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Ships and marine technology — Ship structures —

Part 1: General requirements for their limit state assessment

Navires et technologie maritime — Structures des navires —

Partie 1: Exigences générales pour l'évaluation de l'état limite ultime

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 18072-1 was prepared by Technical Committee ISO/TC 8, *Ships and marine technology*, Subcommittee SC 8, *Structures*.

ISO 18072 consists of the following parts, under the general title *Ships and marine technology — Ship structures*:

— *Part 1: General requirements for their limit state assessment*

— *Part 2: Requirements for their ultimate strength limit state assessment*

ISO/CD 18072-2 is under development by the same working group as ISO 18072-1 (WG 3 of SC 8), while two separate working groups will be established later to develop the rest of the ISO 18072 series, namely ISO 18072-3, *Requirements for their fatigue limit state assessment* and ISO 18072-4, *Requirements for their accidental limit state assessment*.

Introduction

The ISO 18072 series of standards constitutes a common basis for addressing the limit state assessment of ship structures.

It uses the limit state approach rather than the allowable (working) stress approach, since it is now well recognized that the former is a more rational basis than the latter for determining true safety margins of structures. The ability to correctly determine the safety margin is a key to the ability to design a safe, yet economical structure.

Traditional design methods and standards have been based largely on working stress concepts. The standards used by Classification Societies, shipbuilders, and others have evolved over many years, and incorporate analytical methods, as well as experience gained from ships in service. Because the limit state approach explicitly addresses the concept of safety margin, its results differ in some areas compared to those of the working stress approach. Both approaches provide safe and reliable structures, if used appropriately, although neither will guarantee freedom from failures or structural problems. In either approach, a rigorous programme of inspection and maintenance during construction and periodically thereafter, and operational guidelines, supplement the design criteria and assumptions to provide an acceptable level of structural safety throughout a ship's service life.

The ISO 18072 series of standards is intended to serve as a basis for quantitatively defining a consistent and realistic safety margin for ship structures. An ability to more rationally assess the true margin of safety should also lead to improvements in related regulations and design requirements as well. Through its application, the intention is to achieve levels of structural integrity appropriate for ship structures, whatever the nature or combination of the materials used.

This part of ISO 18072 addresses general requirements for the assessment of ship structures based on four types of limit state, namely, serviceability limit state (SLS), ultimate limit state (ULS), fatigue limit state (FLS) and accidental limit state (ALS), while the other parts of ISO 18072 will address specific requirements for these different limit states.

The assessments in accordance with these limit states necessarily require definitions of loading, analysis, materials and construction standards. In-service inspections are prescribed as appropriate in each part of ISO 18072.

It is clear that a strength assessment is closely related to structural design. However, the initial determination of structural dimensions and scantlings is not included in the ISO 18072 series, it being presumed that procedures and guidelines for these are provided in detail elsewhere, such as in the relevant rules and regulations of classification societies or regulatory bodies' requirements.

While ISO 18072 has been prepared in accordance with the principles described in ISO 2394 and ISO 19900:2002, such principles have been extended as necessary to deal with those specific to ship structures.

Ships and marine technology — Ship structures —

Part 1: General requirements for their limit state assessment

1 Scope

This part of ISO 18072 provides general requirements for the limit state assessment of ship structures primarily used in the transport of commercial goods and cargos. For the purposes of assessment, the effects of actions on ship structures are considered in respect of the following limit states: serviceability, ultimate, fatigue and accidental.

The requirements of this part of ISO 18072 are applicable to global ship structures, as well as the structural components and details forming such structures. The requirements are applicable during the design, construction and operation of ship structures. The requirements are also applicable to the conversion of existing structures. Aspects related to quality control and quality assurance are also addressed.

Whilst the major part of this document assumes the use in an assessment of a partial-factor approach, an approach based on probabilistic methods may also be adopted.

Whilst compliance with the requirements of this and other parts of ISO 18072 may be used to demonstrate the structural adequacy of a ship structure or its component, compliance with other international and national standards, rules and regulations is required, as applicable to the ship considered. The ship owner is responsible for ensuring compliance with all such standards, rules and regulations.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 2394, *General principles on reliability for structures*

ISO 19900:2002, *Petroleum and natural gas industries — General requirements for offshore structures*

ISO 19904-1:2006, *Petroleum and natural gas industries — Floating offshore structures — Part 1: Monohulls, semi-submersibles and spars*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 2394, ISO 19900 and ISO 19904-1 apply, except as provided for below. For convenience, some important terms and definitions given in ISO 2394, ISO 19900 or ISO 19904-1 are repeated below, in which case the source is identified in square brackets.

3.1
abnormal
condition that exceeds conventionally specified design conditions and which is used to mitigate against very remote events

[ISO 19904-1:2006]

3.2
accidental design situation
design situation involving exceptional conditions of the structure or its exposure

EXAMPLE Impact, fire, explosion, local failure or loss of intended differential pressure (e.g. buoyancy).

[ISO 19904-1:2006]

3.3
action
external load applied to the structure (direct action) or an imposed deformation or acceleration (indirect action)

EXAMPLE An imposed deformation can be caused by fabrication tolerances, settlement or temperature change.

[ISO 19900:2002]

3.4
action effect
effect of actions on a global structure or structural component

EXAMPLE Internal forces, moments, elastic deformations, stresses, strains or rigid body motions.

3.5
aged structure
an existing structure which suffers age-related deterioration such as corrosion and fatigue cracks

3.6
assessment situation
set of physical conditions during a certain reference period for which the structure demonstrates that relevant limit states are not exceeded

3.7
basic variable
one of a specified set of variables representing physical quantities which characterize actions, material properties or geometrical parameters

3.8
characteristic value
value assigned to a basic variable or action or resistance model which has a prescribed probability of not being violated by unfavourable values

NOTE 1 In the case of an action or action variable, the value normally relates to a reference period.

NOTE 2 In some situations, a variable or model can have two characteristic values, an upper and a lower value.

3.9
design criteria
quantitative formulations that describe the conditions to be fulfilled for each limit state

3.10
design service life
assumed period for which a structure or a structural component is to be used for its intended purpose with anticipated maintenance, but without substantial repair being necessary

[ISO 19904-1:2006]

3.11
design situation
set of physical conditions during a certain reference period for which the design demonstrates that relevant limit states are not exceeded

[ISO 19904-1:2006]

3.12
design value
value of a basic variable or action or strength model derived from a representative value for use in a design verification procedure

NOTE 1 For a ULS design check, a design value for a strength variable or model is found by dividing the representative value of strength by a partial resistance factor, while for an action variable it is found by multiplying the representative value of the action effect by a partial action factor.

NOTE 2 For an FLS, SLS or ALS design check in accordance with the partial-factor design format, all partial factors are equal to unity so that, in these cases, a design value is equal to the representative value.

NOTE 3 In the case of actions and related properties, the value can relate to a reference period.

[ISO 19904-1:2006]

3.13
dynamic action
action that induces motions and accelerations in a structure or a structural component of a magnitude sufficient to require specific consideration

EXAMPLE Action effects arising from slamming or sloshing.

3.14
extreme action
maximum action applied to a structure during its design service life

EXAMPLE Extreme environmental action.

3.15
fit-for-purpose, adjective
fitness-for-purpose, noun
meeting the intent of a standard although not meeting specific provisions of that standard in local areas, such that failure in these areas cannot cause unacceptable risk to life-safety or the environment

[ISO 19904-1:2006]

3.16
global structure
an entire structure or an assembly of structural components

3.17
green water
overtopping of deck by water causing slamming and pressure actions to structures on deck

3.18
limit state
condition beyond which a structure or structural component no longer fulfils relevant design criteria

3.19
merchant cargo ship
a ship carrying merchant cargoes

3.20
nominal value
value assigned to a basic variable or action or strength model determined on a non-statistical basis, typically from acquired experience or physical conditions

EXAMPLE Value published in a recognized code or standard.

NOTE Adapted from ISO 19904-1:2006.

3.21
partial factor
a factor normally greater than unity applied to a representative value of a strength or action to determine its corresponding design value

EXAMPLE Partial action factor, partial resistance factor.

3.22
reference period
period of time used as basis for determining values of basic variables and action models

NOTE This term normally only applies to basic variables related to actions or action effects.

3.23
reliability
ability of a structure or a structural component to fulfil the specified requirements

[ISO 19900:2002]

3.24
repetitive actions
repeatedly applied actions

3.25
representative value
value assigned to a basic variable or action or strength model for verification of a limit state

NOTE 1 The representative value can equal a characteristic value, a nominal value, or other rationally determined value.

NOTE 2 For actions, this can relate to upper or lower characteristic values, dependent on which causes the more onerous condition. In combinations, it can involve multiplying the chosen value by a factor greater or less than unity.

NOTE 3 Adapted from ISO 19904-1:2006.

3.26
return period
average period between occurrences of an event or of a particular value being exceeded

NOTE For environmental events, much engineering design and assessment commonly use the return period measured in years. The return period is equal to the reciprocal of the annual probability of exceedance of the event.

[ISO 19904-1:2006]

3.27
safety margin
a difference between structural strength and maximum value of an action effect, by which a structure or component reserve with respect to failure can be quantified

3.28
scrapping
process of decommissioning a structure and removing hazardous materials at the end of its service life

3.29
slamming
impulsive action with high-pressure peaks that occurs during impact between a portion of the structure and water

NOTE 1 Bottom slamming occurs when the ship's bottom emerges from the water because of pitching, possibly combined with the occurrence of a wave trough. Bow-flare slamming occurs when the upper flared portion of the bow plunges into the water.

NOTE 2 A slamming action to the deck structure is generally referred to as green water.

3.30
sloshing
actions arising from the motion of liquids in partially filled tanks

3.31
stability
hydrostatic stability
ability of a floating structure to generate righting moment after deviation from the equilibrium floating position

3.32
still-water actions
differences between weight and buoyancy effects on a stationary structure

3.33
structural component
structural element, any sub-structure or physically distinguishable part of a structure

EXAMPLE Column, beam, stiffeners, plating, stiffened panel.

