RULES
FOR THE CLASSIFICATION OF
SHIPS

Part 29 – POLAR CLASS SHIPS AND ICE CLASS SHIPS
January 2019

Amendments No. 3
July 2024

CROATIAN REGISTER OF SHIPPING

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

Amendments No. 3 to the
RULES FOR THE CLASSIFICATION OF SHIPS
Part 29 – POLAR CLASS SHIPS AND ICE CLASS SHIPS

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 29 – Polar Class Ships and Ice Class Ships, edition January 2019, as last amended by Amendments No. 2, edition January 2022.

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 1974), Ch. XIV, as adopted by resolution MSC.386(94)

Codes: International Code for Ships Operating in Polar Waters (Polar Code), as adopted by resolutions MSC.385(94) and MEPC.264(68)

Circulars: MSC/Circ.504, MSC.1/Circ.1519

International Association of Classification Societies (IACS)

Unified Requirements (UR):
I1 (Rev.2, 2016), I2 (Rev.4, 2019), I3 (Rev.2, Jan 2023), S6 (Rev.9, Corr.2, Nov 2021)

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 29 – Polar Class Ships and Ice Class Ships, edition January 2019, as last amended by Amendments No. 2, edition January 2022.

ITEM	*DESCRIPTION OF THE AMENDMENTS*
SECTION 6 - MACHINERY INSTALLATIONS	
Section 6 – Machinery installations	Existing Section 6 has been completely revised to include requirements contained in IACS UR I3, Rev.2, January 2023

6 MACHINERY INSTALLATIONS

■ **Section 6 – MACHINERY INSTALLATION** – complete text within this Section has been amended and should be read as follows:

6.1 GOAL

6.1.1 Goal and application

The goal of this Section is to ensure that, machinery installations are capable of delivering the required functionality necessary for safe operation of ships.

The contents of this Section apply to main propulsion, steering gear, emergency and auxiliary systems essential for the safety of the ship and the crew.

The vessel operating conditions are defined in Head 1.3

The requirements herein are additional to those applicable for the basic open water class of the vessel.

6.1.2 Functional Requirements

In order to achieve the goal set out in 6.1.1, the following provisions are to be complied with.

6.1.2.1 Machinery installations are to provide functionality under the anticipated environmental conditions, taking into account the provisions of .1 to .5 below:

.1 Ice accretion and/or snow accumulation;
.2 Ice ingestion from seawater;
.3 Freezing and increased viscosity of liquids;
.4 Seawater intake temperature; and
.5 Snow ingestion.

6.1.2.2 In addition to 6.1.2.1 above, for ships intended to operate in low air temperatures the provisions of .1 and .2 below are to be complied with.

.1 Machinery installations are to provide functionality under the anticipated environmental conditions, also taking into account the .1 and .2 below:
  .1 cold and dense inlet air; and
  .2 loss of performance of battery or other stored energy device.
.2 Materials used are to be suitable for operation at the ships polar service temperature.

6.1.2.3 In addition to 6.1.2.1 and 6.1.2.2 above, for ships ice strengthened in accordance with Section 3 of these Rules, machinery installations are to provide functionality under the anticipated environmental conditions, taking into account loads imposed directly by ice interaction.

6.1.3 Regulations

6.1.3.1 General

In order to comply with the functional requirement of 6.1.2.1, taking into account the anticipated environmental conditions, the provisions of .1 to .3 below are to apply.

.1 Machinery installations and associated equipment are to be protected against the effect of ice accretion and/or snow accumulation, ice ingestion from sea water, freezing and increased viscosity of liquids, seawater intake temperature and snow ingestion.
.2 Working liquids are to be maintained in a viscosity range that ensures operation of the machinery.
.3 Seawater supplies for machinery systems are to be designed to prevent ingestion of ice are to be in accordance with IMO MSC/Circ.504.

6.1.3.2 Ships intended to operate in low air temperatures

In addition to 6.1.3.1, for ships intended to operate in low air temperatures (see 1.4 of Section 1 of these Rules), the provisions of .1 to .3 below are to apply:

.1 In order to comply with 6.1.2.2, exposed machinery and electrical installation and appliances are to function at the polar ser-vice temperature;

.2 In order to comply with 6.1.2.2.1, means are to be provided to ensure that combustion air for internal combustion engines driving essential machinery is maintained at a temperature in compliance with the criteria provided by the engine manufacturer; and

.3 In order to comply with 6.1.2.2.2 materials of exposed machinery and foundations are to be either of the following .1 or .2:

.1 Those complying the requirements specified in Section 2 of these Rules applicable to materials of machinery installations and approved by the *Register*; or

.2 Those complying with other standards offering an equivalent level of safety based on the polar service temperature and complying with 1.8 of Section 1 of these Rules.

6.1.3.3 Ice strengthened ships

In addition to 6.1.3.1 and 6.1.3.2, for ships ice strengthened in accordance with Section 3 of these Rules, in order to comply with 6.1.2.3, the provisions of .1 to .3 below are to apply.

.1 Scantlings of propeller blades, propulsion line, steering equipment and other appendages of category A ships are to be either of the following .1 or .2:

.1 Those complying with the requirements of this Section applicable to scantlings of propeller blades, propulsion line, steering equipment and other appendages and approved by the Register; or

.2 Those complying with other standards offering an equivalent level of safety complying with 1.8 of Section 1 of these Rules.

.2 Scantlings of propeller blades, propulsion line, steering equipment and other appendages of category B ships are to be either of the following .1 or .2 below:

.1 Those complying with the requirements specified in these Rules applicable to scantlings of propeller blades, propulsion line, steering equipment and other appendages and approved by the Register; or

.2 Those complying with other standards offering an equivalent level of safety and approved by the Flag State Administration.

.3 Scantlings of propeller blades, propulsion line, steering equipment and other appendages of ice-strengthened category C ships are to be approved by the Administration or the Register taking into account acceptable standards adequate with the ice types and concentration encountered in the area of operation.

6.1.4 Definitions

6.1.4.1 Definition of Symbols

Table 6.1.4.1
Definition of symbols

Symbol	**Unit**	**Definition**
c	m	chord length of blade section
$c_{0.7}$	m	chord length of blade section at $0.7R$ propeller radius
CP	-	controllable pitch
D	m	propeller diameter
d	m	external diameter of propeller hub (at propeller plane)
d_{pin}	mm	diameter of shear pin
D_{limit}	m	limit value for propeller diameter
EAR		expanded blade area ratio
F_b	kN	maximum backward blade force for the ship's service life (negative sign)
F_{ex}	kN	ultimate blade load resulting from blade failure through plastic bending
F_f	kN	maximum forward blade force for the ship's service life (positive sign)
F_{ice}	kN	ice load
$(F_{ice})_{max}$	kN	maximum ice load for the ship's service life
FP	-	fixed pitch
h_0	m	depth of the propeller centreline from lower ice waterline ($LIWL$)
(H_{ice})	m	Ice block dimension for propeller load definition
I	kgm^2	equivalent mass moment of inertia of all parts on engine side of component under consideration
I_t	kgm^2	equivalent mass moment of inertia of the whole propulsion system

Symbol	**Unit**	**Definition**
k	-	shape parameter for Weibull distribution
$LIWL$	m	lower ice waterline
m	-	slope for S-N curve in log/log scale
M_{BL}	kNm	blade bending moment
MCR	-	maximum continuous rating
N	-	number of ice load cycles
n	rev/s	propeller rotational speed
n_n	rev/s	nominal propeller rotational speed at MCR in free running condition
N_{class}	-	reference number of ice impacts per propeller revolution per ice class
N_{ice}	-	total number of ice load cycles on propeller blade for the ship's service life
N_R	-	reference number of ice load cycles for equivalent fatigue stress (10^8 cycles)
N_Q	-	number of propeller revolutions during a milling sequence
$P_{0.7}$	m	propeller pitch at $0.7R$ radius
$P_{0.7n}$	m	propeller pitch at $0.7R$ radius at MCR in free running condition
$P_{0.7b}$	m	propeller pitch at $0.7R$ radius at MCR in bollard condition
PCD	m	pitch circle diameter
$Q(\varphi)$	kNm	Torque
Q_{Amax}	kNm	maximum response torque amplitude as a simulation result
Q_{emax}	kNm	maximum engine torque
$Q_F(\varphi)$	kNm	Ice torque excitation for frequency domain calculations
Q_{fr}	kNm	friction torque in pitching mechanism; reduction of spindle torque
Q_{max}	kNm	maximum torque on the propeller resulting from propeller/ice interaction
Q_{motor}	kNm	electric motor peak torque
Q_n	kNm	nominal torque at MCR in free running condition
$Q_r(t)$	kNm	response torque along the propeller shaft line
Q_{peak}	kNm	maximum of the response torque $Q_r(t)$
Q_{smax}	kNm	maximum spindle torque of the blade for the ship's service life
Q_{sex}	kNm	extreme spindle torque corresponding to the blade failure load F_{ex}
Q_{vib}	kNm	Vibratory torque at considered component, taken from frequency domain open water TVC
R	m	propeller radius
S	-	Safety factor
S_{fat}	-	Safety factor for fatigue
S_{ice}	-	Ice strength index for blade ice force
r	m	blade section radius
T	kN	Hydrodynamic propeller thrust in bollard condition
T_b	kN	maximum backward propeller ice thrust for the ship's service life
T_f	kN	maximum forward propeller ice thrust for the ship's service life
T_n	kN	propeller thrust at MCR in free running condition
T_r	kN	maximum response thrust along the shaft line
T_{kmax}	kNm	maximum torque capacity of flexible coupling
T_{kmax2}	kNm	T_{kmax} at $N = 1$ load cycle
T_{max1}	kNm	T_{kmax} at $N = 5 \times 10^4$ load cycles
T_{kv}	kNm	vibratory torque amplitude at $N = 10^6$ load cycles
ΔT_{kmax}	kNm	maximum range of T_{kmax} at $N = 5 \times 10^4$ load cycles

Symbol	**Unit**	**Definition**
t	m	maximum blade section thickness
z	-	number of propeller blades
z_{pin}	-	number of shear pins
α_i	deg	duration of propeller blade/ice interaction expressed in rotation angle
γ_ε	-	the reduction factor for fatigue; scatter and test specimen size effect
γ_v	-	the reduction factor for fatigue; variable amplitude loading effect
γ_m	-	the reduction factor for fatigue; mean stress effect
ρ	-	a reduction factor for fatigue correlating the maximum stress amplitude to the equivalent fatigue stress for 10^8 stress cycles
$\sigma_{0.2}$	MPa	proof yield strength (at 0.2% plastic strain) of material
σ_{exp}	MPa	mean fatigue strength of blade material at 10^8 cycles to failure in sea water
σ_{fat}	MPa	equivalent fatigue ice load stress amplitude for 10^8 stress cycles
σ_{fl}	MPa	characteristic fatigue strength for blade material
σ_{ref1}	MPa	reference stress $\sigma_{ref1} = 0.6\ \sigma_{0.2} + 0.4\ \sigma_u$
σ_{ref2}	MPa	reference stress $\sigma_{ref2} = 0.7\ \sigma_u$ or $\sigma_{ref2} = 0.6\ \sigma_{0.2} + 0.4\ \sigma_u$ whichever is less
σ_{st}	MPa	maximum stress resulting from F_b or F_f
σ_u	MPa	ultimate tensile strength of blade material
$(\sigma_{ice})_{bmax}$	MPa	principal stress caused by the maximum backward propeller ice load
$(\sigma_{ice})_{fmax}$	MPa	principal stress caused by the maximum forward propeller ice load
$(\sigma_{ice})_{Amax}$	MPa	maximum ice load stress amplitude at the considered location on the blade
σ_{mean}	MPa	mean stress
$(\sigma_{ice})_A(N)$	MPa	blade stress amplitude distribution

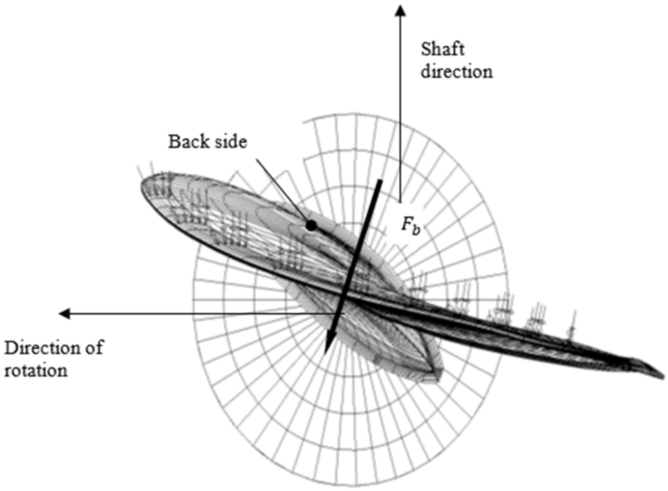
6.1.4.2 Definition of Loads

Table 6.1.4.2
Definition of loads

	Definition	**Use of the load in design process**
F_b	The maximum lifetime backward force on a propeller blade resulting from propeller/ice interaction, including hydrodynamic loads on that blade. The direction of the force is perpendicular to 0.7R chord line. See Figure 6.1.4.2.	Design force for strength calculation of the propeller blade.
F_f	The maximum lifetime forward force on a propeller blade resulting from propeller/ice interaction, including hydrodynamic loads on that blade. The direction of the force is perpendicular to 0.7R chord line.	Design force for calculation of strength of the propeller blade.
Q_{smax}	The maximum lifetime spindle torque on a propeller blade resulting from propeller/ice interaction, including hydrodynamic loads on that blade.	In designing the propeller strength, the spindle torque is automatically taken into account because the propeller load is acting on the blade as distributed pressure on the leading edge or tip area.
T_b	The maximum lifetime thrust on propeller (all blades) resulting from propeller/ice interaction. The direction of the thrust is the propeller shaft direction and the force is opposite to the hydrodynamic thrust.	Is used for estimation of the response thrust T_r. T_b can be used as an estimate of excitation for axial vibration calculations. However, axial vibration calculations are not required in the rules.
T_f	The maximum lifetime thrust on propeller (all blades) resulting from propeller/ice interaction. The direction of the thrust is the propeller shaft direction acting in the direction of hydrodynamic thrust.	Is used for estimation of the response thrust T_r. T_f can be used as an estimate of excitation for axial vibration calculations. However, axial vibration calculations are not required in the rules.

