RULES
FOR THE CLASSIFICATION OF SHIPS

Part 2 – HULL
January 2024

Amendments No. 1
July 2024

CROATIAN REGISTER OF SHIPPING

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By the decision of the General Committee of Croatian Register of Shipping,

Amendments No. 1 to the
RULES FOR THE CLASSIFICATION OF SHIPS
Part 2 – HULL

have been adopted on 21st June 2024 and shall enter into force on 1st July 2024

GENERAL TERMS AND CONDITIONS

(March 2022)

Article 1
GENERAL

1.1 CROATIAN REGISTER OF SHIPPING (hereinafter: the *Register*) shall at all times remain an independent contractor and neither the *Register* nor any of its officers, surveyors, auditors, inspectors, agents, appointers, officers or managers shall act as an employee, servant or agent of any other party in the performance of the Services rendered by the *Register*.

1.2 The *Register* acts as a service provider. The Services provided by the *Register* cannot be construed as a commitment by the *Register* to achieve any result or as a warranty.

1.3 The provision of Services is subject to these General Terms and Conditions. No other terms and conditions shall apply, either expressly or by implication, unless expressly agreed in writing between the Parties.

1.4 These General Terms and Conditions shall be incorporated into, or referred to in any Contract and shall prevail over and exclude any other terms and conditions that the Client may wish to impose.

Any amendments to and/or deviations from these General Terms and Conditions, as well as any additional terms and conditions of the Client, shall be binding or valid only if set forth in writing and duly signed by the authorised representatives of both Parties.

1.5 The invalidity of one or more provisions of these General Terms and Conditions shall not affect the remaining provisions.

1.6 The Client acknowledges that the latest version of these General terms and Conditions and the latest version of applicable Rules apply to the Services provided by the *Register*.

1.7 Definitions in these General Terms and Conditions take precedence over other definitions that may appear in other documents issued by the *Register*.

1.8 The Client should at all times be aware of the provisions of these General Terms and Conditions, as they may be further amended, with their latest up to date version available on the web site of the *Register*.

Article 2
DEFINITIONS

2.1 **Certificate** means either a class certificate or statutory certificate, statement, attestation, statement of compliance, and a report following the Services provided by the *Register*.

2.2 **Certification** means the activity of certification in application of international and national standards and international industry practice provided by the *Register*.

Certification is an appraisement given by the *Register* to the Client and cannot be construed as an implied or express warranty of safety, fitness for purpose, seaworthiness of the vessel or its value for sale, insurance or chartering.

The purpose of Certification is to provide classification and statutory services and assistance to the maritime industry, Flag State Administrations, and regulatory authorities relating to maritime safety and pollution prevention.

2.3 **Classification** includes all activities and Services provided by the *Register* in accordance with the Rules. Classification may or may not be accompanied by the issuance of a Certificate of class with reference to the Rules.

Certificate of class is valid only if issued by the *Register*.

However, Certificate of class should not be construed as a guarantee of the safety, fitness for purpose or seaworthiness of the vessel. It is merely an attestation that the vessel complies with the Rules developed and published by the *Register*.

In addition, the *Register* is not a guarantee of the safety of life or property at sea or the seaworthiness of a vessel because, although the classification of a vessel is based on the assumption that the vessel will be properly loaded, operated, and maintained by competent and qualified personnel, the *Register* has no control over how a vessel is operated and maintained between the periodic surveys it conducts.

2.4 **Statutory certification** means certification made by the *Register* on behalf of the Flag State Administrations when and to the extent that the *Register* has been authorised to do so by the respective Flag State.

Statutory certification and services include the assessment of vessels registered by the Flag State and/or ship management companies to determine whether such ships/companies comply with the applicable requirements of international conventions, codes and national legislation, and the issuance of, or assistance in the issuance of, the appropriate certificates and documents.

Statutory certification includes, but is not limited to, certification, survey, and issuance of statutory certificates on behalf of the Flag State.

In cases where the *Register* acts on behalf of Flag State Administrations, the *Register* shall follow guidance issued by IMO (Resolutions, Circulars, etc.) or by IACS through Unified Interpretations (UI), unless otherwise directed by the Flag State.

2.5 **Client** means the shipowner, company, shipyard and/or party requesting Services or taking ownership of a classed vessel. In cases where shipowners have authorized another party to operate the vessel on their behalf, that party shall be considered as the company.

In addition to the above the Client means the person and/or entity that has requested Services from the *Register* and that has entered into a Contract or an agreement for Services with the *Register*.

2.6 **Parties** means the *Register* and Client together.

2.7 **Party** means the *Register* or the Client.

2.8 **Contract** means the contract in the form of a written agreement between the Client and the *Register* requesting Services, including these General Terms and Conditions and the Rules.

The provisions related to the Contract in these General Terms and Conditions shall apply even if there is no written agreement between the Client and the *Register*.

The Client may request the *Register* in writing to make a change to the contracted Services. However, the *Register* shall not be obligated to accept or execute any such change until a written agreement has been signed with the Client regarding the compensation and the possible impact of the change on the schedule as an addendum to the originally contracted Services.

2.9 **Services** shall mean the services specified in 2.2. 2.3 and 2.4, but also other services related to certification, classification and statutory certification, such as, but not limited to: ISM Code certification, ISPS Code, MLC 2006 certification, fuel oil consumption reporting, IHM certification, approval of manufacturers and service providers, certification of materials and products, training activities, conformity assessment, and any other relevant activities such as third party inspections, testing, shore and shipboard trials.

The Services provided by the *Register* are performed on a random basis and in no case include a full inspection of all items.

The *Register* shall provide the Services in accordance with related Contract(s), the provisions of these General Terms and Conditions, Rules, the international and national standards, the international conventions, the EU Regulations, the Flag State requirements and the industry practices applicable to the particular Service and always assuming that the Client is aware of these standards and the industry practices.

When providing Services, the *Register* does not guarantee the accuracy of the information or advice provided.

In providing Services, the *Register* does not assess compliance with standards other than the Rules, international and national standards, international conventions, EU regulations, Flag State requirements and industry practice, to the extent agreed in writing or specified in the Contract.

2.10 The ***Register*** means the Croatian Register of Shipping, an entity organized and existing under Croatian law, which, according to the Law on the Croatian Register of Shipping (Official Gazette No. 1996/81, 2013/76 and 2020/62) and the Charter of the *Register*, is an independent, not-for-profit, but public welfare oriented, public foundation that performs tasks:

- classification of sea-going ships,
- statutory certification of sea-going ships on behalf of the Flag State Administrations,
- classification of inland navigation vessels,
- statutory certification of inland navigation vessels,
- statutory certification of recreational crafts,
- certification of materials and products,
- conformity assessment of recreational crafts,
- conformity assessment of marine equipment,
- conformity assessment of pressure vessels,
- certification/registration of quality management systems.

2.11 **Vessel** means a ship, vessel, unit or offshore structure of any kind, whether or not connected to the shore or sea/river bed, located at sea or in inland waters and intended for transportation or special operations on the water, as decided by the *Register*.

2.12 **Rules** means the Rules for the classification, guidelines, instructions, or other documented evidence of the *Register* related to the Services provided.

The competent interpretation of the requirements specified in the Rules or other regulations published by the *Register* shall be the exclusive responsibility of the *Register's* Head Office, notwithstanding any possible different interpretations by other parties.

In cases where the Rules do not contain detailed requirements, the specific approval by the *Register* shall be based on the principles of the Rules and shall ensure a safety standard equivalent to that of the Rules.

Article 3
RESPONSIBILITIES

3.1 It is the Client's responsibility to ensure that all surveys required for vessel’s class maintenance are conducted in a timely manner and in accordance with the Rules.

3.2 The *Register* may suspend or withdraw the vessel's existing Certificate of class in the event of serious deficiencies and replace it with a new Certificate of class with a shortened period of validity during which the deficiencies are to be rectified.

In addition, the *Register* shall suspend or withdraw a vessel's Certificate of class if the deficiencies are of such a magnitude as to endanger the class of the vessel, its safety and integrity, the safety of the crew, passengers, or the marine environment, and shall require that the vessel is to be inspected at the first port of call where the necessary repairs are to be carried out.

3.3 The Client should inform the *Register*:

(i) in the event of a change in the intended use of a vessel, a conversion and alteration of the hull, machinery installations and other equipment affecting the Class of the vessel assigned by the *Register*. Conversions and alterations must be made under the supervision of the *Register* and must comply with the requirements of the Rules and/or additional requirements of the *Register*,

(ii) in cases where the vessel has been damaged to such an extent that the Class of the vessel is likely to be affected and the safety and integrity of the vessel is likely to be compromised. In such cases, the vessel must be surveyed at the first port of call or as further directed by the *Register*. The survey shall be to the extent deemed necessary by the *Register*, by taking into account the extent of the damage.

(iii) in cases where class-related deficiencies and/or defects are found as a result of a Flag State inspection or Port State Control. Should the Client fail to notify the *Register* of the detention of the vessel by Port State Authorities due to class related deficiencies, the *Register* reserves the right to suspend or withdraw the Certificate of class.

3.4 The *Register* shall have full control over Certificates issued and may suspend or withdraw a Certificate at any time in its sole discretion if the Client fails to comply with the following requirements set forth in the *Rules for the Classification of Ships, Part 1 - General Requirements, Chapter 1 - General Information*, as applicable:

(i) para. 5.3 - *Maintenance of the validity of Certificate of Class*,
(ii) para. 5.4 - *Period of Validity*,
(iii) para. 5.5 - *Extension of the Period of Validity*,
(iv) para. 5.6 - *Suspension and Reinstatement of Class in the Case of Overdue Surveys*, and
(v) para. 5.7 - *Withdrawal of Class*.

3.5 The *Register* may suspend or withdraw a Certificate at any time in its sole discretion if the Client fails to comply with the following requirements set forth in the *Rules for the Classification of Inland Navigation Vessels, Part 1 - Classification and Surveys, Chapter I - Principles of Classification*, as applicable:

(i) para. 2.8 - *Maintenance of the Validity of the Certificate of Class*,
(ii) para. 2.9 - *Extension of validity of the Certificate of Class*,

and following requirements set forth in the *Rules for the Classification of Inland Navigation Vessels, Part 1 - Classification and Surveys, Chapter II - Classification*, as applicable:

(iii) para. 2.1 – *Suspension of Class*,
(iv) para. 2.2 – *Withdrawal of Class*.

3.6 In addition to clauses 3.2, 3.4 and 3.5 of this Article, the *Register* reserves the right to terminate the Services and related Contract in the event of a breach of the provisions of these General Terms and Conditions.

3.7 If the Client fails to provide the *Register* with the required access or information at the agreed times or fails to prepare for the Service in a timely manner, the *Register* may suspend the provision of the Service until it receives the Client's instructions for access and/or the required information.

The *Register* shall not be liable for the consequences of such suspension, and the Client shall be responsible for the *Register's* additional fees and other unnecessary costs and expenses incurred by the *Register*.

3.8 The Client is obliged to perform timely payments of the invoices for provided Services. However, the *Register* may retain or withhold any Service or Certificate to the Client in the case of outstanding payments, whether mutually related or not, arising out of the entire business relationship with the Client.

Article 4
HEALTH, SAFETY AND ENVIRONMENT

4.1 Both the *Register* and the Client shall apply reasonable standards to promote safety, health, and environmental protection and to provide a safe working environment for their personnel.

4.2 The Client shall provide the *Register* with all access and information necessary for the safe and efficient performance of the requested Services as required by the Rules.

4.3 During the survey, personnel of the *Register* should have secure access to all work that directly or indirectly affects the Service.

4.4 The *Register* has the right to refuse to conduct an activity or visit an area or site if the *Register* in its sole discretion, believes that relevant risks are unacceptable or are not adequately addressed, contained, or otherwise mitigated. Such a decision shall suspend the obligations of both Parties under the Contract without incurring any liability or penalty until the Parties agree on how to proceed.

Article 5
THIRD PARTIES AND SUBCONTRACTORS

5.1 Each specific Contract, including any Certificates issued, relates specifically to the Client, and no rights, obligations, interests, claims, benefits or Certificates issued shall extend to any third party without the prior written consent of the *Register*.

5.2 The Client shall not be entitled to grant any right to use the Certificates to any third party without the prior written consent of the *Register*.

5.3 The Client shall not without *Register's* consent, cede, assign, transfer, subcontract or deal in any manner with all or any of its rights or obligations under any Service and related Contract.

5.4 With regard to third party rights to access information and Certificates under confidentiality clause reference is to be made to Article 9.

Article 6
TAXES

6.1 Each Party shall be responsible for and shall bear all taxes, duties or similar governmental charges levied or imposed on any activity of that Party.

6.2 Prices, fees, rates, or remuneration are exclusive of any form of sales tax, value added tax, administrative fees and services tax and/or other similar taxes, including any surcharges. If any such indirect tax is or becomes applicable to the Services provided under the Contract, the Client shall be responsible for the payment of such indirect taxes.

Article 7
PAYMENT OF INVOICES

7.1 The provision of Services by the *Register*, whether complete or not, shall include payment of fees thirty (30) days after issuance of the invoice for the portion of the Services performed.

7.2 In the event that the Client fails to meet the requirements for payment in accordance with the instalments and terms of payment contained herein, the *Register* reserves the right to charge the Client with the interest rate in accordance with the applicable laws of the Republic of Croatia.

7.3 If the Client disputes an invoice or part of an invoice, the Client shall notify *Register* thereof in writing without undue delay. If no notification is received by the due date, Client shall be deemed to have accepted the invoice in full. If only part of an invoice is disputed, the undisputed amount must be paid by the due date.

Consequently, no disputes arising between the *Register* and the Client shall interfere with prompt payment of invoices by the Client. Any rights of lien or retention in favour of the Client or otherwise, are hereby excluded.

7.4 In the event of cancellation of all or part of the Services prior to their final completion, the Client shall pay all costs incurred by the *Register* on pro-rata basis for the portion of the Services provided to date. In such event, the *Register* will not claim the Client for loss of profit or reduced income. All reasonable costs directly attributable to the early termination and all amounts due to the *Register* at that time shall become immediately due and payable.

7.5 In the event of termination of the Service and related Contract, the *Register* shall be entitled to retain any payments, deposits or prepayments of fees made by the Client prior to the date of termination up to the amount to which the *Register* is entitled.

Article 8
TERMINATION

8.1 The Parties shall have the right to terminate the Services and the related Contract(s) by written notice to the other Party, and without prejudice to Article 7, in the following cases:

(i) if the other Party commits a material breach of these General Terms and Conditions and/or the Contract and fails to rectify such breach in accordance with clause 8.4 of this Article,

(ii) if the other Party becomes insolvent, is unable to pay its debts as they become due, or becomes subject to bankruptcy proceedings, administration, receivership, dissolution, liquidation, winding up or otherwise ceases to carry on its business; or

(iii) for convenience, after giving the other Party thirty (30) days' prior written notice of termination.

8.2 The Classification issued for the relevant vessel and the Certificates previously issued shall remain valid until the effective date of termination or, in the event of such termination, immediately, subject to compliance with Article 3 and Article 7.

8.3 If, in the reasonable opinion of the *Register*, the Client breaches or is suspected of breaching Article 14 or Article 15, the *Register* shall have the right to terminate the Service and related Contract with immediate effect.

8.4 Notwithstanding the provisions of clause 8.1 of this Article, the Party intending to terminate Services for non-compliance or breach of the provisions of these General Terms and Conditions shall notify the other Party of the non-compliance or violation of the provisions of these General Terms and Conditions and set a reasonable deadline of 15 (fifteen) days for the other Party to remedy the breaches of the provisions of these General Terms and Conditions.

If the Party fails to remedy the breaches of the provisions of these General Terms and Conditions within the aforementioned period, the other Party shall have the right to terminate Services without further notice.

8.5 Termination of the Service and related Contract pursuant to the provisions of these General Terms and Conditions shall not give either Party the right to claim any additional compensation, indemnity or reimbursement from the other Party as a result of such termination, but such termination shall not affect any rights or remedies available to a Party at the time the termination becomes effective or any obligations or liabilities incurred by a Party.

Article 9
CONFIDENTIALITY

9.1 The Parties agree to keep confidential all facts, data, information, etc. related to the other Party's business that they have learned in the course of providing Services. Such information and data shall not be disclosed by the Parties to any third party and shall not be used or misused to the detriment of the other Party.

9.2 The *Register* will keep confidential any data, plans or other technical information received from the Client and will not disclose it to any third party outside the *Register*, unless authorised by the Client. This obligation shall continue to apply after termination of the Services. This obligation shall not apply to any data, plans or other technical information that was in the possession of the *Register* prior to being disclosed to the *Register* by or on behalf of the Client, or that becomes publicly available through no fault of the *Register*, or is otherwise provided to the *Register* by an independent source that is under no obligation of confidentiality to the *Register*.

9.3 Certificates issued by the *Register* to the Client as a result of the Services provided shall not be covered by the confidentiality Article.

Notwithstanding the foregoing, the Client shall be entitled to disclose any data to its affiliates involved in the transactions related to the Services or the Client's core activities.