3.34
structural failure
insufficient strength or inadequate serviceability of a structure or structural component or, in a structural check, a condition in which a structure or component thereof does not fulfil its limit state requirement

NOTE Adapted from ISO 19904-1:2006.

3.35
structural resistance
capacity of a structure, component or cross-section of a component to withstand action effects without exceeding a limit state

NOTE 1 Structural resistance is a particular value of structural strength.

NOTE 2 Adapted from ISO 19904-1:2006.

3.36
structural strength
mechanical property of a material indicating its ability to resist actions, usually given in units of stress

3.37
structural system
load-bearing components of a structure and the way in which these components function together

[ISO 19900:2002]

3.38
structure
organized combination of connected parts designed to withstand actions and provide adequate strength, rigidity and stability

3.39
uncertainty
a general description of the randomness of a basic variable or action or strength model which, when quantified, provides a basis by which characteristic values and partial action and strength factors can be determined

EXAMPLE Bias, standard deviation.

4 Symbols and abbreviated terms

NOTE The symbols used generally are listed below. Those which are not general and which are used only in one clause (and are explained there) are not listed.

4.1 Symbols

A accidental action

a_d design value of geometrical parameter

a_r representative value of geometrical parameter

C SLS constraint

E environmental action

f_d design value of material strength

f_r representative value of material strength

F_d design value of action

F_r representative value of action

G permanent action

G_r representative value of permanent action

g limit state function

Q variable action

Q_k characteristic value of variable action

Q_r representative value of variable action

R_d design value of component strength

R_r representative value of component strength

γ_d factor related to model uncertainty or other circumstances that are not taken into account by other γ values

γ_f partial action factor, the value of which reflects the uncertainty or randomness of the action

γ_m partial material factor, the value of which reflects the uncertainty or variability of the material property

γ_n factor by which the importance of the structure and the consequences of failure, including the significance of the type of failure, may be taken into account and whose value depends on the design situation under consideration

γ_R partial resistance factor, the value of which reflects the uncertainty or variability of the component strength as a function of material properties

Δa additive partial geometrical quantity, the value of which reflects the uncertainties of the geometrical parameter

ψ_0 knock-down factor to account for the reduced likelihood of independent actions simultaneously achieving their maximum values

ψ_1, ψ_2 factors relating characteristic values to representative values for variable actions

4.2 Abbreviated terms

ALS accidental limit states

CP cathodic protection

FLS fatigue limit states

SLS serviceability limit states

ULS ultimate limit states

5 General requirements and conditions

5.1 Fundamental requirements

Ship structures are subjected to various types of actions and action effects during construction, in-service and dry-docking, and during related maintenance activities, that range from normal to extreme, abnormal and accidental.

A ship structure and its structural components shall be designed, constructed and maintained so that it performs its intended functions against such actions and effects during its design service life while maintaining floating stability. In particular, it shall fulfil the following performance requirements with appropriate degrees of reliability:

— perform adequately under all expected actions (SLS requirement);
— withstand actions liable to occur during its construction and design service life (ULS requirement);
— does not fail under repetitive actions (FLS requirement);
— subsequent to accidental or abnormal events, shall not be damaged disproportionately to the original cause and shall maintain its structural integrity for a sufficient period under specified environmental conditions (ALS requirement).

Appropriate degrees of structural reliability depend upon:

— the cause and mode of structural failure;
— the possible consequences of structural failure in terms of risk to life, environment and property;
— the expense and effort required to reduce the risk of structural failure;
— different requirements at national, regional or local level.

This part of ISO 18072 presents requirements for ship structures and their components so that the above requirements are fulfilled during construction and design service life.

In the process of limit state assessment, this part of ISO 18072 assumes that the ship structure has been well built, operated and maintained in accordance with either classification requirements and/or other standards.

5.2 Functional requirements

Ships can be categorized depending on their primary functions, for example:

— to transport goods and cargoes;
— to transport passengers;
— to provide military capability;
— to provide fishing;
— to provide dredging;
— to provide recreation;
— to provide supporting services to other ships;
— to provide a platform for scientific research or other miscellaneous functions.

This part of ISO 18072 primarily deals with the general requirements for ships that transport goods and cargoes, although it is readily applicable to other categories of ships. The requirements include those associated with the loading and discharging (unloading) of such goods and cargos.

Particular functional requirements shall be established for each ship taking account of the goods and cargoes to be transported and operational conditions, for which appropriate design situations shall be established and corresponding design criteria provided.

5.3 Materials and structure

Suitable materials shall be specified. In addition to strength, attention shall be paid to ductility or toughness, weldability, and corrosion resistance requirements.

Failure in a structure should occur in a ductile manner rather than a brittle manner. Avoiding brittle failure leads to a structure that does not collapse suddenly, because ductility allows a structure to redistribute internal forces and thus absorbs more energy prior to failure. Adequate ductility in the design of a structure shall be facilitated by:

— meeting requisite material-toughness requirements;

— avoiding failure initiation situations of combined high stress concentrations and undetected weld defects in structural components and details;

— designing structural details and connections, so as to allow a certain amount of plastic deformation, i.e. avoiding “hard spots”;

— arranging the scantlings of structures and their components so as to avoid sudden changes in structural strength or stiffness.

5.4 Structural configuration

5.4.1 General

The choice of the structural system shall be made such that the primary structure is able to maintain adequate structural integrity during normal service and after specified situations that apply actions on the structure. The choice of materials, detailing and method of construction, as well as quality assurance, can influence structural integrity.

5.4.2 Structural scantlings

The initial determination of structural dimensions and scantlings can be made in accordance with the relevant rules and regulations of classification societies or regulatory body requirements.

Calculations based on first principles may also be applied for the structural scantlings.

5.4.3 Hydrostatic stability

Ship floating behaviour shall be consistent with the requirements for stability in intact and damaged configurations, in accordance with recognized standards.

When recognized standards are used to verify stability adequacy, consideration shall also be given to the consequences of the accidental events identified as being relevant for the structure, see 5.9.2.

5.4.4 Compartmentation

Ship structures shall be subdivided into water-/oil-tight compartments by bulkheads to limit the consequences of unintended flooding (see 5.10.4.4). Such bulkheads should be assessed for adequacy to prevent progressive flooding.

The amount of compartmentation shall be determined, based on special conditions and protection measures that can be used to prevent flooding. A risk assessment can assist in this determination.

5.5 Operating routes and extreme metocean conditions

The operating route(s) shall be specified, together with relevant meteorological and oceanographical (metocean) conditions. This metocean information shall identify extreme conditions that recur with an appropriate return period.

Extreme and other metocean parameters should be determined from actual measurements or by suitable validated model data, such as from hindcast models.

EXAMPLE Ships are designed for a return period of 20 to 25 years on a joint probability basis. On the other hand, offshore structures are designed for a return period of 100 years, given a typical design service life of 20 years; site assessment of jack-ups is based on a return period of 50 years (combination of extremes).

5.6 Operational and design-service-life requirements

The loading of goods, cargoes and other items can impose significant still-water bending moments and shears on ship structures, particularly when the loading is not performed in accordance with relevant loading manuals. Such loading, when performed in accordance with a loading manual, shall be treated as ULS and FLS assessments. When not performed in accordance with a loading manual, the loading shall be treated as an ALS assessment.

Service requirements and design service life shall be specified and documented for future reference.

Other hazards likely to occur during the design service life are collisions, grounding, fire, explosion, dropped objects or unintended flooding. These shall be identified as described in 5.9 and should normally be treated within an ALS assessment.

5.7 Material protection

The structural arrangement shall be adequately protected against corrosion. The method of protection shall be suitable for its intended position and purpose.

Protection of material used in ship construction can be achieved through the use of corrosion-resistant materials, the application of suitable coatings to materials that corrode, a cathodic protection system, the adoption of a corrosion margin, or a combination of these.

External surfaces located in the zone that is most severely exposed to wave action should be protected against corrosion by systems that are able to withstand the environmental actions in this zone.

The system for corrosion protection of surfaces that are submerged under seawater (e.g. external surfaces, ballast tanks, etc.) should normally include a cathodic protection (CP) system with the possible addition of a suitable protective coating system. Excessive levels of CP should be avoided to minimize the possibility of debonding of coatings and the possibility of hydrogen absorption, leading to hydrogen-assisted cracking of weld heat-affected zones.

The corrosion protection philosophy (e.g. full corrosion protection throughout the lifetime of the ship structure, corrosion thickness allowance) shall be fully consistent with the assumptions and criteria utilized in the assessment of the minimum dimensions for the scantlings.

When assessing ship structures, the expected rate and extent of any corrosion wastage may be estimated on the basis of calculations, experimental investigations, statistical analysis of measurements, experience from similar structures or a combination of these.

5.8 In-service inspection, maintenance and monitoring

Comprehensive structural inspection and maintenance programmes shall be developed for the structure and emergency and other essential marine equipment, as a means of monitoring the integrity of the ship structure throughout its design service life. Such programmes shall take into account the frequency of inspection.

In-service inspection procedures shall be developed and undertaken to confirm that modifications, alterations, and maintenance are undertaken in compliance with appropriate design drawings, specifications, and procedures.

Inspections shall be undertaken regularly or on special occasions such as, for example, following extreme environmental, abnormal or accidental events.

Failure of corrosion protection, such as coating breakdown, should be examined. Sacrificial anodes should also be examined for depletion and replaced if not in a satisfactory condition, taking due account of inspection intervals. CP potential measurements may be used to demonstrate the satisfactory performance of sacrificial anodes.

Impressed current system anodes and cathodes shall be checked for damage, fouling by marine growth and carbonate deposits.

Any repairs or replacements to the CP system shall be recorded appropriately.

Where repairs are required, these should be undertaken in order to prevent significant deterioration occurring between inspection intervals.

The necessity for relevant parts of the structure to be available for inspection, without unreasonably complicated dismantling, shall be considered during design.

Consideration shall be given to the installation of a hull stress-monitoring system to assist in maintaining action effects during loading and discharging and in extreme environmental events within the capability of the ship structure.