	Definition	**Use of the load in design process**
Q_{max}	The maximum ice-induced torque resulting from propeller/ice interaction on one propeller blade, including hydrodynamic loads on that blade.	Is used for estimation of the response torque Q_r along the propulsion shaft line and as excitation for torsional vibration calculations.
F_{ex}	Ultimate blade load resulting from blade loss through plastic bending. The force that is needed to cause total failure of the blade so that plastic hinge is caused to the root area. The force is acting on $0.8R$.	Blade failure load is used to dimension the blade bolts, pitch control mechanism, propeller shaft, propeller shaft bearing and trust bearing. The objective is to guarantee that total propeller blade failure should not cause damage to other components.
Q_{sex}	Maximum spindle torque resulting from blade failure load	Is used to ensure pyramid strength principle for the pitching mechanism
Q_r	Maximum response torque along the propeller shaft line, taking into account the dynamic behaviour of the shaft line for ice excitation (torsional vibration) and hydrodynamic mean torque on propeller.	Design torque for propeller shaft line components.
T_r	Maximum response thrust along shaft line, taking into account the dynamic behaviour of the shaft line for ice excitation (axial vibration) and hydrodynamic mean thrust on propeller.	Design thrust for propeller shaft line components.

Figure 6.1.4.2
Direction of the backward blade force resultant taken perpendicular to the chord line at radius $\mathbf{0.7}\boldsymbol{R}$. Ice contact pressure at leading edge is shown with small arrows.



6.2 DRAWINGS AND PARTICULARS TO BE SUBMITTED

6.2.1 Details of the intended environmental operational conditions and the required ice strengthening for the machinery, if different from ship's ice class

6.1.2 Detailed drawings and descriptions of the main propulsion, steering, emergency and auxiliary machinery and information on the essential main propulsion load control functions. The descriptions are to include operational limitations.

6.1.3 Description detailing where main, emergency and auxiliary systems are located and how they are protected to prevent problems from freezing, ice and snow accumulation and evidence of their capability to operate in the intended environmental conditions.

6.1.4 Calculations and documentation indicating compliance with the requirements of this Section.

6.3 SYSTEM DESIGN

6.3.1 Systems subject to damage by freezing, shall be drainable.

6.3.2 Vessels classed PC1 to PC5 inclusive shall have means provided to ensure sufficient vessel operation in the case of propeller damage including the Controllable Pitch (CP) mechanism. Sufficient vessel operation means that the vessel should be able to reach safe haven (safe location) where repairs can be undertaken. This may be achieved either by a temporary repair at sea, or by towing, assuming assistance is available. This would lead however to a condition of approval.

6.3.3 Means shall be provided to free a stuck propeller by turning it in reverse direction. This shall also be possible for a propulsion plant intended for unidirectional rotation.

6.3.4 The propeller shall be fully submerged at the ships LIWL.

6.4 MATERIALS

6.4.1 Materials shall be of an approved ductile material. Ferritic nodular cast iron may be used for parts other than bolts. For nodular cast iron an averaged impact energy value of 10 J at testing temperature is regarded as equivalent to the Charpy V test requirements defined below.

6.4.2 Materials exposed to sea water

Materials exposed to sea water, such as propeller blades, propeller hubs and cast thruster bodies shall have an elongation not less than 15% on a test specimen according to IACS UR W2.

Charpy V-notch impact testing is to be carried out for materials other than bronze and austenitic steel. The tests shall be carried out on three specimens at minus 10 ºC, and the average energy value is to be not less than 20 J. However, Charpy V impact test requirements of IACS UR W7 or IACS UR W27 as applicable for ships with ice class notation, shall also be applied to ships covered by this Rules.

6.4.3 Materials exposed to sea water temperature

Charpy V-notch impact testing is to be carried out for materials other than bronze and austenitic steel. The tests shall be carried out on three specimens at minus 10 ºC, and the average energy value is to be not less than 20 J. However, the Charpy V impact test requirements of IACS UR W7 as applicable for ships with ice class notation, shall also be applied to ships covered by this Rules.
This requirement applies to components such as but not limited to blade bolts, CP-mechanisms, shaft bolts, propeller shaft, strut-pod connecting bolts, etc. This requirement does not apply to surface hardened components, such as bearings and gear teeth or sea water cooling lines (heat exchangers, pipes, valves, fittings etc.). For a definition of structural boundaries exposed to sea water temperature see Figure 2.1.3.

6.4.4 Material exposed to low air temperature

Materials of exposed machinery and foundations shall be manufactured from steel or other approved ductile material. An average impact energy value of 20 J taken from three Charpy V tests is to be obtained at 10 ºC below the lowest design temperature. Charpy V impact tests are not required for bronze and austenitic steel.

This requirement does not apply to surface hardened components, such as bearings and gear teeth. For a definition of structural boundaries exposed to air temperature see Figure 2.1.3.

6.5 DESIGN ICE LOADS

6.5.1 These Rules cover open and ducted type propellers situated at the stern of a vessel having controllable pitch or fixed pitch blades. Ice loads on bow-mounted propellers shall receive special consideration at the discretion of *Register*. The given loads are expected, single occurrence, maximum values for the whole ship's service life for normal operational conditions, including loads resulting from directional change of rotation where applicable. These loads do not cover off-design operational conditions, for example when a stopped propeller is dragged through ice. These Rules also cover loads due to propeller ice interaction for azimuthing and fixed thrusters with geared transmission or an integrated electric motor ("geared and podded propulsors"). However, the load models of the regulations do not include propeller/ice interaction loads when ice enters the propeller of a turned azimuthing thruster from the side (radially) or loads when ice blocks hit on the propeller hub of a pulling propeller. Ice loads resulting from ice impacts on the body of thrusters shall be estimated on a case by case basis, however are not included within the following section.

The loads given in item 6.5.3 are total loads including ice-induced loads and hydrodynamic loads (unless otherwise stated) during ice interaction and are to be applied separately (unless otherwise stated) and are intended for component strength calculations only.

F_b is the maximum force experienced during the lifetime of the ship that bends a propeller blade backwards when the propeller mills an ice block while rotating ahead. F_f is the maximum force experienced during the lifetime of the ship that bends a propeller blade forwards when the propeller mills an ice block while rotating ahead. F_b and F_f originate from different propeller/ice interaction phenomena, which do not act simultaneously. Hence they are to be applied separately.
Materials shall be of an approved ductile material. Ferritic nodular cast iron may be used for parts other than bolts. For nodular cast iron an averaged impact energy value

6.5.2 Ice Class Factors

The dimensions of the considered design ice block are $H_{ice} \times 2H_{ice} \times 3H_{ice}$. The design ice block and ice strength index (S_{ice}) are used for the estimation of propeller ice loads. Both H_{ice} and S_{ice} are defined for each Ice class in Table 6.5.2 below.

Table 6.5.2
Design Ice Class Factors

Ice Class	H_{ice} **[m]**	S_{ice} **[-]**
PC1	4.0	1.2
PC2	3.5	1.1
PC3	3.0	1.1
PC4	2.5	1.1
PC5	2.0	1.1
PC6	1.75	1
PC7	1.5	1

6.5.3 Propeller Ice Interaction Loads

6.5.3.1 Maximum backward blade force F_b for open propellers

when $D < D_{limit}$:

$$F_b = 27 \cdot S_{ice} \cdot (n \cdot D)^{0.7} \cdot \left(\frac{EAR}{Z}\right)^{0.3} \cdot D^2 \text{ [kN]} \qquad \text{[Equation 1]}$$

when $D \geq D_{limit}$:

$$F_b = 23 \cdot S_{ice} \cdot (n \cdot D)^{0.7} \cdot \left(\frac{EAR}{Z}\right)^{0.3} \cdot (H_{ice})^{1.4} \cdot D \text{ [kN]} \qquad \text{[Equation 2]}$$

where:

$$D_{limit} = 0.85 \cdot (H_{ice})^{1.4} \text{ [m]} \qquad \text{[Equation 3]}$$

Here n is the nominal rotational speed at MCR in the free running open water condition for CP-propellers and 85% of the nominal rotational speed (at MCR free running condition) for a FP-propeller (regardless driving engine type) [rps].
For vessels with the additional notation Icebreaker, the above stated backward blade force F_b shall be multiplied by a factor of 1.1.

6.5.3.2 Maximum forward blade force F_f for open propellers

when $D < D_{limit}$:

$$F_f = 250 \cdot \left(\frac{EAR}{Z}\right) \cdot D^2 \text{ [kN]} \qquad \text{[Equation 4]}$$

when $D \geq D_{limit}$:

$$F_f = 500 \cdot \left(\frac{1}{1-\frac{d}{D}}\right) \cdot H_{ice} \cdot \left(\frac{EAR}{Z}\right) \cdot D \text{ [kN]} \qquad \text{[Equation 5]}$$

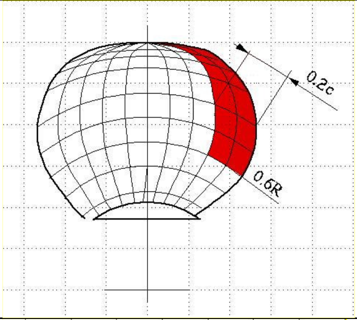
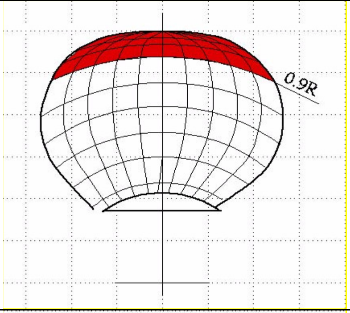
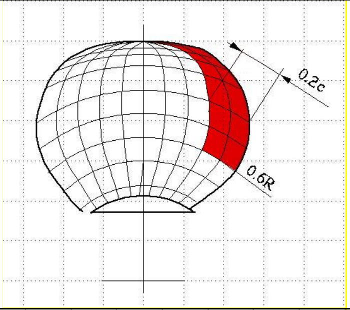
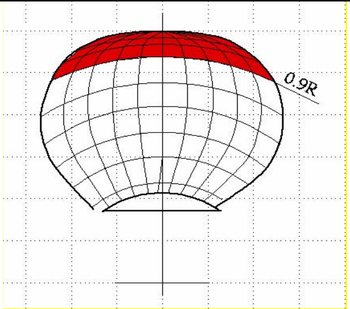
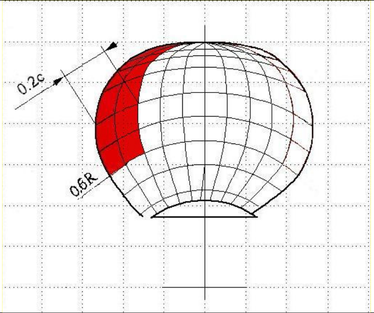
where:

$$D_{limit} = \left(\frac{2}{1-\frac{d}{D}}\right) \cdot H_{ice} \text{ [m]} \qquad \text{[Equation 6]}$$

6.5.3.3 Loaded area on the blade for open propellers

Load cases 1-4 shall be covered, as given in Table 6.5.3.3, for CP and FP propellers. In order to obtain blade ice loads for a reversing propeller, load case 5 shall also be covered for propellers where reversing is possible.

Table 6.5.3.3
Loaded areas and load case definition for open propeller

	Force	**Loaded area**	**Right-handed propeller blade seen from behind**
Load case 1	F_b	Uniform pressure applied on the back of the blade (suction side) to an area from 0.6*R* to the tip and from the leading edge to 0.2 times the chord length.	
Load case 2	50% of F_b	Uniform pressure applied on the back of the blade (suction side) on the propeller tip area outside 0.9*R* radius.	
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6*R* to the tip and from the leading edge to 0.2 times the chord length.	
Load case 4	50% of F_f	Uniform pressure applied on propeller face (pressure side) on the propeller tip area outside 0.9*R* radius.	
Load case 5	60% of F_f or 60% of F_b, whichever is greater	Uniform pressure applied on propeller face (pressure side) to an area from 0.6*R* to the tip and from the trailing edge to 0.2 times the chord length	

6.5.3.4 Maximum backward blade ice force F_b for ducted propellers

when $D < D_{limit}$:

$$F_b = 9.5 \cdot S_{ice} \cdot (n \cdot D)^{0.7} \cdot \left(\frac{EAR}{Z}\right)^{0.3} \cdot D^2 \text{ [kN]} \qquad \text{[Equation 7]}$$

when $D \geq D_{limit}$:

$$F_b = 66 \cdot S_{ice} \cdot (n \cdot D)^{0.7} \cdot \left(\frac{EAR}{Z}\right)^{0.3} \cdot (H_{ice})^{1.4} \cdot D^{0.6} \quad \text{[kN]} \qquad \text{[Equation 8]}$$

where:

$$D_{limit} = 4 \cdot H_{ice} \text{ [m]} \qquad \text{[Equation 9]}$$

n shall be taken as in 6.5.3.1

For vessels with the additional notation Icebreaker, the above stated backward blade force F_b shall be multiplied by a factor 1.1.

