFd} + p_{SFu}}$$

$$\lambda_{bW} = 1 + 0,2\frac{p_{WFd} - p_{WFu}}{p_{WFd} + p_{WFu}}$$

$$\lambda_{sS} = 1 + 0,4\frac{p_{SFd} - p_{SFu}}{p_{SFd} + p_{SFu}}$$

$$\lambda_{sW} = 1 + 0,4\frac{p_{WFd} - p_{WFu}}{p_{WFd} + p_{WFu}}$$

p_{SFd} : Still water pressure, in kN/m², in flooding conditions, at the lower end of the primary supporting member considered

p_{SFu} : Still water pressure, in kN/m², in flooding conditions, at the upper end of the primary supporting member considered

p_{WFd} : Wave pressure, in kN/m², in flooding conditions, at the lower end of the primary supporting member considered.

p_{WFu} : Wave pressure, in kN/m², in flooding conditions, at the upper end of the primary supporting member considered

4 Buckling check

4.1 Buckling of pillars subjected to compression axial load

4.1.1 Compression axial load

The compression axial load in the pillar is to be obtained, in kN, from the following formula:

$$F_A = A_D(\gamma_S p_S + \gamma_W p_W) + \sum_i r(\gamma_S Q_{i,S} + \gamma_W Q_{i,W})$$

where:

A_D : Area, in m^2, of the portion of the deck or the platform supported by the pillar considered

r : Coefficient which depends on the relative position of each pillar above the one considered, to be taken equal to:
- r = 1,0 for the pillar considered
- r = 0,9 for the pillar immediately above that considered
- $r = 0,9^i$ for the i^{th} pillar of the line above the pillar considered, to be taken not less than 0,478

$Q_{i,S}$, $Q_{i,W}$: Still water and wave load, respectively, in kN, from the i^{th} pillar of the line above the pillar considered, if any.

4.1.2 Critical column buckling stress of pillars

The critical column buckling stress of pillars is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cB} = \sigma_{E1} \quad \text{for} \quad \sigma_{E1} \le \frac{R_{eH}}{2}$$

$$\sigma_{cB} = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_{E1}}\right) \quad \text{for} \quad \sigma_{E1} > \frac{R_{eH}}{2}$$

where:

σ_{E1} : Euler column buckling stress, to be obtained, in N/mm², from the following formula:

$$\sigma_{E1} = \pi^2 E \frac{I}{A(f\ell)^2} 10^{-4}$$

I : Minimum net moment of inertia, in cm⁴, of the pillar

A : Net cross-sectional area, in cm², of the pillar

ℓ : Span, in m, of the pillar

f : Coefficient, to be obtained from Tab 5.

4.1.3 Critical torsional buckling stress of built-up pillars

The critical torsional buckling stress of built-up pillars is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cT} = \sigma_{E2} \quad \text{for} \quad \sigma_{E2} \le \frac{R_{eH}}{2}$$

$$\sigma_{cT} = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_{E2}}\right) \quad \text{for} \quad \sigma_{E2} > \frac{R_{eH}}{2}$$

where:

σ_{E2} : Euler torsional buckling stress, to be obtained, in N/mm², from the following formula:

$$\sigma_{E2} = \frac{\pi^2 E I_w}{10^4 I_p \ell^2} + 0,41 E \frac{I_t}{I_p}$$

I_w : Net sectorial moment of inertia of the pillar, to be obtained, in cm⁶, from the following formula:

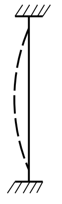
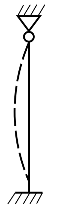
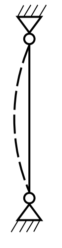
$$I_w = \frac{t_f b_f^3 h_w^2}{24} 10^{-6}$$

h_W : Web height of built-up section, in mm

t_W : Net web thickness of built-up section, in mm

b_F : Face plate width of built-up section, in mm

Table 6 : Coefficient f

Condition of fixation of the pillar	f
Both ends fixed 	0,5
One end fixed, one end pinned 	$\frac{\sqrt{2}}{2}$
Both ends pinned 	1

t_F : Net face plate thickness of built-up section, in mm

I_p : Net polar moment of inertia of the pillar, to be obtained, in cm⁴, from the following formula:

$$I_P = I_{XX} + I_{YY}$$

I_{XX} : Net moment of inertia about the XX axis of the pillar section (see Fig 5)

I_{YY} : Net moment of inertia about the YY axis of the pillar section (see Fig 5)

I_t : St. Venant's net moment of inertia of the pillar, to be obtained, in cm⁴, from the following formula:

$$I_t = \frac{1}{3}[h_w t_w^3 + 2 b_f t_f^3] 10^{-4}$$

4.1.4 Critical local buckling stress of built-up pillars

The critical local buckling stress of built-up pillars is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cL} = \sigma_{E3} \quad \text{for} \quad \sigma_{E3} \le \frac{R_{eH}}{2}$$

$$\sigma_{cL} = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_{E3}}\right) \quad \text{for} \quad \sigma_{E3} > \frac{R_{eH}}{2}$$

where:

σ_{E3} : Euler local buckling stress, to be taken equal to the lesser of the values obtained, in N/mm², from the following formulae:

- $\sigma_{E3} = 78\left(\frac{t_W}{h_W}\right)^2 10^4$
- $\sigma_{E3} = 32\left(\frac{t_F}{b_F}\right)^2 10^4$

t_W, h_W, t_F, b_F : Dimensions, in mm, of the built-up section defined in [4.1.3].