5.9 Hazards

5.9.1 General

Hazardous circumstances, that alone or in combination with normal conditions could cause the SLS or ULS to be exceeded, shall be taken into account.

Possible hazards to the structure and its components include

— an error caused by lack of information, omission, misunderstanding, etc.,

— effects of abnormal actions, or

— operation malfunction that could lead to sinking, explosion, etc.

The measures taken to counter such hazards basically consist of

— careful planning at all phases of development and operation,

— avoiding the structural effects of hazards, by either eliminating the source or by bypassing and overcoming them,

— minimizing the consequences, or

— designing for the hazards.

In considering a specific hazard, an assessment situation shall be defined (see 6.3). This assessment situation will normally be dominated by one hazardous occurrence with expected concurrent normal operating conditions.

5.9.2 Accidental and abnormal events

The possibility of accidental and abnormal events shall be considered, and suitable criteria shall be established, when appropriate. Possible accidental events include, for example, collisions, grounding, unintended flooding, explosions, and dropped objects such as impacts from loading equipment.

5.9.3 Formal risk assessment

Some of the items listed in 5.9.1 and 5.9.2 can be identified, assessed or performed as part of a formal risk assessment, which is an appropriate general procedure for identifying hazards, quantifying the associated risks, and determining approaches for the mitigation of their consequences.

The results of limit state assessment can be used as a basis of consequence analysis in the process of the formal risk assessment.

Accordingly, consideration shall be given to the conduct of an appropriate formal risk assessment prior to the execution of an assessment.

5.10 Assessment situations

5.10.1 General

Actions and combinations of actions, including those caused by environmental actions, to which a ship structure is subjected whilst performing its primary functional role, shall be described as assessment situations associated with normal use of the structure.

Actions to which a structure is subjected when in port, in ballast, and docking afloat and during construction, dry-docking, tank cleaning, and throughout the ship's service life, in general, shall also be covered by suitable assessment situations. Allowance shall be made, as appropriate, for any co-existing environmental actions and any differences between arrival and departure conditions, and for any other actions or action effects that can result in utilizations that exceed the assessment criteria.

Three sets of expected situations shall normally be established as follows.

— Normal conditions which are expected to occur frequently during the design service life of the structure. These define the environmental actions associated with in-service and operational phenomena required for SLS and FLS assessments;

— extreme conditions that recur with a given return period or probability of exceedance. These define the environmental actions associated with in-service and operational phenomena required for ULS assessment;

— accidental or abnormal conditions which are expected to occur infrequently during a structure's design service life. Normally, two situations shall be addressed, the first relating to the intact structure at the time of the event, and the second relating to the damaged structure following the event. The combinations needed to define the actions for these ALS assessments involve in-service and operational phenomena, environmental parameters, and definitions of damage and/or abnormal events.

Normal, extreme and accidental or abnormal values of parameters shall be determined from measurements and other observations along the route or site of operation of the structure, or from predictions by suitable validated simulations (e.g. hindcast models in the case of environmental parameters) of such values.

Effects of normal and extreme environmental actions shall be determined, accounting for resonance and natural period motions and unintended phenomena associated with the structure and its components, the loading or discharging of cargo, and ballasting/deballasting. The effects shall be determined, recognizing that extreme values are not always associated with the maximum values of the action causing the effect. For example, the maximum ship response to waves is normally associated with a wave of length approximately equal to the length of a ship. The height of such waves is usually less than that of the maximum wave height in the return period for extreme conditions.

When accounting for combinations of events, particularly where natural period effects are significant, various combinations of environmental actions and in-service and operational phenomena shall be investigated to determine extreme responses (action effects). Values of the responses to be used in an assessment shall be those responses that have the same probability of exceedance as those required for extreme environmental actions.

The phenomena listed in 5.10.2 through 5.10.4 shall, to the extent relevant, be taken into account in an assessment. Subclause 5.10.2 describes in-service and operational phenomena, 5.10.3 describes the phenomena associated with environmental conditions and 5.10.4 addresses accidental and abnormal phenomena.

These phenomena shall be described by physical characteristics and, where available, statistics. The joint occurrence of different values of the various phenomena shall be defined using appropriate data where available. From this information, appropriate assessment conditions shall be established that consider the following:

- the type of structure;
- the type of cargo to be carried;
- the proposed trading route(s);
- phase of assessment (i.e. new building, conversion, existing structure);
- the limit states.

5.10.2 In-service and operational considerations

5.10.2.1 Cargo loading and discharging situations

All sets of possible goods and cargo loading and discharging situations which include the laden and partial loading conditions shall be established.

Local action effects, such as impacts from loose cargo dropped from cranes, etc., and from the equipment used in loading and discharging, shall be accounted for.

For each component, the situation or combination of situations which gives rise to the severest action effect shall be selected as the cargo loading or discharging assessment situation. The situations given in 5.10.2.2 and 5.10.2.3 shall also be considered in selecting the cargo loading or discharging assessment situation.

5.10.2.2 Ballast situation

The situation where no cargo but only ballast water is loaded shall be considered. Permanent ballast shall also be considered.

5.10.2.3 Partial loading/partial ballast situation

The partial loading and partial ballast situation shall be considered.

5.10.2.4 Operating parameters

The operating parameters, in terms of speed, heading and other relevant factors shall be specified, as appropriate.

5.10.2.5 Structural deterioration

Structural deterioration due to corrosion and mechanical damage from operation and similar (e.g. fatigue cracks, local dents) shall be taken into account, to the extent that may be expected for a well operated and maintained ship. In cases where the actual condition or special circumstances expected may lead to a severer deterioration, such effects shall also be taken into account.

NOTE 1 Corrosion usually appears as non-protective, friable rust, largely on internal surfaces that are unprotected. Two types of corrosion are normally relevant, i.e. general (uniform) corrosion and localized corrosion. The general corrosion reduces the plate thickness uniformly, while localized corrosion, for example, pitting or grooving, causes deterioration in localized regions. The characteristics of corrosion progress are time-variant.

NOTE 2 In design, a design corrosion margin which is determined as a representative maximum predicted thickness loss for the entire life of a structure is added to the structure that has been designed for the relevant design demands alone and subject to a specified maintenance scheme.

NOTE 3 In a localized strength assessment, the corrosion margin which has been added in design is normally not included. However, sensitivity of the hull girder-section modulus to differential loss of the corrosion allowance can need consideration in global strength assessment.

5.10.2.6 Thermal variations

The maximum, average and minimum temperatures of cargoes shall be considered when temperatures are likely to be relevant for structural strength assessment.

5.10.3 Environmental phenomena

5.10.3.1 Waves

Actions caused by waves acting on a structure shall be considered in a strength assessment of the global structure and its structural components. The following information shall be established:

— the sea state characteristics along the operation route(s) of the ship, in terms of height, period, duration, directions and spectra;

— the long-term statistics of these characteristics, which will be used for SLS, FLS and ULS assessment of newly built structures;

— the short-term statistics of these characteristics which will be used for ULS or ALS assessment of existing structures, without or with damage due to structural deterioration or accidental events.

NOTE Today, most larger merchant cargo ships for unrestricted service are normally classed for a service life of 20 to 25 years, and the shipbuilding industry uses a return-period environmental event equivalent to the design service life, as the basis of structural design (see 5.5).

5.10.3.2 Wind

Actions on a structure caused by wind shall be considered for both global and local assessments.

Wind-induced actions shall be determined by means of wind tunnel tests and/or suitable analytical methods. Validated computational fluid dynamic methods may be used where appropriate.

The total wind velocity can be described as the sum of the mean wind component and a gust component.

5.10.3.3 Currents

Actions caused by currents shall be considered for both global and local assessments accounting for both indirect actions, such as current effects on wave encounter frequency, and direct actions, such as when moored. All appropriate sources of currents shall be considered: tidal, wind-driven, etc.

5.10.3.4 Ice and snow

The accumulation of ice and snow on horizontal and vertical surfaces (thickness and density) shall be defined, together with the appropriate parameters for the other environmental phenomena (wind and waves) to be considered in conjunction with ice and snow accumulation. In addition, the possibility of ice build-up through freezing of sea spray, rain or fog shall be considered. Sea ice and iceberg occurrences shall be considered when applicable. Collisions with icebergs shall also be considered in accordance with 5.10.4.2.

5.10.3.5 Temperature

The maximum, average and minimum temperatures of air and sea along the operation route(s) of ships shall be determined when temperatures are relevant for the strength assessment.

5.10.4 Accidental and abnormal situations

5.10.4.1 Loss of hydrostatic stability and of reserve buoyancy

The floating behaviour of the ship shall be consistent with the requirements for stability in both intact and damaged configurations. The loss of reserve buoyancy and stability shall be considered when assessing damaged conditions.

5.10.4.2 Collisions

Actions caused by collisions shall be considered. The range of collisions addressed shall be consistent with those identified as typical for the considered ship type, trading routes and areas, via a suitable risk assessment or from existing information.

The extent of the collision zone shall be based on the following.

— In the case of an impact from another ship, the depth and draught of the striking ship, and on the relative horizontal and vertical motions between the struck and striking ships. Particular attention shall be given to collisions that can occur during operations in and when approaching and leaving port.

— In the case of an impact with a fixed object (natural or artificial), the depth and draught of the considered ship and its motion relative to the object. Particular attention shall be given to ship manoeuvres in moving water (flowing rivers and strong tidal areas) and in the vicinity of bridges and the like.

The magnitude of the collision-induced action shall account for added mass effects.

Structural components located in areas where encounters with harbour structures during berthing, at berth and when departing from a berth, or with assisting ships (e.g. tugs), shall be capable of absorbing the energy due to casual contact.

Emergency and essential marine equipment shall be placed away from possible collision zones.

5.10.4.3 Grounding

Actions caused by grounding shall be considered. The range of groundings addressed shall be consistent with those identified as typical for the considered ship type, trading routes and areas, via a suitable risk assessment or from existing information.