6.5.3.5 Maximum forward blade ice force F_f for ducted propellers

when $D \leq D_{limit}$:

$$F_f = 250 \cdot \left(\frac{EAR}{Z}\right) \cdot D^2 \quad \text{[kN]} \qquad \text{[Equation 10]}$$

when $D > D_{limit}$:

$$F_f = 500 \cdot \left(\frac{EAR}{Z}\right) \cdot D \cdot \frac{1}{\left(1-\frac{d}{D}\right)} \cdot H_{ice} \quad \text{[kN]} \qquad \text{[Equation 11]}$$

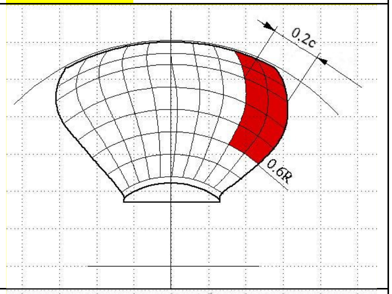
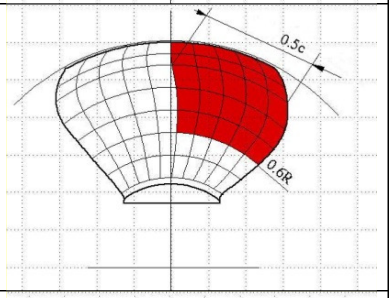
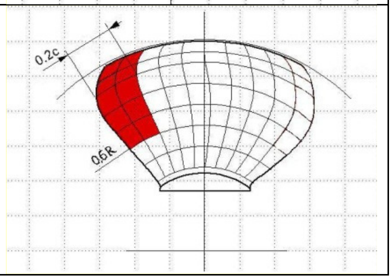
where:

$$D_{limit} = \frac{2}{\left(1-\frac{d}{D}\right)} \cdot H_{ice} \quad \text{[m]} \qquad \text{[Equation 12]}$$

6.5.3.6 Loaded area on the blade for ducted propellers

Load cases 1 and 3 shall be covered as given in Table 6.5.3.6 for all propellers. In order to obtain blade ice loads for a reversing propeller, load case 5 shall also be covered for propellers, where reversing is possible.

Table 6.5.3.6
Loaded areas and load case definition for ducted propellers

	Force	**Loaded area**	**Right-handed propeller blade seen from behind**
Load case 1	F_b	Uniform pressure applied on the back of the blade (suction side) to an area from 0.6R to the tip and from the leading edge to 0.2 times the chord length.	
Load case 3	F_f	Uniform pressure applied on the blade face (pressure side) to an area from 0.6R to the tip and from the leading edge to 0.5 times the chord length.	
Load case 5	60% of F_f or 60% of F_b, whichever is greater	Uniform pressure applied on propeller face (pressure side) to an area from 0.6R to the tip and from the trailing edge to 0.2 times the chord length.	

6.5.3.7 Maximum blade spindle torque Q_{smax} for open and ducted propellers

The spindle torque Q_{smax} around the axis of the blade fitting shall be determined both for the maximum backward blade force F_b and forward blade force F_f, which are applied as per Table 6.5.3.3 and Table 6.5.3.6. If the above method gives a value which is less than the default value given by the formula below, the default value shall be used.

Default value $Q_{smax} = 0.25 \cdot F \cdot c_{0.7}$ [kNm] [Equation 13]

where:

F is taken as either F_b or F_f, whichever has the greater absolute value.

The blade failure spindle torque Q_{sex} is defined under 6.5.4.

6.5.3.8 Load distributions (spectra) for blade loads

The Weibull-type distribution (probability that F_{ice} exceeds $(F_{ice})_{max}$), as given in Figure 6.5.3.8 is used for the fatigue design of the blade.

$$P\left(\frac{F_{ice}}{(F_{ice})_{max}} \geq \frac{F}{(F_{ice})_{max}}\right) = e^{\left(-\left(\frac{F}{(F_{ice})_{max}}\right)^{k} \cdot ln(N_{ice})\right)} \quad \text{[Equation 14]}$$

where:

k = shape parameter of the spectrum

N_{ice} = number of load cycles in the spectrum, see 6.5.3.9

F_{ice} = random variable for ice loads on the blade, $0 \leq F_{ice} \leq (F_{ice})_{max}$.

This results in a blade stress amplitude distribution

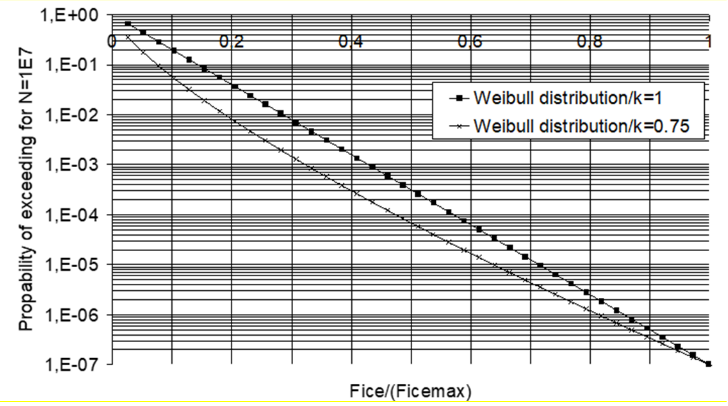
$$(\sigma_{ice})_A(N) = (\sigma_{ice})_{Amax} \cdot \left(1 - \frac{\log(N)}{\log(N_{ice})}\right)^{\frac{1}{k}} \quad \text{[Equation 15]}$$

where:

$(\sigma_{ice})_{Amax} = \frac{(\sigma_{ice})_{fmax} - (\sigma_{ice})_{bmax}}{2}$ [Equation 16]

The shape parameter k = 0.75 shall be used for the ice force distribution of an open propeller and the shape parameter k = 1.0 for that of a ducted propeller blade.

Figure 6.5.3.8
The Weibull-type distribution (probability that F_{ice} exceeds $(F_{ice})_{max}$) that is used for fatigue design



6.5.3.9 Number of ice loads

Number of load cycles N_{ice} in the load spectrum per blade is to be determined according to the formula:

$N_{ice} = k_1 \cdot k_2 \cdot N_{class} \cdot n$ [Equation 17]

where:

N_{class} = reference number of impacts per propeller revolution for each ice class (Table 6.5.3.9)

Table 6.5.3.9
Reference number of impacts

Ice Class	PC1	PC2	PC3	PC4	PC5	PC6	PC7
N_{class}	21 x 10^6	17 x 10^6	15 x 10^6	13 x 10^6	11 x 10^6	9 x 10^6	6 x 10^6

k_1 = 1 for centre propeller
= 2 for wing propeller
= 3 for pulling propeller (wing and centre)

k_2 = 0.8 - f when f < 0
= 0.8 - 0.4·f when 0 ≤ f ≤ 1
= 0.6 - 0.2·f when 1< f ≤ 2.5
= 0.1 when f > 2.5

where the immersion function f is:

$f = \frac{h_0 - H_{ice}}{D/2}$ [Equation 18]

If h_0 is not known, $h_o = D/2$.

For vessels with the additional notation Icebreaker, the above stated number of load cycles N_{ice} shall be multiplied by a factor of 3.

For components that are subject to loads resulting from propeller/ice interaction with all the propeller blades, the number of load cycles (N_{ice}) is to be multiplied by the number of propeller blades (Z).

6.5.4 Blade Failure Load for both Open and Ducted Propellers

6.5.4.1 Bending Force, F_{ex}

The minimum load required resulting in blade failure through plastic bending. This shall be calculated iteratively along the radius of the blade from blade root to 0.5R using below Equation 19 with the ultimate load assumed to be acting at 0.8R in the weakest direction.

The blade failure load is:

$F_{ex} = \frac{0.3 \cdot c \cdot t^2 \cdot \sigma_{ref1}}{0.8 \cdot D - 2 \cdot r} \cdot 10^3$ [kN] [Equation 19]

where:

$\sigma_{ref1} = 0.6 \cdot \sigma_{0.2} + 0.4 \cdot \sigma_u$ [MPa]

σ_u (minimum ultimate tensile strength to be specified on the drawing) and $\sigma_{0.2}$ (minimum yield or 0.2% proof strength to be specified on the drawing) are representative values for the blade material

c, t and r are respectively the actual chord length, maximum thickness and radius of the cylindrical root section of the blade, which is the weakest section outside the root fillet located typically at the termination of the fillet into the blade profile.

The Register may approve alternative means of failure load calculation by means of an appropriate stress analysis reflecting the non-linear plastic material behaviour of the actual blade. A blade is regarded as having failed, if the tip is bent by more than 10% of the propeller diameter.

6.5.4.2 Spindle Torque, Q_{sex}

The maximum spindle torque due to a blade failure load acting at 0.8R shall be determined.

The force that causes blade failure typically reduces when moving from the propeller centre towards the leading and trailing edges. At a certain distance from the blade centre of rotation the maximum spindle torque will occur. This maximum spindle torque shall be defined by an appropriate stress analysis or using equation 20 below.

$Q_{sex} = max(c_{LE0.8}; 0.8 \cdot c_{TE0.8}) \cdot C_{spex} \cdot F_{ex}$ [kNm] [Equation 20]

where :

$C_{spex} = C_{sp} \cdot C_{fex} = 0.7 \cdot \left(1 - \left(4 \cdot \frac{EAR}{Z}\right)^3\right)$ [-] [Equation 21]

C_{sp} is non-dimensional parameter taking into account the spindle arm

C_{fex} is non-dimensional parameter taking into account the reduction of blade failure force at the location of maximum spindle torque.

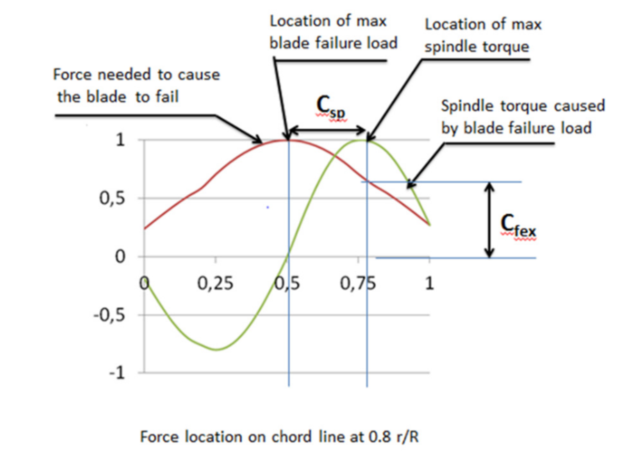
If C_{spex} is below 0.3, a value of 0.3 shall be used for C_{spex}.

$c_{LE0.8}$c is the leading edge portion of the chord length at 0.8R

$c_{TE0.8}$ is the trailing edge portion of the chord length at 0.8R

The figure 6.5.4.2 illustrates the spindle torque values due to blade failure loads across the whole chord length.

Figure 6.5.4.2
Schematic figure showing blade failure load and related spindle torque when the force acts at different location on the chord line at radius 0.8R.



6.5.5 Axial design loads acting on open and ducted propellers

6.5.5.1 Maximum ice thrust on propeller T_f and T_b acting on open and ducted propellers

The maximum forward and backward ice thrusts are given by the following formula:

$T_f = 1.1 \cdot F_f$ [kN] [Equation 22]

$T_b = 1.1 \cdot F_b$ [kN] [Equation 23]

However, the load models within this Rules do not include propeller/ice interaction loads where an ice block hits the propeller hub of a pulling propeller.

6.5.5.2 Design thrust along the propulsion shaft line for open and ducted propellers

The design thrust along the propeller shaft line is to be calculated with the formulae below. The greater value of the forward and backward directional load shall be taken as the design load for both directions. The factors 2.2 and 1.5 take into account the dynamic magnification resulting from axial vibration.

In a forward direction

$T_r = T + 2.2 \cdot T_f$ [kN] [Equation 24]

In a backward direction

$T_r = 1.5 \cdot T_b$ [kN] [Equation 25]

If the hydrodynamic bollard thrust, T, is not known, T is to be taken as follows:

Table 6.5.5.2
Guidance for bollard thrust values

Propeller type	$\boldsymbol{T}$
CP propellers (open)	$1.25\ T_n$
CP propellers (ducted)	$1.1\ T_n$
FP propellers driven by turbine or electric motor	T_n
FP propellers driven by diesel engine (open)	$0.85\ T_n$
FP propellers driven by diesel engine (ducted)	$0.75\ T_n$

Here, T_n is the nominal propeller thrust at MCR in the free running open water condition.

For pulling type propellers ice interaction loads on propeller hub must be considered in addition to the above. These will be specially considered by the *Register*.

6.5.6 Torsional design loads acting on open and ducted propellers

6.5.6.1 Design ice torque on propeller Q_{max} for open propellers

Q_{max} is the maximum torque on a propeller resulting from ice/propeller interaction.

when $D < D_{limit}$:

$Q_{max} = k_{open} \cdot \left(1 - \frac{d}{D}\right) \cdot \left(\frac{P_{0.7}}{D}\right)^{0.16} \cdot (n \cdot D)^{0.17} \cdot D^3$ [kNm] [Equation 26]

where:

k_{open} = 14.7 for PC1 – PC5; and

k_{open} = 10.9 for PC6 – PC7

when $D \geq D_{limit}$:

$Q_{max} = 1.9 \cdot k_{open} \cdot \left(1 - \frac{d}{D}\right) \cdot (H_{ice})^{1.1} \cdot \left(\frac{P_{0.7}}{D}\right)^{0.16} \cdot (n \cdot D)^{0.17} \cdot D^{1.9}$[kNm] [Equation 27]

where:

$D_{limit} = 1.8 \cdot H_{ice}$ [m] [Equation 28]

n is the rotational propeller speed in rev/s in bollard condition. If not known, n is to be taken as follows:

Table 6.5.6.1
Guidance for rotational speeds to calculate torsional loads

Propeller type	**Rotational speed n**
CP propellers	n_n
FP propellers driven by turbine or electric motor	n_n
FP propellers driven by diesel engine	0.85 n_n

For CP propellers, the propeller pitch $P_{0.7}$ shall correspond to MCR in bollard condition. If not known, $P_{0.7}$ is to be taken as 0.7·$P_{0.7n}$, where $P_{0.7n}$ is the propeller pitch at MCR in free running condition.