4.1.5 Critical local buckling stress of pillars having hollow rectangular section

The critical local buckling stress of pillars having hollow rectangular section is to be obtained, in N/mm², from the following formulae:

$$\sigma_{cL} = \sigma_{E4} \quad \text{for} \quad \sigma_{E4} \le \frac{R_{eH}}{2}$$

$$\sigma_{cL} = R_{eH}\left(1 - \frac{R_{eH}}{4\sigma_{E4}}\right) \quad \text{for} \quad \sigma_{E4} > \frac{R_{eH}}{2}$$

where:

σ_{E4} : Euler local buckling stress, to be taken equal to the lesser of the values obtained, in N/mm², from the following formulae:

- $\sigma_{E4} = 78\left(\frac{t_2}{b}\right)^2 10^4$
- $\sigma_{E4} = 78\left(\frac{t_1}{h}\right)^2 10^4$

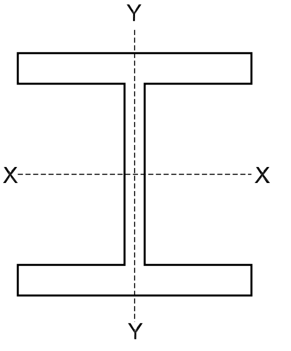
b : Length, in mm, of the shorter side of the section

t_2 : Net web thickness, in mm, of the shorter side of the section

h : Length, in mm, of the longer side of the section

t_1 : Net web thickness, in mm, of the longer side of the section.

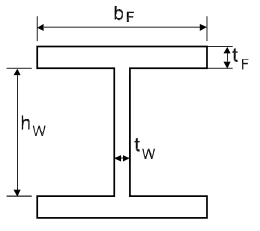
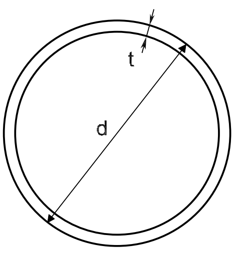
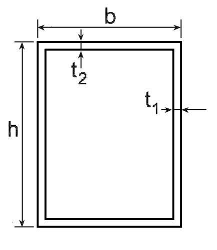
Figure 5 : Reference axes for the calculation of the moments of inertia of a built-up section



4.1.6 Checking criteria

The net scantlings of the pillar loaded by the compression axial stress F_A defined in [4.1.1] are to comply with the formulae in Tab 7.

Table 7 : Buckling check of pillars subjected to with compression axial stress

Pillar cross-section	Column buckling check	Torsional buckling check	Local buckling check	Geometric condition
Built-up 	$\frac{\sigma_{cB}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	$\frac{\sigma_{cT}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	$\frac{\sigma_{cL}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	$\frac{b_F}{t_F} \leq 40$
Hollow tubular 	$\frac{\sigma_{cB}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	Not required	Not required	• $\frac{d}{t} \leq 55$ • $t \geq 5{,}5$ mm
Hollow rectangular 	$\frac{\sigma_{cB}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	Not required	$\frac{\sigma_{cL}}{\gamma_R \gamma_m} \geq 10\frac{F_A}{A}$	• $\frac{b}{t_2} \leq 55$ • $\frac{h}{t_1} \leq 55$ • t_1, $t_2 \geq 5{,}5$ mm

Note 1:

σ_{cB} : Critical column buckling stress, in N/mm², defined in [4.1.2]
σ_{cT} : Critical torsional buckling stress, in N/mm², defined in [4.1.3]
σ_{cL} : Critical local buckling stress, in N/mm², defined in [4.1.4] for built-up section or in [4.1.5] for hollow rectangular section
F_A : Compression axial load in the pillar, in kN, defined in [4.1.1]
A : Net sectional area, in cm², of the pillar.

APPENDIX 1 SCANTLING CHECKS FOR SHIPS LESS THAN 65 M IN LENGTH

Symbols

x, y, z : X, Y and Z co-ordinates, in m, of the calculation point with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]

$F_B = Z_{RB} / Z_{AB}$

$F_D = Z_{RD} / Z_{AD}$

$F_{BH} = Z_{RBH} / Z_{AB}$

$F_{DS} = Z_{RDS} / Z_{AD}$

F_B, F_D, F_{BH} and F_{DS} are to be taken not less than:

- 0,67 when used for the scantling checks of plating
- 0,83 when used for the scantling checks of ordinary stiffeners and primary supporting members

Z_{RB} : Required hull girder section modulus at bottom, in m^3, to be calculated in accordance with Sec 2, [3.2]

Z_{AB} : Actual hull girder section modulus at bottom, in m^3, to be calculated in accordance with Sec 2, [1.3]

Z_{RD} : Required hull girder section modulus at deck, in m^3, to be calculated in accordance with Sec 2, [3.2]

Z_{AD} : Actual hull girder section modulus at deck, in m^3, to be calculated in accordance with Sec 2, [1.3]

Z_{RBH} : Required hull girder section modulus at bottom, in m^3, to be calculated in accordance with Sec 2, [3.2], where the still water and wave bending moments are calculated in hogging condition only

Z_{RDS} : Required hull girder section modulus at deck, in m^3, to be calculated in accordance with Sec 2, [3.2], where the still water and wave bending moments are calculated in sagging condition only