5.10.4.4 Unintended flooding

Actions subsequent to unintended seawater ingress into ship compartments shall be considered. As a minimum, the range and number of compartments considered shall be consistent with relevant regulatory requirements. Unintended flooding can cause hydrostatic instability or loss of reserve buoyancy (see 5.10.4.1).

5.10.4.5 Local damage

Local damage (e.g. dents) caused by cargo handling equipment (e.g. cranes, crawlers) shall be considered.

5.10.4.6 Fire and explosions

The effects of fire and explosions shall be considered. The range and combination of fires and explosions addressed shall be consistent with those identified as typical for the considered ship type via a suitable risk assessment or from existing information, and, as a minimum, shall be consistent with relevant regulatory requirements.

The effects of material property deterioration associated with temperature, during and after the fires and explosions shall be taken into account.

5.11 Construction situations

5.11.1 General

All situations pertinent to construction, including, where appropriate, fabrication, launching, load-out, transportation and out-fitting that can lead to critical action combinations for the ship structure or its components, shall be assessed. Such assessment shall account for appropriate environmental actions.

Initial deformations and residual stresses developed during construction shall be taken into account in particular applications of the limit state assessment.

5.11.2 Welding

The consequences of welding and its quality assurance requirements implemented during fabrication shall be determined. In addition to welding residual stresses, this should identify fracture toughness levels, particularly in more highly stressed regions and at support regions for emergency and essential marine equipment.

5.11.3 Cold-forming

The consequences of cold-forming and its quality assurance requirements implemented during fabrication shall be determined in the form of straining.

5.12 Scrapping

Where appropriate, the situations associated with the scrapping of the ship at the end of its design service life shall be assessed.

5.13 Special requirements

Requirements for construction, operation, inspection and maintenance that can affect the safety and integrity of the structure but are not covered by 5.1 to 5.12, shall also be considered together with their expected concurrent environmental actions.

6 Principles of limit state assessment

6.1 General

The structural performance of the ship structure and its components shall be described with reference to a specified set of limit states, beyond which the structure no longer satisfies its design or assessment requirements. Annex A describes some considerations for limit state design and assessment.

Exceedance of a limit state can be either reversible or irreversible. For the reversible case, removal of the cause of the exceedance allows the structure to return to a desired state. The irreversible case results in permanent localized or global damage, even after removal of the cause of the exceedance.

Limit states may be classified into four categories:

— serviceability limit states (SLS) which represent criteria governing normal functional or operational use;

— ultimate limit states (ULS) which correspond to checking the structure's ability to resist extreme actions and action effects;

— fatigue limit states (FLS) which represent criteria governing the cumulative damage effects of repetitive actions;

— accidental limit states (ALS) which investigate the structure's ability to resist accidental and abnormal events, and the structure's resistance to the effects of specified environmental actions after damage has occurred as a consequence of an accidental or abnormal event.

In a limit state assessment, the various limit states are assessed according to different safety margins. The safety margin, to be achieved in respect of a particular limit state, is a function of its perceived consequences and ease of recovery from that state.

6.2 Limit state considerations

6.2.1 Serviceability limit states (SLS)

The identification of SLS for ship structures shall be based on a number of considerations, including the following:

— unacceptable deformations which affect the efficient use of structural or non-structural components or the functioning of equipment relying on them;

— local damage (including corrosion, cracking) which reduces the durability of the structure or affects the efficiency of structural or non-structural components;

— vibrations, motions or noise which can injure or adversely affect the performance of passengers and personnel;

— motions that exceed the limitations of functionality of equipment or affect the proper functioning of equipment (especially if resonance occurs);

— deformations that spoil the aesthetic appearance of the structure.

The assessment criteria associated with SLS shall typically be based on motions, deflections or vibration limits during normal use of the structure. Excessive deformations can be indicative of excessive vibrations or noise, because inter-relationships exist between the various phenomena being considered but which, for convenience, are usually treated separately.

The SLS criteria shall be defined by the operator of a structure, or by established practice, the primary aim being efficient and economical in-service performance without discomfort to on-board passengers and personnel or excessive routine maintenance.

The acceptable limits necessarily depend on the type, mission and arrangement of the structure. Furthermore, in defining such limits, other disciplines, such as equipment and machinery designers, shall also be consulted.

6.2.2 Ultimate limit states (ULS)

ULS for ship structures include:

- failure of critical components of the structure caused by exceeding the ultimate strength (in some cases reduced by repetitive actions) by any combination of buckling, yielding, rupture or fracture;
- transformation of the structure into a mechanism associated with collapse or excessive deformation.

ULS typically occur under extreme actions or action effects.

An adequate reserve of strength shall exist between the onset of a ULS for part of the structure and a global ULS.

6.2.3 Fatigue limit states (FLS)

The repetitive actions that typically cause FLS of ship structures arise from wave actions, cargo loading and discharging, vibrations, etc.

The intention of an FLS assessment shall be to check whether the structure has an adequate fatigue life. The FLS assessment can also form the basis for planning inspection and maintenance programmes during the design service life of the structure.

6.2.4 Accidental limit states (ALS)

ALS for ship structures potentially relate to:

- serious injury or loss of life;
- pollution of the environment;
- damage and loss of property or financial expenditure.

The intention of an ALS assessment is to ensure that the structure shall be able to tolerate specified accidental and abnormal events and, where damage occurs, subsequently maintains structural integrity for a sufficient period under specified environmental conditions to enable the following to take place, as relevant:

- evacuation of passengers and personnel from the structure;
- control over movement or motion of the structure;
- temporary repairs;
- fire fighting;
- minimizing outflow of cargo or stored material liable to cause environmental damage or pollution.

Such subsequent assessment requires consideration of a reduced extreme environmental situation. This situation should be established with the intention of resulting in the most onerous seasonal action effects for a return period of one year.

Different types of accidental or abnormal events may require different methodologies or different levels of the same methodology to analyze structural resistance during and following such events.

6.3 Limit state assessment situations

Several sets of distinct assessment situations shall be considered. For each set and within each set, different environmental conditions can apply, different safety margins can be required and different criteria can be set.

Limit state assessment situations to be considered usually consist of at least the following:

- persistent situations, having a duration of the same order as the design service life of the structure;
- transient situations, having a shorter duration and varying levels of intensity, e.g. construction, conversion and repair phases;
- accidental and abnormal situations (during and after such events), normally of short duration and low possibility of occurrence.

7 Basic variables

7.1 General

The calculation model expressing each limit state under consideration shall contain a specified set of basic variables. In general, the basic variables correspond to measurable physical quantities.

Normally, the basic variables characterize:

- actions;
- properties of materials;
- geometrical parameters;
- fabrication-induced initial imperfections (usually in the case of limit states relating to buckling and ultimate strength checks);
- structural deterioration (in the case of limit states relating to condition assessment of existing structures, see Clause 11).

7.2 Actions

7.2.1 General

Actions may be classified by

- their variation with time,
- their variation in space, or
- the structural response to such actions.

Different partial action factors apply depending on their classification, and hence a description of each classification is required.

7.2.2 Classification of actions according to their variation with time

Actions shall be classified according to the variation of their magnitude with time as follows

- permanent actions;
- variable actions;
- environmental actions;
- repetitive actions;
- accidental or abnormal actions.

7.2.2.1 Permanent actions (G)

These actions are likely to act throughout a given design situation and for which variations in magnitude with time are

- negligible in relation to the mean value, and
- attain some limiting value.

Permanent actions generally include:

- self-weight of structures;
- weight of permanent fixtures and functional equipment;
- deformations imposed during construction;
- deformations due to differential support settlement during fabrication;
- actions resulting from distortions due to welding;
- actions resulting from external hydrostatic pressure.

7.2.2.2 Variable actions (Q)

These actions are likely to act throughout a given design situation, but do not include environmental actions. Variable actions generally include:

- actions due to passengers and personnel occupancy;
- actions both local and overall associated with loading and discharging of cargo either directly (dropping, etc.) or indirectly (crane actions, crawler actions, etc.);
- actions associated with berthing and departing, including moorings and fendering, tug actions, etc.;
- actions associated with ballasting and deballasting;
- actions associated with stored materials, fuel, equipment, etc.;
- deformations due to global bending of the hull;
- actions associated with possible movement of cargo during transit, including sloshing;

— self-weight of temporary structures and equipment;

— actions caused during construction;

— all moving actions, such as for movable lifting equipment;

— deformations due to temperature changes (including sea and air temperature).

7.2.2.3 Environmental actions (E)

These actions can be repeated, sustained or both repeated and sustained. Environmental actions generally include:

— actions caused by waves;

— actions caused by wind;

— actions caused by current;

— actions resulting from marine growth, snow and accumulated ice, and their indirect effects on variable actions and other environmental actions;

— actions caused by ice (direct);

— environmental temperature changes, as they can induce actions or affect material properties.

7.2.2.4 Repetitive actions

Actions of which the magnitude vary with time and occur repeatedly can lead to cumulative damage effects. The actions are normally wave-induced but can include the effects of sloshing, as well as cargo loading and discharging and ballasting and deballasting if relatively frequent or where long design service lives are planned or experienced.

7.2.2.5 Accidental actions (A)

Accidental actions typically result from:

— collisions;

— grounding;

— dropped objects, including cargo and equipment;

— fire;

— explosions;

— leaks;

— unintended cargo loading or discharging sequences;

— unintended changes in ballast distribution;

— change in intended pressure difference;

— unintended flooding.

7.2.3 Classification of actions according to their variation in space

Actions shall also be classified according to their variation in space as

- fixed actions which have a constant spatial distribution over the global structure, in respect of position, magnitude and orientation, or
- free actions whose position, magnitude and orientation can vary with respect to the structure.

The treatment of free actions requires the consideration of different arrangements and combinations of such actions. Assessment situations shall be determined by arranging and combining free actions, in order to maximize their effects on the structure or on its components.

