No. 106
(July 2009)

IACS Guideline for Rule Development - Ship Structure

CONTENTS

1 INTRODUCTION

1.1 Scope

This guideline is applicable for development of newbuilding structural rules for displacement-type ships intended for worldwide, unrestricted operation. No distinction is made with respect to different ship types, but the effect of various ship characteristics such as length, hull shape, and speed on rule requirements are discussed. The guideline is mainly intended to be used for development of new structural rules. For updating and further development of existing rules, parts of the guideline can be used, as considered relevant in each case.

The guideline provides principles and recommendations to be followed during the rule development process, as well as general requirements that should be incorporated in the rules that are being developed.

In this guideline, the term “rules” is used to signify Ship Structure Rules as issued by Class Societies.

1.2 Objective

The objective of this guideline is to form a common basis for development of ship structural rules, by specifying general principles to be followed in the rule development process, as well as general design principles and requirements that should be incorporated into the rules. Having a common basis for rule development ensure that a systematic and unified process is being followed in the rule development, and will contribute to consistency and transparency of the rule requirements.

In this guideline it is assumed that the decision to develop the new rules has already been taken, and the guideline therefore does not include procedures and specifications for the decision-making process related to whether new rules are needed or not.

The guideline should be used to support new rule development, and is made with a view that the rules should be in compliance with the International Maritime Organization’s Goal-Based New Ship Construction Standards (IMO GBS), Tier I and Tier II.

1.3 Definitions

A list of terms used in this guideline is given in the following:

Abnormal loads	Extreme loads with a return period significantly larger than that assumed for the ULS condition, or special environmental phenomena.
Accident	An unintended event involving fatality, injury, ship loss or damage, other property loss or damage, or environmental damage.
Capacity	The structural strength related to a certain failure mode.
Characteristic load	The reference value of the load to be used in the determination of load effects. For environmental loads, it is normally based upon a defined fractile in the upper end of the distribution function for the load. For operational loads, it is normally the expected values.
Characteristic capacity	The reference value of structural strength to be used in the determination of the design strength. Normally based upon a defined

	fractile in the lower end of the distribution function for the resistance.
Characteristic material strength	The reference value of material strength to be used in the determination of the design strength. Normally taken as a specified minimum value, or based upon a defined fractile in the lower end of the distribution function for the material strength.
Characteristic value	The representative value associated with a prescribed probability of not being unfavourably exceeded during some reference period.
Coating	Protective material applied to steel surfaces for prevention of corrosion.
Consequence	The outcome of an event.
Corrosion addition	Additional thickness added during design to compensate for anticipated reduction in thickness during operation.
Design life	The design life is the nominal period that the ship is assumed to be exposed to operating and/or environmental conditions. The design life is used to select the appropriate design parameters for development of the rule requirements. The ship’s actual service life, i.e. the time from start to end of the ship’s operational phase, may be longer or shorter depending on the actual operating conditions and maintenance of the ship throughout its life cycle.
Design load	A load that is used during design which includes some margin to account for uncertainties. The degree of margin included in the design load may vary depending on the margins included in the criteria elsewhere to account for modelling techniques and/or final acceptance criteria. Many times the design load is associated with the characteristic load.
Dynamic load	A load that is time-varying.
Environmental condition	The meteorological and oceanographic condition describing the environment: waves, wind, current, temperature, sea water level, tide, ice. The wave environmental condition is typically described by a wave scatter diagram.
Environmental loads	Dynamic loads occurring due to external influences, such as waves, wind, current, etc.
Failure mode	A certain type of structural failure, such as buckling, yielding, etc.
Fatigue	Degradation of material caused by cyclic loading.
Formal Safety Assessment (FSA)	A structured and systematic methodology, aimed at enhancing maritime safety, including protection of life, health, the marine environment and property, by using risk analysis and cost benefit assessment.
Frequency	The number of occurrences per unit time (e.g. per year).

Global load	Load acting on the global level of the structure; for the hull girder - such as hull girder bending moment and shear force; for a cargo hold – such as the load acting on the overall bottom, side or bulkhead.
Hazard	A potential to threaten human life, health, property or the environment.
Hull girder	The considered effective whole ship structure, often idealized by a simple beam denoted the hull girder.
Impact load	Load acting over a time period that is shorter than the natural period of the system that the load is acting on.
Load combination	A combination of different loads and load effects, such as combination of static and dynamic loads, and local and global loads.
Loading condition	A specification of operational loads for a certain distribution of deadweight (cargo, ballast, fuel, etc.).
Load scenarios	Relevant scenarios that the ship may encounter, such as seagoing, harbour, loading, etc.
Limit State	A state beyond which the structure no longer satisfies the requirements. The following categories of limit states are relevant for structures: - ULS (ultimate limit states) - FLS (fatigue limit states) - ALS (accidental limit states) - SLS (serviceability limit states)
Local load	Load acting on local structural members, such as sea pressure and internal tank pressure.
Local support members	Local stiffening members which only influence the structural integrity of a plate panel.
Minimum yield stress	The minimum yield strength prescribed by the rules.
Operational loads	Loads occurring as a result of operation and handling of the ship, both static and environmental.
Primary support members	Main structural members such as girders and stringers, which ensure the overall structural integrity of the hull envelope and internal subdivision boundaries.
Partial Factor Format (PFF)	Design format where uncertainties in load and resistance are accounted for by separate partial safety factors.
Redundancy	The ability of the structure to maintain its function when failure of a structural member has occurred.
Reliability	The ability of a structure to perform its function without failure during a specified time interval (=1-failure probability).

Renewal thickness	Thickness at which renewal is required.
Resistance	Capacity of a structural member to withstand loads without mechanical failure e.g. bending resistance, buckling resistance, tension resistance.
Response	Effect of loads acting on the structure, such as motion, displacement or stress.
Risk	The combination of the frequency and the severity of the consequence.
Safety factor	A factor that is used to modify the characteristic load or resistance to account for uncertainties in the method and statistical variation.
Safety Level Approach (SLA)	A risk-based approach where rules are developed by considering certain target safety levels for the relevant limit states.
Slamming load	Impact load caused by the external sea pressure.
Sloshing load	Load occurring due to liquid motion in partly filled tanks.
Specified value	The value of a parameter which is considered as fixed, i.e. without a statistical variation. Sometimes also referred to as nominal value.
Static load	A load that is considered as constant over a long time period time.
Stillwater loads	Loads other than environmental loads.
Strength	Mechanical properties of a material indicating its ability to resist loads, usually given in units of stress.
Wave loads	Dynamic loads occurring due to the influence of waves.
Wave scatter diagram	Representation of wave environment as a joint distribution of significant wave height and zero crossing wave period.
Working Stress Design (WSD)	Design format where uncertainties in load and resistance are accounted for by a single safety factor.

Abbreviations:

ALS	Accidental Limit State
FEM	Finite Element Method
FLS	Fatigue Limit State
FSA	Formal Safety Assessment
GBS	Goal Based Standards
HAZID	Hazard Identification
IACS	International Association of Classification Societies
IMO	International Maritime Organization
NDT	Non-destructive Testing
PFF	Partial Factor Format
SLA	Safety Level Approach
SLS	Serviceability Limit States
SRA	Structural Reliability Analysis

ULS	Ultimate Limit States
UR	Unified Requirement
WSD	Working Stress Design

1.4 Symbols

$g(x)$	Limit state function
p_f	Failure probability distribution
R	Characteristic capacity or material strength
W	Characteristic load or load effect
β	Reliability index
γ	Partial load or resistance factor
η	Permissible utilization factor

2 RULE DEVELOPMENT

2.1 Rule development process

The rule development is generally to follow a systematic and controlled process whereby the need is identified and approved prior to starting the development. Depending on the scope of the project, a detailed work plan which includes the schedule and manpower is to be developed.