C : Coefficient to be taken equal to:

$$C = \frac{1}{2,29 - 1,29F_B}$$

k : Material factor for steel, defined in Ch 4, Sec 1, [2.3]

p_E : Side and bottom design pressure, in kN/m^2, to be obtained from the following formula:

$$p_E = 5L^{1/3}\left[1 - \frac{(T-z)}{2T}\right] + 10(T-z) + p_A \quad \text{for } z \le T$$

$$p_E = (5L^{1/3} + p_A)\frac{10}{10 + (z - T)} \quad \text{for } z > T$$

p_A : Additional pressure, in kN/m^2, to be obtained from the following formulae:

$$p_A = 0,17L - 1,7x \quad \text{for } 0 \le x < 0,1L$$

$$p_A = 0 \quad \text{for } 0,1L \le x < 0,8L$$

$$p_A = 2,25(x - 0,8L) \quad \text{for } 0,8L \le x \le L$$

p_D : Bottom design pressure, in kN/m^2, to be obtained from the following formulae:

$$p_D = \max(10T;\ 6,6D) \quad \text{for } T/D \ge 0,5$$

$$p_D = 10T + 2,5L^{1/3} + p_A \quad \text{for } T/D < 0,5$$

p_L : Liquid design pressure, to be taken as the greater of the values obtained, in kN/m^2 from the following formulae:

$$p_L = 10[(h_a + z_{AP}) - z]\rho_L$$

$$p_L = 10\left[\frac{2}{3}(z_{TAP} - z)\right]\rho_L$$

p_B : Dry bulk cargo pressure, in kN/m^2, to be obtained from the following formula:

$$p_B = 10\rho_B(z_B - z)\left\{(\sin\alpha)^2\left[\tan\left(45^\circ - \frac{\varphi}{2}\right)\right]^2 + (\cos\alpha)^2\right\}$$

p_{DS} : Single bottom design pressure, in kN/m^2, to be obtained from the following formulae:

p_D = 10 D in general

p_D = 10 D + 5 h_T for ships with trunk, where h_T is the trunk height, in m.

h_A : Distance to be taken as the greater of the values obtained, in m, from the following formulae:

$$h_A = [1 + 0,05(L - 50)]\frac{\rho}{\rho_L}$$

without benig taken less than 1,0 m

$$h_A = 10p_{pV}$$

where p_{pV} is the setting pressure, in bar, of safety valves

z_{AP} : Z co-ordinate, in m, of the moulded deck line for the deck to which the air pipes extend

z_{TAP} : Z co-ordinate, in m, of the top of the air pipe of the tank in the z direction

z_B : Z co-ordinate, in m, of the rated upper surface of the bulk cargo (horizontal ideal plane of the volume filled by the cargo); see Ch 5, Sec 6, [3.1.2]

α : Angle, in degrees, between the horizontal plane and the surface of the hull structure to which the calculation point belongs

φ : Angle of repose, in degrees, of the bulk cargo (considered drained and removed); in the absence of more precise evaluation, the following values may be taken:

- $\varphi = 30^o$ in general
- $\varphi = 35^o$ for iron ore
- $\varphi = 25^o$ for cement.

s : Length, in m, of the shorter side of the plate panel or spacing, in m, of ordinary stiffeners, or spacing, in m, of primary supporting members, as applicable

ℓ : Length, in m, of the longer side of the plate panel or span, in m, of ordinary stiffeners, measured between the supporting members, or span, in m, of primary supporting members, as applicable (to be taken according to Ch 4, Sec 3, [3.2] and Ch 4, Sec 3, [4.1]).

ρ : Sea water density, to be taken equal to 1,025 t/m^3

ρ_L : Density, in t/m^3, of the liquid carried, to be taken not less than ρ

ρ_B : Density, in t/m^3, of the dry bulk cargo carried; in certain cases, such as spoils, the water held by capillarity is to be taken into account

1 General

1.1 Application

1.1.1 *(1/7/2003)*

The requirements of this Appendix may be applied, as an alternative to Sec 1, Sec 2 and Sec 3, for the strength check of plating, ordinary stiffeners and primary supporting members in the central part, as defined in Ch 1, Sec 1, [2.1.3], of ships less than 65 m in length.

1.2 Scantling reduction depending on the navigation notation

1.2.1 *(1/7/2003)*

The requirements of this Appendix apply for the structural scantling of ships having the **unrestricted navigation** notation.

For ships with restricted navigation, the required scantling may be reduced by the percentages specified in Tab 1, depending on the navigation notation assigned to the ship.

Table 1 : Scantling reduction percentages depending on the navigation notation *(1/7/2003)*

Navigation notation	Reduction
Summer zone	5%
Tropical zone **Coastal area**	10%
Sheltered area	16%
Note 1: For bulkheads and decks, 50% of the reduction applies.	

1.3 Gross scantling

1.3.1 *(1/7/2003)*

All scantlings referred to in this appendix are gross, i.e. they include the margins for corrosion.

2 Longitudinally framed single bottom

2.1 Scantlings of plating, ordinary stiffeners and primary supporting members

2.1.1 *(1/7/2003)*

The scantlings of plating, ordinary stiffeners and primary supporting members are to be not less than both the values obtained from the formulae in Tab 2 and the minimum values in the table.

3 Transversely framed single bottom

3.1 Scantlings of plating, ordinary stiffeners and primary supporting members

3.1.1 *(1/7/2003)*

The scantlings of plating, ordinary stiffeners and primary supporting members are to be not less than both the values obtained from the formulae in Tab 3 and the minimum values in the table.

4 Bilge

4.1 Bilge plating thickness

4.1.1 *(1/7/2003)*

The thickness of bilge plating is to be not less than that of the adjacent bottom or side plating, whichever is the greater.

5 Double bottom

5.1 Scantlings of plating, ordinary stiffeners and primary supporting members

5.1.1 *(1/7/2003)*

The scantlings of plating, ordinary stiffeners and primary supporting members are to be not less than both the values obtained from the formulae in Tab 4 and the minimum values in the table.