7.2.4 Classification of actions according to the structural response

Actions shall be further classified according to the way in which the structure responds to an action as

- static actions that produce static or quasi-static responses, i.e. no significant acceleration of the structure or its components, or
- dynamic actions that cause motion and acceleration of the structure or its components significant enough to require specific consideration (e.g. rigid body motions, dynamic pressure due to slamming or sloshing).

Where it can be demonstrated to apply, simplified approaches (dynamic amplification factors, inertial load sets) may be used to account for dynamic effects.

7.2.5 Other classifications of actions

Other classifications shall be considered, where necessary, in particular applications. For example, classification according to material-dependent aspects can be needed to address the effects of creep.

7.3 Properties of materials

The values describing the properties of materials and their variability shall be based on either specific qualification tests or *in situ* observations in conjunction with other sources of information.

Properties relating to special test specimens shall be converted to the relevant properties of the actual material in the structure, by the use of conversion factors or functions that take account of scale effect and dependence on time and temperature. The uncertainty associated with material in the structure shall be derived from the uncertainties of the standard test results and of the conversion factor or function.

7.4 Geometrical parameters

Geometrical parameters that define the shape, size and overall arrangement of the structure, its components and cross-sections shall be defined. When the deviation of any of the geometrical parameters from its prescribed value can have a significant effect on the behaviour and the strength of the structure, the magnitude and variability of the deviation shall be taken into account by prescribed tolerance limits. Such an effect can also be reflected in the safety margin required in the limit state assessment.

NOTE In many cases, the random variability of geometrical parameters can be considered to be small compared with the variability of the actions and of material properties. In such cases, the geometrical parameters can be assumed to be non-random, and taken as specified initially in the design stage.

7.5 Fabrication-induced initial imperfections

For particular situations, fabrication-induced initial imperfections in the form of initial distortions and residual stresses affect performance, and consequently can be considered as basic variables in the limit state assessment.

7.6 Structural deterioration

For particular situations especially relating to the assessment of aged structures, consideration of structural deterioration plays a major role. In such circumstances, the parameter quantifying the deterioration may be treated as a basic variable.

Subclause 11.2.4 addresses the requirements for dealing with deterioration when conducting a condition assessment.

NOTE Age-related structural deterioration, such as corrosion and fatigue cracks, is normally time-dependent.

8 Analysis, calculation and model testing

8.1 General

Generally, the process of the limit state assessment consists of the following:

— global action and response modelling; analysis of the global actions to which the structure is subjected including evaluation of natural frequencies and rigid body motions to provide the forces, moments, accelerations and displacements acting on the structure;

— global structural analysis: determination of action effects (generalized internal forces and moments) on cross-sections of the structure;

— global strength modelling: evaluation of cross-sectional strengths;

— local strength modelling: determination of action effects and strengths of localized features and details such as discontinuities of cross-sections and connections and, in the case of complex ship structures, to determine the strengths of components of cross-sections to provide, through integration, cross-sectional strengths.

Additionally, for the SLS assessment, deformation, vibration and noise level effects are evaluated.

For the FLS assessment, action effects at localized features and details (discontinuities and connections) are considered in detail.

For the ALS assessment, the procedure also includes:

— selection of relevant actions (see 7.2.2.5) and the corresponding level of accepted damage (see 6.2.4); in addition, after an event, the structure is assessed to withstand environmental actions for an acceptable time period to enable the evacuation of personnel and for protection of the environment.

The analysis of a structure may be carried out by calculation, model testing or prototype structure testing. A combination of these methods may also be used.

Features of the structure that have a significant influence on its overall stability and integrity shall be checked and maintained throughout all stages of the structure's life.

Where similar structures have been designed for similar conditions, a simplified procedure may be applied if this can be shown to meet the requirements outlined in this part of ISO 18072.

For a probabilistic assessment, analyses of the uncertainties associated with actions, action effects and strengths and their determination are also required.

8.2 Calculation

Calculation models and basic assumptions for the limit state assessment shall describe the actions, responses and action effects according to the limit state under consideration.

For the purpose of analysis, a structure may be idealized as an assembly of one-dimensional components (e.g. beams, columns), two-dimensional components (e.g. plates, stiffened panels, shells) and three-dimensional components (e.g. solids).

For the calculation of global responses and action effects, both static and dynamic analyses shall be applied as appropriate. Linear modelling may be used except in the following cases when non-linear solutions shall be considered unless it can be demonstrated that a linear model alone or with non-linear corrections provides a satisfactory solution:

— extreme wave conditions - when non-uniform ship hull shapes are important (leading, for example, to differences between sagging and hogging bending moments);

— wave threshold effects - green water and similar events;

— accidental events.

For a ULS assessment, a linear analysis of action effects may be used, except in cases where the ULS response of the structure or component is not well understood or documented. In these cases, a non-linear analysis shall be performed accounting for large deflection effects, and the onset and progressive development of material yielding including welding and rolling residual stress and strain-rate effects, as appropriate. Simplified methods and closed-form solutions may also be used, provided they have been documented to realize satisfactory representation of the limit state under consideration.

For an FLS assessment, a linear analysis shall normally be used except when a non-linear fracture mechanics solution is being performed, in which case, the analysis may normally be restricted to an area in the immediate vicinity of the crack tip.

For an ALS assessment, proven theories using unconventional representation of resistances may be considered when appropriate (plastic deformation, reserve strength analysis, etc.), providing the results are reasonably insensitive to minor modifications in the definition of the event considered. In treating free actions, simplified spatial models for each action shall be defined and used, in order to define different action arrangements. For a given structure, the action arrangement that is the most unfavourable shall be selected.

The influence of the environmental conditions on the behaviour of materials shall be considered in the analysis when appropriate.

EXAMPLE High temperatures during a fire influence the strain distribution in, and the strength of, structural components.

8.3 Model testing

A structure or its components may be assessed on the basis of results from appropriate model testing coupled with the use of model analysis to predict the behaviour of the structure.

Validity of the conversion of model test results to full scale shall be ensured. Assessment based on model testing shall account for the inherent uncertainties in the tests by using appropriate partial factors.

Model testing on a small scale shall typically be carried out to verify simplified calculation methods and closed-form formulations.

NOTE Examples of model testing are buckling and plastic collapse testing of stiffened plate structures, and wave basin testing for ship motions.

8.4 Prototype testing

A structure or its components may be assessed on the basis of results from testing of prototype full-scale units relevant to the particular situation under consideration. Assessment based on prototype testing shall account for the inherent uncertainties in the tests by using appropriate partial factors.

8.5 Existing reference

A structure or its components may be assessed on the basis of results from an existing structure relevant to the particular assessment situation under consideration.

9 Limit state assessment requirements

9.1 General

For any limit state assessment, a structure and its components shall normally be expected to demonstrate adequate reliability in respect of all applicable limit states. The following limit state assessment formats shall be applied either alone or in combination:

— probabilistic format;

— partial-factor format.

Application of the probabilistic format shall be in accordance with ISO 2394 and shall normally be used when deriving partial action and resistance factors for application of the partial-factor format. It may also be used to deal with specific issues such as assessment situations, for which partial factors have not been determined.

Application of the partial-factor format may be used for a typical limit state assessment of a ship structure and its components. The application shall be in accordance with the requirements of this part of ISO 18072.

9.2 Partial-factor format

The partial-factor format separates the influence of uncertainties and variabilities originating from different causes by means of partial factors.

When conducting the limit state assessment, the values assigned to basic variables or action or strength models are design values.

Design values of actions, strictly action effects, F_d, shall be determined by multiplying representative values of action effects, F_r, by partial action factors, γ_f:

$$F_d = \gamma_f \cdot F_r \tag{1}$$

Design values of strengths of materials, f_d, shall be determined by dividing representative values of material strengths, f_r, by partial material factors, γ_m:

$$f_d = f_r / \gamma_m \tag{2}$$

Alternatively to Equation (2), design values of component strengths, R_d, may be determined directly from representative values of strengths, R_r, by dividing by partial resistance factors, γ_R:

$$R_d = R_r / \gamma_R \tag{3}$$

Other relevant properties may be treated in a similar way or by introducing an additional safety margin.

Design values of geometrical parameters, a_d, shall be determined from their representative values, a_r, from:

$$a_d = a_r \pm \Delta a \quad (4)$$

For a description of representative and design values for actions, strengths and geometrical parameters, see 9.3, 9.4 and 9.5.

The condition for a limit state not being exceeded may be expressed in the following general form:

$$g(F_d, f_d, R_d, a_d, C, \gamma_n, \gamma_d) > 0 \quad (5)$$

The parameter C in Equation (5) refers to SLS constraints (see 6.2.1) while γ_n and γ_d are factors defined in 4.1. The factor γ_d should take different values, depending on the degree of confidence in the calculation model as an accurate representation of the real structure or structural component.

NOTE Many sources of variability have been identified in design and construction, such as imperfect mathematical modelling, standards of construction, the difference between test and *in situ* material properties and workmanship. A common feature of these uncertainties is that, while it is possible to identify them qualitatively, it is not always possible to quantify them.

9.3 Actions and their combinations

9.3.1 Representative values

Wherever possible, actions and their random variations shall be established on the basis of observations, laboratory tests or field data.

Other sources of information, such as judgment on the basis of experience with the type of use or physical constraints, shall also be taken into account. Values obtained within this group of information are termed “nominal values”.

For different assessment situations (see 6.3), different values may be assigned to each action. These values are called representative values.

Where a representative value is based on a characteristic value, two such values are possible, i.e. an upper and a lower value. In situations where the effect of a reduction in an action is more dangerous for the structure, the lower value shall be taken as the more unfavourable.

Other representative values shall be chosen with regard to some features of the situation, for example, duration of exposure and other phenomena.

A permanent action G generally has a unique representative value. When the action consists of the self-weight of the structure, the value G_r shall be obtained from the intended values of the geometrical parameters (generally taken from drawings) and the mean density of the material. In cases where the uncertainties in the permanent actions are important, the characteristic values shall be used. In such cases, both upper and lower characteristic values shall be defined, if necessary.