The general steps in the rule development process include the following:

- motivation; identification of the need for the new rules
- define objective and scope of the new rules
- formulation or initial development of the rule (can be prescriptive, narrative, analytical, etc.)
- calibration and testing of the rule (can be based on trial application to known designs with good or bad service history)
- development of a background document which includes detailed information on the application, intent and impact of the rule
- review of final rule by people outside of the original development team so that an independent check may be performed
- rule is submitted for publication and implementation

2.2 Motivation for rule development

The necessity of the new rules should be evaluated before the start of the rule development, and the motivation for the development should be identified. The rule development can be triggered by one or more of the following reasons:

- operational experience
- feedback
- safety assessment
- newly identified issue
- novel concepts
- research
- statutory regulations

2.3 Types of rule development

The development of rules can fall into a number of different types such as new rules or updates to existing rules. The scope and amount of background information will depend on whether the rule is a major new development or a minor modification to an existing rule.

2.4 Rule objectives

The rule objectives should be defined at the start of the rule development, and should be clearly stated in the final rule text. The objectives of ship structural rules are generally to identify and control the risks and consequence of structural failure in relation to safety of life, environment and property, and to ensure adequate durability of the hull structure for its intended life.

The overall safety of the hull structure is to be equivalent to, or better than, that currently achieved in relation to life, environment and property. This implies that:

- the structural strength and watertight integrity are adequate for the intended service of the ship.
- the minimum state of the structure, corresponding to a minimum acceptable safety level at which steel renewal is required in order to continue operation is defined.

The target safety level may be assessed using the Formal Safety Assessment approach to rule development, as described in section 2.9.3. Using this approach, a consistent safety level is achieved by requiring that the identified risks are Tolerable and ALARP (As Low As Reasonable Practicable).

The rules should include structural aspects related to the satisfactory durability of the ship. This implies that:

- the ship must be capable of carrying the intended cargo with the required flexibility in operation to fulfil its design role.
- the structure has durability in terms of corrosion wastage allowance and fatigue strength throughout its operational life.

2.5 Scope of rules

It is important to define the scope and basis of the rules prior to starting the development. The scope of the rules will affect the rule development and the applicability of the rule requirements. The scope may be defined by the ship type, part of the ship covered, structural arrangement, failure mode, etc. The scope of the rules is closely linked to the Design Basis used for development of the rules, ref. section 3.6. The scope of the rules should be clearly stated in the final rule text.

2.6 Limitations of the rules

Related to the scope of the rules, it is also important to clearly define the limitations of the rules. The limitations of the rules should be stated in the final rule text so that those applying them and subsequently the ship operators, where appropriate, know the limitations.

2.7 Documentation requirements

The documentation necessary to ensure compliance with the rules should be identified. The rule text should specify the required documentation which is to be submitted for verification by the classification society.

2.8 Safety regime

The boundaries and relationships between rules and the Maritime Safety Regime typically follow a safety hierarchy with the Maritime Safety Regime at the top level. This regime regulates the design, construction and operation of ships through a diverse set of requirements including international and national Regulations and industry Standards, which may influence the ship structure rules. This section lists the aspects that influence the structural performance but are outside the scope of the rules.

2.8.1 International and National Regulations

Ships are designed, constructed and operated in a complex regulatory framework defined internationally by IMO and implemented by flag states or by classification societies on their behalf. Statutory requirements set the Standard for statutory aspects of ships such as life saving, subdivisions, stability, fire protection, etc. These requirements influence the operational and cargo carrying arrangements of the ship and therefore may affect its structural design.

The main applicable regulations for strength of applicable ship types are to be identified such that the rules may either cross reference them or interface with them.

2.8.2 Industry Standards

Industry also specifies requirements (e.g. OCIMF, INTERTANKO) which affect the structural design. The main industry Standards and requirements related to structural design of the applicable ship types are also to be identified such that the rules may either cross reference them or interface with them.

2.8.3 International Association of Classification Societies (IACS)

The rules should also be in compliance with the applicable IACS Standards for Strength concerning the applicable ship types, where relevant.

2.9 Determination of the underlying need and scope for new rules

There are various ways for determining the underlying need and the associated scope for new rules or new rule changes. The ways can range from simple operational experience or feedback to a comprehensive Formal Safety Assessment (FSA). A combination or partial use of these methods may also be used. For development of new rules, it is recommended to carry out a Systematic Review at least, which can be considered as a reduced version of a full FSA.

The process generally follows from the complexity of the issue to be addressed in the rules. Each process has pros and cons that should be considered.

A summary of available processes for determining the underlying need and scope of new rules is included in the following sections.

2.9.1 Experienced-based feedback

This process represents traditional long-standing operational feedback to identify the need for new rules as well as identifying where existing rules need to be improved. Included in this process are needs identified by on-going research as well as the incorporation of rules based on statutory regulations.

2.9.2 Systematic review

For development of new rules, a systematic review should always be carried out early in the rule development process. A systematic review can identify and evaluate the potential hazards on the structure due to operational and environmental influences as well as the likely consequences of these hazards on a ship's structure. The results from a systematic review may be used to define the hazards and consequences that are controlled by the rules and hence may help define the scope of the rules.

A systematic review may cover the structural configurations and arrangements covered by the rules and all phases of the life of a ship. The following situations or phases are identified:

- Design
- Construction
- Operational
- Repair and maintenance
- Scrapping

The systematic review process comprises three stages as follows:

(a) hazard identification:

Examination of the hazards to the hull structure as it is exposed to the marine environment. These hazards may be due to internal and external influences acting on a ship in a marine environment. The aspects covered are as follows:

- hazard identification; reviewing the hazards a ship is exposed to during all phases of its life as defined above.
- qualitative assessment of probabilities of failure events.
- identification of additional hazards if progressive structural failure occurs.

(b) consequence evaluation:

The consequences of structural failure are used as the basis for assessing the relevant limit states and the corresponding acceptance criteria. The purpose is to identify the relative importance of the structural element. The consequence evaluation includes:

- definition of the structural hierarchy of a ship.
- identification of the possible failure consequences.
- assignment of a criticality class to the failure consequence.
- identification of possible progressive structural failure paths.

(c) critical hazard management:

The list of hazards identified in the hazard identification stage is used to determine which risks are to be controlled by the rules and which are not. The safeguards to the risks to be controlled are considered in the assessment of the structural capability and hence reflected in the assumptions incorporated into the Design Basis and Design Principles sections. The risks not controlled by the rules are discussed in Section 2.10, Assumptions.

The failure consequences and criticality classes for each structural component identified in the consequence evaluation stage are matched to the list of hazards in order to establish the criticality of each structural component. From this analysis, appropriate limit state categories and suitable categories of acceptance criteria are selected to control or provide a safeguard against the risk.

2.9.3 Formal Safety Assessment

Formal Safety Assessment (FSA) is a systematic and structured process that may be used in the rule development process, and is an extension of the systematic review described above. Reference is made to the process for carrying out a FSA described in IMO Guidelines for Formal Safety Assessment, which is included in document MSC 83/INF.2, developed with participation of IACS.