5.6.2 Design ice torque on propeller Q_{max} for ducted propellers

when $D < D_{limit}$:

$$Q_{max} = k_{ducted} \cdot \left(1 - \frac{d}{D}\right) \cdot \left(\frac{P_{0.7}}{D}\right)^{0.16} \cdot (n \cdot D)^{0.17} \cdot D^3 \quad \text{[kNm]} \quad \text{[Equation 29]}$$

where:

k_{ducted} = 10.4 for PC1 – PC5; and

k_{ducted} = 7.7 for PC6 – PC7

when $D \geq D_{limit}$:

$$Q_{max} = 1.9 \cdot k_{ducted} \cdot \left(1 - \frac{d}{D}\right) \cdot (H_{ice})^{1.1} \cdot \left(\frac{P_{0.7}}{D}\right)^{0.16} \cdot (nD)^{0.17} \cdot D^{1.9} \text{ [kNm][Equation 30]}$$

where:

$D_{limit} = 1.8 \cdot H_{ice}$ [m] [Equation 31]

n shall be taken as in 6.5.6.1.

For CP propellers, the propeller pitch $P_{0.7}$ shall correspond to MCR in bollard condition. If not known, $P_{0.7}$ is to be taken as 0.7·$P_{0.7n}$, where $P_{0.7n}$ is the propeller pitch at MCR in free running condition.

6.5.6.3 Ice torque excitation for open and ducted propellers

The given excitations are used to estimate the maximum torque likely to be experienced once during the service life of the ship. The following load cases are intended to reflect the operational loads on the propulsion system when the propeller interacts with ice and the corresponding reaction of the complete system. The ice impact and system response cause loads in the individual shaft line components. The ice torque Q_{max} may be taken as a constant value in the complete speed range. When considerations at specific shaft speeds are performed a relevant Q_{max} may be calculated using the relevant speed.

Diesel engine plants without an elastic coupling shall be calculated at the least favourable phase angle for ice versus engine excitation, when calculated in time domain. The engine firing pulses shall be included in the calculations and their standard steady state harmonics can be used. A phase angle between ice and gas force excitation does not need to be regarded in frequency domain analysis. Misfiring does not need to be considered.

If there is a blade order resonance just above MCR speed, calculations shall cover the rotational speeds up to 105% of MCR speed.

See also Guidelines for calculations given in 6.5.7

6.5.6.3.1 Excitation for the time domain calculation

The propeller ice torque excitation for shaft line transient dynamic analysis (time domain) is defined as a sequence of blade impacts which are of half sine shape and occur at the blade. The torque due to a single blade ice impact as a function of the propeller rotation angle is then defined as:

$$Q(\varphi) = C_q \cdot Q_{max} \cdot \sin\left(\varphi(180/\alpha_i)\right) \quad \text{[Equation 32]}$$

when φ rotates from 0 to α_i plus integer revolutions.

$Q(\varphi) = 0$

when φ rotates from α_i to 360 plus integer revolutions.

Where

φ = rotation angle starting when the first impact occurs

C_q and α_i parameters are given in the Table 6.5.6.3.1 below. α_i is the duration of propeller blade/ice interaction expressed in propeller rotation angle.

Table 6.5.6.3.1
Ice impact magnification and duration factors for different blade numbers

Torque excitation	Propeller/ ice interaction	C_q	α_i [deg]			
			Z=3	Z=4	Z=5	Z=6
Excitation case 1	Single ice block	0.75	90	90	72	60
Excitation case 2	Single ice block	1.0	135	135	135	135
Excitation case 3	Two ice blocks (phase shift 360/(2· Z) deg.)	0.5	45	45	36	30
Excitation case 4	Single ice block	0.5	45	45	36	30

The total ice torque is obtained by summing the torque of single blades, taking into account the phase shift 360 deg./Z.

At the beginning and at the end of the milling sequence (within calculated duration) linear ramp functions shall be used to increase C_q to its maximum within one propeller revolution and vice versa to decrease it to zero (see examples for different Z numbers in the appendix).

The number of propeller revolutions during a milling sequence shall be obtained from the formula:

$N_Q = 2 \cdot H_{ice}$ [Equation 33]

The number of impacts is $Z \cdot N_Q$ for blade order excitation.

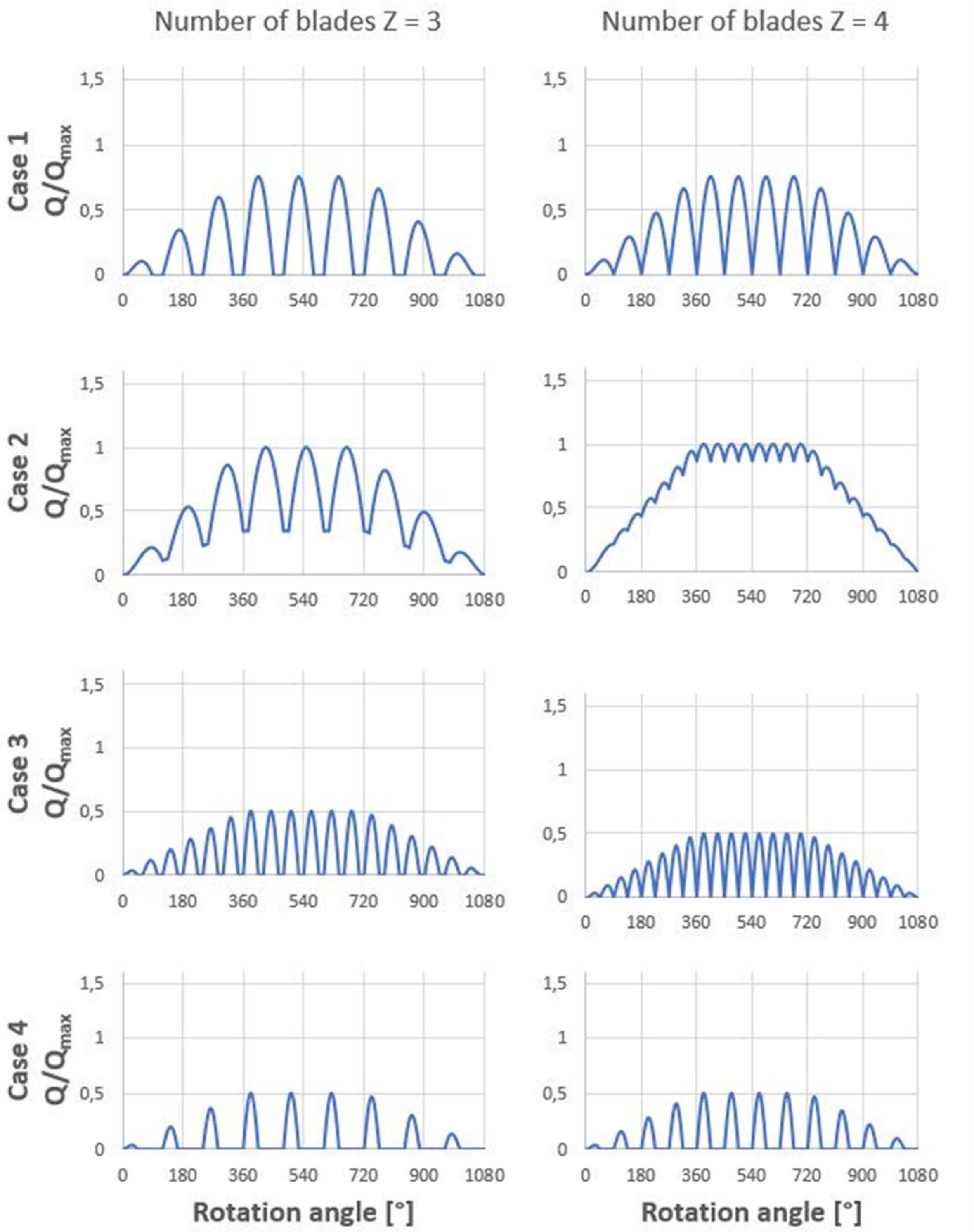
An illustration of all excitation cases for different blade numbers is given in the Figure 6.5.6.3.1.

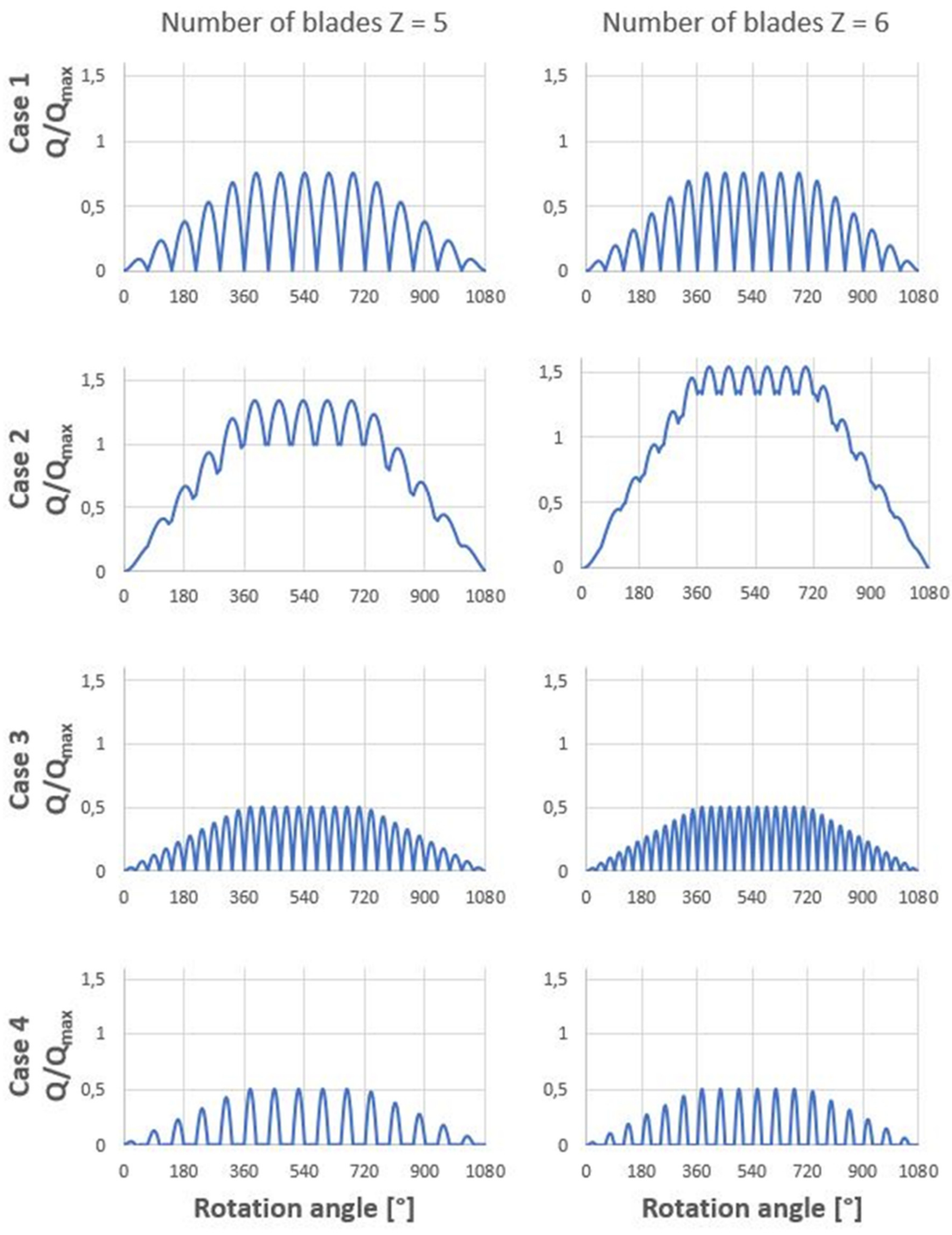
The dynamic simulation shall be performed for all excitation cases starting at MCR nominal, MCR bollard condition and just above all resonance speeds (1st engine and 1st blade harmonic), so that the resonant vibration responses can be obtained. For a fixed pitch propeller plant the dynamic simulation shall also cover bollard pull condition with a corresponding speed assuming maximum possible output of the engine.

If a speed drop occurs down to stand still of the main engine, it indicates that the engine may not be sufficiently powered for the intended service task. For the consideration of loads, the maximum occurring torque during the speed drop process shall be applied. On these cases, the excitation shall follow the shaft speed.