5.2 Open floors in transversely framed double bottom

5.2.1 Frames *(1/7/2003)*

The section modulus of frames constituting open floors is to be not less than the value obtained, in cm^3, from the following formula:

$$w = 0{,}8 s \ell^2 p_D$$

where:

ℓ : Span, in m, of transverse ordinary stiffeners constituting the open floor (see Ch 4, Sec 3, [3.2.2]).

Table 2 : Scantlings of longitudinally framed single bottom structures *(1/7/2006)*

Element	Formulae	Minimum value
Plating	Thickness, in mm, the greater of **(1) (2)**: • $t = s(3,12 + 1,12\sqrt{L})\left(\frac{F_{BH}}{k}\right)^{1/2}$ • $t = 9,75s\left(\frac{T \cdot k}{6,76 - 4,37F_B}\right)^{1/2}$	Minimum thickness, in mm **(3)**: $t = (0,033L + 6,5)\left(\frac{sk}{0,46 + 0,0023L}\right)^{1/2} - 1,0$
Ordinary stiffeners	Section modulus, in cm³: $w = 1,2\, s\, \ell^2\, p_{DS}\, Ck$	
Floors	Section modulus, in cm³: $w = s\, \ell^2\, p_D k$	Minimum web plate thickness, in mm: t = 6,0
Girders **(2)**	Web thickness, in mm: • $t = 0,06\, Lk^{1/2} + 5,0$ for centre girders • $t = 0,06\, Lk^{1/2} + 4,0$ for side girders.	
		Minimum face plate area, in cm²: • A = 8,0 for centre girders • A = 5,0 for side girders.
	Where considered as floor supports, section modulus, in cm³: $w = s\, \ell^2\, p_D k$	

(1) s is to be taken, in m, not less than 0,46 + 0,002L.
(2) For ships equal to or greater than 30 m in length, the web thickness and the flange area may be gradually tapered such as to reach, at the collision and after peak bulkheads, 80% of the values obtained from these formulae.
(3) For the purpose of calculation of the minimum thickness t, the actual spacing s is to be taken not less than 0,46 + 0,0023L

Table 3 : Scantlings of transversely framed single bottom structures *(1/7/2006)*

Element	Formula	Minimum value
Plating	Thickness, in mm, the greater of **(1)**: • $t = \frac{s}{1 + (s/\ell)^2}(7,82 + 1,45L^{1/2})\left(\frac{F_{BH}}{k}\right)^{1/2}$ • $t = 11,75s\left(\frac{T \cdot k}{6,76 - 4,37F_B}\right)^{1/2}$	Minimum thickness, in mm **(4)**: $t = (0,033L + 6,5)\left(\frac{sk}{0,46 + 0,0023L}\right)^{1/2} - 1,0$
Floors	Section modulus, in cm³ **(2)**: $w = 0,43\, s\, \ell^2\, p_D k$	Minimum web plate thickness, in mm: $t = 10\, h_W + 2,0$
Girders **(3)**	Web thickness, in mm: • $t = 0,06\, Lk^{1/2} + 5,0$ for centre girders • $t = 0,06\, Lk^{1/2} + 4,0$ for side girders.	
		Minimum face plate area, in cm²: • A = 8,0 for centre girders • A = 5,0 for side girders.

Note 1:
h_w : Height, in m, of floors at the centreline to be taken not less than B/16.
(1) s is to be taken, in m, not less than 0,46 + 0,002L.
(2) For ordinary stiffeners located within the engine room area, the required section modulus is to be increased by 40% with respect to that obtained from this formula.
(3) For ships equal to or greater than 30 m in length, the web thickness and the flange area may be gradually tapered such as to reach, at the collision and after peak bulkheads, 80% of the values obtained from these formulae.
(4) For the purpose of calculation of the minimum thickness t, the actual spacing s is to be taken not less than 0,46 + 0,0023L

Table 4 : Scantlings of double bottom structures *(1/7/2006)*

<table>
<tr><th>Element</th><th>Formula</th><th>Minimum value</th></tr>
<tr><td>Bottom plating</td><td>As specified in:
• [2] for longitudinally framed structure
• [3] for transversely framed structure</td><td>Minimum thickness, in mm (7):
$t = (0,033L + 6,5)\left(\frac{sk}{0,46 + 0,0023L}\right)^{1/2} - 1,0$</td></tr>
<tr><td>Bottom ordinary stiffeners</td><td>Section modulus, in cm^3, the greater of:
• $w = 1,2\, s\, \ell^2\, p_D\, C\, k$
• the value required in [8.1] for tank bulkheads, where the pressure is reduced by an amount, in kN/m^2, not greater than 0,3T, for ordinary stiffeners of bottoms that constitute boundary of compartments intended to carry liquids.</td><td></td></tr>
<tr><td>Inner bottom plating</td><td>Thickness, in mm, the greater of: (1) (2) (3)
• $t = 0,04\, L\, k^{1/2} + 5\, s + 2$ (4)
• $t = 1,35\, s\, (p_B\, k)^{1/2}$ for inner bottoms that constitute boundary of compartments intended to carry dry bulk cargoes
• $t = 1,35\, s\, (p_L\, k)^{1/2}$ for inner bottoms that constitute boundary of compartments intended to carry liquids</td><td>Minimum thickness, in mm:
t = 5,0</td></tr>
<tr><td colspan="3">(1) For ships equal to or greater than 30 m in length, this thickness may be gradually tapered such as to reach, at the collision and after peak bulkheads, 90% of the value obtained from this formula.
(2) For plating located within the engine room area, this thickness is to be increased by 10% with respect to that obtained from this formula.
(3) For margin plates inclined downward with respect to the inner bottom plating, this thickness is to be increased by 20% with respect to that obtained from this formula.
(4) For ships with one of the following service notations:
• general cargo ships, intended to carry dry bulk cargo in holds
• bulk carrier ESP
• ore carrier ESP
• combination carrier ESP
this thickness is to be increased by 2 mm unless the plating is protected by a continuous wooden ceiling.
(5) For ships equal to or greater than 30 m in length, this thickness may be gradually tapered such as to reach, at the collision and after peak bulkheads, a thickness reduced by $2\, k^{1/2}$ mm with respect to that obtained from this formula.
(6) For floors located within the engine room with transversely framed structure, this thickness is to be increased by 1 mm with respect to that obtained from this formula.
(7) For the purpose of calculation of the minimum thickness t, the actual spacing s is to be taken not less than 0,46 + 0,0023L</td></tr>
</table>