FSA may be useful in particular for rule development projects with a large scope or with a large impact on existing rules or structural requirements, for either the rule development itself or documenting the process carried out. The following steps are included in a full FSA:

Step 1 identification of hazards;
Step 2 risk analysis;
Step 3 risk control options;
Step 4 cost benefit assessment; and
Step 5 recommendations for decision-making.

Step 4, cost benefit assessment, is the method described for defining the target safety. It means that an optimum safety level can be determined considering the cost of marginally increasing the net scantling and the risk reduction effect this would have in term of improved safety, reduced risk of environmental damage and reduced risk of property loss, ref. MSC 81/INF.6. Alternatively, the target safety level may be set at a higher level based on principles of safety equivalency.

Depending on the scope of the rules to be developed, at times Steps 4 and 5 are not utilized. In that case, the process will be similar to the systematic review described in 2.9.2.

2.10 Assumptions

Structural rules developed using this guideline will typically only address the hull structural aspects of classification. In order to achieve the safety level targeted by the rules, a number of aspects related to design, construction and operation of the ship are assumed to be ensured by the parties involved in the application and implementation of the rules. A summary of these assumptions are given in the following:

(a) general aspects:

- relevant information and documentation involved in the design, construction and operation is communicated between all parties. Design documentation according to rule requirements is provided.

- quality systems are applied to the design, construction, operation and maintenance activities to assist compliance with the requirements of the rules.

(b) design aspects:

- the owner specifies the intended use of the ship, and the ship is designed according to operational requirements as well as the structural requirements given in the rules
- the builder identifies and documents the operational limits for the ship so that the ship can be safely and efficiently operated within these limits
- verification of the design is performed by the builder to check compliance with provisions contained in the rules in addition to national and international regulations
- the design is performed by appropriately qualified, competent and experienced personnel
- the classification society performs a technical review of the design plans and related documents for a ship to verify compliance with the appropriate classification rules.

(c) construction aspects:

- the builder provides adequate supervision and quality control during the construction
- construction is carried out by qualified and experienced personnel
- workmanship, including alignment and tolerances, is in accordance with acceptable shipbuilding standards
- the Classification Society performs surveys to verify that the construction and quality control are in accordance with the approved plans and procedures.

(d) operational aspects:

- personnel involved in operations are aware of, and comply with, the operational limitations of the ship
- operations personnel receive sufficient training such that the ship is properly handled to ensure that the loads and resulting stresses imposed on the structure are minimised
- the ship is maintained in good condition and in accordance with the Classification Society survey scheme and international and national regulations and requirements
- the Classification Society performs surveys to verify that the ship is maintained in class in accordance with the Classification Society survey scheme.

2.11 Consequence study

When a new set of structural rules have been developed, a consequence study must be carried out to evaluate the consequence of the new rules. The consequence study will evaluate the effect of the new rules on existing ships. The effects should be hold against damage statistics and operational experience. The number of ships evaluated must be sufficient to cover the range of ship types, sizes and structural configurations that the rules are applicable for.

The consequence study will show if the rules will provide a consistent safety level for the range of ship structures that is covered by the rules. This means that the rules should have a similar impact on different ships, if the ships have a similar damage statistics and operational experience.

If the consequence study reveals that the new rules give unintended results, it is necessary to re-assess the load and strength models used. The rule development will thus be an iterative process where several of the steps in the development may be repeated until satisfactory results are obtained.

2.12 Documentation and transparency

Transparency of the rules themselves as well as the development of those rules is desirable so that designers can be aware of the true issues that are being addressed in the rules. In addition, industry has been calling for increased transparency over the years. Therefore background information is to be given for all rules as well as rule changes.

Technical information and comparison with current rules, where applicable, are helpful for the reviewers of rules to understand how the requirements have been developed, as well as the consequence of the rules. Typically in the past brief reasons for new rules or rule modifications have included phrases such as “industry practice” or “incorporation of IACS URs”. It is acceptable to include this information in a background information to indicate one reason or explanation of the rule, but should not be given as the sole reason.

The technical background documentation should not only explain how to use the rules, but also how the requirements have been developed, proof of validation, and results from consequence studies.

3 RULE PRINCIPLES

3.1 General principles

The rules are to be based on the following overall basic principles, where requirements to transparency, modularity and consistency are applied whenever possible:

- structural safety can be demonstrated for all hazards identified for each design situations in the systematic review
- the structural safety can be demonstrated by utilising limit state methods.
- the design complies with the Design Basis, ref. Section 3.6
- consistent load scenarios are applied to all aspects of the structural assessment
- structural requirements with respect to loads, capacity models and assessment criteria are presented in a modular format. Consequently, each component of the requirement is clearly identified.
- material properties are documented for high criticality class elements exposed to loads and service temperatures enhancing the risk for brittle fracture

Ship structures should be designed such that they have inherent redundancy. The ship’s structure works in a hierarchical manner and, as such, failure of structural elements lower down in the hierarchy should not result in immediate consequential failure of elements higher up in the hierarchy. This aim can be expanded as follows:

- failure of plating should not lead to immediate consequent failure of stiffened panels
- failure of local support members should not lead to immediate consequent failure of primary support members
- failure of primary support members should be gradual, and should not progress into total collapse of hull girder

The structure is designed such that permanent deformations are minimised. Permanent deformations of local panel or individual stiffened plate members may be acceptable provided that this does not affect the structural integrity or containment integrity or the performance of structural or other systems.

The structure is designed such that the incidence of in service cracking is minimised, particularly in locations which affect:

- structural integrity or containment integrity
- the performance of structural or other systems
- the ability to identify, inspect and repair cracks

The ship is to have adequate redundancy and strength margin to survive in the event that the ship structure is accidentally damaged, in the event of flooding of compartments.

3.2 Limit State Design Principles

3.2.1 General principles for limit state design

The rules are to be based on the principles of limit state design. Limit state design is a systematic approach where each structural element is evaluated with respect to possible failure modes related to the design scenarios identified. For each failure mode, one or more limit states may be relevant. By consideration of all relevant limit states, the limit load for the structural element is found as the minimum limit load resulting from all the relevant limit states.

A limit state can be defined as a condition beyond which the structure, or part of a structure, no longer satisfies the requirements. The structural performance of the hull or components of it should generally be described with reference to a specified set of limit states that separate desired states of the structure from undesired states. The limit states are divided into the four following categories:

- ultimate limit states (ULS), which correspond to the maximum load-carrying capacity or, in some cases, to the maximum applicable strain or deformation, under intact (undamaged) conditions

- serviceability limit states (SLS), which correspond to conditions beyond which specified service requirements are no longer met

- fatigue limit states (FLS), which correspond to degradation due to the effect of time varying (cyclic) loading

- accidental limit states (ALS), which concern the ability of the structure to resist accident situations

The effect of exceeding a limit state may be irreversible or reversible.

- In the reversible case, the structure will return to its original state after the load has been removed. The damage or malfunction will remain only as long as the cause of the limit state being exceeded is present. As soon as this cause ceases to act, a transition from the undesired state back to the desired state occurs.

- In the irreversible case, the structure will exhibit some permanent deformation and hence not return to its original state after the load has been removed. The damage or malfunction associated with the limit state being exceeded will remain until the structure has been repaired.

The irreversible state is suitable for application to structural items where aesthetics are not important and any permanent deformations do not lead to degradation of structural performance or affect operational performance.