Figure 6.5.6.3.1

The following illustrations show the excitation torque for all torsional load cases given in this UR for different blade numbers (Z). The plots have been made using data for PC7 (H_{ice} = 1.5)




Number of blades Z = 5
Number of blades Z = 6
Case 1
Case 2
Case 3
Case 4
Q/Q$_{max}$
1,5
1
0,5
0
0
180
360
540
720
900
1080
Rotation angle [°]

6.5.6.3.2 Frequency domain excitation

For frequency domain calculations the following torque excitation may be used. The excitation has been derived so that the time domain half sine impact sequences have been assumed to be continuous and the Fourier series components for blade order and twice the blade order components have been derived. The frequency domain analysis is generally considered as conservative compared to the time domain simulation provided there is a first blade order resonance in the considered speed range.

$$Q_{F(\varphi)} = Q_{max} \cdot \left(C_{q0} + C_{q1} \cdot \sin(Z \cdot E_0 \cdot \varphi + \alpha_1) + C_{q2} \cdot \sin(2 \cdot Z \cdot E_0 \cdot \varphi + \alpha_2)\right) \quad \text{[kNm]} \qquad \text{[Equation 34]}$$

where:

C_{q0} = mean torque component

C_{q1} = first blade order excitation amplitude

C_{q2} = second blade order excitation amplitude

φ = angle of rotation

$\alpha_{1,2}$ = phase angle of excitation component

Z = number of blades

Table 6.5.6.3.2
Coefficients for simplified excitation torque estimation

Torque excitation	Z=3					
	C_{q0}	C_{q1}	α_1	C_{q2}	α_2	E_0
Excitation case 1	0,375	0.375	-90	0	0	1
Excitation case 2	0.7	0.33	-90	0.05	-45	1
Excitation case 3	0.25	0.25	-90	0	0	2
Excitation case 4	0.2	0.25	0	0.05	-90	1
Torque excitation	Z=4					
	C_{q0}	C_{q1}	α_1	C_{q2}	α_2	E_0
Excitation case 1	0.45	0.36	-90	0.06	-90	1
Excitation case 2	0.9375	0	-90	0.0625	-90	1
Excitation case 3	0.25	0.251	-90	0	0	2
Excitation case 4	0.2	0.25	0	0.05	-90	1
Torque excitation	Z=5					
	C_{q0}	C_{q1}	α_1	C_{q2}	α_2	E_0
Excitation case 1	0.45	0.36	-90	0.06	-90	1
Excitation case 2	1.19	0.17	-90	0.02	-90	1
Excitation case 3	0.3	0.25	-90	0.048	-90	2
Excitation case 4	0.2	0.25	0	0.05	-90	1
Torque excitation	Z=6					
	C_{q0}	C_{q1}	α_1	C_{q2}	α_2	E_0
Excitation case 1	0.45	0.375	-90	0.05	-90	1
Excitation case 2	1.435	0.1	-90	0	0	1
Excitation case 3	0.3	0.25	-90	0.048	-90	2
Excitation case 4	0.2	0.25	0	0.05	-90	1

Torsional vibration responses shall be calculated for all excitation cases.

The results of the relevant excitation cases at the most critical rotational speeds are to be used in the following way:

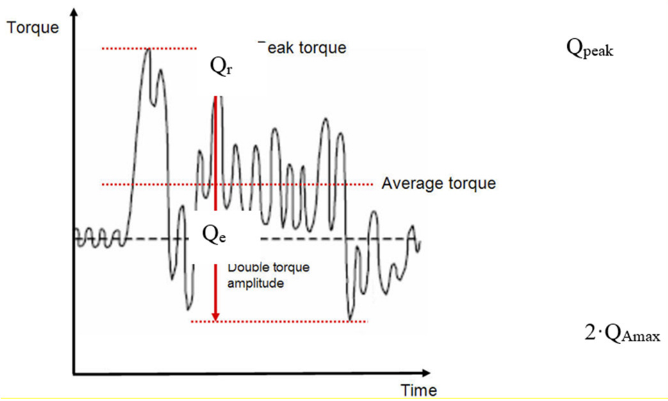
The highest response torque (between the various lumped masses in the system) is in the following referred to as peak torque Q_{peak}.

The highest torque amplitude during a sequence of impacts is to be determined as half of the range from max to min torque and is referred to as Q_{Amax}.

An illustration of Q_{Amax} is given in Figure 6.5.6.3.2. It can be determined by

$$Q_{Amax} = \left(\frac{max(Q_r(time)) - min(Q_r(time))}{2}\right) \quad \text{[kNm]} \qquad \text{[Equation 35]}$$

Figure 6.5.6.3.2
Interpretation of different torques in a measured curve, as example



6.5.6.4 Design torque along shaft line

a) If there is no relevant first order propeller torsional resonance in the range 20% (of n_n) above and 20% below the maximum operating speed in bollard condition (see Table 8), the following estimation ([Equation 36] and [Equation 37] respectively) of the maximum response torque can be used to calculate the design torque along the propeller shaft line.

$Q_r = Q_{emax} + Q_{vib} + Q_{max} \cdot \frac{I}{I_t}$ [kNm] [Equation 36]

Equation 36 is to be applied for directly coupled two stroke Diesel engines without flexible coupling.

For all other plants:

$Q_r = Q_{emax} + Q_{max} \cdot \frac{I}{I_t}$ [kNm] [Equation 37]

where:

- I = equivalent mass moment of inertia of all parts on engine side of component under consideration and
- I_t = equivalent mass moment of inertia of the whole propulsion system.

All the torques and the inertia moments shall be reduced to the rotation speed of the component being examined.

If the maximum torque, Q_{emax}, is not known, it shall be taken as follows:

Table 6.5.6.4
Guideline for the determination of maximum motor torque

Propeller type	Q_{emax}
Propellers driven by electric motor	Q_{motor}
CP propellers not driven by electric motor	Q_n
FP propellers driven by turbine	Q_n
FP propellers driven by diesel engine	0.75 Q_n

Note: Q_{motor} is the electric motor peak torque.

b) If there is a first blade order torsional resonance in the range 20% (of n_n) above and 20% below the maximum operating speed (bollard condition), the design torque (Q_r) of the shaft component shall be determined by means of a dynamic torsional vibration analysis of the entire propulsion line in the time domain or alternatively in the frequency domain. It is then assumed that the plant is sufficiently designed to avoid harmful operation in barred speed range.

6.5.7 Guideline for torsional vibration calculation

The aim of torsional vibration calculations is to estimate the torsional loads for individual shaft line components over the lifetime in order to determine scantlings for safe operation. The model can be taken from the normal lumped mass elastic torsional vibration model (frequency domain) including the damping. Standard harmonics may be used to consider the gas forces. The engine torque - speed curve of the actual plant shall be applied.

For time domain analysis the model should include the ice excitation at propeller, the mean torques provided by the prime mover and the hydrodynamic mean torque produced by the propeller as well as any other relevant excitations. The calculations should cover the variation of phase between the ice excitation and prime mover excitation. This is extremely relevant for propulsion lines with direct driven combustion engines.

For frequency domain calculations the load should be estimated as a Fourier component analysis of the continuous sequence of half sine load peaks. The first and second order blade components should be used for excitation. The calculation should cover the whole relevant shaft speed range. The analysis of the responses at the relevant torsional vibration resonances may be performed for open water (without ice excitation) and ice excitation separately. The resulting maximum torque can be obtained for directly coupled plants by the following superposition:

$Q_{peak} = Q_{emax} + Q_{opw} + Q_{ice}$ [kNm] [Equation 38]

where:

Q_{emax} is the maximum engine torque at considered rotational speed

Q_{opw} is the maximum open water response of engine excitation at considered shaft speed and determined by frequency domain analysis

Q_{ice} is the calculated torque using frequency domain analysis for the relevant shaft speeds, ice excitation cases 1-4, resulting in the maximum response torque due to ice excitation.

6.6 DESIGN

6.6.1 Design Principle

The propulsion line shall be designed according to the pyramid strength principle in terms of its strength. This means that the loss of the propeller blade shall not cause any significant damage to other propeller shaft line components.

The propulsion line components shall withstand maximum and fatigue operational loads with the relevant safety margin. The loads do not need to be considered for shaft alignment or other calculations of normal operational conditions.

6.6.2 Fatigue design in general

The design loads shall be based on the ice excitation and where necessary (shafting) dynamic analysis, described as a sequence of blade impacts (6.5.6.3.1). The shaft response torque shall be determined according 6.5.6.4.

The propulsion line components are to be designed so as to prevent accumulated fatigue failure when considering the relevant loads using the linear elastic Miner's rule as defined below.

$D = \frac{n_1}{N_1} + \frac{n_2}{N_2} + \cdots + \frac{n_k}{N_k} \leq 1$ [Equation 39]

or

$D = \sum_{J=1}^{j=k} \frac{n_j}{N_j} \leq 1$ [Equation 40]

Where:

k is the number of stress levels

$N_{1 \ldots k}$ is the number of load cycles to failure of the individual stress level class

$n_{1 \ldots k}$ is the accumulated number of load cycles of the case under consideration, per class

D Miners damage sum

GUIDANCE: The stress distribution should be divided into a frequency load spectrum having minimum 10 stress blocks (every 10 % of the load). Calculation with 5 stress blocks has been found to be too conservative. The maximum allowable load is limited by $\sigma_{ref\,2}$ for propeller blades and yield strength for all other components. The load distribution (spectrum) should be in accordance with the Weibull distribution.

6.6.3 Propeller blades

6.6.3.1 Calculation of blade stresses due to static loads

The blade stresses (equivalent and principal stresses) shall be calculated for the design loads given in item 6.5.3. Finite element analysis (FEA) shall be used for stress analysis as part of the final approval for all propeller blades. The von Mises stresses, taken as σ_{st} , shall comply with Equation 42.

Alternatively, the following simplified [Equation 41] can be used in estimating the blade stresses for all propellers in the root area (r/R < 0.5) for final approval

$\sigma_{st} = C_1 \frac{M_{BL}}{100 \cdot ct^2}$ [MPa] [Equation 41]

where:

- constant C_1 is the $\frac{actual\ stress}{stress\ obtained\ with\ beam\ equation}$. (If the actual value is not available, C_1 should be taken as 1.6.)
- $M_{BL} = (0.75 - r/R) \cdot R \cdot F$, for relative radius r/R < 0.5

- F is the maximum of F_b and F_f , whichever is greater.

6.6.3.2 Acceptability criterion for static loads

The following criterion for calculated blade stresses shall be fulfilled:

$$\frac{\sigma_{ref\,2}}{\sigma_{st}} \geq 1.3 \quad [\text{-}] \qquad \text{[Equation 42]}$$

where:

σ_{st} calculated stress for the design loads. If FE analysis is used in estimating the stresses, von Mises stresses shall be used.

6.6.3.3 Fatigue design of propeller blade

6.6.3.3.1 General

For materials with a two slope S-N curve (Figure 6.6.3.3.1a) the fatigue calculations defined in this chapter are not required if the following criterion is fulfilled.

$$\sigma_{exp} \geq B_1 \cdot \sigma_{ref\,2}{}^{B_2} \cdot log(N_{ice})^{B_3} \qquad \text{[Equation 43]}$$

where:

$B1$, $B2$ and $B3$ are coefficients for open and ducted propellers, given in the Table **6.6.3.3.1** below.

Table 6.6.3.3.1
Coefficients to check a dispense from fatigue calculation

	Open propeller	**Ducted propeller**
$B1$	0.00328	0.00223
$B2$	1.0076	1.0071
$B2$	2.101	2.471

Where the above criterion is not fulfilled the fatigue requirements defined below shall be applied:

The fatigue design of the propeller blade is based on an estimated load distribution for the service life of the ship and the S-N curve for the blade material. An equivalent stress σ_{fat} that produces the same fatigue damage as the expected load distribution shall be calculated according to Miner's rule and the acceptability criterion for fatigue should be fulfilled as given in this section. The equivalent stress is normalised for 100 million cycles.

The blade stresses at various selected load levels for fatigue analysis are to be taken proportional to the stresses calculated for maximum loads given in section 5.3.

The peak principal stresses σ_f and σ_b are determined from F_f and F_b using FEA. The peak stress range $\Delta\sigma_{max}$ and the maximum stress amplitude σ_{Amax} are determined on the basis of load cases 1 and 3, 2 and 4.

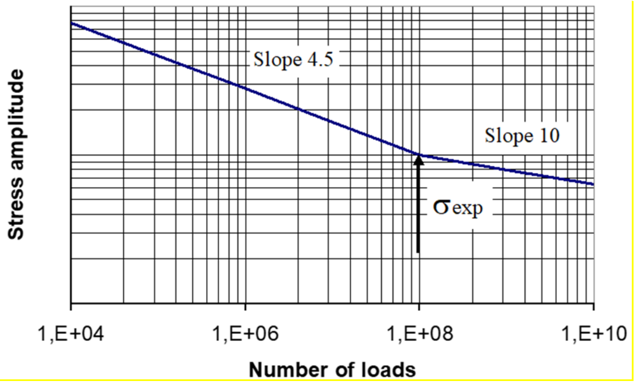
$$\Delta\sigma_{max} = 2 \cdot \sigma_{Amax} = |(\sigma_{ice})_{f\,max}| + |(\sigma_{ice})_{b\,max}| \qquad \text{[Equation 44]}$$

The load spectrum for backward loads is normally expected to have a lower number of cycles than the load spectrum for forward loads. Taking this into account in a fatigue analysis introduces complications that are not justified considering all uncertainties involved.

For the calculation of equivalent stress two types of S-N curves are available.

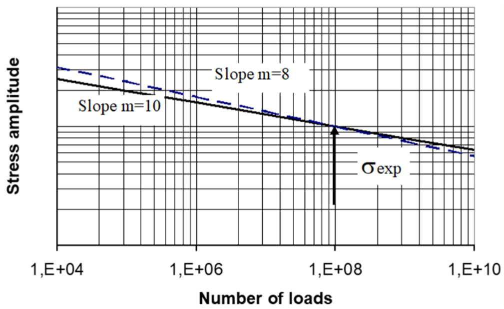
Two slope S-N curve (slopes 4.5 and 10), see Figure 6.6.3.3.1a.

Figure 6.6.3.3.1a
Two-slope S-N curve



One slope S-N curve (the slope can be chosen), see Figure 6.6.3.3.1b.

Figure 6.6.3.3.1b
Constant-slope S-N curve



The type of the S-N-curve shall be selected to correspond with the material properties of the blade. If the S-N-curve is not known the two slope S-N curve shall be used.

6.6.3.3.2 Equivalent fatigue stress

Note: A more general method of determining the equivalent fatigue stress of propeller blades is described in 6.6.5, where the principal stresses are considered according to 6.5.3 using the Miner's rule. For a total number of load blocks n_{bl} > 100, both methods deliver the same result. Therefore, they are regarded as equivalent.

The equivalent fatigue stress for 10^8 cycles which produces the same fatigue damage as the load distribution is:

$\sigma_{fat} = \rho \cdot (\sigma_{ice})_{max}$ [Equation 45]

where:

$(\sigma_{ice})_{max} = 0.5 \cdot \left((\sigma_{ice})_{f\,max} - (\sigma_{ice})_{b\,max}\right)$ [Equation 46]

$(\sigma_{ice})_{max}$ = mean value of the principal stress amplitudes resulting from design forward and backward blade forces at the location being studied.