Element	Formula	Minimum value
Inner bottom ordinary stiffeners	Section modulus, in cm^3, the greater of: • $w = s \ell^2 p_D C k$ • the value required in [8.1] for tank bulkheads, for ordinary stiffeners of inner bottoms that constitute boundary of compartments intended to carry liquids. • the greater of: - $w = \dfrac{0,84 s \ell^2 p_B C' k}{1 + 0,12 \frac{z}{N}}$ - $w = 0,75 s \ell^2 p_B k$ for ships with a service notation: **general cargo ships** (intended to carry dry bulk cargo in holds), **bulk carrier ESP**, **ore carrier ESP**, **combination carrier ESP** • the greater of: - $w = \dfrac{0,84 s \ell^2 p_L C' k}{1 + 0,12 \frac{z}{N}}$ - $w = 0,75 s \ell^2 p_L k$ for ships with a service notation: **combination carrier ESP**, **oil tanker**, or **chemical tanker** where: $C' = 1 + (C - 1)(1 - z / N)$ N : Z co-ordinate, in m, of the centre of gravity of the hull transverse section, with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4].	
Centre girder	Web thickness, in mm **(5)** $t = \dfrac{22B + 25(T + 10)}{100} k^{1/2} + 4$	Minimum web thickness, in mm: t = 6,0

(1) For ships equal to or greater than 30 m in length, this thickness may be gradually tapered such as to reach, at the collision and after peak bulkheads, 90% of the value obtained from this formula.
(2) For plating located within the engine room area, this thickness is to be increased by 10% with respect to that obtained from this formula.
(3) For margin plates inclined downward with respect to the inner bottom plating, this thickness is to be increased by 20% with respect to that obtained from this formula.
(4) For ships with one of the following service notations:
- **general cargo ships**, intended to carry dry bulk cargo in holds
- **bulk carrier ESP**
- **ore carrier ESP**
- **combination carrier ESP**

this thickness is to be increased by 2 mm unless the plating is protected by a continuous wooden ceiling.
(5) For ships equal to or greater than 30 m in length, this thickness may be gradually tapered such as to reach, at the collision and after peak bulkheads, a thickness reduced by 2 $k^{1/2}$ mm with respect to that obtained from this formula.
(6) For floors located within the engine room with transversely framed structure, this thickness is to be increased by 1 mm with respect to that obtained from this formula.
(7) For the purpose of calculation of the minimum thickness t, the actual spacing s is to be taken not less than 0,46 + 0,0023L

Element	Formula	Minimum value
Side girders	Web thickness, in mm **(5)** • For longitudinally framed structure: $t = 0{,}054\,L\,k^{1/2} + 4{,}5$ • For transversely framed structure: $t = \frac{22B + 25(T + 10)}{100}k^{1/2} + 3$	Minimum web thickness, in mm: t = 6,0
Floors	Web thickness, in mm **(6)** where: $t = f_S\left[\frac{22B + 25(T + 10)}{100}k^{1/2} + 1\right]$ f_S : Coefficient to be taken equal to: • 1,1 for longitudinally framed structure • 1,0 for transversely framed structure	Minimum web thickness, in mm: t = 6,0

(1) For ships equal to or greater than 30 m in length, this thickness may be gradually tapered such as to reach, at the collision and after peak bulkheads, 90% of the value obtained from this formula.
(2) For plating located within the engine room area, this thickness is to be increased by 10% with respect to that obtained from this formula.
(3) For margin plates inclined downward with respect to the inner bottom plating, this thickness is to be increased by 20% with respect to that obtained from this formula.
(4) For ships with one of the following service notations:
- **general cargo ships**, intended to carry dry bulk cargo in holds
- **bulk carrier ESP**
- **ore carrier ESP**
- **combination carrier ESP**

this thickness is to be increased by 2 mm unless the plating is protected by a continuous wooden ceiling.
(5) For ships equal to or greater than 30 m in length, this thickness may be gradually tapered such as to reach, at the collision and after peak bulkheads, a thickness reduced by 2 $k^{1/2}$ mm with respect to that obtained from this formula.
(6) For floors located within the engine room with transversely framed structure, this thickness is to be increased by 1 mm with respect to that obtained from this formula.
(7) For the purpose of calculation of the minimum thickness t, the actual spacing s is to be taken not less than 0,46 + 0,0023L

5.2.2 Reverse frames *(1/7/2003)*

The section modulus of reverse frame constituting open floors is to be not less than the value obtained, in cm³, from the following formula:

$$w = 0{,}7 s \ell^2 p_D$$

where:

ℓ : as indicated in [5.2.1].