3.2.2 Limit states (ULS, FLS, SLS, ALS)

The four categories of limit states are described in the following:

ULS - Ultimate Limit States

The limit states concern the following under the action of the maximum loads effects during the design life of the ship:

(a) the safety of life, and/or

(b) environment, and/or

(c) property (ship and cargo)

Ultimate limit states include:

(a) attainment of the maximum structural capacity of sections, members or connections by rupture, excessive deformations or instability (buckling)

(b) excessive yielding, transforming the structure or part of it into a plastic mechanism

The effect of exceeding an ultimate limit state is almost always irreversible and causes failure the first time the limit state is exceeded.

SLS - Serviceability Limit States

The limit states concern the following under the action of the specified loads during the design life of the ship:

(a) the functioning of the hull structure or structural members or equipment under normal operation, and/or

(b) comfort of people, and/or

(c) the appearance of the hull structure or part of it

Serviceability limit states include:

(a) unacceptable deformations which affect the efficient use or appearance of structural or non-structural elements or the functioning of equipment or the comfort of people

(b) excessive vibrations which cause discomfort to people or affect non-structural elements or the functioning of equipment

(c) local damage which may reduce the working life of the structure or affect the efficiency or appearance of structural or non-structural elements

In the context of serviceability limit state, the term “appearance” is concerned with such criteria as high deflection and extensive cracking, rather than aesthetics.

FLS - Fatigue Limit States

The limit states concern the following under the actions of time varying loading:

(a) the durability of the hull structure or structural members, and/or

(b) loss of containment (leakage through cracks), and/or

(c) the appearance of local structural details

Fatigue limit states include:

(a) attainment of fatigue capacity of structural members due to cyclic loads

(b) cracking which may lead to loss of containment

ALS - Accidental Limit States

The limit states concern the following in intact (undamaged) conditions with abnormal loads:

(a) the safety of life, and/or

(b) environment, and/or

(c) property (ship and cargo)

Accidental limit states include:

(a) loss of structural strength without loss of containment

(b) loss of structural strength and loss of containment

3.3 Design considerations

The rules should include requirements accounting for general design principles, such as:

- Structural continuity
- Watertightness / weathertightness
- Compartmentation
- Accessibility / Human Element Consideration
- Structural redundancy
- Loading / discharge considerations

The above items are part of the functional requirements in IMO GBS Tier II (see Appendix 1). Relevant GBS Tier II and information and documentation requirements in Tier III requirements should be considered in the rule development.

3.4 Corrosion protection

Coating requirements should be in compliance with the requirements of applicable IMO requirements. For corrosion prevention of seawater ballast tanks in displacement-type ships of 500 gross tonnage and over, reference is made to SOLAS Chapter II-1 Regulation 3-2.

3.5 Net thickness approach

The rules should specify a certain allowance for corrosion. This is called the net thickness approach and the objective of the approach is to:

- Provide a direct link between the thickness used for strength calculations during the new building stage and the renewal thickness, i.e. the minimum thickness accepted during the operational phase.

- Enable the status of the structure with respect to corrosion to be clearly ascertained throughout the life of the ship.

The net thickness approach can typically be summarised as follows:

- Strength requirements specify the net thickness

- The new building gross thickness is given by adding the required corrosion addition to the net thickness
- The corrosion wastage allowance is obtained by deducting from the corrosion addition a small thickness which is the corrosion anticipated to occur in the period between surveys.
- The renewal thickness is obtained by subtracting the wastage allowance, and any additional thickness specified by the owner, from the gross as built thickness

Any additional thicknesses specified by the owner, as Owner's extras, are not included in the assessment of the required new building thickness.

The approach should distinguish between local and global corrosion. As the hull girder cross section does not corrode evenly, the reduction of the hull girder sectional properties will at any given time be less than the sum of the allowable local wastage allowance for members contributing to the longitudinal strength.

For fatigue assessment, the variation in corrosion over time should be accounted for.

3.6 Design basis

Information about the underlying basis for the hull structure rule requirements are to be listed in the rules. This information will be available for reference by those who will later update the rules and to the designers when applying the hull structural rules. Parts of this information which are relevant to the ship operation (e.g. the permissible still water bending moment and shear force) should also be available to the ship's operating personnel so they are aware of any underlying operational limits associated with the ship's structure.

The following sections (3.6.1 to 3.6.7) list the minimum scope of design basis information that is to be included in the rules. Specific detail minimum values which are to be incorporated are indicated where applicable.

3.6.1 Design life

The specified design life, corresponding to a structural safety level, is to be defined in the rules. The design life is a parameter in determination of rule load formulations, fatigue requirements, and wastage allowances. The actual service life, including seagoing time, harbour time, maintenance and repair time, may be shorter or longer than the specified design life.

The design life used as basis for the rules is not to be less than 25 years.

3.6.2 Design speed

The rule development should consider the effect of ship speed, in order to determine whether the rule requirements need to account for speed effects. If relevant, the rule requirements may be developed under the assumption of a fixed speed or as a function of speed. If the requirements are formulated as a function of speed, the design speed is to be specified by the designer.

The design speed is defined as the maximum service speed. The maximum service speed means the greatest speed which the ship is designed to maintain in service at her deepest sea-going draught at the maximum propeller RPM and corresponding engine MCR (Maximum Continuous Rating). This does not relieve the responsibilities of the owner and personnel to properly handle the ship and reduce speed or change heading in severe weather.

3.6.3 Service temperature

As material creeps in high temperature and becomes brittle in low temperature, service temperature and cargo temperature for the design life of the ship are to be taken into consideration in ship design. Rule requirements to material quality are based on a certain assumed service temperature, which should be stated in the rule text.

For ships intended to operate in areas with low air temperatures, e.g. regular service during winter seasons to Arctic or Antarctic waters, the materials in exposed structures are to be selected based on the area where the ship is intended to operate.

3.6.4 Loading patterns

Design purpose, i.e. cargoes intended to be carried, is to be considered first when defining the ship loading conditions. Relevant loading conditions of the ship are normally defined by the designer.

The following information is required to be considered for loading conditions in the rules:

- seagoing and harbour loading conditions
- specified design loading conditions; and
- inclining and stability report, loading manual, loading instrument, and operation manual specifying operational limits with the aim to satisfy related regulations.

Draughts covered in the rules are to cover the most critical situations, and should include as a minimum:

- maximum and minimum draughts amidships specified by the designer;
- scantling draught for structural design and assessment by the designer; and
- other draughts specified for some particular structures, e.g. minimum ballast draught, minimum draught forward, etc.

All draughts are to comply with relevant regulation requirements.

3.6.5 Environmental conditions

The rule requirements are to be based on wave-induced loads covering the worst anticipated wave environment and related long-term sea state spectrum.

The minimum environmental conditions to be used in the rules are the North Atlantic wave environment according to IACS Rec.34 standard wave data.

3.6.6 Cargo and ballast

The rule requirements are to consider the effect of the different types of cargo and ballast that may be carried by the ship. The assumptions made regarding cargo and ballast properties during the rule development are to be stated in the rules.

Effects of individual internal cargoes on corrosion and abrasion of hull structure are to be considered in using net scantling approach.

Due to different physical states, effect of free water surface upon stability and effect of sloshing pressure upon structure are to be considered for liquid cargo, while internal friction force is to be considered for solid cargoes in bulk.

If the density of the cargo to be carried is not a fixed value, a design cargo density is to be specified for structural design assessment.