Representative values of variable actions Q_r shall be defined by one of the following:

— the characteristic value Q_k;

— the frequent value $\psi_1 Q_k$, where $\psi_1 \leqslant 1$;

— the sustained value (quasi-permanent value) $\psi_2 Q_k$, where $\psi_2 \leqslant 1$;

— the expected repeated action history values (for FLS assessment).

For particular situations, other representative values may be specified.

The representative value shall be taken as the maximum (or minimum) value that produces the most unfavourable effect in the structure under consideration. The value shall be determined either as being for permanent actions, i.e. mean or calculated, or as a specified value from a recognized source (e.g. classification society rules or national regulations).

If representative values for variable or accidental actions cannot be determined from statistical data or where appropriate data are not available, the corresponding values may then be estimated on the basis of available information. In this case, the representative value corresponds to a nominal value.

Representative values of environmental influences are normally characteristic values defined by an annual exceedance probability of the response to environmental conditions. Alternatively, the environmental action itself may be defined to have a specified return period, if adequate data on the joint occurrence of meteorological and oceanographic (metocean) conditions and on the ship's response characteristics so permit and provided that the partial factors are selected accordingly.

Some accidental actions may be defined by authorities rather than being based on an annual exceedance probability.

In treating repetitive actions for FLS assessment, rather than determining a single representative value, it is necessary to establish their variation in magnitude with time, in order to determine the number of repeated actions of each magnitude.

9.3.2 Design values

An action shall be introduced into the calculation by its design values, which are obtained from the representative values by multiplication by partial factors, as defined by Equation (1).

The partial factors γ_f shall take account of

— the possibility of unfavourable deviations of the actions from their representative values, and

— uncertainty in the calculations of actions.

The partial factor γ_f depends on the limit state considered. In particular, the factors for ULS and for SLS are different: for the SLS, γ_f is normally 1,0. Also, the partial factors γ_f may be different for different action sources within an action type (see 7.2).

9.3.3 Combinations of actions

A combination of actions is an assembly of the design values of a set of different actions considered simultaneously in the checking of a limit state. Actions that are mutually exclusive should not enter together into the same combination. The actions shall be combined so that they produce the most unfavourable effect on the structure for the limit state considered.

To take account of the reduced probability of simultaneous occurrence of unfavourable values of several independent actions, values of variable actions may be reduced by a factor ψ_0. This shall, in principle, be done so that the probability of exceeding the design action effect achieves the same level of reliability otherwise achieved by this part of ISO 18072.

In the ULS assessment, the following two types of combinations shall be applied:

— fundamental combinations (i.e. combinations of permanent actions, variable actions and normal environmental actions);

— extreme combinations (i.e. combinations of permanent actions, variable actions and extreme environmental actions, for example, related to a specified return period for environmental conditions).

Accidental or abnormal actions shall be included in ALS combinations only. Accident combinations shall normally include permanent actions, variable actions and one accidental action. An accident combination shall also account for effects associated with an accidental situation, such as the decrease of strength due to temperature during a fire.

For the FLS assessment, the cumulative damage effect of all repetitive actions during the design service life of the structure shall be considered and taken into account, if relevant.

For particular applications, other combinations may also be applied. For each of these types of combinations, special sets of combination factors may be specified.

9.4 Material properties and component strengths

9.4.1 Representative values

The characteristic value of a material property shall be specified as that value which has a specified probability of being attained in a hypothetical unlimited test series and corresponds to a fractile in the distribution of the material property. Material values specified by recognized codes and standards may be assumed to be characteristic values. Representative values of material properties normally coincide with characteristic values.

In cases where the material property varies in time or where environmental action effects cause alterations to the material, the characteristic value shall be chosen to take such alterations into account.

For the FLS assessment, rather than using a simple characteristic material property value, a fatigue endurance curve is generally required, representing the material or component endurance when subjected to repetitive actions of various magnitudes.

For component strengths, characteristic values shall be those values which have a specified probability of not being attained in a hypothetical unlimited test series and correspond to a fractile in the distribution of the component strength, usually the 5 % fractile where the lower value of component strength is unfavourable and the 95 % fractile where the higher value of component strength is unfavourable. However, the uncertainties associated with strength model testing, and with the interpretation of the test results, usually lead to representative values of component strengths that depart significantly from the 5 % (or 95 %) values.

Component strengths are normally expressed as functions of the geometry of the component and of the strength of the material from which it is constructed. Such component strengths can generally be expected to include the uncertainties associated with geometry parameters but not the uncertainties associated with material strengths.

9.4.2 Design values

Design values of material strength (or other material properties) shall be obtained from representative values using Equation (2). The partial factor γ_m shall take into account the following:

— the possibility of unfavourable deviations of material strength, interpreted as a random variable, from its characteristic value;

— possible inaccurate assessment of the strength of sections or parts of the structure (if not included in γ_m);

— uncertainties in geometrical parameters, if they are not taken into account according to 9.5.2 or included in γ_m;

— uncertainties in the relationship between the material properties of the structure and those measured by tests on control specimens, for example, uncertainties in the conversion factor or function according to 8.4.

The value of the partial factor γ_m depends on the material property, the actual limit state and component strength uncertainty.

Design values of component strengths shall be obtained from their representative values using Equation (3). In this case, the partial factor γ_R shall take account of the above uncertainties and, in addition:

— uncertainties in the relevant design expression for strength, i.e. the calculation model, see 9.8.

9.5 Geometrical parameters

9.5.1 Representative values

The representative values of geometrical parameters usually correspond to the nominal values specified in the design.

9.5.2 Design values

In cases where deviations of the geometrical parameters have insignificant effects or where the effects are accounted for by partial factors, representative values of geometrical parameters may be used as design values.

9.6 Fabrication-induced initial imperfections

The need to consider values of fabrication-induced initial imperfections depends on the type of assessment being conducted. The effects of fabrication-induced initial imperfections that lie within normal construction tolerance requirements are usually implicitly included in the equations adopted for component strength models and thus do not require explicit consideration.

Some component strength models can be readily modified to account for fabrication-induced initial imperfections that fall outside tolerance requirements, in which case the corresponding partial resistance factor may still be appropriate. Other strength models can require considerable additional effort, including the introduction of parameters to represent the fabrication-induced initial imperfections, as well as comparison of strength predictions with relevant test results in order to statistically quantify strength model uncertainties. Such uncertainty assessment can also possibly provide for the derivation of appropriate partial resistance factors which, as a minimum, shall coincide with the value of the partial resistance factor corresponding to the within-tolerance component strength model.

For structural components where little or no construction experience exists, appropriate mathematical models may be used to estimate likely levels of fabrication-induced initial imperfections. In such cases, allowance shall be made to account for likely differences between the mathematical model representation of fabrication-induced initial imperfections and those expected in practice, and the sensitivity of the corresponding strength model to the magnitude of the fabrication-induced initial imperfections.

9.7 Structural deterioration

9.7.1 Representative values

Representative values of each type of structural deterioration shall normally be determined as the 95 % fractile from measurements or model testing, which shall give more unfavourable situations.

When measurements or model testing are not available, relevant mathematical models may be used to predict such representative values.

9.7.2 Design values

Design values for structural deterioration shall be obtained from representative values multiplied by a factor ($\geqslant$ 1,0) whose value depends on the sensitivity of the component strength model to the magnitude of such structural deterioration, and whether the representative value is based on measurements or model testing, or on a mathematical model. If based on a mathematical model, the factor applied to convert representative values into design values shall be larger than the equivalent factor based on measurements or model testing.

9.8 Uncertainties in calculation models

Uncertainties in calculation models shall be evaluated through the use of small-scale model tests, prototype full-scale tests and measurements, detailed (e.g. non-linear) mathematical models, or comparisons between simplified and detailed mathematical models. The uncertainties shall be taken into account when deriving corresponding partial action and resistance factors.

9.9 Determination of partial-factor values

The partial-factor format is intended to be the normal method for executing the limit state assessment. In this format, the appropriate level of structural reliability is obtained through partial factors (or other additive safety margins) derived in accordance with ISO 2394.

NOTE SLS partial factors are normally taken as 1,0. Different safety levels are achieved by using different values of factor C in Equation (5). ALS partial factors are normally taken as 1,0 because the inherent uncertainties in the actions and the resistances are large, and because of the safety margin implicit in the representative value adopted for actions.

10 Quality control and quality assurance

10.1 General

Quality control procedures and quality assurance processes shall be implemented during planning, design, construction and operation of a structure, in order that the properties of the structure, when completed and when in use, are consistent with the assumptions made during design. This is important because the present standard for the limit state assessment presumes that the ship has been well built, operated and maintained.

The general requirements are to ensure the following:

— fulfilment of the design requirements;

— mitigation of the potential for error and unfavourable deviations from design plans and specifications.

10.2 Responsibilities

Responsibilities shall be defined and documented for all activities and their interfaces during all phases of development. Scopes of individual responsibility shall be made known to all concerned.

10.3 Inspection during construction

10.3.1 Materials inspection

Inspection shall verify that all materials being incorporated into any portion of the structural system are in accordance with the specified requirements. Materials procurement and delivery practices shall ensure the traceability of materials, including consumables used in fabrication, by marking and record keeping.

10.3.2 Fabrication inspection

Fabrication inspection shall address all specified design requirements, including the parameters of processes applied to components during different phases of fabrication, dimensional control, alignment, tolerances, orientation, surface treatments, assembly weights, etc.

NOTE 1 Ship structures are typically fabricated by a heat process such as flame cutting and welding, and subsequently initial imperfections in the form of initial geometric distortions and residual stresses develop and reduce structural capacity, hence the need to satisfy relevant tolerance limits.

NOTE 2 When local heating is applied to steel, the heated zone will tend to expand but, because it is surrounded by cooler material, it will be subjected to compressive stresses. Upon cooling, the heated zone shrinks locally, generating tensile stresses of sufficient magnitude to distort the surrounding structure if not adequately controlled.

NOTE 3 Both welding residual stresses and distortions are minimized by application of proper welding procedures and fabrication methods. Effective welding procedures include the correct positioning of components before welding, appropriate weld sequencing, minimizing of weld metal volume, minimizing the number of passes, preheating and post-weld heat treatment.