9.4 Notwithstanding clause 9.1 and clause 9.2 of this Article, the *Register* shall have the right to disclose the Confidential Information to the following parties if required by regulations of:

- (i) authorised representatives of the Flag State Administration,
- (ii) authorised audit teams (i.e., accreditation body or EC auditors),
- (iii) the International Association of Classification Societies (IACS),
- (iv) a court of competent jurisdiction, government agency, or other relevant public authority, in accordance with applicable law, court order, or other public regulation.

9.5 The Client acknowledges that the *Register* is required to provide access to information to the EU Commission or any person acting on its behalf in accordance with applicable EU requirements and that the Client shall give the EU Commission with unrestricted access to the vessels for the purpose of inspection.

9.6 The obligations in this Article shall survive the conclusion of the Service or the termination of related Contract and shall continue for as long as the relevant information remains confidential.

Article 10
INTELLECTUAL PROPERTY

10.1 Each Party shall be the sole owner of all rights to its Intellectual Property created before or after the effective date of these General Terms and Conditions, whether or not associated with any Contract between the Parties.

10.2 The Intellectual Property developed by the *Register* for the provision of the Services, including but not limited to drawings, calculations and reports, shall remain the exclusive property of the *Register*.

Article 11
PROFESSIONAL ETHICS

11.1 Each of the Parties warrants that, with respect to the matters contemplated herein, neither it nor its affiliates has made or will make, directly or indirectly, any offer, payment, gift or authorization of money to any government official or employee, political party, public official or candidate for the benefit or advantage thereof.

11.2 In providing the Services, the *Register* shall strictly adhere to the requirements of its Code of Ethics relating to business activities.

Article 12
FORCE MAJEURE

12.1 For the purposes of these General Terms and Conditions, the term "Force Majeure" includes any event that directly or indirectly prevents the Parties from fulfilling their obligations due to events beyond their control, such as: strikes, wars, riots, piracy, civil commotion, malicious damage, pandemic, compliance with laws or government orders, rules, regulations or directives, sanctions and embargoes, accidents, defects of plants or machinery, seizures, fires, floods, storms and the like.

12.2 If either Party is prevented or delayed from performing its obligations by Force Majeure, such Party shall promptly notify the other Party in writing of the circumstances of the Force Majeure and its influence and, after such notification, shall not be liable for performance of any obligations prevented by the influence of the Force Majeure during its duration. Upon termination of the influence of the Force Majeure, the same Party should proceed with the planned activities in order to fulfil its obligations.

12.3 If one of the Parties is prevented by Force Majeure in its activities and fulfilment of its obligations and this event lasts continuously for three (3) months, the other Party shall be entitled to terminate the Service and related Contract without liability.

12.4 Neither of the Parties shall be liable for non-compliance with these General Terms and Conditions due to Force Majeure. If one of the Parties is prevented from fulfilling its obligations under these General Terms and Conditions due to Force Majeure, it shall immediately notify the other Party in writing within a reasonable period of time, stating the reasons for the Force Majeure and providing relevant evidence, if any.

Article 13
INDEMNIFICATIONS

13.1 Each Party shall indemnify the other Party against all claims arising out of the performance of the Services in respect of bodily injury, illness or death of any of its employees or other representatives and in respect of loss of or damage to the Party's property.

This provision shall apply whether or not the damage is caused or contributed to by the negligence of the other Party. Both Parties are obliged to take out separate insurances for these liabilities.

13.2 The Client shall indemnify the *Register* from and against all claims arising from the Client's violation of the provisions of these General Terms and Conditions and from the misuse of the Certificates issued by the *Register*.

13.3 The Client shall indemnify the *Register* against any financial responsibility or amounts arising from non-payment, late payment or payment of withholding taxes to the non-relevant tax authority or any other relevant governmental body.

13.4 Each Party shall notify the other Party without undue delay as soon as it becomes aware of any incident that could give rise to a claim against the other Party in respect of the Service provided and related Contract.

Article 14
ANTI-CORRUPTION

14.1 Each Party agrees that in performing its obligations under any Service, it will ensure that its affiliates, employees and/or agents, subsidiaries, subcontractors, consultants, and any other persons providing Services will:

- (i) comply with all applicable anti-bribery and anti-corruption laws (collectively, Anti-Bribery Laws) and, in particular, do not, directly or indirectly, offer, promise, grant, authorise the payment of, or confer any financial or other benefit on any public or government official:
  - to a public or governmental official to obtain or retain business with the intent to influence such official in his or her capacity as an official, if such official is not permitted or required by written law to be influenced by the offer, promise or gift; or
  - to another person with the intent to induce or reward the improper performance of a function or activity or for any other illegal purpose,
- (ii) maintain adequate systems and procedures designed to prevent activities, practises, or conduct in connection with services that would constitute an offence under an anticorruption law; and
- (iii) take reasonable steps to prevent similar acts by customers, contractors, subcontractors, agents and other third parties, persons under its control or influence.

14.2 Any failure by a Party to comply with or ensure compliance with its obligations under this Article shall, notwithstanding anything to the contrary in these General Terms and Conditions, be deemed a breach of these General Terms and Conditions which shall entitle the other Party to suspend and/or terminate the Services by notice in writing with immediate effect without further liability to the other Party except for any liability which may have arisen prior to the date of termination or suspension (as the case may be).

14.3 If a Party elects to suspend the provision of Services under these General Terms and Conditions pursuant to this Article, it shall have the sole and absolute discretion to determine:

(i) when it will resume performance (if at all); and

(ii) extend the period for performance of its obligations under the Services in its sole discretion.

Article 15
SANCTIONS

15.1 Each Party shall conduct all activities in compliance with all laws, statutes, rules, economic and trade sanctions (including, but not limited to, U.S. sanctions and EU sanctions) and regulations applicable to such Party, including, but not limited to: child labour, forced labour, collective bargaining, discrimination, abuse, working hours and minimum wages, anti-bribery, anti-corruption, copyright and trademark protection, personal data protection.

15.2 Each Party hereby represents and warrants that it is not or will not be subject to any economic or trade sanctions ("Sanctions") imposed by the United States of America, the European Union, the United Kingdom, any EU Member State, or the United Nations with respect to any country and/or by any sanction giver with respect to any company/individual.

15.3 Each Party represents and warrants that it will strictly comply with all Sanctions.

15.4 Nothing in these General Terms and Conditions shall be construed as causing or obligating either Party to act or refrain from acting in a manner inconsistent with, punishable by, or prohibited by any Sanctions.

15.5 Neither Party shall be obligated to perform any obligation arising under these Terms and Conditions (including, without limitation, the obligation to):

(i) perform, deliver, accept, sell, purchase, pay or receive any funds to, from or through any person or entity; or

(ii) engage in any other action whatsoever,

if doing so violates or is inconsistent with sanctions and/or recommendations of international (intergovernmental) organisations to combat the financing of terrorism and other criminal activities and/or money laundering or exposes such Party to investigation or penalties.

15.6 In the event that a Party breaches any Sanctions or the Party's Business and/or Transactions arising out of or in connection with these General Terms and Conditions breach any Sanctions or otherwise violate the recommendations of one or more international (intergovernmental) organisations for combating the financing of terrorism and other criminal activities and/or money laundering, the other Party shall be entitled to terminate these General Terms and Conditions by written notice with immediate effect without incurring any liability to the other Party, except for liabilities (if any) incurred prior to the date of termination.

Article 16
LIABILITY

16.1 The *Register* is not, and cannot be considered as, an underwriter, consulting engineer, naval architect, shipbuilder, shipowner, or ship management company, nor can it assume the obligations and responsibilities associated with such functions, although the *Register's* experience may enable it to respond to inquiries about matters not covered by its Rules, policies, instructions, or other documented evidence.

16.2 The practices and procedures of the *Register* shall be selected by the *Register* in its sole and absolute discretion based on its experience and knowledge and in accordance with generally accepted professional standards in the relevant field of classification societies.

16.3 Nothing herein contained shall release any designer, naval architect or engineer, shipbuilder or manufacturer, shipyard, vendor, supplier, contractor or subcontractor, repairer or owner, from any information, report, certificate or similar document issued in connection with the provision of Services by the *Register*, operator, manager or other person or entity from any express or implied warranty or other contractual obligation or responsibility, or from any negligent act, error or omission of any kind whatsoever, nor shall they create any right, claim or benefit for any third party.

16.4 The *Register* shall exercise due care in the selection or appointment of its surveyors and all other employees whose presence and work is necessary for the provision of the Services.

16.5 If any person or entity using the Services of the *Register* suffers any loss, damage or expense that is or is shown to have been caused by a negligent act, omission or error of the *Register's* officers, surveyors, auditors, inspectors, agents, appointers, officers or managers, or those purporting to act in the name of and on behalf of the *Register*, or a negligent inaccuracy, advice, report or evidence given by or in the name of or/and on behalf of the *Register*, then the liability of the *Register* is limited in respect of any direct or indirect claim shall be limited to an amount not exceeding five times the fee charged or to be charged by the *Register* for the relevant Service.

16.6 Any liability for consequential damages is expressly excluded.

For purposes of this clause, consequential damages include, without limitation:

(i) indirect or consequential damages,

(ii) loss and/or delay of production, loss of products, loss of use, loss of bargain, loss of revenue, loss of profit or anticipated profit, loss of business and business interruption, in each case directly or indirectly.

16.7 The Parties are not entitled to assign the performance of obligations under these General Terms and Conditions or parts thereof to third parties without the prior written consent of the other Party.

16.8 If during the term of the Contract, there is a transfer of function due to change of status (merger, acquisition, division, etc.), all obligations and rights under these General Terms and Conditions and associated Contract will be transferred to the legal successor of the Party concerned.

Article 17
GOVERNING LAW AND RESOLVING OF DISPUTES

17.1 These General Terms and Conditions and any dispute or claim between the Parties arising from or in connection with it, or the Services provided hereunder, will be governed and interpreted in accordance with the English law.

17.2 The Parties shall use their reasonable efforts to resolve any claim or dispute arising in relation to rendered Service by negotiations within a reasonable time.

17.3 Should the Parties fail to resolve any claim or dispute by negotiations, the dispute shall be exclusively subject to the jurisdiction of the Permanent Arbitration Court with the Croatian Chamber of Economy in Zagreb, Republic of Croatia.

17.4 The Parties agree to keep the any arbitration proceedings confidential.

17.5 Notwithstanding the above, any claim not presented within three (3) months of the completion of the particular Services, or within three (3) months of from the date when the events which are relied on were first discovered by the Client, shall be deemed waived and absolutely time barred.

17.6 Any objections against the line adopted by any of the *Register's* servants in fulfilling their duties or against the conclusions reached are to be raised to the *Register* by the Party as soon as possible.

If the Party is not satisfied with the final conclusions and interpretations by the *Register* the arbitration lays upon the Commission for appeal for Classification and Statutory certification of ships, which is to be formed according to the Regulation 39 of the Charter of the *Register*.

INTRODUCTORY NOTES

These amendments shall be read together with the requirements in the Rules for the Classification of Ships, Part 2 – Hull, edition January 2024.

Table 1 contains review of amendments, where items changed or added in relating to previous edition are given, with short description of each modification or addition. All major changes throughout the text are shaded.

This Part of the Rules includes the requirements of the following international Organisations:

International Maritime Organization (IMO)

Conventions:	International Convention for the Safety of Life at Sea, 1974 (SOLAS 74) and all subsequent and applicable amendments adopted up to MSC 106 Protocol of 1988 relating to the International Convention for the Safety of Life at Sea, 1974, as amended (SOLAS PROT 1988) International Convention for the Prevention of Pollution from Ships 1973, as modified by the Protocol of 1978 relating thereto (MARPOL 73/78) and all subsequent and applicable amendments adopted up to MEPC 80 Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships, 1973, as modified by the Protocol of 1978 relating thereto
Resolutions:	MSC.482(103)
Circulars:	MSC.188(79)/Rev.1

International Association of Classification Societies (IACS)

Unified Requirements (UR):	F1 (Rev.1, 2002), F2 (Rev.2, 2012), M76 (2016), S1 (Rev.7, 2010), S1A (Rev.6, 2010), S2 (Rev.2, June 2019), S3 (Rev.2, June 2023), S4 (Rev. 4, 2017), S5 (Rev.1, corr. 1, June 2019), S6 (Rev.9, 2018), S6 (Rev.9, Corr.1, Mar 2021), S6 (Rev.9, Corr.2, Nov 2021), S7 (Rev.4, 2010), S10 (Rev.7, Feb 2023), S10 (Rev.7, Corr.1 June 2023), S11 (Rev.10, Dec 2020), S11A (2015), S12 (Rev.5, 2010), S13 (Rev.2, Corr.1, 2014), S14 (Rev.7, Dec 2022), S17 (Rev.10, Mar 2019), S18 (Rev.10, Mar 2019), S19 (Rev.5, 2004), S20 (Rev.6, 2014), S22 (Rev.3, 2004), S23 (Rev.4, 2007), S28 (Rev.3, 2010), S31 (Rev.4, 2007), S33 (Rev.3, Feb 2020), S34 (2015), S35 (Feb 2023), W31 (Rev.3, Mar 2023), Z8 (Rev.1, 1995), Z9 (Rev.2, 1997), Z10.1 (Rev.25, Feb 2023), Z10.2 (Rev. 37, Feb 2023), Z10.4 (Rev.18, Feb 2023)
Unified Interpretations (UI):	MPC94 (2008), SC93 (Rev.2, Feb 2021), SC122 (Rev.1, Corr.1 2008), SC154 (Corr.1, Sep 2021), SC179 (Rev. 3, 2021), SC180 (Rev. 4, 2021), SC207 (Corr.2, Jan 2020), SC208 (Corr.2, 2009), SC209 (Rev.1, Dec 2019), SC210 (2006), SC223 (Rev.3, Corr.1, 2014), SC258 (2013), SC259 (Rev.1, Corr.1, 2014)
Recommendations (Rec.):	Rec. 20 (Rev.1, 2007), Rec. 83 (2003), Rec. 94 (2007)
Other requirements:	Finnish-Swedish Ice Class Rules, 2017 Guidelines for the Application of the Finnish - Swedish Ice Class Rules, 8 January 2019

TABLE 1 – REVIEW OF AMENDMENTS

This review comprises amendments in relation to the Rules for the Classification of Ships, Part 2 – Hull, edition January 2024.

ITEM	*DESCRIPTION OF THE AMENDMENTS*
SECTION 4 – LONGITUDINAL STRENGTH	
Item 4.6.1	Item has been amended in order to include implications of the inclusion of new IACS UR S35, Feb 2023 in the Annex E of the Rules
SECTION 12 – STEM AND STERNFRAME	
Sub-item 12.3.6.1.4	Sub-item has been amended in order to include requirements of revised IACS UR S10, Rev.7, Feb 2023
SECTION 13 – SUPERSTRUCTURES AND DECKHOUSES	
Sub-item 13.3.3.2	Sub-item has been amended in order to include requirements of revised IACS UR S3, Rev.2, June 2023
ANNEX D – BASIC GUIDELINES FOR DIRECT CALCULATION OF SHIP STRUCTURES	
Item D.1.1	Item has been amended in order to include implications of the inclusion of new IACS UR S35, Feb 2023 in the Annex E of the Rules
ANNEX E – BUCKLING STRENGTH ASSESSMENT OF SHIP STRUCTURAL ELEMENTS	
Heads E.1, E.2, E.3, E.4, E.5, Appendix 1	New Annex E has been added to include requirements of new IACS UR S35, Feb 2023 - Requirements On Buckling Strength Assessment of Ship Structural Elements

4 LONGITUDINAL STRENGTH

■ **Head 4.6 BUCKLING STRENGTH,** item 4.6.1 has been partly changed and should be read as follows:

4.6.1 These requirements apply to plate panels and longitudinals subject to hull girder bending and shear stresses. This Section is not applicable for the buckling of hatch covers structures, for which Annex E apply.

12 STEM AND STERNFRAME

■ **Head 12.3 STERN FRAME,** sub-item 12.3.6.1.4 has been partly changed and should be read as follows:

12.3.6 Rudder trunk

12.3.6.1 Materials, welding and connection to hull

12.3.6.1.4 The fillet shoulder radius *r*, in [mm] (see Fig. 12.3.6.1.4) is to be as large as practicable and to comply with the following formulae:

r = $0.1 d_c / k$,

without being less than:

r = 60 mm, when $\sigma \geq 40 / k$, [N/mm²]

r = 30 mm, when $\sigma < 40 / k$ [N/mm²]

where:

d_c = rudder stock diameter axis defined in S10.4.2.

σ = bending stress in the rudder trunk, in [N/mm²].

k = material factor for the rudder trunk as given in the *Rules, Part 3 – Hull Equipment,* Section 2, respectively.

13 SUPERSTRUCTURES AND DECKHOUSES

■ **Head 13.3 SUPERSTRUCTURE END BULKHEADS AND DECKHOUSE WALLS,** sub-item 13.3.3.2 has been partly changed and should be read as follows:

13.3.3 Scantlings

13.3.3.2 Plate thickness

The thickness of the plating is to be determined according to the following formula:

$$t = 0{,}95 \cdot s \cdot \sqrt{p_A \cdot k} + t_k \text{ [mm]}$$

but not less than:

$$t_{min} = \left(5{,}0 + \frac{L}{100}\right) \cdot \sqrt{k}$$, for the lowest tier;

$$t_{min} = \left(4{,}0 + \frac{L}{100}\right) \cdot \sqrt{k}$$, for the upper tiers, however, not less than 5,0 mm.