3.6.7 Fabrication quality

The rules assume that ships which are designed and assessed according to the rules are fabricated in compliance with a controllable and transparent fabrication standard, and are fabricated and supervised by competent and qualified personnel. Quality control through the fabrication process covers, but is not restricted to, material, pre-fabrication, alignment, assembly, welding, surface treatment and equipment. Reference is made to IACS Rec.47 for further details concerning fabrication quality control.

3.7 Safety equivalence

The rules should include consideration to safety equivalence. Normally, structural arrangements outside those specified in the rules are allowed in design. The prerequisite is that these novel designs can ensure a safety level that is not lower than the safety level of the designs of similar type given in the rules.

4 RULE FORMAT

The rule requirements may be presented in various formats, or a combination of formats, depending on the nature of the specific requirement. Typical rule formats follow typical design methodologies. Many rules are experience-based and have provided the industry with safe ships for a large number of years. The Working Stress Design (WSD) format has been used as the main method to verify the structural design in the rules. Modern rules are often based on the Partial Factor Format (PFF) method, and may have been calibrated by Structural Reliability Analysis (SRA). SRA may also be used to prove safety equivalency, to calibrate rules for innovative designs or for extending the scope of the rules to new environmental conditions.

The rule requirements associated with the assessment of the scantlings are most often based on one of the following formats:

- Working Stress Design (WSD), also known as the permissible or allowable stress method;

- Partial Factor Format (PFF), also known as Load and Resistance Factor Design (LRFD).

For both WSD and PFF, the design assessment conditions and corresponding acceptance criteria are given. These conditions are associated with the probability level of the combined ‘expected’ and ‘extreme’ loads covered by static and dynamic load combinations.

The load and response, strength and capacity assessment methods are given in Chapters 6-8 of this guidance. For each design criterion, compatible loading and capacity models are to be adopted. In the loading and capacity models for the assessments, appropriate model uncertainties are to be considered.

The following sections (4.1 to 4.4) include more details on the most common rule formats.

4.1 Working Stress Design Format

The Working Stress Design (WSD) format, also known as the allowable/permissible stress method, is one format that can be adopted in the rules. As a single safety factor is applied in the WSD format, the method is easy to apply, and it is still adopted in many structural rules.

The WSD method has the following composition:

$$W_{stat} + W_{dyn} \quad \leq \eta R$$

Where:

W_{stat}	simultaneously occurring characteristic static loads or load effects in terms of stresses
W_{dyn}	simultaneously occurring characteristic dynamic loads or load effects. The dynamic loads are typically a combination of local and global load components
R	characteristic capacity or material strength (e.g. yield stress or buckling capacity)
η	permissible utilisation factor (resistance factor). The utilisation factor includes consideration of uncertainties in loads, structural capacity and the consequence of failure

In any case, WSD becomes a simplest form of Partial Factor format with one PSF. The effect of the simpler format, as compared to PSF is a higher variability in the resulting safety when the rule is applied.

4.2 Partial Factor Format

The Partial Factor Format is another commonly used design format, which should typically be used in design calculations for safety critical cases.

The PFF method has the following expression:

$$\sum_{k=1}^{n} \gamma_k W_k \leq R / \gamma_m$$

where

γ_k the partial factors associated with the load, or the load factors

W_k the characteristic loads or load effects

γ_m the partial factor associated with the capacity (resistance), or the resistance factors

R characteristic capacity or material strength

The partial factors used in the rule can be derived with the help of probabilistic methods (SRA) as described in Section 4.4.

The PFF method separates the influence of individual uncertainties and variability originating from different causes by means of partial factors for each load and capacity component. The WSD method addresses the same limit states as the PFF method, but accounts for the influence of uncertainty by a single usage factor. The PFF method allows for a more flexible and targeted rule design assessment when complex load and structural models are employed, and makes it possible to obtain a more consistent safety level.

4.3 Safety factor calibration

Both the WSD and PFF method have to ensure a consistent and acceptable safety level for all combinations of static and dynamic load effects. The safety factors for both the Working Stress Design method and Partial safety Factor method are calibrated for the various rule requirements such that consistent and acceptable safety level for all combinations of static and dynamic load effects are achieved.

The calibration of rule requirement should take account of service experience. As the in-service experience suggest that the structural strength of existing fleets are acceptable, the new rule requirements should therefore arrive at strength which is at least equal to the existing strength.

The databases maintained by classification societies can be used for calibration and continued rule improvement. Survey report and damage cases normally serve as suitable sources of data for this purpose.

4.4 Probabilistic methods

Probabilistic methods are used to address the probability of structural failure reflecting uncertainties in models, loads, geometries, material properties, and strength modelling that can affect the performance of a structure or structural system. The Structural Reliability Analysis is a probabilistic method for presenting structural rule requirements. Probabilistic methods are mainly used as a tool for calibration of safety factors against a target safety level, for the purpose of attaining a consistent safety level using deterministic methods.

The basic variables involved in design are defined as random variables and treated with probabilistic procedures; hence, the reliability can be determined.

As an example, if we assume the structural capacity is C and load is L, both of which are random variables, then the margin of safety can be expressed as:

$$M=C-L=g(x)$$

and its probability density function is $f_M(x)$.

The probability that a structure will collapse during any reference period is then given by:

$$P_f = \int_{\propto}^{0} f_M(x)dx$$

Both L and C can be related to many random variables. Hence, $f_M(x_1, x_2, x_3, \ldots x_n)$ is the joint probability density function. Then the overall probability of failure is:

$$P_f = \int_{g(x_1 x_2 \cdots x_n) \le 0} f_M(x_1 x_2 \cdots x_n) dx_1 dx_2 \cdots dx_n$$

In a Structural Reliability Analysis (SRA), the limit state should be established and described by a limit state function $g(x_1, x_2, x_3, \ldots x_n)$ of basic variables $(x_1, x_2, x_3, \ldots x_n)$.

The structural performance of a whole structure or part of it should be described with reference to a specified set of limit states which separate desired state of the structure from undesired ones. The limit state should be described by a function of failure which is expressed in terms of basic variables.

For numerical structural reliability analysis, the reliability problem is transformed from the basic variable space (the n-dimensional space of the basic variable **x**) to a standards normal space (the space of standardised normal distributions **u**). In this **u**-space the shortest distance between the point at the limit state and the origin is defined as the reliability index. This point closest to the origin is referred to as the Design Point.

A reliability index, ß which is a substitute for the failure probability p_f, can also be expressed as:

$$ß = - \Phi^{-1}(p_f)$$

where Φ is the standardised normal distribution (Φ^{-1} the inverse standardised normal distribution).

The target nominal failure probability should be assessed in terms of failure modes and their failure consequences. This could either be done based on cost-benefit analysis, as described in Section 2.9.3, or the target could be set at a higher level.

The structural reliability method also provides a rational method to calibrate partial safety factors. Various methods depending on the level of assessment and choice of variable distribution type are available. Attention should be given to the sensitivity of results from varying level of assessment and distribution type assumed.

In the application of probability based methods, the aim is often to target the critical structural components. The classification of criticality class of the various structural components facilitates the selection of acceptance criteria and capacity model such that the more critical elements have stricter requirements (lower probability of failure) than less critical elements.

4.5 Testing

Due to structural complexities or uncertainty of loads, individual ship designs may be based on a combination of tests and calculations. Testing may be carried out, for example, if:

- adequate calculation models are not available;

- a large number of similar components are to be used;

- need to confirm by control checks assumptions made in the design.

Rule requirements may accommodate design assisted by test results. However, the rules shall include specific testing requirements for the performance and result reporting. The objective of which is to achieve the level of reliability required for the relevant design situation, taking account of statistical uncertainty due to a limited number of test cases.