6 Side

6.1 Sheerstrake width

6.1.1 *(1/7/2003)*

For ships greater than 20 m in length, the width of the sheerstrake is to be not less than the value obtained, in m, from the following formula:

$$b = 0{,}715 + 0{,}425\frac{L}{100}$$

Table 5 : Scantlings of side structures *(1/7/2003)*

Element	Formula	Minimum value
Plating	Thickness, in mm **(1) (2)**: • for longitudinally framed structure: $t = 6,1\ s\ (Tk)^{1/2}$ • for transversely framed structure: $t = 7,2\ s\ (Tk)^{1/2}$	Minimum thickness, in mm: t = 4,0
Ordinary stiffeners	Section modulus, in cm^3, the greater of: • for longitudinal ordinary stiffeners: $w = 0,675\ s\ \ell^2\ p_E k$ • for transverse frames **(3)**: $w = 0,75 s \ell^2 p_H f_c R k$	Minimum section modulus, in cm^3: w = 20
Primary supporting members	Section modulus, in cm^3, the greater of: • for longitudinal and vertical primary supporting members: $w = K_{CR} s \ell^2 p_H k$ • for vertical primary supporting members not associated with side girders, in ships with a transversely framed side: $w = 0,75 s \ell^2 \left(p_E + \frac{n_S h_2 B}{12}\right) k$	Minimum thickness, in mm: t = 5,0

Note 1:

p_H : Design pressure, in kN/m^2, to be obtained from the following formula:
$p_H = p_E + 0,083 h_2 B$
For transverse frames of ‘tweendecks:
- p_H is to be taken not less than 0,37L where the upper end is located below the full load waterline
- p_H is to be taken not less than 0,23L - $2d_P$ where the upper end is located above the full load waterline and aft of the collision bulkhead
- p_H is to be taken not less than 0,3L where the upper end is located above the full load waterline and forward of the collision bulkhead.

d_p : Vertical distance, in m, measured between the design deck (first deck above the full load waterline extending for at least 0,6L) and the deck above the frame

h_2 : Sum of the heights, in m, of all ‘tweendecks above the deck located at the top of the frame without being taken less than 2,5m; for ‘tweendecks intended as accommodation decks and located above the design deck (first deck above the full load waterline extending for at least 0,6L), half of the height may be taken; for ‘tweendecks above a deck which is longitudinally framed and supported by deck transverses, a height equal to 0 may be taken

f_c : Coefficient depending on the type of connection and the type of frame as defined in Tab 6

R : Coefficient depending on the location of the ordinary stiffeners:
- R = 0,8 for ordinary stiffeners in hold and engine room
- R = 1,4 for ordinary stiffeners in ‘tweendecks.

K_{CR} : Coefficient to be taken equal to:
- K_{CR} = 0,4 for vertical primary supporting members located outside machinery spaces and not associated with side girders, in ships with a transversely framed side
- K_{CR} = 0,5 for vertical primary supporting members located inside machinery spaces and not associated with side girders, in ships with a transversely framed side
- K_{CR} = 0,9 in other cases.

n_S : Number of transverse ordinary stiffener spaces between vertical primary supporting members.

(1) For ships equal to or greater than 30 m in length, this thickness may be gradually tapered such as to reach, at the collision and fore peak bulkheads, 80% of the value obtained from this formula, without being less than 5 mm.

(2) s is to be taken, in m, not less than 0,46 + 0,002L.

(3) Where the span is the same, it is not necessary to assume a section modulus of ‘tweendeck frame greater than that of the frame below.

Table 6 : Coefficient f_C *(1/7/2003)*

Type of connection	Type of frame	f_C
Brackets at both ends	Hold frames	0,62
	‘Tweendeck frames	0,80
Bracket at one end and without bracket at the other	Hold or ‘tweendeck frames	1,20
Without brackets at both ends	Hold or ‘tweendeck frames	1,20

6.2 Plating, ordinary stiffeners and primary supporting members

6.2.1 *(1/7/2003)*

The scantlings of plating, ordinary stiffeners and primary supporting members are to be not less than both the values obtained from the formulae in Tab 5 and the minimum values in the table.

In addition, the scantlings of plating, ordinary stiffeners and primary supporting members of sides that constitute boundary of compartments intended to carry liquids are to be not less than the values required in [8.1] for tank bulkheads.

6.3 Sheerstrake thickness

6.3.1 *(1/7/2003)*

For ship greater than 20 m in length, the thickness of the sheerstrake is to be increased by 1 mm with respect to that obtained from the formulae in [6.2.1]. In any case, it is to be not less than that of the stringer plate.

7 Decks

7.1 Stringer plate width

7.1.1 *(1/7/2003)*

The width of the stringer plate is to be not less than the value obtained, in m, from the following formula:

$$b = 0,35 + 0,5\frac{L}{100}$$

7.2 Minimum scantlings of pillars

7.2.1 *(1/7/2003)*

The thickness, in mm, of hollow (tubular or rectangular) pillars is to be not less than the greater of 5 mm and d / 35, where d is the nominal diameter, in mm, for tubular pillar cross-sections or the larger side, in mm, for rectangular pillar cross-sections.

The thickness, in mm, of the face plate of built-up pillars is to be not less than b_f / 36, where b_f is the face plate width, in mm.

7.3 Scantlings of plating, ordinary stiffeners and primary supporting members

7.3.1 *(1/7/2003)*

The scantlings of plating, ordinary stiffeners and primary supporting members are to be not less than both the values obtained from the formulae in Tab 7 and the minimum values in the table.

In the case of decks subjected to wheeled loads, their scantlings are also to comply with the relevant requirements in Ch 7, Sec 1, Ch 7, Sec 2 and Ch 7, Sec 3.

In addition, the scantlings of plating, ordinary stiffeners and primary supporting members of decks that constitute boundary of compartments intended to carry liquids are to be not less than the values required in [8.1] for tank bulkheads.