For ships with L< 65m, the minimum thickness of plating should be as follows:
t_{min} = 5 mm for the lowest unprotected front
4 mm for all other cases

where:
s and p_A are as defined above.
When determining p_A, z is to be measured to the middle of the plate field.

ANNEX D GUIDELINES FOR DIRECT CALCULATIONS OF SHIP STRUCTURE

■ **Head D.1 BASIC GUIDELINES FOR DIRECT CALCULATION OF SHIP STRUCTURES**, item D.1.1 has been partly changed and should be read as follows:

D.1.1 General

The objective of this Appendix to the Rules [1)] is to provide basic guidelines and instructions for application of direct calculations to ship structural response and feasibility (measured by adequacy criteria/parameters). This Appendix to the Rules [1)] is not applicable for the buckling of hatch covers structures, for which Annex E apply.

ANNEX E BUCKLING STRENGTH ASSESSMENT OF SHIP STRUCTURAL ELEMENTS

■ **ANNEX E – Buckling strength assessment of ship structural elements,** new Annex has been added and should be read as follows:

E1 APPLICATION

E.1.1 General

E.1.1.1 Application

E.1.1.1.1 This Annex is to be applied only for buckling of hatch covers structures when it is referred to the applicable Section 7.10 in the *Rules for the classification of ships, Part 3 - Hull equipment*.

This Annex is not applicable for buckling of plate panels and longitudinals in longitudinal strength calculations subject to hull girder bending and shear forces, for which Section 4.6 and Annex D apply.

E.1.1.1.2 These requirements establishes a general buckling assessment procedure as illustrated in Figure E.1.1 and is to be applied in conjunction with Section 7.10 in the *Rules for the classification of ships, Part 3 - Hull equipment* for hatch cover structures.

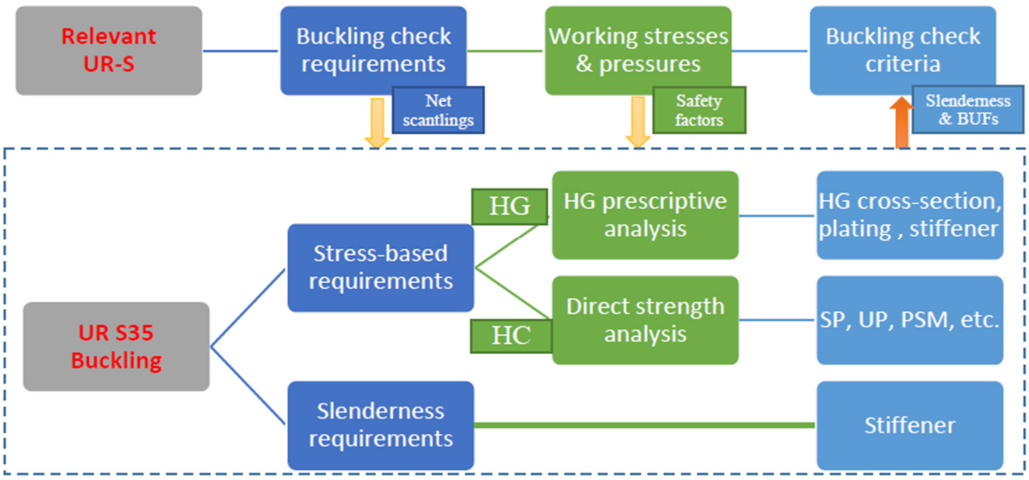


Figure E.1.1
Overview of applying this Requirements in conjunction with the Rules

E.1.1.2 Assumption

E.1.1.2.1 For each structural member, the characteristic buckling strength is to be taken as the most unfavourable/critical buckling failure mode.

E.1.1.2.2 Unless otherwise specified, the scantling requirements of structural members in this Appendix are based on net scantling.

E.1.1.2.3 In this Appendix, compressive and shear stresses are to be taken as positive, tension stresses are to be taken as negative.

E.1.1.3 Scope

E.1.1.3.1 The buckling checks are to be performed according to:

- E.2 for the slenderness requirements of longitudinal and transverse stiffeners,
- E.3 for the prescriptive buckling requirements of plates, longitudinal and transverse stiffeners, primary supporting members and other structures subject to hull girder stresses,
- E.4 for the buckling requirements of the FEM analysis for the plates, stiffened panels and other structures,
- E.5 for the buckling capacity of prescriptive and FEM buckling requirements.

E.1.1.3.2 Stiffeners

The buckling check of the stiffeners referred to this Appendix is applicable to the stiffeners fitted along the long edge of the buckling panel.

E.1.2 Terminology and Assumptions

E.1.2.1 Buckling

E.1.2.1.1 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 [E.1.2.1.2] 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.

E.1.2.1.2 Buckling behavior

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.

E.1.2.1.3 Assessment methods

The buckling assessment is carried out according to one of the two following methods, taking into account different boundary condition types:

- Method A:
  All the edges of the elementary plate panel are forced to remain straight (but free to move in the in-plane directions) due to the surrounding structure/neighbouring plates. The elementary plate is integrated in the structure, which means that it is surrounded by plates that give a strong in plane support. A typical example is a double bottom girder supporting a longitudinal bulkhead.
- Method B:

The edges of the elementary plate panel are not forced to remain straight due to low in-plane stiffness at the edges and/or no surrounding structure/neighbouring plates. The elementary plate is not surrounded by plates which means that the in-plane support is weak. A typical example is a double bottom girder not supporting a longitudinal bulkhead.

E.1.2.2 Net scantling approach

E.1.2.2.1 General

Unless otherwise specified, all the scantling requirements, including slenderness requirements, in this requirements are based on net scantlings obtained by removing full corrosion addition t_c from the gross offered thicknesses.

E.1.2.2.2 Corrosion addition

Corrosion addition t_c referred to in this Requirements is defined in the *Rules for the classification of ships, Part 3 – Hull equipment*, 7.10.2.5.

E.1.2.2.3 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 the *Rules for the classification of ships, Part 3 – Hull equipment*, 7.10.2.5.

E.1.2.3 Structural idealisation

E.1.2.3.1 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 Figure E.1.2.

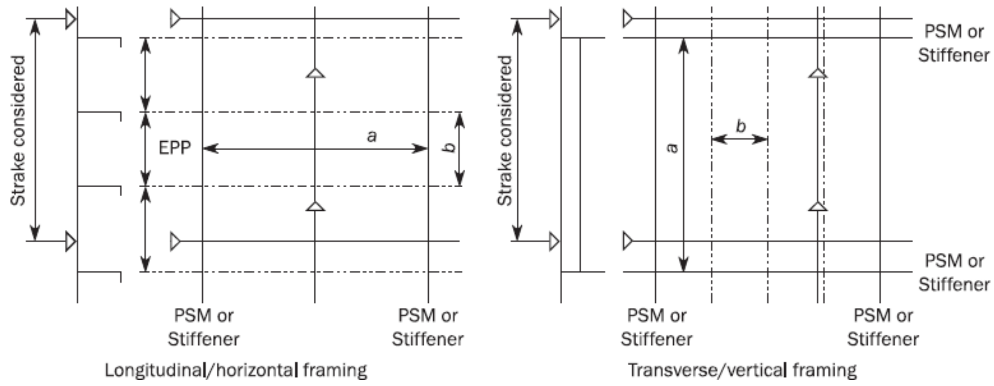


Figure E.1.2
Elementary plate panel (EPP) definition

E.1.2.3 Buckling utilisation factor

E.1.2.3.1 The utilisation factor η is defined as the ratio between the applied loads and the corresponding ultimate capacity or buckling strength.

E.1.2.3.2 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 Figure E.1.1, and is to be taken as:

$$\eta_{act} = \frac{W_{act}}{W_U} = \frac{1}{\gamma_c}$$

where:

W_{act} = Equivalent applied stress, see Figure E.1.3.

W_U = Equivalent buckling capacity, see Figure E.1.3.

γ_c = Stress multiplier factor at failure as calculated in item E.5.

For each typical failure mode, the corresponding capacity of the panel is calculated by applying the actual stress combination and then increasing or decreasing the stresses proportionally until collapse.

Figure E.1.3 illustrates the buckling capacity and the buckling utilisation factor of a structural member subject to σ_x and σ_y stresses.

where:

σ_x, σ_y = Membrane stresses, in [N/mm[2]], applied, respectively, in x direction and in y direction

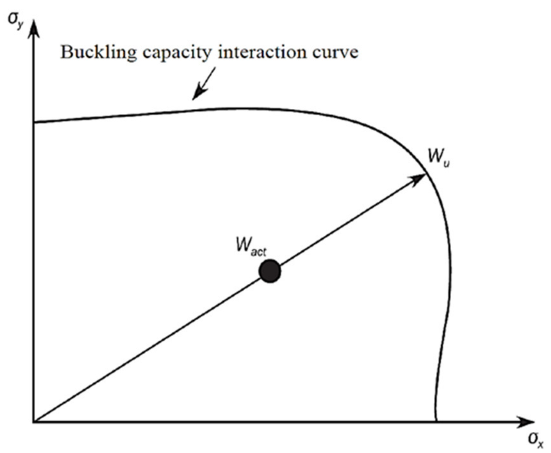


Figure E.1.3
Example of buckling capacity and buckling utilisation factor

E.1.2.4 Allowable buckling utilisation factor

E.1.2.4.1 General structural elements

The allowable buckling utilisation factor η_{all} is defined in the *Rules for the classification of ships, Part 3 – Hull equipment*, 7.10.3.6.3.5.

E.1.2.5 Buckling acceptance criteria

E.1.2.5.1 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 item E.1.2.3.2.

η_{all} = Allowable buckling utilisation factor as defined in item E.1.2.4.1.

E2 SLENDERNESS REQUIRMENTS

Definition of symbols

b_{f-out} = Maximum distance, in mm, from mid thickness of the web to the flange edge, in [mm], as shown in Figure E.2.1

b_f = Width of the flange or face plate of the stiffener, in [mm] as shown in Figure E.2.1 and Figure E.2.2

b = Breadth of the unstiffened part of the plating between stiffeners and/or primary supporting members, in [mm]

b_1 = Width of the attached plate enclosed by the U-type stiffener, in [mm], as shown in Figure E.2.2

b_2 = Width of the attached plate between adjacent U-type stiffeners, in [mm] as shown in Figure E.2.2

d_f = Breadth of the extended part of the flange for L2 profiles, in [mm], as shown in Figure E.2.1

e_f = Distance from attached plating to centre of flange, in mm, as shown in Figure E.2.1. For its detailed definition, refer to E.5, Symbols

l = Span of stiffeners, in [m]

s = Stiffener spacing, in [mm]

h_w = Depth of stiffener web, in [mm], as shown in Figure E.2.1

R_{eH} = Specified minimum yield stress, in [N/mm2]

t_f Net flange thickness, in [mm]

t_p Net thickness of plate, in [mm]

t_w Net web thickness, in [mm]

E.2.1 Structural elements

E.2.1.1 General

The stiffener elements except for U-type stiffeners are to comply with the applicable slenderness and proportion requirements given in E.2.2.

E.2.2 Stiffeners

E.2.2.1 Proportions of stiffeners

E.2.2.1.1 Net thickness of all stiffener types

The net thickness of stiffeners is to satisfy the following criteria:

a) Stiffener web plate:

$$t_w \geq \frac{h_w}{C_w}\sqrt{\frac{R_{eH}}{235}}$$

b) Flange:

$$t_f \geq \frac{b_{f-out}}{C_f}\sqrt{\frac{R_{eH}}{235}}$$

where:

C_w, C_f : Slenderness coefficients given in Table E.2.1.

If requirement b) 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:

$$b_{f-out-max} = C_f t_f \sqrt{\frac{235}{R_{eH}}}$$

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 Table 1, and the edge stiffener can be assessed as a flat bar stiffener according to item E.2.1.1. The requirement to flange in item E.2.2.1.2 shall still apply.

Table E.2.1
Slenderness coefficients

Type of Stiffener	C_w	C_f
Angle and L2 bars	75	12
T-bars	75	12
Bulb flats	45	-
Flat bars	22	-

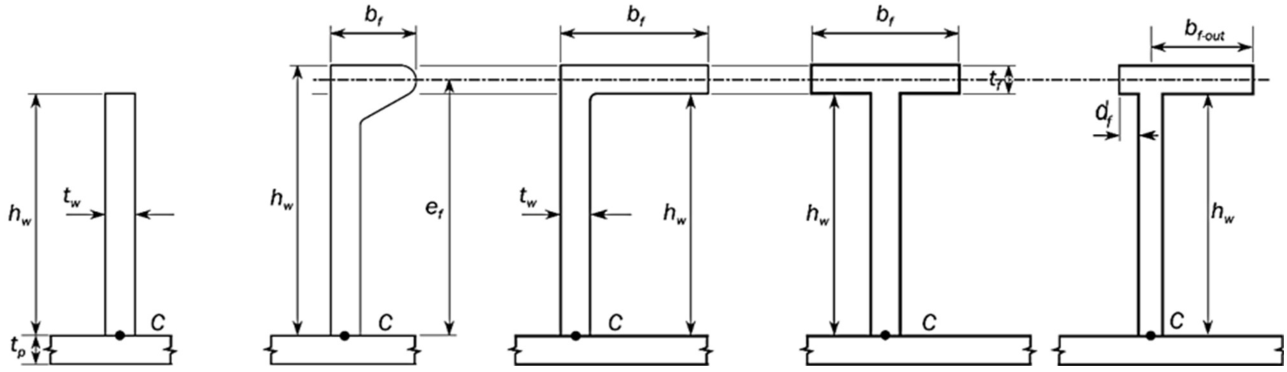


Figure E.2.1
Dimensions of typical stiffener cross sections

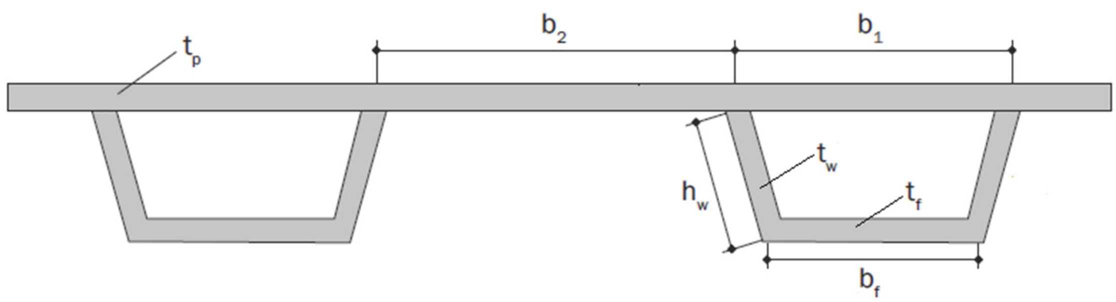


Figure E.2.2
Dimensions of a U-type stiffener cross section

E.2.2.1.2 Net dimensions of angle bars, L2 bars and T-bars

The total flange breadth b_f, in [mm], for angle and T-bars is to satisfy the following criterion: $b_f \geq 0.2h_w$

E.2.3 Primary supporting members

E.2.3.1 Proportions and stiffeners

E.2.3.1.1 Proportions of web plates and flanges

The scantlings of webs and flanges of primary supporting members are to comply with the *Rules for the classification of ships, Part 3 – Hull equipment*, 7.10.

E3 PRESCRIPTIVE BUCKLING REQUIREMENTS

Symbols

η_{all} = Allowable buckling utilisation factor, as defined in E1, item 1.2.4.1.

LCP = Load Calculation Point, as defined in item E.3.1.2.1.

EPP = Elementary Plate Panel, i.e. the unstiffened part of the plating between stiffeners and/or primary supporting members

E.3.1 General

E.3.1.1 Scope

E.3.1.1.1 This section 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.

E.3.1.1.2 The hull girder buckling strength requirements apply along the full length of the ship.

E.3.1.1.3 Design load sets

The buckling checks are to be performed for all design load sets, with pressure combination defined in the *Rules for the classification of ships, Part 3 – Hull equipment*, 7.10.2.6.

For each design load set, and for all dynamic load cases, the lateral pressure is to be determined and applied at a load calculation point as described in E.3.1.2.1. It is to be applied together with the hull girder stress combinations given in the relevant Rules.

E.3.1.2 Definitions

E.3.1.2.1 Load calculation point

The load calculation points (LCP) for both elementary plate panels (EPP) and stiffeners are defined as follows:

a) LCP for hull girder stresses of EPP
The hull girder stresses for EPP are to be calculated at the load calculation points defined in Table E.3.1.