$(\sigma_{ice})_{f\,max}$ = principal stress resulting from forward load

$(\sigma_{ice})_{b\,max}$ = principal stress resulting from backward load

In the calculation of $(\sigma_{ice})_{max}$, case 1 and case 3 or case 2 and case 4 are considered as pairs for $(\sigma_{ice})_{f\,max}$, and $(\sigma_{ice})_{b\,max}$ calculations. Case 5 is excluded from the fatigue analysis.

Calculation of parameter ρ for two-slope S-N curve

The error of the following method to determine the parameter ρ is sufficiently small, if the number of load cycles N_{ice} is in the range $5 \cdot 10^6 \leq N_{ice} \leq 10^8$

The parameter ρ relates the maximum ice load to the distribution of ice loads according to the regression formula

$\rho = C_1 \cdot (\sigma_{ice})_{max}{}^{C_2} \cdot \sigma_{fl}{}^{C_2} \cdot log(N_{ice})^{C_4}$ [Equation 47]

where:

$\sigma_{fl} = \gamma_{\varepsilon1} \cdot \gamma_{\varepsilon2} \cdot \gamma_v \cdot \gamma_m \cdot \sigma_{exp}$ is the blade material fatigue strength at 10^8 load cycles, see 6.6.3.3.3.

The coefficients C_1, C_2 , C_3 , and C_4 are given in Table 6.6.3.3.2a

Table 6.6.3.3.2a
Coefficients to evaluate material fatigue strength

	Open propeller	**Ducted propeller**
C_1	0.000747	0.000534
C_2	0.0645	0.0533
C_3	-0.0565	-0.0459
C_4	2.22	2.584

Calculation of parameter ρ for constant-slope S-N curve

For materials with a constant-slope S-N curve, see Figure 6.6.3.3.1b, - the factor ρ shall be calculated from the following formula:

$$\rho = \left(G\frac{N_{ice}}{N_R}\right)^{\frac{1}{m}}\left(ln(N_{ice})\right)^{-\frac{1}{k}}$$ [Equation 48]

where:

k = shape parameter of the Weibull distribution

k = 1.0 for ducted propellers and

k = 0.75 for open propellers

N_R = reference number of load cycles (=10^8)

Values for the parameter G are given in Table 6.6.3.3.2b below. Linear interpolation may be used to calculate the value of G for m/k ratios other than those given in the Table 6.6.3.3.2b.

Table 6.6.3.3.2b
Value for the parameter ***G*** for different m/k ratios

m/k	***G***	**m/k**	***G***	**m/k**	***G***
3	6	5.5	287.9	8	40320
3.5	11.6	6	720	8.5	119292
4	24	6.5	1871	9	362880
4.5	52.3	7	5040	9.5	1.133×10^6
5	120	7.5	14034	10	3.623×10^6

6.6.3.3.3 Acceptability criterion for fatigue

The equivalent fatigue stress σ_{fat} at all locations on the blade shall fulfil the following acceptability criterion:

$$\frac{\sigma_{fl}}{\sigma_{fat}} \geq 1.5$$ [Equation 49]

where:

$$\sigma_{fl} = \gamma_{\varepsilon 1}\cdot\gamma_{\varepsilon 2}\cdot\gamma_v\cdot\gamma_m\cdot\sigma_{exp}$$ [Equation 50]

$\gamma_{\varepsilon 1}$ = reduction factor due to scatter (equal to one standard deviation)

$\gamma_{\varepsilon 2}$ = reduction factor for test specimen size effect

γ_v = reduction factor for variable amplitude loading.

γ_m = reduction factor for mean stress.

σ_{exp} = mean fatigue strength of the blade material at 10^8 cycles to failure in seawater

σ_{exp} in Table 15 has been defined from the results of constant amplitude loading fatigue tests at 10^7 load cycles and 50% survival probability and has been extended to 10^8 load cycles.

Fatigue strength values and correction factors other than those given in Table 6.6.3.3.3 may be used, provided the values are determined under conditions approved by the *Register*.

The S-N curve characteristics are based on two slopes, the first slope 4.5 is from 1000 to 10^8 load cycles; the second slope 10 is above 10^8 load cycles.

The maximum allowable stress for one or low number of cycles is limited to σ_{ref2}/S, with S=1.3 for static loads.

The fatigue strength σ_{fat} is the fatigue limit at 100 million load cycles.

The geometrical size factor ($\gamma_{\varepsilon 2}$) is:

$$\gamma_{\varepsilon 2} = 1 - a\cdot ln\left(\frac{t}{0.025}\right)$$ [Equation 51]

where:

"a" is as given in Table 6.6.3.3.3 below and "t" is the maximum blade thickness at the considered point

The mean stress effect (γ_m) is

$$\gamma_m = 1.0 - \left(\frac{1.4 \cdot \sigma_{mean}}{\sigma_u}\right)^{0.75} \qquad \text{[Equation 52]}$$

The following values should be used for the reduction factors if actual values are not available: $\gamma_{\varepsilon 1}$ = 0.85, γ_v = 0.75, and γ_m= 0.75.

Table 6.6.3.3.3

Mean fatigue strength $\boldsymbol{\sigma_{exp}}$ for different material types at 10^8 load cycles and stress ratio R = -1 with a survival probability of 50%.

Mean fatigue strength σ_{exp} for different material types at 10^8 load cycles			
Bronze and brass (a=0.10)		Stainless steel (a=0.05)	
Mn-Bronze, CU1 (high tensile brass)	84 MPa	Ferritic (12Cr 1Ni)	144*) Mpa
Mn-Ni-Bronze, CU2 (high tensile brass)	84 Mpa	Martensitic (13Cr 4Ni/13Cr 6Ni)	156 Mpa
Ni-Al-Bronze, CU3	120 Mpa	Martensitic (16Cr 5Ni)	168 Mpa
Mn-Al-Bronze, CU4	113 Mpa	Austenitic (19Cr 10Ni)	132 Mpa

*) This value may be used, provided a perfect galvanic protection is active. Otherwise, a reduction of about 30 MPa shall be applied.

6.6.4 Blade bolts, propeller hub and CP mechanism

6.6.4.1 General

The blade bolts, CP mechanism, propeller boss and the fitting of the propeller to the propeller shaft shall be designed to withstand the maximum static and fatigue design loads (as applicable), as defined in 6.5.3 and 6.6.3. The safety factor S against yielding due to static loads and against fatigue shall be greater than 1.5, if not stated otherwise. The safety factor S for loads, resulting from propeller blade failure as defined in 6.5.4 shall be greater than 1.0 against yielding.

Provided that calculated stresses duly considering local stress concentrations are less than yield strength, or maximum of 70% of σ_u of respective materials, detailed fatigue analysis is not required. In all other cases components shall be analysed for cumulative fatigue. An approach similar to that used for shafting assessment may be applied (6.5).

6.6.4.2 Blade bolts

Blade bolts shall withstand the following bending moment considered around a tangent on bolt pitch circle, or any other relevant axis for non-circular joints, parallel to considered root section:

$$M_{bolt} = S \cdot F_{ex\left(0.8\frac{D}{2} - r_{bolt}\right)} \quad \text{[kNm]} \qquad \text{[Equation 53]}$$

where:

r_{bolt} = radius to the bolt plane [m]

S = 1.0 safety factor

Blade bolt pre-tension shall be sufficient to avoid separation between mating surfaces when the maximum forward and backward ice loads defined in 5.3 (open and ducted propellers respectively) are applied. For conventional arrangements, the following formula may be applied:

$$d_{bb} = 41 \cdot \sqrt[2]{\frac{F_{ex} \cdot (0.8 \cdot D - d) \cdot S \cdot \alpha}{\sigma_{0.2} \cdot Z_{bb} \cdot PCD}} \quad \text{[mm]} \qquad \text{[Equation 54]}$$

where:

α = 1.6 torque guided tightening
= 1.3 elongation guided
= 1.2 angle guided
= 1.1 elongated by other additional means
other factors may be used, if evidence is demonstrated

d_{bb} effective diameter of blade bolt in way of thread [mm]

Z_{bb} number of blade bolts

S = 1.0 safety factor

6.6.4.3 CP mechanism

Separate means, e.g. dowel pins, shall be provided in order to withstand the spindle torque resulting from blade failure Q_{sex} (6.5.4.2) or ice interaction Q_{smax} (6.5.3.7), whichever is greater. Other components of the CP mechanism shall not be damaged by the maximum spindle torques (Q_{smax}, Q_{sex}). One third of the spindle torque is assumed to be consumed by friction, if not otherwise documented trough further analysis.

The diameter of fitted pins d_{fp} between the blade and blade carrier can be calculated using the formula:

$$d_{fp} = 66 \cdot \sqrt{\frac{(Q_s - Q_{fr})}{PCD \cdot z_{pin} \cdot \sigma_{0.2}}} \quad \text{[mm]} \quad \text{[Equation 55]}$$

where:

$Q_s = max(S \cdot Q_{smax}; S \cdot Q_{sex})$ [kNm] [Equation 56]

S = 1.3 for Q_{sex} and

= 1.0 for Q_{sex}

Q_{fr} = friction between connected surfaces = 0.33·Q_s

The *Register* may approve alternative Q_{fr} calculation according to reaction forces due to F_{ex}, or F_f, F_b whichever is relevant, utilising a friction coefficient = 0.15.

The stress in the actuating pin can be estimated by

$$\sigma_{vMises} = \sqrt{\left(\frac{\left(F \cdot \frac{h_{pin}}{2}\right)}{\frac{\pi \cdot d_{pin}^3}{32}}\right)^2 + 3 \cdot \left(\frac{F}{\frac{\pi}{4} \cdot d_{pin}^2}\right)^2} \quad \text{[MPa]} \quad \text{[Equation 57]}$$

where:

$$F = \frac{Q_S - Q_{fr}}{l_m} \quad \text{[kN]} \quad \text{[Equation 58]}$$

l_m distance pitching centre of blade – axis of pin [m]

h_{pin} height of actuating pin [mm]

d_{pin} diameter of actuating pin [mm]

Q_{fr} friction torque in blade bearings acting on the blade palm and caused by the reaction forces due to F_{ex}, or F_f, F_b whichever is relevant; taken to one third of spindle torque Q_s

The blade failure spindle torque Q_{sex} shall not lead to any consequential damage.

Fatigue strength is to be considered for parts transmitting the spindle torque from the blade to a servo system considering the ice spindle torque acting on one blade. The maximum amplitude Q_{samax} is defined as:

$$Q_{samax} = \frac{Q_{sb} + Q_{sf}}{2} \text{[kNm]} \quad \text{[Equation 59]}$$

where:

Q_{sb} spindle torque due to $|F_b|$ [kNm]

Q_{sf} spindle torque due to $|F_f|$ [kNm]

6.6.4.4 Servo pressure

The design pressure for the servo system shall be taken as the pressure caused by Q_{smax} or, Q_{sex} when not protected by relief valves on the hydraulic actuator side, reduced by relevant friction losses in bearings caused by the respective ice loads. The design pressure shall in any case not be less than relief valve set pressure.

6.6.6.5 Propulsion line components

The ultimate load resulting from total blade failure F_{ex} as defined in 6.5.4 shall consist of combined axial and bending load components, wherever this is significant. The minimum safety factor against yielding is to be 1.0 for all shaft line components.

The shafts and shafting components, such as bearings, couplings and flanges shall be designed to withstand the operational propeller/ice interaction loads as given in 6.5.

The given loads are not intended to be used for shaft alignment calculation.

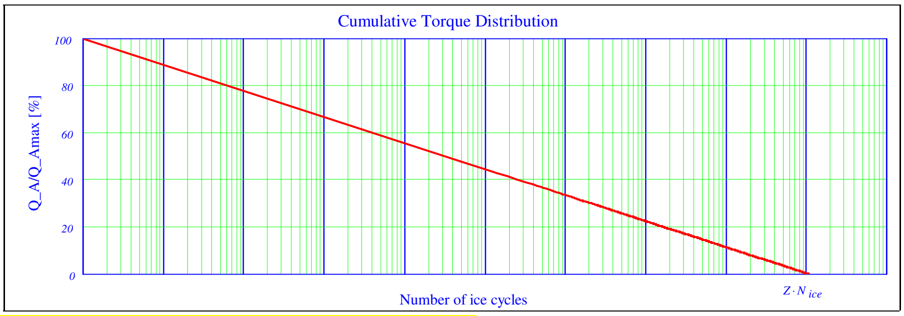
Cumulative fatigue calculations shall be conducted according to the Miner's rule. A fatigue calculation is not necessary, if the maximum stress is below fatigue strength at 10^8 load cycles.

The torque and thrust amplitude distribution (spectrum) in the propulsion line is to be taken as (because Weibull exponent k = 1):

$$Q_A(N) = Q_{Amax} \cdot \left(1 - \frac{log(N)}{log(Z \cdot N_{ice})}\right) \quad \text{[Equation 60]}$$

This is illustrated by the example in the Figure 6.6.6.5a.

Figure 6.6.6.5a
Cumulative torque distribution

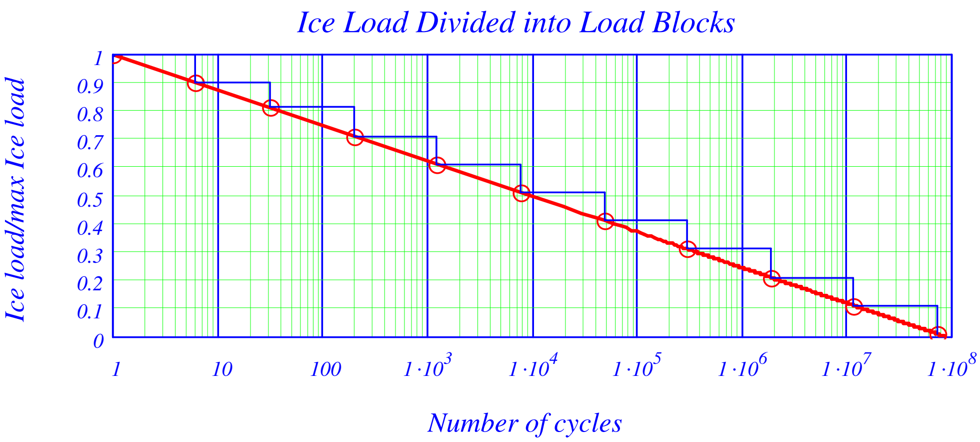


The number of load cycles in the load spectrum is defined as $Z \cdot N_{ice}$.