5 APPLICATION OF RULE PRINCIPLES

Rule requirements are to be developed using the rule principles outlined in Section 3 and the rule formats as presented in Section 4. The rule requirements are often a combination of prescriptive requirements and direct calculation requirements, as described in the following.

The first step in the development of prescriptive requirements is to apply the defined loads to the structure under consideration and employ the appropriate limit state model to determine the required scantling in the initial design.

Strength verification by use of direct analysis is mostly related to employing the FE analysis and this is the second step in the application of principle, i.e. the verification. This is normally done based on the proposed structure generated in the initial design, but may also be used to design parts of the structure where prescriptive requirements are not available. In the verification process, the suitability of the structure is to be assessed with respect to SLS and ULS.

Fatigue strength may be assessed with different methods of varying complexity. Prescriptive requirements may be derived based on simplified fatigue assessment, and may be assessed during the initial scantlings phase of the design. More complex methods, involving direct assessment of Stress Concentration Factors by use of finite element methods, may be used to verify the fatigue strength in the verification phase of the design.

In addition to the above, the rules need to include requirements to cover ALS, where considered relevant.

5.1 Prescriptive requirements

Prescriptive requirements may be used in the early part of the design phase to establish the initial scantlings of the structure which will later be augmented by the strength assessment using the finite element method. Two common types of prescriptive requirements are described in the following.

5.1.1 Minimum requirements

Minimum requirements can be adopted in the rules for plate thickness, and stiffness and proportion of support members. For longitudinal strength of hull girders, the minimum section modulus and minimum hull inertia requirement are used.

The rules can specify minimum thickness for local support members and primary support members. These are empirical in essence, and can for instance be expressed as a function of ship principal dimensions. In the minimum thickness requirement the general robustness, corrosion, wear and contact, and durability issues are to be considered. These may be based upon a detailed study of existing empirical Class requirements.

Stiffness and proportion requirements are typically defined as maximum allowable slenderness ratios or minimum inertia requirements. For local support members, the proportions of stiffener spacing to plate thickness, web depth to thickness, or the flange breadth to thickness, are the measure of the slenderness of the structural element.

In formulating these requirements, local buckling is the main concern for the web plate and the torsional buckling for face plates or flanges. To ensure the lateral stability of stiffeners and longitudinals, the minimum stiffness of stiffeners is usually also prescribed in the rules.

For primary support members, similar requirements are often specified for the web plates and flange/face plates of primary support members. To ensure lateral stability, the torsional buckling of primary support members is normally controlled by tripping brackets with required spacing.

Attention should also be made to the proportion of pillars, brackets and edge stiffening.

It should be noted that the inclusion of prescriptive minimum requirements may be reduced if more explicit requirements are included in the rules to address the same concerns, such as lateral stability, stiffness, deflection, buckling, etc. The extent of the explicit requirements would have to cover those areas of the ship which would have been covered by the associated minimum requirements.

5.1.2 Load-dependent prescriptive requirements

The rules define a set of loads which structural member may experience, based on the operational characteristics of the ship taking account of cargo distribution, ballast distribution, draught and internal and external dynamic conditions, and then to identify load maxima which are used to obtain the required scantling for the structural members.

For each structural member, a series of static and dynamic design load set are defined, each one with load components that seek to maximise the loading on the structural member by taking “worst case” internal and external loadings together with the effect of global hull girder stresses. The dynamic load components are combined using dynamic combination factors specified for each design load set.

The combined loads give a total stress in the structural member which is not permitted to exceed the acceptance criteria for the member. The acceptance criteria are formulated using the methods outlined in Chapter 4.

5.2 Strength verification

Strength verification and/or direct analysis should be required in the rules for areas which can not be accurately assessed by prescriptive requirements. However strength verification and/or direct analysis should also be required for members which are assessed by prescriptive requirements and where additional detailed strength investigation are necessary, for example, where dimensions of structural members are mainly influenced by interaction with other structural members (e.g. floors and longitudinal stiffeners of the bottom structure).

Strength verification and/or direct analysis should be required in the rules for areas which can not be accurately assessed by prescriptive requirements or where additional detailed strength investigation is warranted, for example, where dimensions of structural members are mainly influenced by interaction with other structural members (e.g. floors and longitudinal stiffeners of the bottom structure). When the initial scantlings have been determined, a strength verification should be carried out to verify the adequacy of the initial design.

Assessment of the hull and structural elements for compliance with rule requirements is a process that needs to be carried out in a systematic manner.

Strength verification requirements are based on load-capacity methods and typically cover:

- Hull girder ultimate strength

- Strength assessment using the Finite Element (FE) analysis

5.2.1 Hull girder ultimate strength

If relevant for the considered ship type and size, the rules should include requirements for verification of the ultimate hull girder strength. The hull girder strength will normally be increasingly important with increasing ship length. Hull girder ultimate bending moment capacity assessment considers the strength of the hull girder in yielding and buckling collapse modes. In the sequence of hull girder failure, the point at which the capacity of the structure becomes insufficient to support the imposed moment is called the hull girder ultimate bending moment capacity.

The overall bending may be in hogging or sagging, depending on the imposed loadings and consequently both hogging and sagging hull girder capacity are to be checked for satisfactory strength in the most severe load combination.

It is noted that for some cargo ships, the deck structure has been identified to be the most critical element of the hull girder as there is little redundancy and structural failure may lead to a progressive collapse of the hull girder in sagging.

The criterion for the ultimate strength of the hull girder may be given in a Partial Factor Format (PFF), and partial factors are to be calibrated using structural reliability analysis and service experience of the ship fleet. Rather than using the PFF, alternative methods for specifying the ultimate strength may also be used either explicitly or implicitly, however the calibration using the service experience of the ship fleet is still to be carried out.

In structural reliability analysis, the uncertainties in environment, structural load effects and strength parameters are to be accounted for. Uncertainties in the prediction models are also to be considered:

- The still water distribution takes account of the actual loadings which might occur;
- The uncertainty associated with the wave bending moment due to environment model and hydrodynamic analysis;
- The uncertainty for the moment capacity due to the effects of material property variation, geometrical uncertainty and strength modelling uncertainty.

Various methods with different degree of complexity can be used for the assessment. Examples are:

- Single step Method
- Incremental-iterative Procedure
- Non-linear FE Analysis

When using the PFF, the calculated hull girder ultimate bending capacity is to satisfy the following design criteria:

$$\gamma_{stat} W_{stat} + \gamma_{dyn} W_{dyn} \leq R / \gamma_m$$

Where:

γ_{stat} partial safety factor that accounts for the uncertainties related to static loads

W_{stat}	simultaneously occurring static loads (or load effects in terms of stresses)
γ_{dyn}	partial safety factor that accounts for the uncertainties related to dynamic loads
W_{dyn}	simultaneously occurring dynamic loads or load effects
R	characteristic structural capacity (ultimate hull girder bending moment)
γ_m	the partial factor associated with the capacity (resistance), or the resistance factors

5.2.2 Strength assessment using FEM analysis

The rules should specify applicable requirements for direct FE assessment of the ship hull on the global and local level, as considered necessary for the ship type covered by the rules.

If the behaviour of the hull structure is to be adequately represented, and the response accurately obtained, the most advanced method is to analyze the whole ship model taking an element size such that reference stresses for strength assessment can be obtained. The displacements or hull girder sectional forces and moments obtained by the whole ship model are applied to the boundaries of the hold model mentioned below.