Table E.3.1
Load calculation points (LCP) coordinates for plate buckling assessment

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 Figure E.3.1)	Outboard and inboard ends of the EPP (points A1 and A2 in Figure E.3.1)	Mid-point of EPP (point B in Figure E.3.1)
z coordinate	Corresponding to *x* and *y* values		

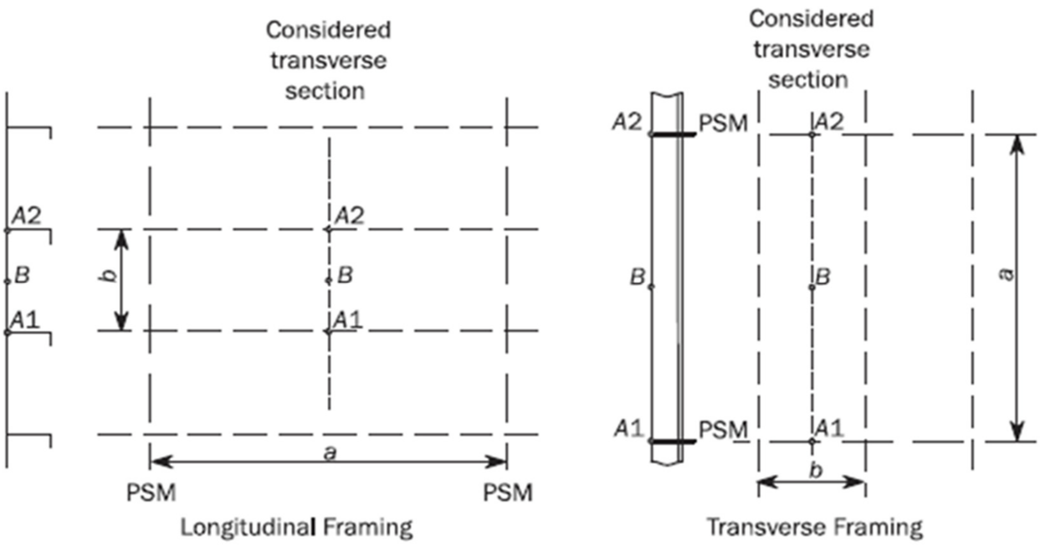


Figure E.3.1
LCP for plate buckling assessment

b) 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.

c) 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.

d) 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:

$P = \frac{p_U + p_L}{2}$ when the upper end of the vertical stiffener is below the lowest zero pressure level.

$P = \frac{l_1}{l}\frac{p_L}{2}$ when the upper end of the vertical stiffener is at or above the lowest zero pressure level, see Figure E.3.2.

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.

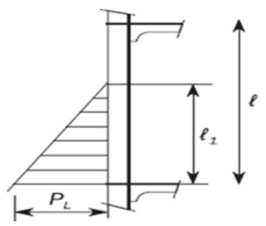


Figure E.3.2
Definition of pressure for vertical stiffeners

E.3.1.3 Equivalent plate panel

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 t1. The width beq of this equivalent plate panel, in [mm], is defined by the following formula:

$$b_{eq} = l_1 + l_2 \left(\frac{t_1}{t_2}\right)^{1.5}$$

where:

l_1 = Width of the part of the plate panel with the smaller plate thickness, t_1 , in [mm], as defined in Figure E.3.3

l_2 = Width of the part of the plate panel with the greater plate thickness, t_2 , in [mm], as defined in Figure E.3.3.

E.3.1.3.1 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.

E.3.1.3.2 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.

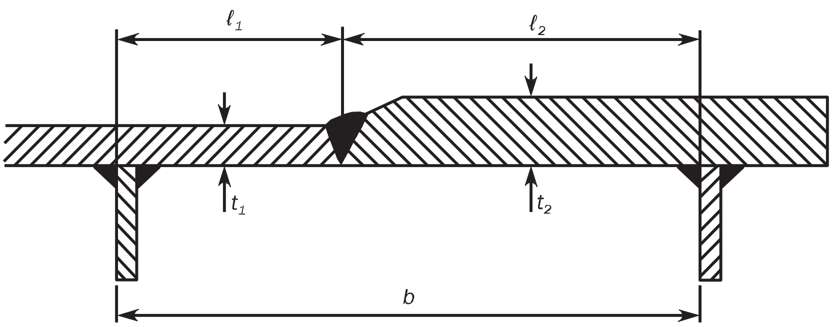


Figure E.3.3
Plate thickness change over the width b

E.3.2 Buckling criteria

E.3.2.1 Overall stiffened panels

E.3.2.1.1 The buckling strength of overall stiffened panels is to satisfy the following criterion:

$\eta_{overall} \leq \eta_{all}$

where:

$\eta_{overall}$ = Maximum utilisation factor, as defined in E.5, item E.5.2.1.

E.3.3.2 Elementary plate panels

E.3.3.2.1 The buckling strength of elementary plate panels is to satisfy the following criterion:

$\eta_{plate} \leq \eta_{all}$

where:

η_{plate} = Maximum plate utilisation factor calculated according to SP-A, as defined in E.5, item E.5.2.2.

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 E.5, Table E.5.4 corresponding to the shorter edge of the plate panel clamped are to be considered together with a mean σ_y stress and $\psi_y = 1$.

E.3.2.3 Stiffeners and side frames of single-side skin ships

E.3.2.3.1 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 E.5, item E.5.2.3.

NOTE 1: This buckling check can only be fulfilled when the overall stiffened panel buckling check, as defined in item E.3.3.1, 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.

E.3.2.4 Vertically corrugated longitudinal bulkheads

E.3.2.4.1 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

$\eta_{shear} = \frac{\tau_{bhd}}{\tau_c}$

τ_{bhd} = Hull girder shear stress, in [N/mm^2], in the longitudinal bulkhead as defined in item E.3.2.

τ_c = Shear critical stress, in [N/mm^2], as defined in E5, E.5.2.2.3.

E.3.2.5 Horizontally corrugated longitudinal bulkheads

E.3.2.5.1 Each corrugation unit within the extension of half flange, web and half flange (i.e. single corrugation as shown in grey in Figure E.3.4) is to satisfy the following criterion:

$\eta_{column} \leq \eta_{all}$

where:

η_{column} = Overall column buckling utilisation factor, as defined in E.5, item E.5.3.1.

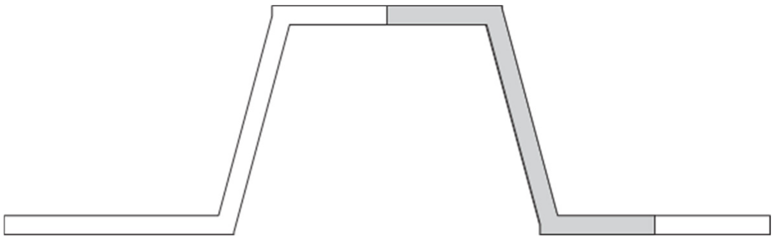


Figure E.3.4
Single corrugation

E4 BUCKLING REQUIREMENTS FOR DIRECT STRENGTH ANALYSIS

Symbols

R_{eH_P} = Yield stress of the plate panel, as defined in E.4.2.1.3

R_{eH_S} = Yield stress of the stiffener, as defined in E.4.2.1.3

α = Aspect ratio of the plate panel, as defined in the Symbol list of E.5

η_{all} = Allowable buckling utilisation factor, as defined in E.1, 1.2.3.1

E.4.1 General

E.4.1.1 Scope

E.4.1.1.1 The requirements of this Section 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.

E.4.1.1.2 All structural elements in the direct strength analysis are to be assessed individually. The buckling checks are to be performed for the following structural elements:

- Stiffened and unstiffened panels, including curved panels.
- Web plate in way of openings.

E.4.2 Stiffened and unstiffened panels

E.4.2.1 General

E.4.2.1.1 The plate panel of hull structure is to be modelled as stiffened panel (SP) or unstiffened panel (UP), with either Method A or Method B as defined in E.1, E.1.2.1.3 to be used for the calculation of the plate buckling capacity.

E.4.2.1.2 Average thickness of plate panel

Where the plate thickness along a plate panel is not constant, the panel used for the buckling assessment is to be modelled according to the *Rules for the classification of ships, Part 3 – Hull equipment*, Section 7.10, with a weighted average thickness t_{avr}, in [mm], taken as:

$$t_{avr} = \frac{\sum_1^n A_i t_i}{\sum_1^n A_i}$$

where:

A_i = Area of the *i*-th plate element, in [mm²]

t_i = Net thickness of the i-th plate element, in [mm]

n = Number of finite elements defining the buckling plate panel.

E.4.2.1.3 Yield stress of plate panel and stiffener

The yield stress R_{eH_P}, in [N/mm²], of a plate panel is taken as the minimum value of the specified yield stresses of the elements within the plate panel.

The yield stress R_{eH_S}, in [N/mm²] of a stiffener is taken as the minimum value of the specified yield stresses of the elements within the stiffener.

E.4.2.2 Stiffened panels

E.4.2.2.1 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 *Rules for the classification of ships, Part 3 – Hull equipment*, Table 7.10.3.6.1-2.

E.4.2.2.2 If the stiffener properties or stiffener spacing vary within the stiffened panel, the calculations are to be performed separately for all configurations of the plate panels, i.e. for each stiffener and plate between the stiffeners. The plate thickness, stiffener properties and stiffener spacing at the considered location are to be assumed for the whole panel.

E.4.2.2.3 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.

E.4.2.3 Unstiffened panels

E.4.2.3.1 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 FEM analysis, an equivalent rectangular panel is to be defined according to E.4.2.3.2 for irregular geometry and E.4.2.3.3 for triangular geometry and to comply with buckling assessment.

E.4.2.3.2 Modeling of an unstiffened panel with irregular geometry

Unstiffened panels with irregular geometry are to be idealised to equivalent rectangular panels for plate buckling assessment according to the following procedure:

a) The four corners closest to a right angle (90 deg) in the bounding polygon for the plate are identified as shown in Figure E.4.1, a).

b) The distances along the plate bounding polygon between the corners (as shown in Figure E.4.1, b) are calculated, i.e. the sum of all the straight line segments between the end points.

c) The pair of opposite edges with the smallest total length is identified, i.e. the minimum of (d1 + d3) and (d2 + d4).

d) A line joins the middle points of the chosen opposite edges as shown in Figure E.4.1, c) (a middle 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 a of the capacity model, measured from one end point.

e) The length of shorter side, b, in [mm], is to be taken as:

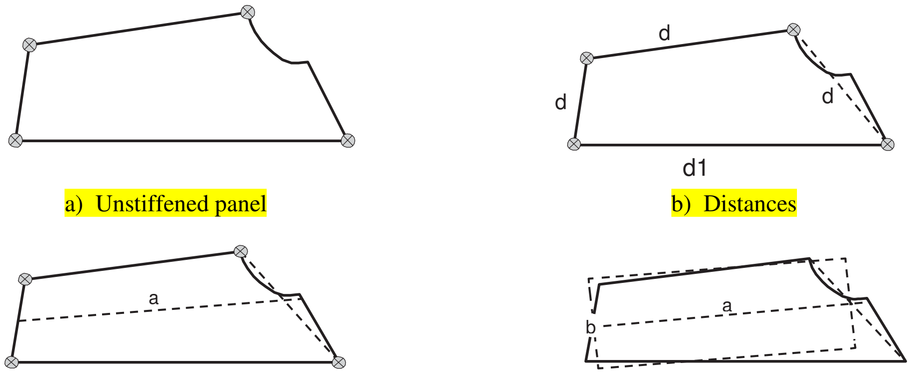
$$b = \frac{A}{a}$$

where:

A = Area of the plate, in [mm²]

a = Length defined in (d), in [mm]

d) 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.



a) Unstiffened panel
b) Distances
c) Join line a
d) Side

Figure E.4.1
Irregular unstiffened panel modelling

E.4.2.3.3 Modeling of an unstiffened panel with triangular geometry

Unstiffened panels with triangular geometry are to be idealised to equivalent rectangular panels for plate buckling assessment according to the following procedure:

a) Medians are constructed as shown in Figure E.4.2, a).

b) The longest median is identified as shown in Figure E.4.2, b). This median, the length of which is l_1 in [mm], defines the longitudinal direction for the capacity model.

c) The width l_2 of the model, in [mm], as shown in Figure E.4.2, c), is to be taken as:

$$l_2 = \frac{A}{l_1}$$

where:

A = Area of the plate, in [mm²]

d) The lengths of the shorter side b and the longer side a, in [mm], of the equivalent rectangular panel are to be taken as:

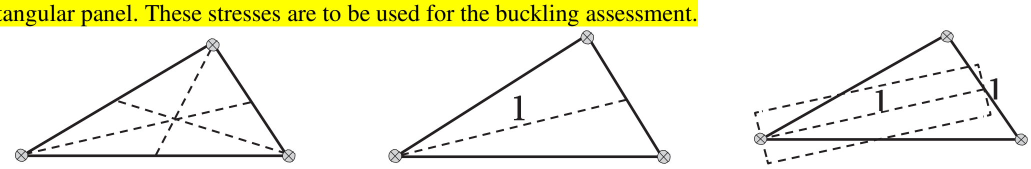
$$b = \frac{l_2}{C_{tri}}$$

$$a = l_1 C_{tri}$$

where:

$$C_{tri} = 0.4\frac{l_2}{l_1} + 0.6$$

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.



a) Medians
b) Longest median l_1
c) Width l_2 of the model

Figure E.4.2
Triangular unstiffened panel modelling

E.4.2.4 Reference stresses

E.4.2.4.1 The stress distribution is to be taken from the direct strength analysis and applied to the buckling model.

E.4.2.4.2 For FEM analysis, the reference stresses are to be calculated using the stress based reference stresses, as defined in Appendix 1.

E.4.2.5 Lateral pressure

E.4.2.5.1 The lateral pressure applied to the direct strength analysis is also to be applied to the buckling assessment unless otherwise stated in the *Rules for the classification of ships, Part 3 – Hull equipment*, 7.10.3.6.3.3.

4.2.5.2 For FEM analysis, where the lateral pressure is not constant over a buckling panel defined by a number of finite plate elements, an average lateral pressure, in [N/mm^2], is calculated using the following formula:

$$P_{avr} = \frac{\sum_1^n A_i P_i}{\sum_1^n A_i}$$

where:

A_i = Area of the i-th plate element, in [mm2]

P_i = Lateral pressure of the i-th plate element, in [N/mm²]

n = Number of finite elements in the buckling panel.

E.4.2.6 Buckling criteria

E.4.2.6.1 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 E.5, E.5.2.2 where UP-A model is to be used.

E.4.2.6.2 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 E.5, E.5.2.2 where UP-B model is to be used.

E.4.2.6.3 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} = Maximum stiffened panel utilisation factor taken as the maximum of:

- the overall stiffened panel capacity, as defined in E.5, E.5.2.1
- the plate capacity calculated according to Method A, as defined in E.5, E.5.2.2
- the stiffener buckling strength as defined in E.5, E.5.2.3, considering separately the properties (thickness, dimensions), the pressures defined in 4.2.5.2 and the reference stresses of each EPP at both sides of the stiffener.

NOTE 1: The stiffener buckling capacity check can only be fulfilled when the overall stiffened panel capacity, as defined in E.5, E.5.2.1, is satisfied.

E.4.2.6.4 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} = Maximum stiffened panel utilisation factor taken as the maximum of:

- the overall stiffened panel capacity, as defined in E.5, E.5.2.1
- the plate capacity calculated according to Method B, as defined in E.5, E.5.2.2
- the stiffener buckling strength as defined in E.5, E.5.2.3, considering separately the properties (thickness, dimensions), the pressures defined in 4.2.5.2 and the reference stresses of each EPP at both sides of the stiffener.

NOTE 1: The stiffener buckling capacity check can only be fulfilled when the overall stiffened panel capacity, as defined in E.5, E.5.2.1, is satisfied.

E.4.2.6.5 Web plate in way of openings

The web plate of primary supporting members in way of openings is to satisfy the following criterion:

$\eta_{opening} \leq \eta_{all}$

where:

$\eta_{opening}$ = Maximum web plate utilisation factor in way of openings, as defined in E.5, E.5.2.4.