7.4 Scantlings of pillars subjected to compressive axial load

7.4.1 *(1/7/2003)*

The area of solid, tubular or prismatic pillars made of steel, having ultimate minimum tensile strength within the range 400-490 N/mm^2, and of pillars consisting of hollow profiles made of steel, having ultimate minimum tensile strength within the range 400-540 N/mm^2, subjected to compression axial load is to be not less than the value obtained, in cm^2, from the following formula:

$$A = \frac{0,7A_D p_2 + Q_N}{12,5 - 0,045\lambda}$$

where:

p_2 : Design pressure, in kN/m^2, to be taken equal to:

- the greater of:
  $p_2 = 3,0$
  $p_2 = 1,3\ p_1$
  for pillars located below exposed deck areas
- $p_2 = 0,6\ p_0$, for pillars located below unexposed accommodation areas and above the strength deck
- $p_2 = p_0$ in other cases

p_0, p_1 : Design pressures, in kN/m^2, defined in Pt E, Ch 20, Sec 3, Tab 9

λ : Slenderness of the pillar, to be obtained from the following formula:
$\lambda = 100\ \ell / \rho$

ρ : Minimum radius of gyration, in cm, of the pillar cross-section

A_D : Area, in m^2, of the portion of the deck supported by the pillar considered

Q_N : Load from pillar above, in kN, if any, or any other concentrated load

d : Nominal diameter, in mm, for tubular pillar cross-sections or the larger side, in mm, for rectangular pillar cross-sections

b_f : face plate width, in mm

Scantlings of pillars other than those above are to be considered by the Society on a case-by-case basis.

Table 7 : Scantlings of deck structures *(1/7/2003)*

Element	Formula	Minimum value
Strength deck plating **(1) (2)**	Thickness, in mm **(1)**: • for longitudinally framed structure - $t = s(1,4L^{1/2} - 1,1)(F_{DS}/k)^{1/2}$ - $t = 1,05s(L \cdot k)^{1/2}$ • for transversely framed structure, the greater of: - $t = \frac{s}{1+(s/l)^2}(1,98L^{1/2} - 1,5)(F_{DS}/k)^{1/2}$ - $t = 1,3s(Lk)^{1/2}$	Minimum thickness, in mm: $t = (5s + 0,022L + 2,3)\ k^{1/2}$
Lower deck and platform plating	Thickness, in mm **(2)**: • for longitudinally framed structure, the greater of: - $t = 5\ s + 0,022\ Lk^{1/2} + 1,5$ - $t = 10\ s$ • for transversely framed structure, the greater of: - $t = 6\ s + 0,026\ Lk^{1/2} + 2,0$ - $t = 10\ s$	
Ordinary stiffeners	Section modulus, in cm^3: $w = 0,75\ C_1\ C_2\ s\ \ell^2\ (p_0 + p_1)\ k$	
Primary supporting members	Section modulus, in cm^3: $w = 0,1\ C_3\ C_4\ s\ \ell^2\ (p_0 + p_1)\ k$ Moment of inertia, in cm^4: $I = 2,5\ w\ \ell$	Minimum thickness, in mm: $t = 5,0$

Note 1:

p_0, p_1 : Design pressure, in kN/m^2, defined in Tab 8
C_1 : Coefficient equal to $(L/110)^{0,5}$, to be taken not less than 0,6
C_2 : Coefficient, defined in Tab 9
C_3 : Coefficient, defined in Tab 10
C_4 : Coefficient equal to:
- C_4= 0,50 for weather deck area aft of 0,075 L from the FE and for accommodation decks above the design deck, as defined in Tab 8
- C_4 = 1,0 in other cases.

(1) s is to be taken, in m, not less than 0,46 + 0,002 L
(2) For ships equal to or greater than 30 m in length, this thickness may be gradually tapered such as to reach, at the collision bulkhead, 80% of the value obtained from this formula.

Table 8 : Deck design pressure *(1/7/2003)*

Type of deck **(1)**	Location	p_0, in kN/m²	p_1, in kN/m²
Decks located below the design deck **(2)**	Any location	• $10h_{TD}$ in general • 9 for accommodation decks	0
Design deck	Exposed area, forward of 0,075L from the FE	15	• 23 for ordinary stiffeners • $37-d_p$ for primary supporting members
	Exposed area, aft of 0,075L from the FE	11	Girders and longitudinal ordinary stiffeners: • 14 for single deck ships • 10 for other ships Other structures: • 18 for single deck ships • 12 for other ships
	Unexposed area	• $10h_{TD}$ in general • 9 for accommodation decks	Girders and longitudinal ordinary stiffeners: • 0 Other structures: • 4 for single deck ships • 0 for other ships
Decks located above the design deck and to which side plating extends	Exposed area, forward of 0,075L from the FE	15	• $37-d_p$ for primary supporting members • $23-d_p$ for ordinary stiffeners
	Exposed area, aft of 0,075L	• 10 in general • 3 for shelter decks	• $15,4(T/D_0)-d_p$ with $0,7 \le T/D_0 \le 0,85$ in general • 0 for higher decks
	Unexposed area	• $10h_{TD}$ in general • 9 for accommodation decks	0
Decks located above the design deck and to which side plating does not extend	Exposed area, aft of 0,075L from the FE	• 5 in general • 3 for shelter decks	• $15,4(T/D_0)-d_p$ with $0,7 \le T/D_0 \le 0,85$ in general • 0 for higher decks
	Unexposed area	• $10h_{TD}$ in general • 9 for accommodation decks	0

Note 1:

d_p : Vertical distance, in m, measured from the deck under consideration to the design deck

h_{TD} : 'Tweendeck height, in m

D_0 : Vertical distance, in m, measured from the design deck to the base line.

(1) Design deck: first deck above the full load waterline extending for at least 0,6L.