10.3.3 Launching inspection

Following launching, inspection shall be undertaken to ensure that it has not resulted in damage to the structure prior to its use.

10.4 In-service inspection and maintenance

The structure shall be maintained in such a way that it can fulfil its intended use with an appropriate margin of safety. Inspection shall be undertaken at regular intervals and on special occasions, to check for possible structural damage or deterioration.

Maintenance shall be specified accounting for the importance, use, accessibility and durability of components, the environmental conditions and the protection against external actions. Repairs shall be undertaken promptly to avoid deterioration between inspections.

References regarding inspection and maintenance shall be made to applicable rules and conventions requiring surveys and inspections.

10.5 Operational limits

Relevant information on operational limits shall be provided, in a usable form, to personnel responsible for the ship's operation and maintenance.

The information shall include at least the following:

- a loading manual defining tank-filling patterns and levels, specific gravities of relevant fluids, and load cases;
- any sea state limits and headings relative to such seas;
- corrosion limits;
- ambient temperature limits;
- cargo temperature limits.

10.6 Records and documentation

During all phases (planning, design, construction and operations), relevant data shall be recorded and documented for future reference.

11 Condition assessment of existing structures

11.1 General

The limit state assessment shall be carried out for the purpose of a condition assessment of existing structures. The need for a condition assessment shall be considered when an existing structure

— has approached its design service life,

— has deteriorated or has been damaged significantly,

— will be used in a manner inconsistent with the original design assumptions,

— has departed from the original basis of design, for example, because of conversion, or

— is intended to undergo a major structural modification.

The assessment shall determine fitness-for-purpose, for those aspects of the design that have been identified as no longer complying with original design criteria. This may involve justifying a deviation from the basis of design or conducting modifications to the structure or its operations, to achieve compliance with the intent of this part of ISO 18072.

Where operational experience shows that the acceptability of aspects of a design is uncertain, fitness-for-purpose shall be determined by specific assessment, and appropriate measures taken to maintain acceptable standards of performance.

11.2 Survey of structural conditions

11.2.1 General

When an existing structure requires the condition assessment, it cannot be assumed that the structure condition and the actions originally used for design remain valid.

Parameters relating to the original structure that can be more rationally defined from information generated at the time of design, construction and installation (for example, weights and material properties) shall be reviewed, and may be taken into account in the condition assessment.

11.2.2 In-service and operating conditions

Any significant changes from the original in-service and operational design situations that affect the limit states of the structure shall be reviewed.

11.2.3 Environmental conditions

The original design environmental criteria shall be reviewed, based on available data. The criteria shall be increased or reduced, if necessary, and used in the condition assessment.

11.2.4 Structural deterioration

11.2.4.1 General

The records of testing, inspection and maintenance conducted during the structure’s operating life shall be reviewed to ascertain if there are any defects or trends of deterioration that require repair or justification in the limit state assessment process. When such records are insufficient or incomplete, further surveys shall be conducted, to the extent necessary to redefine the values of the parameters required for the condition assessment.

11.2.4.2 Fabrication-induced initial imperfections

Fabrication-induced initial imperfections can be expected to change with operational use; generally geometrical distortions increase whilst residual stresses reduce. Account shall be taken of such modifications when use is made in a condition assessment of initial records taken at the time of construction, or of updated records taken as a precursor to a condition assessment.

11.2.4.3 Corrosion wastage

The effect of corrosion wastage shall be included in the assessment. The magnitude of such wastage shall be defined by measurements. To account for the future impact of wastage on the performance of a structure, use may be made of calibrated mathematical models for time-dependent corrosion wastage.

NOTE The mathematical models for predicting time-dependent corrosion wastage are usually developed by a statistical analysis of corrosion measurements. Because corrosion is a function of many variables and uncertainties are involved, such as the type of corrosion protection system employed, type of cargo, temperature, humidity, etc., care is required in the application of such models.

11.2.4.4 Fatigue cracks

The effect of accumulated fatigue damage shall be included in the assessment. The magnitude of such damage shall be defined by measurements, fracture mechanics or crack growth studies and/or detailed fatigue analyses of prior service, and the results of the structure’s inspection histories.

11.2.4.5 Local impacts

The effect of local impact damage (e.g. dents) shall be included in the assessment. The magnitude of such damage shall be defined by measurements.

11.3 Action effects

Currently recognized methods of action calculation shall be used. When available, records of measured actions and responses of the structure may be taken into consideration.

Joint occurrence of environmental parameters, for both direction and probability of joint occurrence may be considered, provided that the overall probability of extreme action occurrence is not less than that required.

Where the structure has been instrumented and the measured actions and responses calibrated against the measured environment, these records may be used in a condition assessment.

NOTE The assessment is normally based on current methods of action calculation. Where appropriate, more advanced methods of action calculation can be used to represent the development of actions in a more realistic and possibly a less conservative manner.

11.4 Strength

Currently recognized methods of strength calculation shall be used. The effects of deterioration (see 11.2.4), or modifications on the strength of the structure shall be taken into account.

If a structure that has been originally designed to meet previous editions of this or other standards is assessed, it shall be checked using the procedures given in this part of ISO 18072.

11.5 Fatigue

The adequacy of the fatigue life for the intended remaining life of the structure shall be addressed, and shall be taken into account when planning any future inspection and maintenance requirements.

The accumulated fatigue damage shall be assessed via fracture mechanics or crack growth studies and/or detailed fatigue analyses of prior service, and the results of the structure’s inspection histories. Details with the highest fatigue utilizations shall be inspected for fatigue cracks before service.

11.6 Limit state assessment format

Either the probabilistic or partial-factor format may be adopted in a condition assessment, see 9.1.

When using the probabilistic format, it may be necessary to determine an appropriate target reliability for the condition assessment of the structure using a probabilistic assessment of a new version of the same or similar structure.

It may not be possible to show that individual components of older structures meet normal code requirements or normal levels of reliability. In such cases, yielding or failure of individual components may be considered, provided the remaining parts of the structural system have sufficient reserve strength to redistribute the effect of the action. A global ultimate strength analysis is one approach that may be used to demonstrate that the safety margin against limit states of the structural system meets acceptable levels. The effect of action redistribution on low- as well as high-cycle fatigue may also need to be considered.

When it is not possible to show that the structure is acceptable by analysis, repairs or strengthening may be required. Alternatively, when strengthening is not a viable option, decreased reliability of the structural system can be acceptable, provided that the consequences of component failure are acceptable.

11.7 Updating of inspection and maintenance programmes

Relevant information and data resulting from a condition assessment of an existing structure shall be used in the planning of future inspection and maintenance programmes for the structure.

Where decreased reliability of the structural system has been accepted, inspection and maintenance programmes for the affected components shall be modified accordingly.

Annex A
(informative)

Considerations for limit states

A.1 SLS

SLS criteria are normally based on limits for deflections, vibration or noise during normal use. In practice, excessive deformation can also be indicative of excessive vibration or noise reflecting inter-relationships between the criteria being considered but defined separately for convenience.

The SLS criteria are normally defined by the operator of a structure, or by established practice, the primary aim being efficient and economical in-service performance without complaints from passengers or operational personnel, or excessive routine maintenance. Acceptable limits necessarily depend on the type, mission and arrangement of the structure. Furthermore, when defining such limits, consultation with other disciplines, such as machinery designers, is required.

For steel plate elements, elastic buckling-based criteria are often employed with SLS criteria, in some cases to prevent such occurrence, and in other cases to allow elastic buckling to a known and controlled degree.

Elastic plate buckling and the related effects, such as relatively large lateral deflections, are not acceptable if such effects are likely to be detrimental. On the other hand, since plates have reserve strength beyond elastic buckling up to their ultimate strength, allowing elastic buckling in a controlled manner usually leads to a more efficient structure.

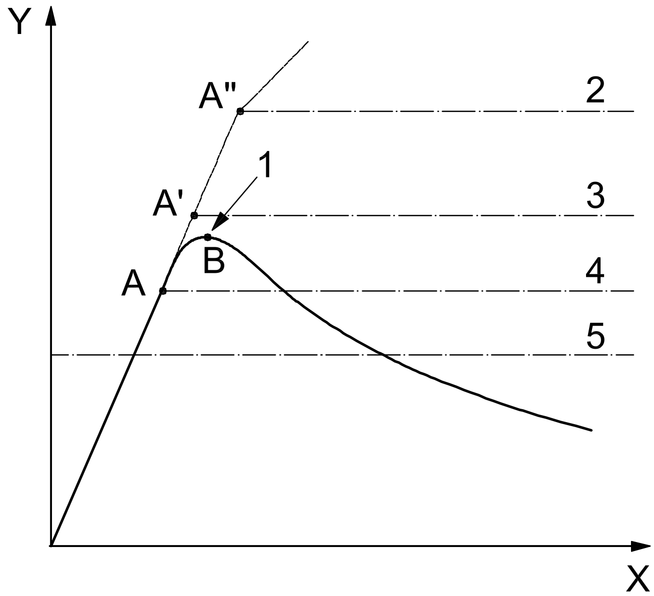
A.2 ULS

ULS criteria are normally based on plastic collapse or ultimate strength performance. In the past, simplified ULS criteria for many types of structures, including merchant ship structures, has tended to rely on estimates of the buckling strength of components, usually based on their elastic buckling strength adjusted by a simple plasticity correction factor. This is represented by point A in Figures A.1 and A.2. In such a scheme, the structural designer does not use detailed information on the post-buckling behaviour of individual components and their interactions. The true ultimate strength represented by point B in Figures A.1 and A.2 is usually higher, although not necessarily so, since the true ultimate strength is not evaluated.

In any event, as long as the strength level associated with point B remains unknown (as it is with allowable stress design or linear elastic design methods), it is difficult to determine the true safety margin.

When the ULS criteria are used, the safety margin of a structure is evaluated by comparison of the ultimate strength with the extreme applied actions (or action effects) to which they are subjected, as shown in Figure A.3.