E5 BUCKLING CAPACITY

Symbols

A_p = Net sectional area of the stiffener attached plating, in [mm^2], taken as:

$A_p = st_p$

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 E.5.2.3.5

b_{eff1} = Effective width of the attached plating of a stiffener, in [mm], without the shear lag effect taken as:

when $\sigma_x > 0$

for prescriptive assessment:

$b_{eff1} = \frac{C_{x1}b_1+C_{x2}b_2}{2}$

for FE analysis:

$b_{eff1} = C_x b$

when $\sigma_x \leq 0$

$b_{eff1} = b$

b_f = Breadth of the stiffener flange, in [mm]

b_1, b_2 = Width of the plate panel on each side of the considered stiffener, in [mm]

C_{x1}, C_{x2} = Reduction factor define in Table E.5.4, calculated for the EPP1 and EPP2 on each side of the considered stiffener according to case 1

C_x = Reduction factor as defined in E.5.2.2.3

d = Length, in [mm], of the side parallel to the axis of the cylinder corresponding to the curved plate panel, as shown in Table E.5.5

d_f = Distance in [mm], for the extension of flange for L2 profiles, as shown in Figure E.2.1

E = Young's modulus of the material, in [N/mm²]

e_f = Distance, in [mm], from the attached plating to the flange centre, as shown in Figure E.2.1, depending on the profile type:

- $e_f = h_w$ for flat bar profile
- $e_f = h_w - 0.5t_f$ for bulb profile
- $e_f = h_w + 0.5t_f$ for angle, L2 and T profiles

F_{long} = Correction factor defined in E.5.2.2.4

F_{tran} = Correction factor defined in E.5.2.2.5

h_w = Depth of the stiffener web, in [mm], as shown in Figure E.2.1 and Figure E.2.2

l = Span of the stiffener, in [mm], equal to the spacing between the primary supporting members

R = Radius of the curved plate panel, in [mm]

R_{eH_P} = Specified minimum yield stress of the plate, in [N/mm²]

R_{eH_S} = Specified minimum yield stress of the stiffener, in [N/mm²]

S = Partial safety factor, unless otherwise specified in the *Rules for the classification of ships, Part 3 – Hull equipment*, 7.10.3.6.3.4, to be taken as 1.0

s = Stiffener spacing, in [mm]

t_p = Net thickness of the plate panel, in [mm]

t_w = Net thickness of the stiffener web, in [mm]

t_f = Net thickness of the stiffener flange, in [mm]

x-axis = For a rectangular buckling panel, local axis parallel to its long edge

y-axis = For a rectangular buckling panel, local axis perpendicular to its long edge

α = Aspect ratio of the plate panel, to be taken as: $\alpha = \frac{a}{b}$

β = Coefficient taken as: $\beta = \frac{1-\psi}{\alpha}$

ω = Coefficient taken as: $\omega = min(3, \alpha)$

σ_x = Stress applied on the edge along x axis of the buckling panel, in [N/mm²]

σ_y = Stress applied on the edge along y axis of the buckling panel, in [N/mm²]

σ_1 = Maximum stress, in [N/mm²]

σ_2 = Minimum stress, in [N/mm²]

σ_E = Elastic buckling reference stress, in [N/mm²], to be taken as:

- for the application of plate limit state according to E.5.2.2.1:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{b}\right)^2$$

- for the application of curved plate panels according to E.5.2.2.6:

$$\sigma_E = \frac{\pi^2 E}{12(1-\nu^2)}\left(\frac{t_p}{d}\right)^2$$

τ = Applied shear stress, in [N/mm²]

τ_c = Ultimate buckling shear stresses, in [N/mm²], as defined in E.5.2.2.3

ν = Poisson's ratio of the material

ψ = Edge stress ratio, to be taken as: $\psi = \frac{\sigma_2}{\sigma_1}$

γ = Stress multiplier factor acting on loads. When γ is such that the loads reach the interaction formulae, then: $\gamma = \gamma_c$

γ_c = Stress multiplier factor at failure

γ_{GEB} = Stress multiplier factor of global elastic buckling capacity

E.5.1 General

E.5.1.1 Scope

E.5.1.1.1 This section contains the methods for determination of the buckling capacities of plate panels, stiffeners, primary supporting members and columns.

E.5.1.1.2 For the application of this section, the stresses σ_x, σ_y and τ applied on the structural members are defined in:

- E3 for hull girder prescriptive buckling requirements
- E4 for the FEM analysis buckling requirements.

E.5.1.1.3 Ultimate buckling capacity

The ultimate buckling capacity is calculated by applying the actual stress combination and then increasing or decreasing the stresses proportionally until the interaction formulae defined in E.5.2.1.1, E.5.2.2.1, and E.5.2.3.4 are equal to 1,0.

E.5.1.1.4 Buckling utilisation factor

The buckling utilisation factor η of the structural member is equal to the highest utilisation factor obtained for the different buckling modes.

E.5.1.1.5 Lateral pressure

The lateral pressure is to be considered as constant in the buckling strength assessment.

E.5.2 Buckling capacity of plates and stiffeners

E.5.2.1 Overall stiffened panel capacity

E.5.2.1.1 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 E.5.2.3.4:

$$\frac{\gamma_c}{\gamma_{GEB}} = 1$$

where the stress multiplier factor corresponding to global elastic buckling capacity, γ_{GEB} , is 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 for different load combinations as defined in E.5.2.1.2, E.5.2.1.3 and E.5.2.1.4, respectively. For the calculation of $\gamma_{GEB,bi+\tau}$, $\gamma_{GEB,bi}$ and $\gamma_{GEB,\tau}$, neither σ_x nor σ_y shall be taken less than 0.

σ_x, σ_y = Applied normal stresses to the plate panel, in [N/mm2], to be taken as defined in E.5.2.2.7

τ = Applied shear stress, in [N/mm2], to be taken as defined in 2.2.7.

E.5.2.1.2 The stress multiplier factor $\gamma_{GEB,bi}$ for the stiffened panel subjected to biaxial loads is taken as:

$$\gamma_{GEB,bi} = \frac{\pi^2}{L_{B1}^2 L_{B2}^2}\frac{[D_{11}L_{B2}^4 + 2(D_{12}+D_{33})n^2L_{B1}^2L_{B2}^2 + n^4D_{22}L_{B1}^4]}{L_{B2}^2N_x + n^2L_{B1}^2N_y}$$

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 E.2, Figure E.2.2.

N_y = Load per unit length applied on the edge along y axis of the stiffened panel, in [N/mm], taken as $N_y = c\sigma_y t_p$

L_{B1} = Stiffener span, in [mm], equal to spacing between primary supporting members, i.e. $L_{B1} = l$

For vertically stiffened side shell of single side skin bulk carriers, $L_{B1} = 0.8l$.

L_{B2} = Width of the stiffened panel, 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 stresses in the attached plating acting perpendicular to the stiffener axis:

$c = 0.5(1+\psi)$ for $0 \le \psi \le 1$

$c = \dfrac{1}{2(1-\psi)}$ for $\psi < 0$

ψ = Edge stress ratio for case 2 according to Table E.5.4

$\sigma_{x,av}$ = Average stress for both plate and stiffener with Poisson correction, taken as:

$\sigma_{x,av} = \sigma_x - \nu c\sigma_y A_s/(A_p + A_s) \ge 0$ for $\sigma_x > 0$ *and* $\sigma_y > 0$

$\sigma_{x,av} = \sigma_x$ for $\sigma_x \le 0$ or $\sigma_y \le 0$

$D_{11}, D_{12}, D_{22}, D_{33}$ = Bending stiffness coefficients, in [Nmm], of the stiffened panel, defined in general as:

$$\left.\begin{aligned} D_{11} &= \frac{EI_{eff}10^4}{s} \\ D_{12} &= \frac{Et_p^3\nu}{12(1-\nu^2)} \\ D_{22} &= \frac{Et_p^3}{12(1-\nu^2)} \\ D_{33} &= \frac{Et_p^3}{12(1+\nu)} \end{aligned}\right\}$$

For stiffened panels fitted with U-type stiffeners, D_{12} and D_{22} are defined as:

$$D_{22} = \frac{Et_p^3}{12(1-\nu^2)}\left[1.2 + 4.8 \times Min\left(1.0, \frac{b_1^2}{h_w(b_1+b_2)}\right) \times Min\left(1.0, \left(\frac{t_w}{t_p}\right)^3\right)\right]$$

$D_{12} = \nu D_{22}$

h_w = Breadth of U-type stiffener web a defined in Figure E.2.2

I_{eff} = Moment of inertia, in [cm4], of the stiffener including the effective width of the attached plating, same as I defined in E.5.2.3.4.

E.5.2.1.3 The stress multiplier factor $\gamma_{GEB,\tau}$ for the stiffened panel subjected to pure shear load is taken as:

$$\gamma_{GEB,\tau} = \frac{\sqrt[4]{D_{11}^3D_{22}}}{(L_{B1}/2)^2N_{xy}}\left[8.125 + 5.64\sqrt{\frac{(D_{12}+D_{33})^2}{D_{11}D_{22}}} - 0.6\frac{(D_{12}+D_{33})^2}{D_{11}D_{22}}\right] \quad for\ D_{11}D_{22} \ge (D_{12}+D_{33})^2$$

$$\gamma_{GEB,\tau} = \frac{\sqrt{2D_{11}(D_{12}+D_{33})}}{(L_{B1}/2)^2N_{xy}}\left[8.3 + 1.525\frac{D_{11}D_{22}}{(D_{12}+D_{33})^2} - 0.493\frac{D_{11}^2D_{22}^2}{(D_{12}+D_{33})^4}\right] \quad for\ D_{11}D_{22} < (D_{12}+D_{33})^2$$

where:

$N_{xy} = \tau t_p$

E.5.2.1.4 The stress multiplier factor $\gamma_{GEB,bi+\tau}$ for the stiffened panel subjected to combined loads is taken as:

$$\gamma_{GEB,bi+\tau} = \frac{1}{2}\gamma_{GEB,\tau}{}^2\left[-\frac{1}{\gamma_{GEB,bi}} + \sqrt{\frac{1}{\gamma_{GEB,bi}{}^2} + 4\frac{1}{\gamma_{GEB,\tau}{}^2}}\right]$$

where $\gamma_{GEB,bi}$ and $\gamma_{GEB,\tau}$ are as defined in E.5.2.1.2 and E.5.2.1.3, respectively.

E.5.2.2 Plate capacity

E.5.2.2.1 Plate limit state

The plate limit state is based on the following interaction formulae:

$$\left(\frac{\gamma_{c1}\sigma_x S}{\sigma_{cx}}\right)^{e_0} - B\left(\frac{\gamma_{c1}\sigma_x S}{\sigma_{cx}}\right)^{\frac{e_0}{2}}\left(\frac{\gamma_{c1}\sigma_y S}{\sigma_{cy}}\right)^{\frac{e_0}{2}} + \left(\frac{\gamma_{c1}\sigma_y S}{\sigma_{cy}}\right)^{e_0} + \left(\frac{\gamma_{c1}|\tau|S}{\tau_c}\right)^{e_0} = 1$$

$$\left(\frac{\gamma_{c2}\sigma_x S}{\sigma_{cx}}\right)^{\frac{2}{\beta_p^{0.25}}} + \left(\frac{\gamma_{c2}|\tau|S}{\tau_c}\right)^{\frac{2}{\beta_p^{0.25}}} = 1 \ for \ \sigma_x \geq 0$$

$$\left(\frac{\gamma_{c3}\sigma_y S}{\sigma_{cy}}\right)^{\frac{2}{\beta_p^{0.25}}} + \left(\frac{\gamma_{c3}|\tau|S}{\tau_c}\right)^{\frac{2}{\beta_p^{0.25}}} = 1 \ for \ \sigma_y \geq 0$$

$$\frac{\gamma_{c4}|\tau|S}{\tau_c} = 1$$

with

$\gamma_c = Min(\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4})$

and the corresponding buckling utilization factor defined as

$$\eta_{plate} = \frac{1}{\gamma_c}$$

where:

σ_x, σ_y = Normal stresses applied on the plate panel, in [N/mm2], to be taken as defined in E.5.2.2.7

τ = Shear stress applied on the plate panel, in [N/mm2], to be taken as defined in E.5.2.2.7

σ_{cx} = Ultimate buckling stress, in [N/mm2], in the direction parallel to the longer edge of the buckling panel, as defined in E.5.2.2.3

σ_{cy} = Ultimate buckling stress, in [N/mm2], in the direction parallel to the shorter edge of the buckling panel, as defined in E.5.2.2.3

τ_c = Ultimate buckling shear stresses, in [N/mm2], as defined in E.5.2.2.3

$\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4}$ = 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 = Coefficients given in Table E.5.1

e_0 = Coefficients given in Table E.5.1

β_p = Plate slenderness parameter taken as:

$$\beta_p = \frac{b}{t_p}\sqrt{\frac{R_{eH\_P}}{E}}$$

Table E.5.1
Definition of coefficients B and e_0

Applied stress	B	e_0
$\sigma_x \geq 0$ and $\sigma_y \geq 0$	$0.7 - 0.3\,\beta_p/\alpha^2$	$2/\beta_p^{0.25}$
$\sigma_x < 0$ or $\sigma_y < 0$	1.0	2.0

E.5.2.2.2 Reference degree of slenderness

The reference degree of slenderness is to be taken as:

$$\lambda = \sqrt{\frac{R_{eH\_P}}{K\sigma_E}}$$

where:

K = Buckling factor, as defined in Table E.5.4 for plane plate panels and Table E.5.5 for curved plate panels.

E.5.2.2.3 Ultimate buckling stresses

The ultimate buckling stresses of plate panels, in [N/mm2], are to be taken as:

$\sigma_{cx} = C_x R_{eH\_P}$

$\sigma_{cy} = C_y R_{eH\_P}$

The ultimate buckling stress of plate panels subject to shear, in [N/mm2], is to be taken as:

$$\tau_c = C_\tau \frac{R_{eH\_P}}{\sqrt{3}}$$

where:

$C_x, C_y, C_\tau =$ Reduction factors, as defined in Table E.5.4.

- For the 1st Equation of E.5.2.2.1, 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 C_y is calculatzed according to Table E.5.4, using the value of c_1 given in Table E.5.2

Table E.5.2
Definition of coefficient $\boldsymbol{c_1}$

Plate panels	c_1
SP-A	$c_1 = \left(1 - \frac{1}{\alpha}\right) \geq 0$
UP-A	
Vertically stiffened single-side skin between hopper and topside tanks	
Corrugations of corrugated bulkhead	
SP-B	$c_1 = 1$
UP-B	

The boundary conditions for plates are to be considered as simply supported, see cases 1, 2 and 15 of Table E.5.4. If the boundary conditions differ significantly from simple support, a more appropriate boundary condition can be applied according to the different cases of Table E.5.4 subject to the agreement of the *Register*.

E.5.2.2.4 Correction factor $\boldsymbol{F_{long}}$

The correction factor *Flong* depending on the edge stiffener types on the longer side of the buckling panel is defined in Table E.5.3. An average value of *Flong* is to be used for the plate panels having different edge stiffeners. For stiffener types other than those mentioned in Table E.5.3, the value of c is to be agreed by the *Register*. In such a case, a value of c higher than those mentioned in Table E.5.3 can be used, provided it is verified by buckling strength check of panel using non-linear FE analysis and deemed appropriate by the *Register*.

Table E.5.3
Correction factor $\boldsymbol{F_{long}}$

<table>
<tr><th colspan="3">Structural element types</th><th>F_{long}</th><th>c</th></tr>
<tr><td colspan="3">Unstiffened Panel</td><td>1.0</td><td>N/A</td></tr>
<tr><td rowspan="6">Stiffened Panel</td><td colspan="2">Stiffener not fixed at both ends</td><td>1.0</td><td>N/A</td></tr>
<tr><td rowspan="5">Stiffener fixed at both ends</td><td>Flat bar (1)</td><td rowspan="4">$F_{long} = c + 1 \ for \ \frac{t_w}{t_p} > 1$
$F_{long} = c\left(\frac{t_w}{t_p}\right)^3 + 1 \ for \ \frac{t_w}{t_p} \leq 1$</td><td>0.10</td></tr>
<tr><td>Bulb profile</td><td>0.30</td></tr>
<tr><td>Angle and L2 profiles</td><td>0.40</td></tr>
<tr><td>T profile</td><td>0.30</td></tr>
<tr><td>Girder of high rigidity (e.g. bottom transverse)</td><td>1.4</td><td>N/A</td></tr>
</table>

Structural element types			F_{long}	c
		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 - For $b_2 < b_1$: $F_{long} = 1$ - For $b_2 \geq b_1$: $F_{long} = \left(1.55 - 0.55\frac{b_1}{b_2}\right)\left[1 + c\left(\frac{t_w}{t_p}\right)^3\right]$ - 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 E.5.2.3.2.				
(2) b_1, b_2 and t_w are defined in E.1, Figure E.2.2.				

E.5.2.2.5 Correction factor F_{tran}

The correction factor $Ftran$ 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:

$F_{tran} = Max(3 - 0.08(F_{tran0} - 6)^2, 1.0) \leq 2.25$

where:

$F_{tran0} = Min\left(\frac{b_2}{b_1} + \frac{6b_2^2}{\pi^2 h_w(b_1+b_2)}\left(\frac{t_w}{t_p}\right)^3, 6\right)$ for EPP b_2

$F_{tran0} = Min\left(\frac{b_1}{b_2} + \frac{6b_1^2}{\pi^2 h_w(b_2+b_1)}\left(\frac{t_w}{t_p}\right)^3, 6\right)$ for EPP b_1

with b_1, b_2 and h_w as defined in E.2, Figure E.2.2.

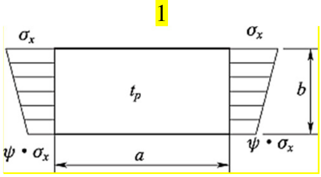
Coefficient F defined in Case 2 of Table E.5.3 is to be replaced by the following formula:

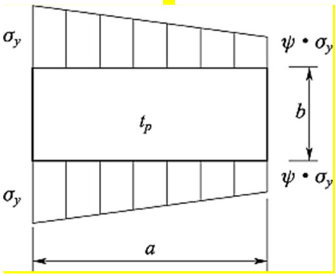
$F = \left[1 - \left(\frac{K_y}{0.91F_{tran}} - 1\right)/\lambda_p^2\right]c_1 \geq 0$

- For other cases: $F_{tran} = 1$.