(2) For platforms and flats located in the machinery space, p_0+p_1 is to be not less than 25 kN/m².

Table 9 : Coefficient C_2 *(1/7/2003)*

Type of ordinary stiffener	Location	C_2
Longitudinal	Strength deck and decks below, within 0,4 L amidships	$1,44C_{HG}$
	Strength deck, forward of 0,12 L from the fore end	1,00
	Other	0,63
Transverse	Single span or end span	0,56
	Intermediate span	0,63

Note 1:

C_{HG} : Coefficient to be obtained from the following formulae:

$$C_{HG} = \frac{1}{2,29 - 1,29F'} \quad \text{for } F' < 0,73$$

$$C_{HG} = 0,74 \quad \text{for } 0,73 \le F' \le 0,84$$

$$C_{HG} = \frac{1}{3,25 - 2,25F'} \quad \text{for } F' > 0,84$$

F' : Coefficient equal to:

$$F' = F_D \frac{z - N}{z_D - N} \quad \text{for } z \ge N$$

$$F' = F_B \frac{N - z}{N} \quad \text{for } z < N$$

N : Z co-ordinate, in m, of the centre of gravity of the hull transverse section, with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4]

z_D : Z co-ordinate, in m, of the strength deck, defined in Ch 6, Sec 1, [2.2], with respect to the reference co-ordinate system defined in Ch 1, Sec 2, [4].

7.5 Scantlings of pillars subjected to compressive axial load and bending moments

7.5.1 *(1/7/2003)*

The scantlings of pillars subjected to compression axial load and bending moments are to be considered by the Society on a case-by-case basis.

7.6 Stringer plate thickness

7.6.1 *(1/7/2003)*

The thickness of the stringer plate is to be increased by 1 mm with respect to that obtained from the formulae in [7.3.1]. In any case, it is to be not less than that of the sheerstrake.

Table 10 : Coefficient C_3 *(1/7/2003)*

Type of primary supporting member	Location	C_3
Longitudinal (deck girder)	Constituting longitudinal coamings of hatchways on the strength deck	7,25
	Deck girders of strength deck and decks below, extending more than 0,15 L amidship	$10,88\ C_{HG}$
	Other	4,75
Transverse (deck beam)	Constituting front beams of hatchways on the strength deck	5,60
	Other	4,75

Note 1:

C_{HG} : Coefficient, defined in Tab 9

8 Tank bulkheads

8.1 Scantlings of plating, ordinary stiffeners and primary supporting members

8.1.1 *(1/7/2003)*

The scantlings of plating, ordinary stiffeners and primary supporting members are to be not less than both the values obtained from the formulae in Tab 11 and the minimum values in the table.

9 Watertight bulkheads

9.1 Scantlings of plating, ordinary stiffeners and primary supporting members

9.1.1 *(1/7/2003)*

The scantlings of plating, ordinary stiffeners and primary supporting members are to be not less than both the values obtained from the formulae in Tab 12 and the minimum values in the table.

10 Non-tight bulkheads

10.1 Scantlings of plating, ordinary stiffeners and primary supporting members

10.1.1 *(1/7/2003)*

The sbcantlings of plating, ordinary stiffeners and primary supporting members are to be not less than both the values obtained from the formulae in Tab 13 and the minimum values in the table.

Table 11 : Scantlings of tank bulkheads *(1/7/2003)*

Element	Formula	Minimum value
Plating	Thickness, in mm: $t=1,35s(p_L k)^{1/2}$	Minimum thickness, in mm: t = 5,5
Ordinary stiffeners	Section modulus, in cm³ **(1)**: $w = 0,465 s \ell^2 p_L k$	Minimum section modulus, in cm³ w=20,0
Primary supporting members	Section modulus, in cm³ $w = s \ell^2 p_L k$	

(1) For ordinary stiffeners without brackets at both ends, this modulus is to be increased by 90% with respect to that obtained from this formula.

Table 12 : Scantlings of watertight bulkheads *(1/7/2003)*

Element	Formula	Minimum value
Plating	Thickness, in mm **(1)**: • $t = 3,8\ s\ (hk)^{1/2}$ in general • $t = 4,35\ s\ (hk)^{1/2}$ for the collision bulkhead	Minimum thickness, in mm: t = 5,0
Ordinary stiffeners	Section modulus, in cm³ **(2)**: • $w = 3\ s\ \ell^2\ h_B k$ in general • $w = 3,7\ s\ \ell^2\ h_B k$ for the collision bulkhead	Minimum section modulus, in cm³: w = 10,0
Primary supporting members	Section modulus, in cm³: • $w = 6\ s\ \ell^2\ h_B k$ in general • $w = 6,75\ s\ \ell^2\ h_B k$ for the collision bulkhead	

Note 1:
h : Vertical distance, in m, between the lowest point of the plating and the highest point of the bulkhead.
h_B : Vertical distance, in m, between the mid-span point of the ordinary stiffener and the highest point of the bulkhead.
(1) For the lower strake, this thickness is to be increased by 1 mm with respect to that obtained from this formula.
(2) For ordinary stiffeners without brackets at both ends, this modulus is to be increased by 90% with respect to that obtained from this formula.

Table 13 : Scantlings of non-tight bulkheads *(1/7/2003)*

Element	Formula
Plating	Minimum thickness, in mm: • t = 5,0 for bulkhead acting as pillar • t = 4,0 for bulkhead not acting as pillar.
Vertical ordinary stiffeners	Net section modulus, in cm³: • $w = 2,65\ s\ \ell^2 k$ for bulkhead acting as pillar • $w = 2,00\ s\ \ell^2\ k$ for bulkhead not acting as pillar.