The Weibull exponent should be considered as k = 1.0 for both open and ducted propeller torque and bending forces. The load distribution is an accumulated load spectrum, and the load spectrum should be divided into a minimum of ten load blocks when using the Miner summation method.

The load spectrum used counts the number of cycles for 100% load to be the number of cycles above the next step, e.g. 90 % load. This ensures that the calculation is on the conservative side. Consequently, the fewer stress blocks used the more conservative the calculated safety margin.

Figure 6.6.6.5b
Example of ice load distribution (spectrum) for the shafting (***k*** = 1)



The load spectrum is divided into n_{bl}-number of load blocks for the Miner summation method.

The following formula can be used for calculation of the number of cycles for each load block.

$$n_i = N_{ice}^{1-\left(1-\frac{i}{n_{bl}}\right)^k} - \sum_{i=1}^{i} n_{i-1} \qquad \text{[Equation 61]}$$

where:

i = single load block i and n_{bl} is the number of load blocks

6.6.5.1 Propeller fitting to the shaft

6.6.5.1.1 Keyless cone mounting

The friction capacity (at 0° C) shall be at least S = 2.0 times the highest peak torque Q_{peak} as determined in 5.6 without exceeding the permissible hub stresses.

The necessary surface pressure $P_{0°C}$ can be determined as:

$$P_{0°C} = \frac{2 \cdot S \cdot Q_{peak}}{\pi \cdot \mu \cdot {D_S}^2 \cdot L \cdot 10^3} \quad \text{[MPa]} \quad \text{[Equation 62]}$$

where:

μ = 0.15 for steel-steel,

= 0.13 for steel-bronze

D_S = is the shrinkage diameter at the mid-length of the taper [m]

L = is the effective length of taper [m]

Above friction coefficients may be increased by 0.04 if glycerine is used in wet mounting.

6.5.1.2 Key mounting

Key mounting is not permitted.

6.5.1.3 Flange mounting

The flange thickness is to be at least 25% of the required aft end shaft diameter (IACS UR M34).

Any additional stress raisers such as recesses for bolt heads shall not interfere with the flange fillet unless the flange thickness is increased correspondingly.

The flange fillet radius is to be at least 10% of the required shaft diameter.

The diameter of shear pins shall be calculated according to the following equation:

$$d_{pin} = 66 \cdot \sqrt[2]{\frac{Q_{peak} \cdot S}{PCD \cdot z_{pin} \cdot \sigma_{0.2}}} \text{[mm]} \qquad \text{[Equation 63]}$$

where

z_{pin} = number of shear pins

S = 1.3 safety factor

The bolts are to be designed so that the blade failure load F_{ex} (6.5.4) in backward direction does not cause yielding of the bolts. The following equation should be applied:

$$d_b = 41 \cdot \sqrt{\frac{F_{ex} \cdot \left(0.8 \cdot \frac{D}{PCD} + 1\right) \cdot \alpha}{\sigma_{0.2} \cdot z_b}} \text{ [mm]} \qquad \text{[Equation 64]}$$

where:

α = 1.6 torque guided tightening

= 1.3 elongation guided

= 1.2 angle guided

= 1.1 elongated by other additional means

other factors may be used, if evidence is demonstrated

d_b diameter flange bolt [mm]

z_b number of flange bolts

6.6.5.2 Propeller shaft

The propeller shaft is to be designed to fulfil the following:

6.6.5.2.1 The blade failure load F_{ex} (5.4) applied parallel to the shaft (forward or backwards) shall not cause yielding. The bending moment need not to be combined with any other loads. The diameter d_p in way of the aft stern tube bearing shall not be less than:

$$d_p = 160 \cdot \sqrt[3]{\frac{F_{ex} \cdot D}{\sigma_{0.2} \cdot \left(1 - \frac{d_i^4}{d_p^4}\right)}} \text{ [mm]} \quad \text{[Equation 65]}$$

where:

d_p = propeller shaft diameter [mm]

d_i = propeller shaft inner diameter [mm]

Forward from the aft stern tube bearing the shaft diameter may be reduced based on direct calculation of the actual bending moment, or by the assumption that the bending moment caused by F_{ex} is linearly reduced to 25% at the next bearing and in front of this linearly to zero at third bearing.

Bending due to maximum blade forces F_b and F_f have been disregarded since the resulting stress levels are much lower than the stresses caused by the blade failure load.

6.6.5.2.2 The stresses due to the peak torque Q_{peak} shall have a minimum safety factor of S=1.5 against yielding in plain sections and S=1.0 in way of stress concentrations in order to avoid bent shafts.

Minimum diameter of:

plain shaft:

$$d_p = 210 \cdot \sqrt[3]{\frac{Q_{peak} \cdot S}{\sigma_{0.2} \cdot \left(1 - \frac{d_i^4}{d^4}\right)}} \quad \text{[mm]} \qquad \text{[Equation 66]}$$

notched shaft:

$$d_p = 210 \cdot \sqrt[3]{\frac{Q_{peak} \cdot S \cdot \alpha_t}{\sigma_{0.2} \cdot \left(1 - \frac{d_i^4}{d^4}\right)}} \quad \text{[mm]} \qquad \text{[Equation 67]}$$

where:

α_t = local stress concentration factor in torsion.

Notched shaft diameter shall in any case not be less than the required plain shaft diameter.

6.6.5.2.3 The torque amplitudes (5.6.4) with the corresponding number of load cycles shall be used in an accumulated fatigue evaluation where the safety factor is S_{fat}=1.5. If the plant has high engine excited torsional vibrations (e.g. direct coupled 2-stroke engines), this shall also be considered.

6.6.5.2.4 The fatigue strengths σ_F and τ_F (3 million cycles) of shaft materials may be assessed on the basis of the material's yield or 0.2% proof strength as:

$$\sigma_F = 0.436 \cdot \sigma_{0.2} + 77 = \tau_F \cdot \sqrt{3} \quad \text{[MPa]} \quad \text{[Equation 68]}$$

This is valid for small polished specimens (no notch) and reversed stresses, see "VDEH 1983 Bericht Nr. ABF11 Berechnung von Wöhlerlinien für Bauteile aus Stahl".

The high cycle fatigue (HCF) is to be assessed based on the above fatigue strengths, notch factors (i.e. geometrical stress concentration factors and notch sensitivity), size factors, mean stress influence and the required safety factor of 1.6 at 3 million cycles increasing to 1.8 at 10^9 cycles.

The low cycle fatigue (LCF) representing 10^4 cycles is to be based on the smaller value of yield or 0.7 of tensile strength/√3. The criterion utilises a safety factor of 1.25.

The LCF and HCF as given above represent the upper and lower knees in a stress-cycle diagram. Since the required safety factors are included in these values, a Miner sum of unity is acceptable.

6.6.5.3 Intermediate shafts

The intermediate shafts are to be designed to fulfil 6.5.2.2 to 6.5.2.4.

6.6.5.4 Shaft connections

6.6.5.4.1 Shrink fit couplings (keyless)

See 6.6.5.1.1. A safety factor of S = 1.8 shall be applied.

6.6.5.4.2 Key mounting

Key mounting is not permitted.

6.6.5.4.3 Flange mounting

The flange thickness is to be at least 20% of the required shaft diameter (IACS UR M34).

Any additional stress raisers such as recesses for bolt heads shall not interfere with the flange fillet unless the flange thickness is increased correspondingly.

The flange fillet radius is to be at least 8% of the shaft diameter (IACS UR M34).

The diameter of ream fitted (light press fit) bolts shall be chosen so that the peak torque is transmitted with a safety factor of 1.9. This accounts for a prestress. Pins shall transmit the peak torque with a safety factor of 1.5 against yielding ([Equation 63]).

The bolts are to be designed so that the blade failure load (5.4) in backward direction does not cause yielding.

6.6.5.4.4 Splined shaft connections

Splined shaft connections can be applied where no axial or bending loads occur. A safety factor of S = 1.5 against allowable contact and shear stress resulting from Q_{peak} shall be applied.

6.6.5.4.5 Gear transmissions

6.6.5.4.5.1 Shafts

Shafts in gear transmissions shall meet the same safety level as intermediate shafts, but where relevant, bending stresses and torsional stresses shall be combined (e.g. by von Mises for static loads). Maximum permissible deflection in order to maintain sufficient tooth contact pattern shall be considered for the relevant parts of the gear shafts.

6.6.5.4.5.2 Gearing

The gearing shall fulfil following three acceptance criteria:

- Tooth root stresses
- Pitting of flanks
- Scuffing

In addition to above 3 criteria subsurface fatigue may need to be considered.

Common for all criteria is the influence of load distribution over the face width. All relevant parameters are to be considered, such as elastic deflections (of mesh, shafts and gear bodies), accuracy tolerances, helix modifications, and working positions in bearings (especially for multiple input single output gears).

The load spectrum (see 6.6.5) may be applied in such a way that the numbers of load cycles for the output wheel are multiplied by a factor of (number of pinions on the wheel / number of propeller blades Z). For pinions and wheels operating at higher speeds the numbers of load cycles are found by multiplication with the gear ratios. The peak torque (Q_{peak}) is also to be considered during calculations.

Cylindrical gears can be assessed on the basis of the international standard ISO 6336 series (i.e. ISO 6336-1:2019, ISO 6336-2:2019, ISO 6336-3:2019, ISO 6336-4:2019, ISO 6336-5:2016 and ISO 6336-6:2019), provided that "method B" is used. Standards defined by the *Register* can also be applied provided that they are considered equivalent to the above mentioned ISO 6336.

For Bevel Gears the methods or standards used or acknowledged by the *Register* can be applied provided that they are properly calibrated.

Tooth root safety shall be assessed against the peak torque, torque amplitudes (with the pertinent average torque) as well as the ordinary loads (open water free running) by means of accumulated fatigue analyses. The resulting factor of safety is to be at least 1.5. (Ref ISO 6336 Pt 1, 3 and 6 and IACS UR M56)

The safety against pitting shall be assessed in the same way as tooth root stresses, but with a minimum resulting safety factor of 1.2. (Ref ISO 6336-1:2019, ISO 6336-2:2019 and ISO 6336-6:2019 as well as IACS UR M56).

The scuffing safety (flash temperature method – ref. ISO/TR 13989-1:2000 and ISO/TR 13989-2:2000) based on the peak torque shall be at least 1.2 when the FZG class of the oil is assumed one stage below specification.

The safety against subsurface fatigue of flanks for surface hardened gears (oblique fracture from active flank to opposite root) is to be assessed at the discretion of the *Register*. (It should be noted that high overloads can initiate subsurface fatigue cracks that may lead to a premature failure. In lieu of analyses UT inspection intervals may be used.)

6.6.5.4.5.3 Bearings

See section 6.6.5.8.

6.6.5.4.5.4 Gear wheel shaft connections

The torque capacity shall be at least 1.8 times the highest peak torque Q_{peak} (at considered rotational speed) as determined in 6.5 without exceeding the permissible hub stresses of 80% yield.

6.6.5.5 Clutches

Clutches shall have a static friction torque of at least 1.3 times the peak torque Q_{peak} and dynamic friction torque 2/3 of the static.

Emergency operation of clutch after failure of e.g. operating pressure shall be made possible within reasonably short time. If this is arranged by bolts, it shall be on the engine side of the clutch in order to ensure access to all bolts by turning the engine.

6.6.5.6 Elastic couplings

There shall be a separation margin of at least 20% between the peak torque and the torque where any twist limitation is reached.

$Q_{peak} < 0.8 \cdot T_{kmax}\ (N = 1)$ [kNm] [Equation 69]

There shall be a separation margin of at least 20% between the maximum response torque Q_{peak} (see Figure 6.5.6.3.2) and the torque where any mechanical twist limitation and/or the permissible maximum torque of the elastic coupling, valid for at least a single load cycle (N=1), is reached.

A sufficient fatigue strength shall be demonstrated at design torque level $Q_r(N = x)$ and $Q_A(N = x)$. This may be demonstrated by interpolation in a Weibull torque distribution (similar to Figure 6.5.5):

$\frac{Q_r(N=x)}{Q_r(N=1)} = 1 - \frac{\log(x)}{\log(Z \cdot N_{ice})}$ [-] [Equation 70]

respectively

$\frac{Q_A(N=x)}{Q_A(N=1)} = 1 - \frac{\log(x)}{\log(Z \cdot N_{ice})}$ [-] [Equation 71]

Where Q_r (N=1) corresponds to Q_{peak} and Q_A (N=1) to Q_{Amax}.

Q_r (N=5E4)$\cdot S < T_{Kmax}$ (N=5E4) [kNm] [Equation 72]

Q_r (N=1E6)$\cdot S < T_{KV}$ [kNm] [Equation 73]

Q_A (N=5E4)·S < ΔT_{max} (N=5E4) [kNm] [Equation 74]

S is the general safety factor for fatigue, equal to 1.5.

The torque amplitude (or range Δ) shall not lead to fatigue cracking, i.e. exceeding the permissible vibratory torque. The permissible torque may be determined by interpolation in a Weibull torque distribution where T_{Kmax1} respectively ΔT_{Kmax} refer to 50000 cycles and T_{KV} refer to 10^6 cycles.