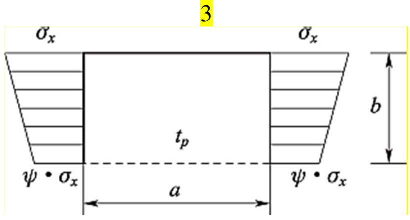
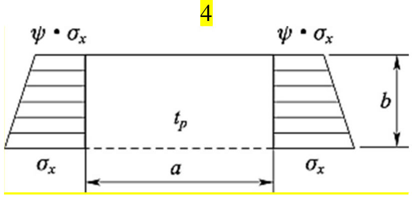
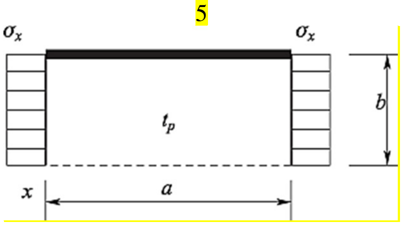
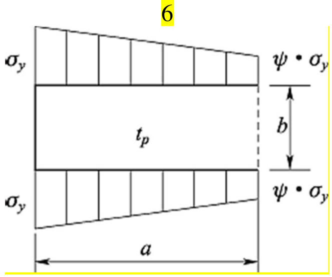
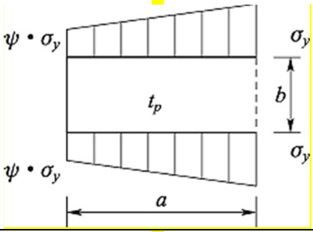
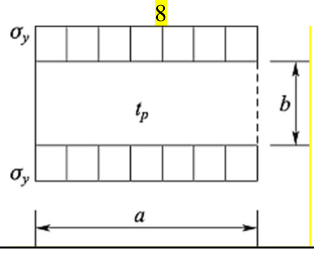
Table E.5.4

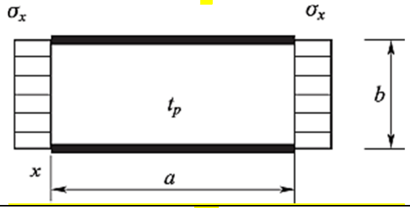
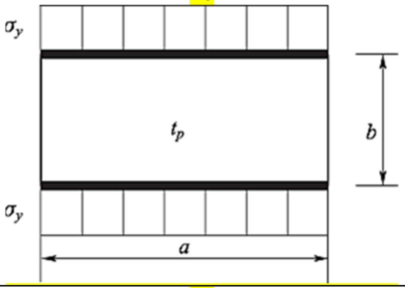
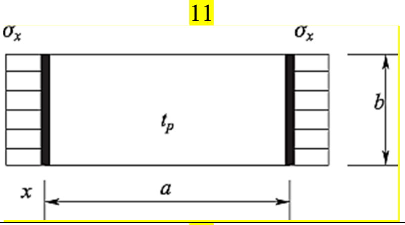
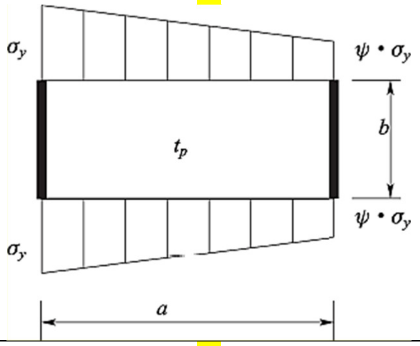
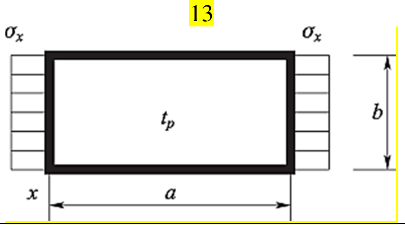
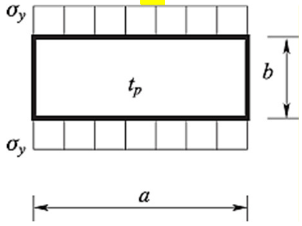
Buckling factor K and reduction factor C for plane plate panels

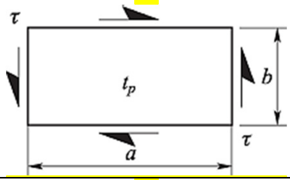
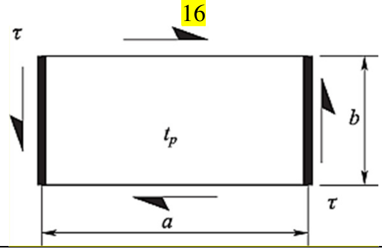
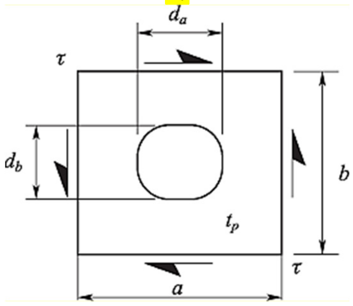
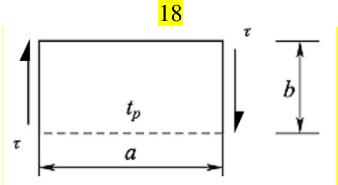
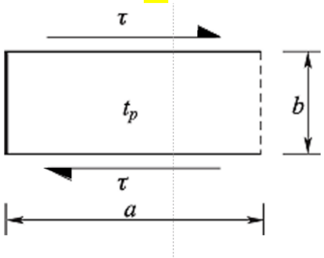
Case	**Stress ratio ψ**	**Aspect ratio α**	**Buckling factor K**	**Reduction factor C**
1 	$1 \geq \psi \geq 0$		$K_x = F_{long}\frac{8.4}{\psi + 1.1}$	When $\sigma_x \leq 0$, $C_x = 1$ When $\sigma_x > 0$, $C_x = 1$ for $\lambda \leq \lambda_c$ $C_x = c\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > \lambda_c$ where: $c = (1.25 - 0.12\psi) \leq 1.25$
	$0 > \psi > -1$		$K_x = F_{long}[7.63 - \psi(6.26 - 10\,\psi)]$	

<table>
<tr><th>Case</th><th>Stress ratio ψ</th><th colspan="2">Aspect ratio α</th><th>Buckling factor K</th><th>Reduction factor C</th></tr>
<tr><td></td><td>$\psi \le -1$</td><td colspan="3">$K_x = F_{long}[5.975(1-\psi)^2]$</td><td>$\lambda_c = \frac{c}{2}\left(1+\sqrt{1-\frac{0.88}{c}}\right)$</td></tr>
<tr><td rowspan="7">2

</td><td rowspan="3">$1 \ge \psi \ge 0$</td><td colspan="3">$K_y = \frac{F_{tran} \cdot 2\left(1+\frac{1}{\alpha^2}\right)^2}{1+\psi+\frac{(1-\psi)}{100}\left(\frac{2.4}{\alpha^2}+6.9f_1\right)}$</td><td rowspan="7">When $\sigma_y \le 0$, $C_y = 1$
When $\sigma_y > 0$
$C_y = c\left(\frac{1}{\lambda} - \frac{R+F^2(H-R)}{\lambda^2}\right)$
where:
$c = (1.25 - 0.12\psi) \le 1.25$
$R = \lambda\left(1-\frac{\lambda}{c}\right)$ for $\lambda < \lambda c$
$R = 0.22$ for $\lambda \ge \lambda c$
$\lambda_c = 0.5c\left(1+\sqrt{1-\frac{0.88}{c}}\right)$
$F = \left(1-\frac{\left(\frac{K}{0.91}-1\right)}{\lambda_p^2}\right)c_1 \ge 0$
$\lambda_p^2 = \lambda^2 - 0.5$ for $1 \le \lambda_p^2 \le 3$
c_1 as defined in [E.5.2.2.3]
$H = \lambda - \frac{2\lambda}{c(T+\sqrt{T^2-4})} \ge R$
$T = \lambda + \frac{14}{15\lambda} + \frac{1}{3}$</td></tr>
<tr><td>$\alpha \le 6$</td><td colspan="2">$f_1 = (1-\psi)(\alpha-1)$</td></tr>
<tr><td>$\alpha > 6$</td><td colspan="2">$f_1 = 0.6\left(1-\frac{6\psi}{\alpha}\right)\left(\alpha+\frac{14}{\alpha}\right)$ but not greater than $14.5 - \frac{0.35}{\alpha^2}$</td></tr>
<tr><td rowspan="4">$1 - \frac{4\alpha}{3} \le \psi < 0$</td><td colspan="3">$K_y = \frac{200F_{tran}(1+\beta^2)^2}{(1-f_3)(100+2.4\beta^2+6.9f_1+23f_2)}$</td></tr>
<tr><td>$\alpha > 6(1-\psi)$</td><td colspan="2">$f_1 = 0.6\left(\frac{1}{\beta}+14\beta\right)$
but not greater than $14.5 - 0.35\beta^2$
$f_2 = f_3 = 0$</td></tr>
<tr><td>$3(1-\psi) \le \alpha \le 6(1-\psi)$</td><td colspan="2">$f_1 = \frac{1}{\beta} - 1$
$f_2 = f_3 = 0$</td></tr>
<tr><td>$1.5(1-\psi) \le \alpha < 3(1-\psi)$</td><td colspan="2">$f_1 = \frac{1}{\beta} - (2-\omega\beta)^4 - 9(\omega\beta-1)\left(\frac{2}{3}-\beta\right)$
$f_2 = f_3 = 0$</td></tr>
</table>

Case	**Stress ratio ψ**	**Aspect ratio α**	**Buckling factor K**	**Reduction factor C**
		$1-\psi \le \alpha < 1.5(1-\psi)$	For $\alpha > 1.5$ $f_1 = 2\left(\frac{1}{\beta} - 16\left(1-\frac{\omega}{3}\right)^4\right)\left(\frac{1}{\beta}-1\right)$ $f_2 = 3\beta - 2$ $f_3 = 0$ For $\alpha \le 1.5$ $f_1 = 2\left(\frac{1.5}{1-\psi} - 1\right)\left(\frac{1}{\beta}-1\right)$ $f_2 = \frac{\psi(1-16f_4^2)}{1-\alpha}$ $f_3 = 0$ $f_4 = (1.5 - Min(1.5, \alpha))^2$	
		$0.75(1-\psi) \le \alpha < 1-\psi$	$f_1 = 0$ $f_2 = 1 + 2.31(\beta - 1) - 48\left(\frac{4}{3} - \beta\right)f_4^2$ $f_3 = 3f_4(\beta - 1) - \left(\frac{f_4}{1.81} - \frac{\alpha - 1}{1.31}\right)$ $f_4 = (1.5 - Min(1.5, \alpha))^2$	
	$\psi < 1 - \frac{4\alpha}{3}$	$K_y = 5.972F_{tran}\frac{\beta^2}{1-f_3}$ where $f_3 = f_5\left(\frac{f_5}{1.81} + \frac{1+3\psi}{5.24}\right)$ $f_5 = \frac{9}{16}(1 + Max(-1, \psi))^2$		

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
3 	$1 \geq \psi \geq 0$		$K_x = \frac{4(0.425 + 1/\alpha^2)}{3\psi + 1}$	For UP-A: $C_x = 1$ for $\lambda \leq 0.75$ $C_x = \frac{0.75}{\lambda}$ for $\lambda > 0.75$ For UP-B: $C_x = 1$ for $\lambda \leq 0.7$ $C_x = \frac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
	$0 > \psi > -1$		$K_x = 4\left(0.425 + \frac{1}{\alpha^2}\right)(1 + \psi) - 5\psi(1 - 3.42\psi)$	
4 	$1 \geq \psi \geq -1$		$K_x = \left(0.425 + \frac{1}{\alpha^2}\right)\frac{3 - \psi}{2}$	
5 	—	$\alpha \geq 1.64$	$K_x = 1.28$	
		$\alpha < 1.64$	$K_x = \frac{1}{\alpha^2} + 0.56 + 0.13\alpha^2$	
6 	$1 \geq \psi \geq 0$		$K_y = \frac{4(0.425 + \alpha^2)}{(3\psi + 1)\alpha^2}$	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 $\lambda > 0.7$
	$0 > \psi \geq -1$		$K_y = 4(0.425 + \alpha^2)(1 + \psi)\frac{1}{\alpha^2} - 5\psi(1 - 3.42\psi)\frac{1}{\alpha^2}$	
7 	$1 \geq \psi \geq -1$		$K_y = (0.425 + \alpha^2)\frac{(3 - \psi)}{2\alpha^2}$	
8 	—		$K_y = 1 + \frac{0.56}{\alpha^2} + \frac{0.13}{\alpha^4}$	

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
9 	—		$K_x = 6.97$	$C_x = 1$ for $\lambda \leq 0.83$ $C_x = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
10 	—		$K_y = 4 + \frac{2.07}{\alpha^2} + \frac{0.67}{\alpha^4}$	$C_y = 1$ for $\lambda \leq 0.83$ $C_y = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
11 	—	$\alpha \geq 4$	$K_x = 4$	$C_x = 1$ for $\lambda \leq 0.83$ $C_x = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
		$\alpha < 4$	$K_x = 4 + 2.74\left(\frac{4-\alpha}{3}\right)^4$	
12 	—		$K_y = K_y$ determined as per case 2	For $\alpha < 2$ $C_y = C_{y2}$ For $\alpha \geq 2$ $C_y = \left(1.06 + \frac{1}{10\alpha}\right) C_{y2}$ where: C_{y2} : C_y determined as per case 2
13 	—	$\alpha \geq 4$	$K_x = 6.97$	$C_x = 1$ for $\lambda \leq 0.83$ $C_x = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
		$\alpha < 4$	$K_x = 6.97 + 3.1\left(\frac{4-\alpha}{3}\right)^4$	
14 	—		$K_y = \frac{6.97}{\alpha^2} + \frac{3.1}{\alpha^2}\left(\frac{4-1/\alpha}{3}\right)^4$	$C_y = 1$ for $\lambda \leq 0.83$ $C_y = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$

<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>$K_\tau = \sqrt{3}\left(5.34 + \frac{4}{\alpha^2}\right)$</td><td rowspan="3">$C_\tau = 1$ for $\lambda \le 0.84$
$C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$</td></tr>
<tr><td>16
</td><td>–</td><td>–</td><td>$K_\tau = \sqrt{3}\left[5.34 + Max\left(\frac{4}{\alpha^2}, \frac{7.15}{\alpha^{2.5}}\right)\right]$</td></tr>
<tr><td>17
</td><td>–</td><td>–</td><td>$K_\tau = K_{\tau case15} r$
$K_{\tau case15}$: K_τ according to case 15
r : Opening reduction factor taken as
$r = \left(1 - \frac{d_a}{a}\right)\left(1 - \frac{d_b}{b}\right)$
with
$\frac{d_a}{a} \le 0.7$ and $\frac{d_b}{b} \le 0.7$</td></tr>
<tr><td>18
</td><td>–</td><td>–</td><td>$K_\tau = \sqrt{3}\left(0.6 + \frac{4}{\alpha^2}\right)$</td><td rowspan="2">$C_\tau = 1$ for $\lambda \le 0.84$
$C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$</td></tr>
<tr><td>19
</td><td>–</td><td>–</td><td>$K_\tau = 8$</td></tr>
<tr><td colspan="5">Edge boundary conditions:
- - - - - - Plate edge free
———— Plate edge simply supported
▬▬▬▬ Plate edge clamped</td></tr>
<tr><td colspan="5">Note 1: Cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.</td></tr>
</table>

E.5.2.2.6 Curved plate panels

This requirements for curved plate limit state is applicable when $R/t_p \leq 2500$. Otherwise, the requirement for plate limit state given in E.5.2.2.1 is applicable.

The curved plate limit state is based on the following interaction formula:

$$\left(\frac{\gamma_c \sigma_{ax} S}{C_{ax} R_{eH\_P}}\right)^{1.25} - 0.5\left(\frac{\gamma_c \sigma_{ax} S}{C_{ax} R_{eH\_P}}\right)\left(\frac{\gamma_c \sigma_{tg} S}{C_{tg} R_{eH\_P}}\right) + \left(\frac{\gamma_c \sigma_{tg} S}{C_{tg} R_{eH\_P}}\right)^{1.25} + \left(\frac{\gamma_c \tau \sqrt{3} S}{C_{\tau} R_{eH\_P}}\right)^{2} = 1.0$$

with the corresponding buckling utilization factor defined as

$$\eta_{curved\_plate} = \frac{1}{\gamma_c}$$

where:

σ_{ax} = Axial stress applied to the cylinder corresponding to the curved plate panel, in [N/mm2], In case of tensile axial stresses, $\sigma_{ax} = 0$.

σ_{tg} = Tangential stress applied to the cylinder corresponding to the curved plate panel, in [N/mm2]. 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 Table E.5.5.

The stress multiplier factor, γ_c of the curved plate panel need not be taken less than the stress multiplier factor, γ_c obtained from E.5.2.2.1 for an expanded plane panel.