For cargo ships such as tankers and bulk carriers, a cargo hold analysis is usually applied to evaluate the strength of the primary support members in the hull structure, especially for larger ships. In some cases, a simplified 2D frame analysis may however be sufficient.

The finite element analysis is to be employed to verify that the stresses, deflection and buckling capability of the structural elements are within acceptable limits for the applied design loads. A linear three dimensional finite element analysis is carried out to obtain the structural response required for capacity assessment of the primary support members.

Important steps involved in the FE analysis are:

- Structural modelling,
- FE analysis load cases,
- Load components calculation,
- Application of loads to the FE model,
- Applying boundary conditions at model ends, and
- Evaluation of the FE results.

FE analysis is employed to assess the overall strength of the structure and is not intended to determine the stresses at structural details and discontinuities. Fine mesh FE analysis may be needed to assess the scantlings in areas of high stress gradient, such as brackets, openings, etc. Local FEM models are used both for stress assessment, and for assessment of stress concentration for fatigue assessment.

5.3 Fatigue strength assessment

The rules should specify requirements for fatigue assessment of fatigue critical locations and details. The rules assume that design life of hull structure details equals the ship's design life, and require that fatigue life assessed for hull structural details are not lower than the design fatigue life.

Requirements for fatigue assessment are to be specified for ship structural details subject to alternating stress and stress concentration which are considered to be vulnerable to fatigue cracking.

The fatigue strength assessment is usually performed by confirming that the cumulative fatigue damage over the anticipated service life at the location to be assessed is less than the acceptance criteria.

It is noted that there are other methods than those mentioned here, e.g. based on fracture mechanics. If other methods are to be incorporated into the rules, each step is to be documented and basic parameters specified such that the requirements may be consistently applied.

5.3.1 Fatigue loads

Wave induced dynamic loads acting on the structure, including internal cargo and ballast water inertia loads due to ship movement, as well as static loads on the structure, are to be considered in fatigue assessment. The phase difference of the different load effects are to be accounted for.

Fatigue loads are to be determined under the North Atlantic wave environment specified in Section 3.6.5. Fatigue predominant load conditions vary according to structures of different functions and locations.

For fatigue strength assessment of high-cycle fatigue, the long-term distribution of stress range in structural members is derived based on the short-term distribution of stress range with the consideration of the frequency of long-term wave statistics. Generally, the long-term distribution of stress range in structural members approximates the Weibull probabilistic distribution model.

5.3.2 SN-curves

A common way of representing fatigue strength is by use of SN-curves, which are derived on the basis of extensive fatigue tests.

The effect of geometric stress concentration may be accounted for in the SN-curve, giving different SN-curves for different structural details. Alternatively, one basic S-N curve may be used, and the effect of local geometry accounted for by use of stress concentration factors.

Other effects that will influence the fatigue strength are listed in the following. The effects may be accounted for in the SN-curve itself, or by stress correction factors.

a. Corrosive environment

b. Welding residual stresses

c. Mean compressive and tensile stress

d. Plate thickness

e. Weld profile control or post processing of weld

Experimental S-N curves are defined by their mean fatigue life and standard deviation. The mean S-N curve gives the stress level S at which the structural detail will fail with a probability level of 50 percent after N loading cycles. S-N curves considered in the present rules are based upon a statistical analysis of appropriate experimental data and represent two standard deviations below the mean lines.

5.3.3 Cumulative damage assumption

A common way to estimate the long-term cumulative fatigue damage is to apply the Miner-Palmgren's linear damage rule:

$$D = \sum_i \frac{n_i}{N_i}$$

where:

D	accumulated fatigue damage
n_i	number of stress cycles in stress block i
N_i	number of cycles to failure at stress block i

The fatigue strength is assessed referring to the allowable damage. The allowable damage should be specified considering the criticality of the detail, and the accessibility for inspection of the detail. The fatigue strength assessment is performed by confirming that the calculated cumulative fatigue damage satisfies the specified acceptance criteria.

5.3.4 Nominal stress approach

Nominal stress is the stress calculated using coarse mesh finite element analysis, or beam element analysis, based on applied loads and the sectional properties of the structure. As effects of structural geometry and welding on stress concentration are not taken into account in nominal stress approach, structural node types and welding details are to be considered in S-N curves selection.

5.3.5 Hot spot stress approach

For a typical structural detail, the stress concentration factor (SCF) may be obtained by testing or using FE regression analysis which, combined with nominal stress, results in hot spot stress for fatigue assessment. The corresponding S-N curves need not cover geometry stress concentration. Tests for obtaining SCF are to be carried out in compliance with relevant requirements and when using FE regression analysis, element properties including size and transition method are to satisfy relevant technique requirements.

For a non-typical structural detail, the hot spot fatigue stress may be directly obtained by using fine mesh FEM. The size of element mesh and means of hot spot stress interpolation are to be specified in the rules.

5.3.6 Low-cycle fatigue

When the repeated number of cycles to crack initiation is less than 10^4, the fatigue failure mode is called ‘Low-cycle fatigue’. Low-cycle fatigue tends to occur in high stress field and the stress attained low-cycle fatigue may exceed the yield stress. Therefore, it is preferable not to apply a usual SN curve in stress function formula, but a SN curve in strain function formula.

5.4 Accidental Limit State Assessment

The Accidental Limit States represents situations of accidental or abnormal events. The rule requirements should ensure that the structure resists the loads occurring in such events, and that it maintains its integrity and performance.

Assessment of the ALS may in general be considered in two steps:

1. Accidental load assessment

2. Residual strength assessment

For the accidental load assessment, the resistance of the structure in the intact condition is checked under the action of accidental or abnormal loads.

For the residual strength assessment, the resistance of the structure in the damaged condition is checked under the action of “normal” environmental loads.

The ALS assessment may be done by direct calculation of the effects imposed by the loads on the structure, or indirectly, by design of the structure as tolerable to accidents. Examples of the latter are required compartmentation of ships, which provides sufficient integrity to survive certain collision scenarios without further calculations.

The inherent uncertainty of the frequency and magnitude of the accidental loads, as well as the approximate nature of the methods for determination of accidental load effects, shall be recognized.

If non-linear, dynamic finite element analysis is applied for design, it shall be verified that all local failure modes, e.g. strain rate, local buckling, joint overloading, joint fracture, are accounted for implicitly by the modelling adopted, or else subjected to explicit evaluation.

5.4.1 Accidental load assessment

The overall objective of design against accidental loads is to achieve a system where the main safety functions are not impaired by the design accidental loads.

Accidental loads occurring in an accidental or abnormal situation may be caused by one of the following events:

- Impact due to collision, grounding or dropped objects

- Fire or explosion

- Accidental flooding

- Operational accident, such as overloading of tanks or cargo holds

- Failure of mooring lines

- Abnormal environmental conditions

    - Extreme loads with a smaller probability of occurrence than for ULS assessment, but derived using ordinary wave statistics and wave modelling
    - Unexpected phenomena, such as rogue waves, which may have a different statistical distribution, and may need a different wave model for load assessment

When the structure is subjected to the accidental loads, the acceptance criterion is usually survival, meaning that local structural damages may be accepted provided that the overall safety is not impaired.

The most common accidental load considered for ship structures is flooding of compartments. It is partly covered by requirements to subdivision of compartments, and partly by requirements to local and global strength under the action of flooding loads.

Other accidental loads have traditionally not been considered in ship structural rules, but for new rules it should be evaluated whether other loads need to be included in the assessment.