See illustration in below Figure 6.6.5.6a, Figure 6.6.5.6b and Figure 6.6.5.6c.

$T_{Kmax1} \geq Q_r\ at\ 5 \cdot 10^4$ load cycles [kNm] [Equation 75]

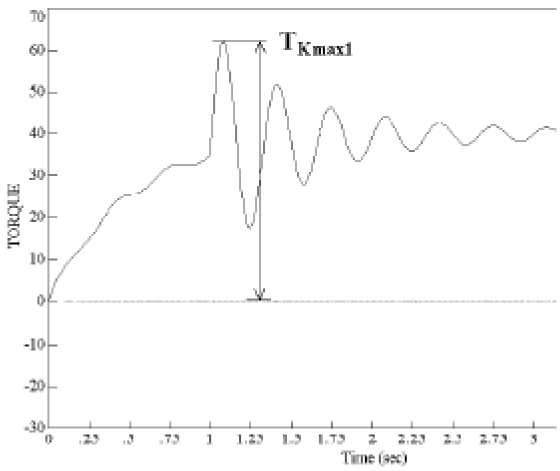


Figure 6.6.5.6a

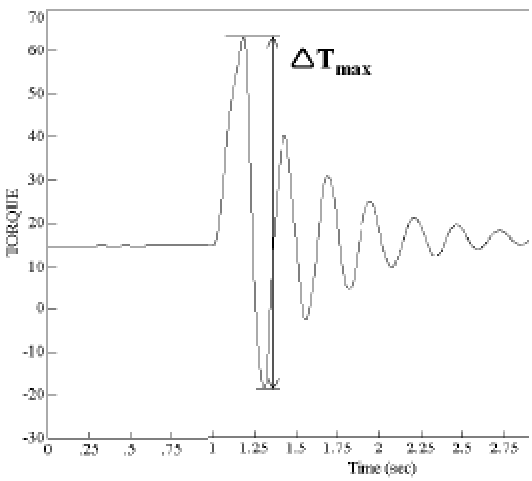


Figure 6.6.5.6b

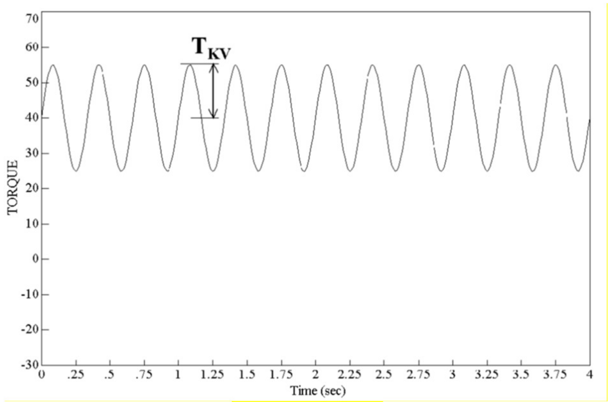


Figure 6.6.5.6c

6.6.5.7 Crankshafts

Special considerations apply for plants with large inertia (e.g. flywheel, tuning wheel or PTO) in the non-driving end front of the engine (opposite to main power take off).

6.6.5.8 Bearings

The aft stern tube bearing as well as the next shaft line bearing are to withstand F_{ex} as given in 6.5.4, in such a way that the ship can maintain operational capability. Rolling bearings are to have an L_{10a} lifetime of at least 40 000 hours according to ISO 281:2007. Thrust bearings and their housings are to be designed to withstand with a safety factor S = 1.0 the maximum response thrust 6.5.5 and the axial force resulting from the blade failure load F_{ex} in 6.5.4. For the purpose of calculation, except for F_{ex}, the shafts are assumed to rotate at rated speed. For pulling propellers special consideration is to be given to loads from ice interaction on the propeller hub.

6.6.5.9 Seals

Seals are to prevent egress of pollutants and be suitable for the operating temperatures. Contingency plans for preventing the egress of pollutants under failure conditions are to be documented.

Seals installed are to be suitable for the intended application. The manufacturer is to provide service experience in similar applications and/or testing results for consideration.

6.6.6 Azimuthing main propulsors

In addition to the above requirements, special consideration shall be given to those loading cases which are extraordinary for propulsion units when compared with conventional propellers. The estimation of load cases shall reflect the way the thrusters are intended to operate on the specific ship. In this respect, for example, the loads caused by the impacts of ice blocks on the propeller hub of a pulling propeller shall be considered. Furthermore, loads resulting from the thrusters operating at an oblique angle to the flow shall be considered. The steering mechanism, the fitting of the unit, and the body of the thruster shall be designed to withstand the loss of a blade without damage. The loss of a blade shall be considered for the propeller blade orientation which causes the maximum load on the component being studied. Typically, top-down blade orientation places the maximum bending loads on the thruster body.

Azimuth thrusters shall also be designed for estimated loads caused by thruster body/ice interaction. The thruster body shall withstand the loads obtained when the maximum ice blocks, which are given in section 6.5.2, strike the thruster body when the ship is at a typical ice operating speed. In addition, the design situation in which an ice sheet glides along the ship’s hull and presses against the thruster body should be considered. The thickness of the sheet should be taken as the thickness of the maximum ice block entering the propeller, as defined in section 6.5.2.

6.7 PRIME MOVERS

6.7.1 Propulsion engines

Engines are to be capable of being started and running the propeller in bollard condition.

Propulsion plants with CP propeller are to be capable being operated even when the CP system is at full pitch as limited by mechanical stoppers.

6.7.2 Starting arrangements

The capacity of the air receivers shall be sufficient to provide, without recharging, not less than 12 consecutive starts of the propulsion engine, if this has to be reversed for going astern or 6 consecutive starts if the propulsion engine does not have to be reversed for going astern.

If the air receivers serve any other purposes than starting the propulsion engine, they shall have additional capacity sufficient for these purposes.

The capacity of the air compressors shall be sufficient for charging the air receivers from atmospheric to full pressure in one (1) hour, except for a ship with the ice class PC6 to PC1, if its propulsion engine has to be reversed for going astern, in which case the compressor shall be able to charge the receivers in half an hour.

6.7.3 Emergency power units

Provisions shall be made for heating arrangements to ensure ready starting from cold of the emergency power units at an ambient temperature applicable to the Polar Class of the ship.

Emergency power units shall be equipped with starting devices with a stored energy capability of at least three consecutive starts at the above mentioned temperature. The source of stored energy shall be protected to preclude critical depletion by the automatic starting system, unless a second independent mean of starting is provided. A second source of energy shall be provided for an additional three starts within 30 min., unless manual starting can be demonstrated to be effective.

6.8 EQUIPEMENT FASTENING LOADING ACCELERATIONS

6.8.1 General

Essential equipment and supports shall be suitable for the accelerations as indicated in the following paragraphs. Accelerations are to be considered as acting independently.

6.8.2 Longitudinal Impact Accelerations, a_1

Maximum longitudinal impact acceleration at any point along the hull girder,

$$a_1 = \frac{F_{IB}}{\Delta} \cdot \left(1.1 \cdot \tan(\gamma + \varphi) + \left(7 \cdot \frac{H}{L}\right)\right) \quad [\text{m/s}^2] \quad [\text{Equation 76}]$$

6.8.3 Vertical acceleration, a_v

Combined vertical impact acceleration at any point along the hull girder,

$a_v = 2.5 \cdot \left(\frac{F_{IB}}{\Delta}\right) \cdot F_X$ [m/s^2] [Equation 77]

where is:

F_X = 1.3 at FP
= 0.2 at midships
= 0.4 at AP
= 1.3 at AP for vessels conducting ice breaking astern
Intermediate values to be interpolated linearly.

6.8.4 Transverse impact acceleration, a_t

Combined transverse impact acceleration at any point along hull girder,

$a_t = 3F_i \frac{F_X}{\Delta}$ [m/s^2] [Equation 78]

where is:

F_X= 1.5 at FP
= 0.25 at midships
= 0.5 at AP
= 1.5 at AP for vessels conducting ice breaking astern
Intermediate values to be interpolated linearly.

where:

φ = maximum friction angle between steel and ice, normally taken as 10 [degrees]
γ = bow stem angle at waterline [degrees]
Δ = displacement
L = length between perpendiculars [m]
H = distance in meters from the water line to the point being considered [m]
F_{IB} = vertical impact force, defined in IACS UR I2.13.2.1
F_i = total force normal to shell plating in the bow area due to oblique ice impact, defined in IACS UR I2.3.2.1

6.9 AUXILIARY SYSTEMS

6.9.1 Machinery shall be protected from the harmful effects of ingestion or accumulation of ice or snow. Where continuous operation is necessary, means should be provided to purge the system of accumulated ice or snow.

6.9.2 Means should be provided to prevent damage to tanks containing liquids due to freezing.

6.9.3 Vent pipes, intake and discharge pipes and associated systems shall be designed to prevent blockage due to freezing or ice and snow accumulation.

6.10 SEA INLETS AND COOLING WATER SYSTEMS

6.10.1 Cooling water systems for machinery that is essential for the propulsion and safety of the vessel, including sea chest inlets, shall be designed for the environmental conditions applicable to the ice class.

6.10.2 At least two sea chests are to be arranged as ice boxes (sea chests for water intake in severe ice conditions) for ice class PC1 to PC5 inclusive. The calculated volume for each of the ice boxes shall be at least 1m^3 for every 750 kW of the totally installed power. For PC6 and PC7 there shall be at least one ice box located preferably near centre line.

6.10.3 Ice boxes are to be designed for an effective separation of ice and venting of air.

6.10.4 Sea inlet valves are to be secured directly to the ice boxes. The valve shall be a full bore type.

6.10.5 Ice boxes and sea bays are to have vent pipes and are to have shut off valves connected directly to the shell.

6.10.6 Means are to be provided to prevent freezing of sea bays, ice boxes, ship side valves and fittings above the load water line.

6.10.7 Efficient means are to be provided to re-circulate cooling seawater to the ice box. Total sectional area of the circulating pipes is not to be less than the area of the cooling water discharge pipe.

6.10.8 Detachable gratings or manholes are to be provided for ice boxes. Manholes are to be located above the deepest load line. Access is to be provided to the ice box from above.

6.10.9 Openings in ship sides for ice boxes are to be fitted with gratings, or holes or slots in shell plates. The net area through these openings is to be not less than 5 times the area of the inlet pipe. The diameter of holes and width of slot in shell plating is to be not less than 20 mm. Gratings of the ice boxes are to be provided with a means of clearing. The means of clearing is to be of a type using low pressure steam. Clearing pipes are to be provided with screw-down type non return valves.

6.11 BALLAST TANKS

6.11.1 Efficient means are to be provided to prevent freezing in fore and after peak tanks and wing tanks located above the water line and where otherwise found necessary.

6.12 VENTILATION SYSTEMS

6.12.1 The air intakes for machinery and accommodation ventilation are to be located on both sides of the ship at locations where manual de-icing is possible. Anti-icing protection of the air inlets may be accepted as an equivalent solution to location on both sides of the ship and manual de-icing at the *Register's* discretion. Notwithstanding the above, multiple air intakes are to be provided for the emergency generating set and are to be as far apart as possible.

6.12.2 The temperature of the inlet air shall be suitable for:

- the safe operation of the machinery; and
- the thermal comfort in the accommodation.

Accommodation and ventilation air intakes shall be provided with means of heating, if needed.

6.13 STEERING SYSTEMS

6.13.1 Rudder stops are to be provided. The design ice force on rudder shall be transmitted to the rudder stops without damage to the steering system.

An ice knife shall in general be fitted to protect the rudder in centre position. The ice knife shall extend below BWL. Design forces shall be determined according to the IACS I2.15.

6.13.2 The rudder actuator is to comply with the following requirements in item 6.13.2.1 and item 6.13.2.2:

6.13.2.1 The rudder actuator is to be designed for a holding torque obtained by multiplying the open water torque resulting from the application of SOLAS Reg. II-1 /29.3.2 (considering however a maximum speed of 18 knots, by following factors:

Ice Class	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Factor	5	5	3	3	3	1.5	1.5

6.13.2.2 The design pressure for calculations to determine the scantlings of the rudder actuator is to be at least 1.25 times the maximum working pressure corresponding to the holding torque defined in 6.13.2.1 (Derived from SOLAS Reg. II-1 / 29.2.2).

6.13.3 The rudder actuator is to be protected by torque relief arrangements, assuming the following turning speeds [deg/s] without an undue pressure rise (ref IACS UR M42 for undue pressure rise):

Table 6.13.3
Steering gear turning speeds

Ice Class	PC1 and PC2	PC3 to PC5	PC6 and PC7
Turning speeds [deg/s]	10	7.5	6

If the rudder and actuator design can withstand such rapid loads, this special relief arrangement is not necessary and a conventional one may be used instead (IACS UR M42).

6.13.4 Additionally for icebreakers, fast-acting torque relief arrangements are to be fitted in order to provide effective protection of the rudder actuator in case of the rudder being pushed rapidly hard over against the stops.

For hydraulically operated steering gear, the fast-acting torque relief arrangement is to be so designed that the pressure cannot exceed 115% of the set pressure of the safety valves when the rudder is being forced to move at the speed indicated in Table 6.13.4, also when taking into account the oil viscosity at the lowest expected ambient temperature in the steering gear compartment.

For alternative steering systems the fast-acting torque relief arrangement is to demonstrate an equivalent degree of protection to that required for hydraulically operated arrangements.

The turning speeds to be assumed for each ice class are shown in table 6.13.4 below.

Table 6.13.4
Steering gear turning speeds for icebreakers

Ice Class	PC1 and PC2	PC3 to PC5	PC6 and PC7
Turning speeds [deg/s]	40	20	15

The arrangement is to be designed such that steering capacity can be speedily regained.

6.14 ALTERNATIVE DESIGN

6.14.1 As an alternative to this Section – a comprehensive design study may be submitted and may be requested to be validated by an agreed test programme.