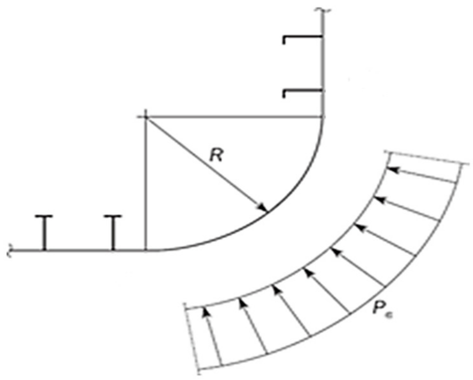
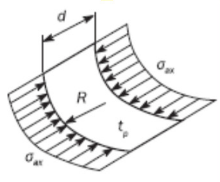
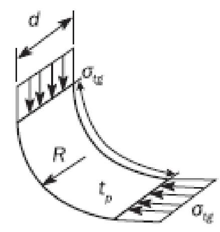
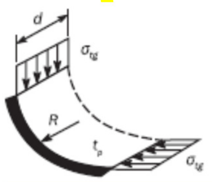
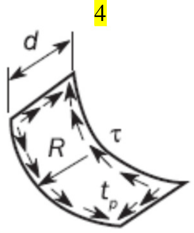


Figure E.5.1
Transverse stiffened bilge plating

Table E.5.5
Buckling factor K and reduction factor C for curved plate panel with $\boldsymbol{R/t_p} \le$ **2500**

Case	**Aspect ratio**	**Buckling factor *K***	**Reduction factor *C***
1 	$\frac{d}{R} \le 0.5\sqrt{\frac{R}{t_p}}$	$K = 1 + \frac{2}{3}\frac{d^2}{Rt_p}$	For general application: $C_{ax} = 1$ for $\lambda \le 0.25$ $C_{ax} = 1.233 - 0.933\lambda$ for $0.25 < \lambda \le 1$ $C_{ax} = 0.3/\lambda^3$ for $1 < \lambda \le 1.5$ $C_{ax} = 0.2/\lambda^2$ for $\lambda > 1.5$ For curved single fields, e.g. bilge strake, which are bounded by plane panels as shown in Figure E.5.1: $C_{ax} = \frac{0.65}{\lambda^2} \le 1.0$
	$\frac{d}{R} > 0.5\sqrt{\frac{R}{t_p}}$	$K = 0.267\frac{d^2}{Rt_p}\left[3 - \frac{d}{R}\sqrt{\frac{t_p}{R}}\right] \ge 0.4\frac{d^2}{Rt_p}$	
2 	$\frac{d}{R} \le 1.63\sqrt{\frac{R}{t_p}}$	$K = \frac{d}{\sqrt{Rt_p}} + 3\frac{(Rt_p)^{0.175}}{d^{0.35}}$	For general application: $C_{tg} = 1$ for $\lambda \le 0.4$ $C_{tg} = 1.274 - 0.686\lambda$ for $0.4 < \lambda \le 1.2$ $C_{tg} = \frac{0.65}{\lambda^2}$ for $\lambda > 1.2$ For curved single fields, e.g. bilge strake, which are bounded by plane panels as shown in Figure E.5.1: $C_{tg} = \frac{0.8}{\lambda^2} \le 1.0$
	$\frac{d}{R} > 1.63\sqrt{\frac{R}{t_p}}$	$K = 0.3\frac{d^2}{R^2} + 2.25\left(\frac{R^2}{dt_p}\right)^2$	
3 	$\frac{d}{R} \le \sqrt{\frac{R}{t_p}}$	$K = \frac{0.6d}{\sqrt{Rt_p}} + \frac{\sqrt{Rt_p}}{d} - 0.3\frac{Rt_p}{d^2}$	As in load case 2.
	$\frac{d}{R} > \sqrt{\frac{R}{t_p}}$	$K = 0.3\frac{d^2}{R^2} + 0.291\left(\frac{R^2}{dt_p}\right)^2$	
4 	$\frac{d}{R} \le 8.7\sqrt{\frac{R}{t_p}}$	$K = \sqrt{3}\sqrt{28.3 + \frac{0.67d^3}{R^{1.5}t_p^{1.5}}}$	$C_\tau = 1$ for $\lambda \le 0.4$ $C_\tau = 1.274 - 0.686\lambda$ for $0.4 < \lambda \le 1.2$ $C_\tau = \frac{0.65}{\lambda^2}$ for $\lambda > 1.2$
	$\frac{d}{R} > 8.7\sqrt{\frac{R}{t_p}}$	$K = \sqrt{3}\frac{0.28d^2}{R\sqrt{Rt_p}}$	
Explanations for boundary conditions: - - - - - - - - - - - - Plate edge free. ———————— Plate edge simply supported. ▬▬▬▬▬▬ Plate edge clamped.			

E.5.2.2.7 Normal and shear stresses applied to plate panels

The normal stress, σ_x and σ_y, in [N/mm2], to be applied for the overall stiffened panel capacity and the plate panel capacity calculations as given in E.5.2.1.1 and E.5.2.2.1 respectively, are to be taken as follows:

- For FEM analysis, the reference stresses as defined in E.4, E.4.2.4.
- For prescriptive assessment of the overall stiffened panel capacity and the plate panel capacity, the axial or transverse compressive stresses at load calculation points of the considered stiffener or the considered elementary plate panel, as defined in the *Rules for the classification of ships, Part 3- Hull equipment*, Section 7.10, 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 E.3.1.2.1.
- For grillage analysis where the stresses are obtained based on the beam theory, the following values:

$$\sigma_x = \frac{\sigma_{xb}+\nu\sigma_{yb}}{1-\nu^2}$$

$$\sigma_y = \frac{\sigma_{yb}+\nu\sigma_{xb}}{1-\nu^2}$$

where:

σ_{xb}, σ_{yb} = Stresses, in [N/mm2], from grillage beam analysis, respectively along x axis and y axis of the plate attached to the PSM.

The shear stress τ, in [N/mm2], to be applied for the overall stiffened panel capacity and the plate panel capacity calculations as given in E.5.2.1.1 and E.5.2.2.1 respectively, are to be taken as follows:

- For FEM analysis, the reference shear stresses as defined in E.4, E.4.2.4,
- For prescriptive assessment of the plate panel capacity, the shear stresses at load calculation points of the considered elementary plate panel, as defined in the E.1.2.3.1,
- Prescriptive assessment of the overall stiffened panel capacity, the shear stresses calculated according to E.3, for E.3.2.1.1, at the following load calculation point:
  - the middle of the full span, ℓ, of the considered stiffener
  - at at the intersection point between the stiffener and its attached plating
- For grillage beam analysis, $\tau = 0$ in the plate attached to the PSM.

E.5.2.3 Stiffeners

E.5.2.3.1 Buckling modes

The following buckling modes are to be checked:

- Stiffener induced failure (*SI*)
- Associated plate induced failure (*PI*).

E.5.2.3.2 Effective web thickness of flat bars

For accounting the decrease of stiffness due to local lateral deformation in the case of flat bars, their net sectional area As , net section modulus Z and moment of inertia I, when applied in the formulae of E.5.2.1 and E.5.2.3.4, are to be calculated using, instead of tw , the effective web thickness t_{w_red}, in [mm], equal to:

$$t_{w\_red} = t_w\left(1-\frac{2\pi^2}{3}\left(\frac{h_w}{s}\right)^2\left(1-\frac{b_{eff1}}{s}\right)\right)$$

E.5.2.3.3 Idealisation of bulb bars

Bulb bars are to be considered as equivalent angle bars. The net dimensions of the equivalent built-up section are to be obtained, in [mm], from the following formulae.

$$h_w = h'_w - \frac{h'_w}{9.2} + 2$$

$$b_f = \alpha\left(t'_w + \frac{h'_w}{6.7} - 2\right)$$

$$t_f = \frac{h'_w}{9.2} - 2$$

$$t_w = t'_w$$

where:

h'_w, t'_w = Net height and thickness of a bulb section, in mm, as shown in Figure 2.

α = Coefficient equal to:

$$\alpha = 1.1 + \frac{(120-h'_w)^2}{3000} \quad \text{for } h'_w \le 120$$

$$\alpha = 1.0 \quad \text{for } h'_w > 120$$

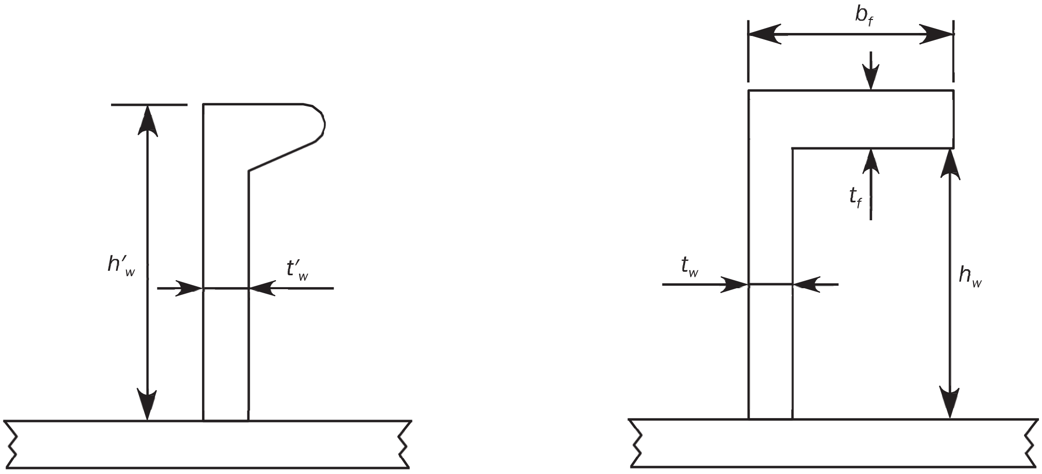


Figure E.5.2
Idealisation of bulb stiffener

E.5.2.3.4 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:

$$\frac{\gamma_c\sigma_a+\sigma_b+\sigma_w}{R_{eH}} S = 1$$

where:

$\sigma_a =$ Effective axial stress, in [N/mm²], at mid span of the stiffener, acting on the stiffener with its attached plating.

$$\sigma_a = \sigma_x \frac{st_p+A_s}{b_{eff1}t_p+A_s}$$

σ_x = Nominal axial stress, in [N/mm²], acting on the stiffener with its attached plating:

- for FE analysis, σ_x is the FE corrected stress, as defined in E.5.2.3.6, in the attached plating in the - direction of the stiffener axis
- for prescriptive assessment, σ_x is the axial stress at load calculation point of the stiffener, as defined in the *Rules for the classification of ships, Part 3 – Hull equipment*, 7.10.3.1.1.
- for grillage beam analysis, σ_x is the stress acting along the x axis of the attached buckling panel

σ_b= Bending stress in the stiffener, in [N/mm²]:

$$\sigma_b = \frac{M_0+M_1+M_2}{1000Z}$$

R_{eH} = Specified minimum yield stress of the material, in [N/mm²]

- $R_{eH} = R_{eH\_S}$ for stiffener induced failure (*SI*).
- $R_{eH} = R_{eH\_P}$ 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
- $M_2 = C_{snip} w_{na} \gamma \sigma_x (A_p + A_s)$ for stiffeners sniped at one or both ends.

C_{sl} = 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*).

C_{sl} = Deformation reduction factor to account for global slenderness, to be taken as:

- $C_{sl} = 1 - \frac{1}{12}\lambda_G^4$ 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:

$$\lambda_G = \sqrt{\frac{\gamma_{ReH}}{\gamma_{GEB}}}$$

$$\gamma_{ReH} = \frac{\text{Min}\,(R_{eH\_P},\ R_{eH\_S})}{\sqrt{\sigma_{x,av}^2+\sigma_y^2-\sigma_{x,av}\sigma_y+3\tau^2}}$$

Z = Net section modulus of the stiffener, in [cm3], including effective width of the attached plating according to E.5.2.3.5, to be taken as:

- the section modulus calculated at the top of the stiffener flange for stiffener induced failure (*SI*)
- the section modulus calculated at the attached plating for associated plate induced failure (*PI*)

C_{PI} = Associated 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_1 = Bending moment, in [Nmm], induced by:

- lateral pressure P:

$M_1 = C_i \frac{|P|sl^2}{24\times 10^3}$ for continuous stiffener

$M_1 = C_i \frac{|P|sl^2}{8\times 10^3}$ for sniped stiffener

$M_1 = C_i \frac{|P|sl^2}{14.2\times 10^3}$ for stiffener sniped at one end and continuous at the other end

- concentrated forces:

$M_1 = C_{CL}|M_{CL}|10^6$

P = Lateral pressure, in [kN/m^2]:

- for FEM analysis, P is the average pressure P_{avr} as defined in E4, E.4.2.5.2 in the attached plating
- for prescriptive assessment, P is the pressure calculated at load calculation point of the stiffener, as defined in E.3.1.2.1

C_{CL} = Concentrated load coefficient:

- $C_{CL} = -1$ for stiffener induced failure (*SI*)
- $C_{CL} = 1$ for associated plate induced failure (*PI*)

C_i = Pressure coefficient:

- $C_i = C_{SI}$ for stiffener induced failure (*SI*)
- $C_i = C_{PI}$ for plate induced failure (*PI*)

M_{CL} = Bending moment, in [kNm], taken as the maximum bending moment in absolute value induced by the concentrated load in the area between ℓ//3 and 2ℓ//3 of the stiffener span.

This bending moment may be evaluated by means of beam analysis, taking into account the condition of fixity at the ends of the stiffener.

M_0 = Bending moment, in [Nmm], due to the lateral deformation w_0 of the stiffener:

$M_0 = F_E C_{sl} \frac{\gamma}{\gamma_{GEB}-\gamma} w_0$ with precondition $\gamma_{GEB} - \gamma > 0$

γ_{GEB} = Stress multiplier factor of global elastic buckling capacity as defined in E.5.2.1

F_E = Ideal elastic buckling force of the stiffener, in [N]

$F_E = \left(\frac{\pi}{l}\right)^2 EI \cdot 10^4$

I = Moment of inertia of the stiffener, in [cm^4], including effective width of the attached plating according to E.5.2.3.5. I is to satisfy the following criterion:

$I \geq \frac{st_p^3}{12\cdot 10^4}$

t_p = Net thickness of the attached plating, in [mm], to be taken as:

- for prescriptive requirements: the mean thickness of the two attached plating panels
- for FEM analysis: the thickness of the considered EPP on one side of the stiffener

w_0 = Assumed imperfection, in [mm], to be taken as:

$w_0 = l/1000$.

w_{na} = Distance, in [mm], from the mid-point of attached plating to the neutral axis of the stiffener calculated with the effective width of the attached plating according to E.5.2.3.5

σ_w = Stress due to torsional deformation, in [N/mm^2], to be taken as:

For stiffener induced failure (SI):

For $\sigma_a > 0$

$\sigma_w = E y_w e_f \Phi_0 \left(\frac{m_{tor}\pi}{l_{tor}}\right)^2 \left(\frac{1}{1-\frac{\gamma\sigma_a}{\sigma_{ET}}} - 1\right)$ with precondition $\sigma_{ET} - \gamma\sigma_a > 0$

For $\sigma_a \leq 0$

$\sigma_w = 0$

For plate induced failure (PI):

$\sigma_w = 0$

y_w = Distance, in mm, from the centroid of the stiffener cross-section to the free edge of the stiffener flange, to be taken as:

- $y_w = \frac{t_w}{2}$ for flat bar
- $y_w = b_f - \frac{h_w t_w^2 + t_f b_f^2}{2A_s}$ for angle and bulb profiles
- $y_w = b_{f-out} + 0.5t_w - \frac{h_w t_w^2 + t_f(b_f^2 - 2b_f d_f)}{2A_s}$ for L2 profile
- $y_w = \frac{b_f}{2}$ for T profile.

l_{tor} = Stiffener span, in mm, taken equal to spacing between primary supporting members, i.e. $l_{tor} = l$. 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

Φ_0 = Coefficient taken as:

$$\Phi_0 = \frac{l_{tor}}{m_{tor} h_w} 10^{-4}$$

σ_{ET} = Reference stress for torsional buckling, in [N/mm2]:

$$\sigma_{ET} = \frac{E}{I_p}\left[\left(\frac{m_{tor}\pi}{l_{tor}}\right)^2 I_\omega \cdot 10^2 + \frac{1}{2(1+\nu)} I_T + \left(\frac{l_{tor}}{m_{tor}\pi}\right)^2 \varepsilon \cdot 10^{-4}\right]$$

I_p = Net polar moment of inertia of the stiffener, in [cm4], about point C (see Figure E.2.1), as defined in Table E.5.6

I_T = Net Saint Venant's moment of inertia of the stiffener, in [cm^4] as defined in Table E.5.6

I_ω = Net sectorial moment of inertia of the stiffener, in [cm^6], about point C (see Figure E.2.1), as defined in Table E.5.6

m_{tor} = Number of half waves within l_{tor}, taken as a positive integer so as to give smallest reference stress for torsional buckling

ε = Degree of fixation, in [mm2], to be taken as:

- $\varepsilon = \left(\frac{3b}{t_p^3} + \frac{2h_w}{t_w^3}\right)^{-1}$ for bulb, angle, L2 and T profiles;
- $\varepsilon = \left(\frac{t_p^3}{3b}\right)$ for flat bars.