To obtain a safe and economic structure, the ultimate strength, as well as the extreme action effect, requires accurate assessment. In order to assess a structure's damage tolerance and survivability, ALS criteria are required in addition to ULS criteria, see A.4.



Key

X displacement

Y load

1 ultimate strength

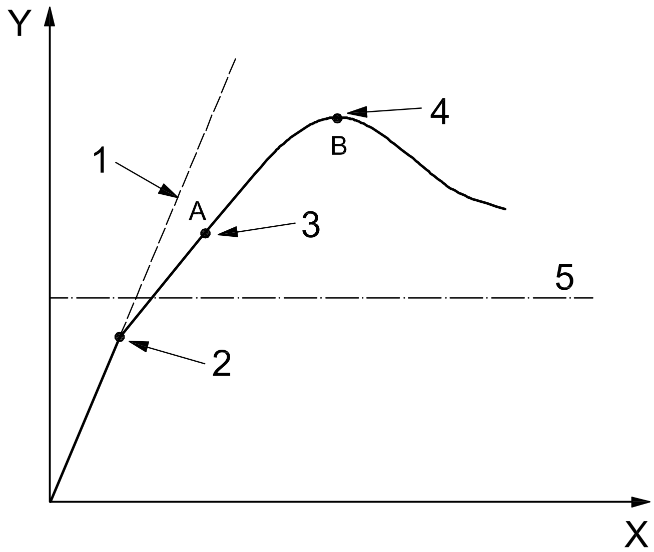
2 buckling strength (elastic calculation)

3 fully plastic strength

4 buckling strength (plasticity correction)

5 design load level

Figure A.1 — Design considerations of a plate element based on the ultimate limit states



Key

X displacement

Y load

1 linear elastic response

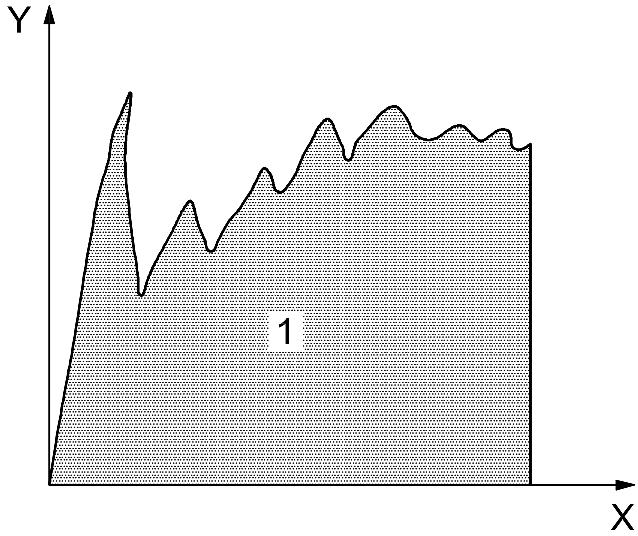
2 proportional limit

3 buckling strength

4 ultimate strength

5 design load level

Figure A.2 — Design considerations of a global system structure based on the ultimate limit states



Key

X displacement

Y accidental load

1 energy absorption

Figure A.3 — Energy absorption of the structure under accidental action

A.3 FLS

FLS criteria are required to ensure that a structure has an adequate fatigue life. Predicted fatigue lives are often used as a basis for planning efficient inspection and maintenance programmes during the service life of the structure.

Required fatigue lives for structural components are normally based on the structure's service life, as specified by the operator or other responsible body such as a class society. The fatigue life is usually taken as the design service life of the structure for readily accessible and non-critical components. Longer required fatigue lives are usually necessary for critical and/or non-accessible components. The shorter the specified fatigue life, the shorter the inspection interval needed to ensure crack-free operation.

FLS checks are normally required of every potential source of fatigue cracking which includes welded joints and local areas of stress concentrations. FLS criteria are usually based on the cumulative fatigue damage of a structure under repetitive actions, as measured by the so-called Palmgren-Miner cumulative damage accumulation rule. A particular value of the Miner sum (e.g. unity) is taken to be synonymous with the crack becoming critical. FLS criteria normally result in a reduced Miner's sum, implying that cracks are unlikely to form.

Fatigue damage at a crack initiation site is affected by a number of factors, such as the stress range, local stress concentration characteristics, and the number of stress range cycles.

Two FLS approaches are typically considered for steel structures, namely:

— S-N curve approach (S = fluctuating stress, N = associated number of cycles);

— fracture mechanics approach.

In the *S*-*N* curve approach, the Palmgren-Miner cumulative damage rule is applied, together with the relevant *S*-*N* curve. This approach normally follows three steps:

— define the histogram of cyclic stress ranges;

— select the relevant *S*-*N* curve;

— calculate the cumulative fatigue damage.

Defining the stress range can be challenging because there are four methods by which it is determined, namely:

— nominal stress method;

— hot-spot stress method;

— notch stress method;

— notch strain method.

The nominal stress method uses the nominal stresses in the field remote from the stress concentration area, together with *S*-*N* curves that implicitly include effects of both structural geometry and of weldments. In the nominal stress method, therefore, the *S*-*N* curve for structural details is selected, depending on the detail type and weld geometry involved. A large number of *S*-*N* curves for various types of weldments, as well as geometry, are generally needed and, indeed, are available. Notwithstanding, when a structural detail is being considered, it has to be categorized as belonging to a particular category which often requires a certain amount of judgment.

The hot-spot stress method uses a well-defined hot-spot stress in the stress concentration area, to take into account the effect of structural geometry alone, while the weld effect is incorporated into the *S*-*N* curve. This is a very popular approach but it presents practical difficulties. The most basic of these pertains to the hot-spot stress concept itself, which is more appropriate for surface cracks than for imbedded cracks. Difficulties also arise in the consistent definition of hot-spot stresses across a range of weldments and structural geometries, and in the estimation of the hot-spot structural stress needed for the application in regions of stress concentrations. For instance, care is required in the extrapolation of the stress to the weld toe for calculating the stress concentration factor and in the selection of the relevant *S*-*N* curve for different weld types.

The notch stress method uses the stresses at the notch calculated, taking into account the effects of both the structural geometry and the weld, while the *S*-*N* curve is developed representing the fatigue properties of the base material, the material in the heat-affected zone, or in the weld material, as appropriate. A significant advantage of the notch stress method is that it includes the effect of weld toe geometry in the calculation of fatigue damage. A practical difficulty is that relevant parameters (e.g. the weld toe angle) need to be known with some confidence.

The notch strain method uses strains at the notch when low cycle fatigue is predominant, because working stresses are sometimes greater than the material yield stress, and hence stress-based approaches are less appropriate.

The fracture mechanics approach considers that one or more postulated cracks of small size exist in the structure, and predicts fatigue damage during the process of crack propagation including any coalescence and through-thickness cracking, to subsequent fracture. In this approach, a major task is the prior establishment of the relevant crack growth equations or “laws”. The crack growth rate is often expressed as a function of stress-intensity factor range (called the Paris-Erdogan law) at the crack tip only, on the assumption that the yielded area around the crack tip is relatively small. In reality, crack propagation behaviour is affected by many other parameters (e.g. mean stresses, stress ratio, load sequence, crack retardation, crack closure, crack growth threshold stress-intensity range) in addition to stress-intensity factor range.

To achieve greater fatigue durability in a structure, it is important to minimize stress concentrations, potential flaws (e.g. misalignment, poor materials) and structural deterioration, including corrosion and fatigue effects. Interrelated to FLS criteria is the maintenance regime to be used. In some cases, it is more economical to allow a certain level of possible fatigue damage, as long as the structure performs its function until repairs are made after the fatigue symptoms are detected. In other cases, fatigue damage is not normally allowed because it is inconvenient to inspect the structure or to interrupt operation. The former approach is applied, as long as regular inspections and related maintenances are possible, while the latter approach is applied if there are likely to be difficulties associated with inspections and thus the high likelihood of undetected fatigue damage.

A.4 ALS

ALS criteria aim to

— avoid injury or loss of life on the structure or in the surrounding area,

— avoid pollution of the environment, and

— minimize damage or loss of property or financial exposure.

To achieve this, the main safety functions of the structure are not to be impaired during any accidental event or within a certain time period after the event.

The main safety functions of a structure that are not to be compromised during an accident or abnormal event, or within an appropriate period of time after such event, are the following:

— usability of escape ways;

— integrity of shelter areas;

— strength of the global structure;

— safety control systems;

— integrity of the environment.

ALS criteria need to be formulated so that these main safety functions perform successfully, and the following are considered to be at an adequate level:

— energy absorption related to structural crashworthiness;

— strength and residual strength of the global structure and its components;

— allowable tensile strains to avoid tearing or rupture;

— endurance of fire protection.

Since structural damage characteristics and the behaviour of damaged structures depend on the type of accident, it is not straightforward to establish universally applicable ALS criteria. Typically, for a given type of structure, design accidental scenarios and associated performance criteria are decided on the basis of risk assessment.

In the case of ships, possible accidental or abnormal events include collisions, grounding, fire, explosion, dropped objects or unintended flooding.

In selecting the target ALS performance levels for such events, the approach is normally to tolerate a certain level of damage consistent with a greater aim, such as survivability or minimized consequences.

ALS criteria for impact-type actions are typically written using energy absorption-related criteria, together with a view that the safety of the structure is not seriously compromised or the environment is not degraded. Energy absorption during an accident is usually calculated by integrating the area under the load-displacement curve of the structure under accidental actions, as shown in Figure A.3.

A.5 Dynamic actions

Whether or not an action is regarded as dynamic is dependent on the structure and the nature of the source of the action.

For simplicity, dynamic actions in the absence of dynamic amplification effects are often treated as equivalent static actions in which the dynamic effects, which depend on the behaviour of the structure, are taken into account properly by either an appropriate increase in the magnitude of the primary static action or by the addition of a representative set of inertial actions as appropriate for the type of structure.

To deal directly with dynamic actions, account is to be taken of the profile of the actions, including peak values, duration and decay type.

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