A_w = Net area of the stiffener web, in [mm^2]

A_f = Net area of the stiffener flange, in [mm^2]

Table E.5.6

Moments of inertia I_p, I_T, and I_ω

	Flat bars[(1)]	Bulb, angle, L2 and T profiles
I_p	$\frac{h_w^3 t_w}{3 \cdot 10^4}$	$\left(\frac{A_w(e_f - 0.5t_f)^2}{3} + A_f e_f^2\right) 10^{-4}$
I_T	$\frac{h_w t_w^3}{3 \cdot 10^4}\left(1 - 0.63\frac{t_w}{h_w}\right)$	$\frac{(e_f - 0.5t_f)t_w^3}{3 \cdot 10^4}\left(1 - 0.63\frac{t_w}{e_f - 0.5t_f}\right) + \frac{b_f t_f^3}{3 \cdot 10^4}\left(1 - 0.63\frac{t_f}{b_f}\right)$
I_ω	$\frac{h_w^3 t_w^3}{36 \cdot 10^6}$	For bulb, angle and L2 profiles[(2)]: $\frac{A_f^3 + A_w^3}{36 \cdot 10^6} + \frac{e_f^2}{10^6}\left(\frac{A_f b_f^2 + A_w t_w^2}{3} - \frac{(A_f(b_f - 2d_f) + A_w t_w)^2}{4(A_f + A_w)} - A_f d_f(b_f - d_f)\right)$ For T profile: $\frac{b_f^3 t_f e_f^2}{12 \cdot 10^6}$

(1) t_w is the net web thickness, in [mm].
t_{w_red} as defined in E.5.2.3.2 is not to be used in this table.
(2) d_f is to be taken as 0 for bulb and angle profiles.

E.5.2.3.5 Effective width of attached plating

The effective width beff , in [mm], of the stiffener attached plating is to be taken as:

- For $\sigma_x > 0$:
  - For FE analysis,

    $b_{eff} = Min(C_x b, \chi_s s)$
- For prescriptive assessment,

  $b_{eff} = Min\left(\frac{C_{x1} b_1 + C_{x2} b_2}{2}, \chi_s s\right)$
  - For $\sigma_x \le 0$:

  $b_{eff} = \chi_s s$

where:

χ_s = Effective width coefficient to be taken as:

$$\chi_s = \frac{1.12}{1+\frac{1.75}{\left(\frac{\ell_{eff}}{s}\right)^{1.6}}} \le 1.0 \quad \text{for} \quad \frac{\ell_{eff}}{s} \ge 1$$

$$\chi_s = 0.407\frac{\ell_{eff}}{s} \quad \text{for} \quad \frac{\ell_{eff}}{s} < 1$$

ℓ_{eff} = Effective length of the stiffener, in [mm], taken as:

$\ell_{eff} = \frac{l}{\sqrt{3}}$ for stiffener fixed at both ends

$\ell_{eff} = 0.75l$ for stiffener simply supported at one end and fixed at the other

$\ell_{eff} = l$ for stiffener simply supported at both ends

E.5.2.3.6 FE corrected stresses for stiffener capacity

When the reference stresses σ_x and σ_y obtained by FE analysis according to E4, E.4.2.4 are both compressive, σ_x is to be corrected according to the following formula:

- If $\sigma_x < \nu\sigma_y$

  $\sigma_{xcor} = 0$
- If $\sigma_x \ge \nu\sigma_y$

  $\sigma_{xcor} = \sigma_x - \nu\sigma_y$

E.5.2.4 Primary supporting members

E.5.2.4.1 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 Table E.5.7.

The interaction formulae of E.5.2.2.1 are to be used with:

$\sigma_x = \sigma_{av}$

$\sigma_y = 0$

$\tau = \tau_{av}$

where:

σ_{av} = Weighted average compressive stress, in [N/mm2], in the area of web plate being considered, i.e. P1, P2 or P3 as shown in Table E.5.7

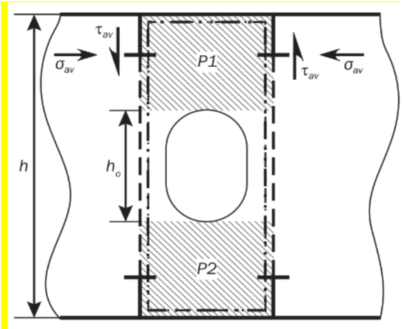
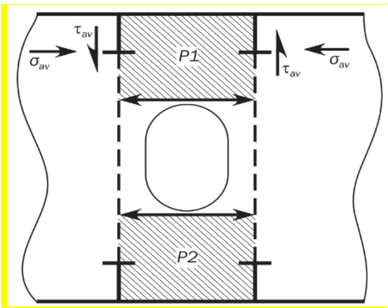
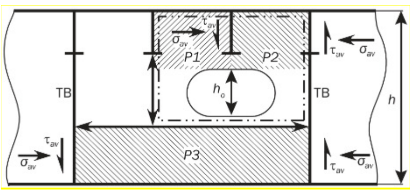
τ_{av} = Weighted average shear stress, in [N/mm2]:

- for opening modelled in primary supporting members:

  τ_{av} is the weighted average shear stress in the area of web plate being considered, i.e. P1, P2 or P3 as shown in Table E.5.7
- for opening not modelled in primary supporting members:

  τ_{av} is the weighted average shear stress given in Table E.5.7.

Table E.5.7
Reduction factors C_x, C_y and C_τ

<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 Table E.5.4, 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 Table E.5.4.</td><td>When case 17 of Table E.5.4 is applicable:
A common reduction factor is to be applied to areas P1 and P2 using case 17 in Table E.5.4 with:
$\tau_{av} = \tau_{av}\,(web)$</td></tr>
<tr><td>When case 17 of Table E.5.4 is not applicable:
Separate reduction factors are to be applied to areas P1 and P2 using case 18 or case 19 in Table E.5.4 with:
$\tau_{av} = \tau_{av}\,(web)h/\,(h - h0)$</td></tr>
<tr><td>(b) With edge reinforcements:

</td><td>Separate reduction factors are to be applied for areas P1 and P2 using Cx for case 1 or Cy for case 2 in Table E.5.4 with stress ratio:
$\psi = 1.0$</td><td>Separate reduction factors are to be applied for areas P1 and P2 using case 15 in Table E.5.4.</td><td>Separate reduction factors are to be applied to areas P1 and P2 using case 15 in Table E.5.4 with:
$\tau_{av} = \tau_{av}\,(web)h/\,(h - h0)$</td></tr>
<tr><td>(c) Example of hole in web:

</td><td colspan="3">Panels P1 and P2 are to be evaluated in accordance with (a). Panel P3 is to be evaluated in accordance with (b).</td></tr>
<tr><td colspan="4">Where:
h Height, in m, of the web of the primary supporting member in way of the opening.
h0 Height in m, of the opening measured in the depth of the web.
$\tau_{av}\,(web)$ Weighted average shear stress, in [N/mm2], over the web height h of the primary supporting member.
Note (1) Web panels to be considered for buckling in way of openings are shown shaded and numbered P1, P2, etc.
Note (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>

E.5.2.4.2 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 Table E.5.6.

E.5.2.4.3 The equivalent plate panel of web plate of primary supporting members crossed by perpendicular stiffeners is to be idealised as shown in Figure E.5.3.

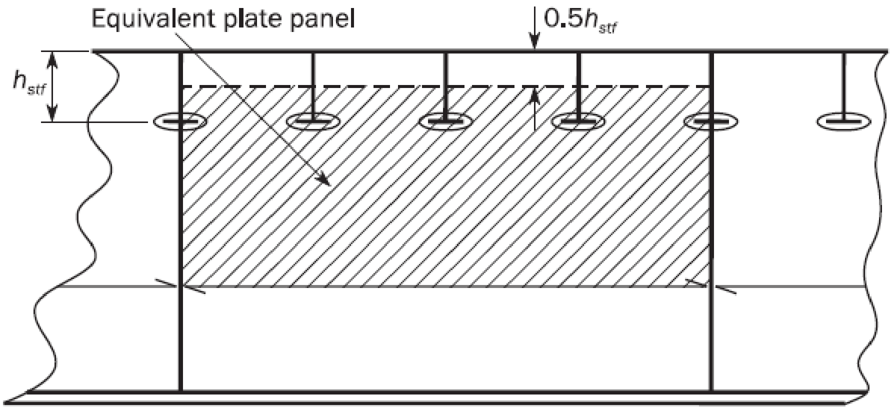


Figure E.5.3
Web plate idealization

The correction of panel breadth is also applicable for other slot configurations, provided the web or the collar plate is attached to at least one side of the passing stiffener.

E.5.2.5 Stiffened panels with U-type stiffeners

E.5.2.5.1 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, bf and hw (see Figure E.2.2) 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 Table E.5.4, the correction factor Flong for U-type stiffeners as defined in Table E.5.3 is to be used; and in the calculation of K_y as defined in Case 2 of Table E.5.4, the *Ftrans* for U-type stiffeners as defined in E.5.2.2.5 is to be used.
- The face plate and web plate panels bf and hw are to be assessed using UP-B model with *Flong* = 1 and *Ftrans* = 1.

E.5.2.5.2 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 $\sigma_w = 0$, 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 tw and height equal to the distance between the attached plate and the face plate of the stiffener.
- Effective width of the attached plating, beff taken as the sum of the beff 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, *beff1*, taken as the sum of the *beff1* calculated for the EPP b_1 and b_2 respectively.

E.5.3 Buckling capacity of other structures

E.5.3.1 Column buckling of corrugations

E.5.3.1.1 Buckling utilisation factor

The column buckling utilisation factor, η, for axially compressed corrugations is to be taken as:

$$\eta_{column} = \frac{\sigma_{av}}{\sigma_{cr}}$$

where:

σ_{av} = Average axial compressive stress in the member, in [N/mm2]

σ_{cr} = Minimum critical buckling stress, in [N/mm2], taken as:

- $\sigma_{cr} = \sigma_E$ for $\sigma_E \le 0.5R_{eH\_S}$
- $\sigma_{cr} = \left(1 - \frac{R_{eH\_S}}{4\sigma_E}\right) R_{eH\_S}$ for $\sigma_E > 0.5R_{eH\_S}$

σ_E = Minimum elastic buckling stress, in [N/mm2], according to E.5.3.1.2.

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.

E.5.3.1.2 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:

$$\sigma_E = \pi^2 E f_{end} \frac{I}{A l_{pill}^2} 10^{-4}$$

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.

APPENDIX 1 STRESS BASED REFERENCE STRESSES

Symbols

a = Length, in [mm], of the longer side of the plate panel as defined in E5

b = Length, in [mm], of the shorter side of the plate panel as defined in E5

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 E5

τ_i = Actual membrane shear stress, in [N/mm^2], at the centroid of the i-th plate element of the buckling panel

E.1 STRESS BASED METHOD

E.1.1 Introduction

E.1.1.1 This Appendix provides a method to determine stress distribution along the edges of the considered buckling panel by 2nd order polynomial curve, by linear distribution using the 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 the plate element transferred into the local system of the considered buckling panel.

E.1.1.2 Definition

A regular panel is a plate panel of rectangular shape. An irregular panel is a plate panel which is not regular, as detailed in E4, E.4.2.3.1.

E.1.2 Stress application

E.1.2.1 Regular panel

The reference stresses are to be taken as defined in E.2.1 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 a/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 E.2.2 for an irregular panel.

E.1.2.2 Irregular panel and curved panel

The reference stresses of an irregular panel or a curved panel are to be taken as defined in E.2.2.

E.2 REFERENCE STRESSES

E.2.1 Regular panel

E.2.1.1 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 2nd order polynomial curve:

$$\sigma_x = Cx^2 + Dx + E$$

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.

$$\Pi = \sum_{i=1}^{n} A_i\left[\sigma_{xi} - (Cx_i^2 + Dx_i + E)\right]^2$$

The unknown coefficients C, D and E must yield zero first derivatives, $\partial\Pi$ with respect to C, D and E, respectively.

$$\begin{cases} \dfrac{\partial\Pi}{\partial C} = 2\sum_{i=1}^{n} A_i x_i^2\left[\sigma_{xi} - \left(Cx_i^2 + Dx_i + E\right)\right] = 0 \\ \dfrac{\partial\Pi}{\partial D} = 2\sum_{i=1}^{n} A_i x_i\left[\sigma_{xi} - \left(Cx_i^2 + Dx_i + E\right)\right] = 0 \\ \dfrac{\partial\Pi}{\partial E} = 2\sum_{i=1}^{n} A_i\left[\sigma_{xi} - \left(Cx_i^2 + Dx_i + E\right)\right] = 0 \end{cases}$$

The unknown coefficients C, D and E can be obtained by solving the 3 above equations.

$\sigma_{x1} = \frac{1}{b}\int_0^b \sigma_x(x)dx = \frac{b^2}{3}C + \frac{b}{2}D + E$

$\sigma_{x2} = \frac{1}{b}\int_{a-b}^{a} \sigma_x(x)dx = \left(a^2 - ab + \frac{b^2}{3}\right)C + \left(a - \frac{b}{2}\right)D + E$

If $-\frac{D}{2C} < \frac{b}{2}$ or $-\frac{D}{2C} > a - \frac{b}{2}$, σ_{x3} is to be ignored. Otherwise, σ_{x3} is taken as:

$\sigma_{x3} = \frac{1}{b}\int_{x_{min}}^{x_{max}} \sigma_x(x)dx = \frac{b^2}{12}C - \frac{D^2}{4C} + E$

where:

$x_{min} = -\frac{b}{2} - \frac{D}{2C}$

$x_{max} = \frac{b}{2} - \frac{D}{2C}$

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, σ_x applied on the shorter edge of the attached plate is to be taken as:

$\sigma_x = \dfrac{\sum_{i=1}^{n} A_i\sigma_{xi}}{\sum_{i=1}^{n} A_i}$

The edge stress ratio ψ_x for the stress σ_x is equal to 1.0.

E.2.1.2 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.

$\Pi = \sum_{i=1}^{n} A_i\left[\sigma_{yi} - (A + Bx_i)\right]^2$

The unknown coefficients A and B must yield zero first partial derivatives $\partial\Pi$ with respect to A and B respectively:

$\frac{\partial\Pi}{\partial A} = 2\sum_{i=1}^{n} A_i\left[\sigma_{yi} - (A + Bx_i)\right] = 0$

$\frac{\partial\Pi}{\partial B} = 2\sum_{i=1}^{n} A_i x_i\left[\sigma_{yi} - (A + Bx_i)\right] = 0$

The unknown coefficients A and B are obtained by solving the two previous equations, as follows:

$A = \dfrac{(\sum_{i=1}^{n} A_i\sigma_{yi})(\sum_{i=1}^{n} A_i x_i^2) - (\sum_{i=1}^{n} A_i x_i)(\sum_{i=1}^{n} A_i x_i\sigma_{yi})}{(\sum_{i=1}^{n} A_i)(\sum_{i=1}^{n} A_i x_i^2) - (\sum_{i=1}^{n} A_i x_i)^2}$

$B = \dfrac{(\sum_{i=1}^{n} A_i)(\sum_{i=1}^{n} A_i x_i\sigma_{yi}) - (\sum_{i=1}^{n} A_i x_i)(\sum_{i=1}^{n} A_i\sigma_{yi})}{(\sum_{i=1}^{n} A_i)(\sum_{i=1}^{n} A_i x_i^2) - (\sum_{i=1}^{n} A_i x_i)^2}$

The transverse stress is to be taken as:

$\sigma_y = max(A, A + Ba)$

The edge stress ratio is to be taken as:

$\psi_y = \frac{min(A, A+Ba)}{max(A, A+Ba)}$ for $\sigma_y > 0$

$\psi_y = 1\ for\ \sigma_y \le 0$

E.2.1.3 Shear stress

The shear stress τ is to be calculated using a weighted average approach, and is to be taken as:

$$\tau = \frac{\sum_{i=1}^{n} A_i \tau_i}{\sum_{i=1}^{n} A_i}$$

E.2.2 Irregular panel and curved panel

E.2.2.1 Reference stresses

The longitudinal, transverse and shear stresses are to be calculated using a weighted average approach. They are to be taken as:

$$\sigma_x = \frac{\sum_{i=1}^{n} A_i \sigma_{xi}}{\sum_{i=1}^{n} A_i}$$

$$\sigma_y = \frac{\sum_{i=1}^{n} A_i \sigma_{yi}}{\sum_{i=1}^{n} A_i}$$

$$\tau = \frac{\sum_{i=1}^{n} A_i \tau_i}{\sum_{i=1}^{n} A_i}$$

The edge stress ratios are to be taken as follows:

$$\psi_x = 1$$

$$\psi_y = 1$$

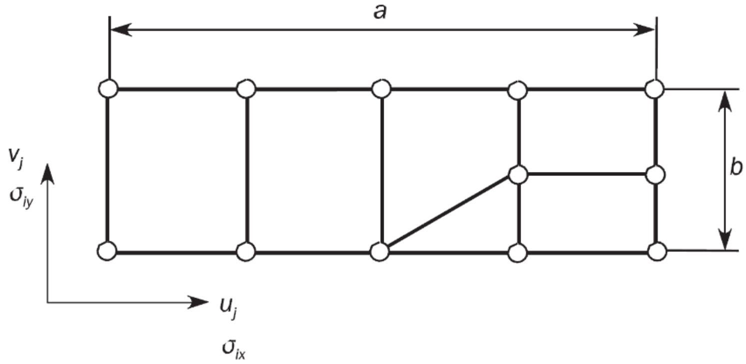


Figure E.1.1
Buckling panel