5.4.2 Residual strength assessment

For the residual strength assessment, the strength in certain specified damaged conditions, such as collision, grounding or flooding, may be verified. For this case, a “normal” level of environmental loads is considered, together with relevant stillwater loads.

The extent of damage to be considered need to be defined. The damage extent due to collision or grounding may be based upon statistical data from accidents. In that case, the appropriate probability level to use for selection of the damage extent must be defined. Alternatively, direct nonlinear finite element calculations may be used. In that case, appropriate collision scenarios to consider must be defined, i.e. type of striking ship or rock, ship direction and ship speed.

Next, the environmental loads occurring in the damaged condition must be defined. The environmental loads for this assessment are typically reduced compared to the extreme loads, to account for the low joint probability of occurrence of structural damage and severe weather. As an example, it is more likely that a collision or grounding will occur close to shore, where the weather is likely to be less severe than further ashore.

When selecting the damage cases and environmental loads to consider, the overall objective should be to achieve an appropriate overall joint probability of occurrence.

Since the joint probability of occurrence normally will be a low value, safety factors of 1.0 is usually applied.

The most relevant residual strength assessment for ship structures is the residual strength assessment of the hull girder in the damaged condition. The residual strength calculations should take into account the ultimate reserve capacity of the hull girder, including permanent deformation and post-buckling behaviour.

5.5 Relation between prescriptive requirements and direct calculations

In the case where both prescriptive requirements and direct calculations are used, the rules need to define the relation between the various requirements.

In areas where direct calculations more accurately reflect the load and structural behaviour of the structure when compared to load-capacity prescriptive rule requirements, the results from the direct calculations typically overrule the prescriptive requirements. However, the baseline minimum requirements defines the floor and scantlings are not to be reduced by any form of alternative calculations.

Load-capacity based prescriptive rule requirements may be substituted by direct analysis provided the loads used for the alternative capacity model are identical to those used in the prescriptive requirement. It should be noted that in effect the direct analysis is replacing a given prescriptive rule. The scantling may not however be reduced below the required scantling arising from a requirement controlling a different failure mode.

The philosophy is that a coarse approach should be more conservative than a detailed approach. Hence, the prescriptive requirements are targeted to be more conservative than the requirement based on direct analysis.

6 LOAD ASSESSMENT

6.1 Introduction

Structural rules typically include requirements covering the operation phase of the ship life. The following load situations are identified:

- At sea - loaded and ballast voyages between ports, offshore loading/unloading, and other relevant conditions
- Harbour - operations in harbours, sheltered waters, ports, and terminals
- Through life - degradation issues, such as corrosion and fatigue

6.2 Load Scenarios

The rules should include a realistic set of load scenarios based on:

- Normal operations at sea
- Normal operations in harbour
- Accidental situations

The load scenarios are used to develop rule requirements that will be used for design and assessment of the ship structure. Design situations can be classified as corresponding to either normal operation or accidental operation. The general principles behind the application of the load scenarios to the structural rule assessment are as follows:

- Load scenarios are sufficiently severe and varied so as to encompass all conditions that can reasonably occur during normal operation.
- Load scenarios that result as a consequence of accident situations during normal operation.
- Load scenarios during temporary situations are included where these loads are part of or routinely necessary to maintain normal operation of the ship, such as mooring, propeller inspection, hydrostatic testing, etc.

It should be noted that there are additional temporary situations, e.g., during construction and repair, which fall outside the scope of the Classification Society rules.

6.3 Load Categorization

The loads can be split into two main categories, namely

- Operational loads
- Accidental loads

The operational loads category can be further subdivided into two distinct load groups:

1. Static or still water loads:

- Loads caused by the ship's loading condition, including self weight due to gravity, fixed equipment loads, weight of cargo, fuel oil, and water ballast.

- Loads caused by buoyancy loads and mass/buoyancy induced shear forces and bending moments.

- Loads due to varying thermal conditions.

2. Environmental loads:

- Cyclic loading caused by wave action, including pressure loading on side shell, inertial loads due to ship motions, and the induced shear forces and bending moments.

- Impact loads caused by wave impact, bottom slamming and liquid sloshing in tanks.

Although cargo, ballast and still water loads change, (e.g. different loading conditions, unloading/loading, etc.) and they are technically time varying loads, they are usually treated as static loads. Environmental loads are dynamic or time varying loads caused by external influences.

The accidental load scenarios include loads that result as a consequence of an accident, such as flooding. Various types of accidental loads are described in Section 5.4.

6.4 Operational Loads

All loading conditions that may be dimensioning for the hull structure are to be included. As a minimum, the assessment of the structural capability of the design is to include the following set of seagoing load conditions:

- Homogeneously full load condition.

- Partial load conditions, where single or groups of cargo holds or tanks are empty.

- Normal ballast condition, which is the standard operating condition in ballast.

- Heavy ballast condition, which is the standard operating condition in severe weather.

- Conditions that reflect the ballast water exchange operations. These are to be used to review the minimum draught forward (bottom slamming) and minimum draught aft (propeller emergence) and still water loads.

- Loading/unloading operations.

- Tank testing.

- Towing and mooring loads.

- Other conditions that may result in higher still water global hull girder loads.

Based on the loading conditions considered, design load limits are derived, which are not to be exceeded during operation.

6.5 Static Local Loads

The external hydrostatic pressure is to be applied proportional to the local distance to the still waterline. For normal structural assessment the minimum design ballast draught and maximum design draught (scantling draught) are often used to cover the most critical situation.

For internal tanks, the internal tank pressure is to be applied proportional to the local distance to the head of the tank with allowances for possible overpressure, such as height of air pipes.

In the case of dry cargo, such as bulk cargo or containers, the load distribution resulting from the cargo needs to be specially considered for each type of cargo.

In accordance with the load scenario principles given in Section 6.2, the most unfavourable combination of loads is to be considered, as an example, the worst possible combination of adjacent filled and unfilled tanks or cargo holds with the ship at a light or deep draught, as appropriate, is typically assumed. Reference should also be made to the actual or typical operational limits of the type of ship that the rules are being developed for.

6.6 Static Global Loads

The still water shear forces and bending moments are to be determined for all the loading conditions specified under operational loads, Section 6.4.

Loading the ship in conditions other than those specified are normally acceptable, provided that the still water shear forces and bending moments are calculated using the onboard approved loading computer and are lower than or equal to permissible values.

The effects of variation in consumable items, such as fuel oil and fresh water, are to be included in the assessment of the still water global loads.

6.7 Miscellaneous loads

The loading arising during emergency towing operations, such as towing line loads, are to be taken into account.

The following loads are normally not considered, but need to be accounted for special applications:

- Wind loads (relevant for mooring loads for fittings and support structure)
- Tug and berthing loads (relevant for towing loads for fittings and supporting structure)
- Ice loads (relevant for ice-going ships with voluntary ice class notation)

The following load scenarios are not included:

- Unloading or loading aground
- Docking loads
- Loadings as a result of helicopter operations

If other loads or scenarios are found to be critical for a certain type of structure, these loads should also be considered.

6.8 Environmental Loads

The dynamic loads that act on ships arise primarily as a consequence of the external environment. The main environmental factor is wave action, which gives rise to the resulting major load effects. The magnitude and frequency of these environmental dynamic loads are affected by the following aspects:

- The encountered wave environment, which depends on the trading pattern and the design life (see Section 3.6).
- The loading condition, as draught, displacement and distribution of deadweight/lightweight affect the ship motion response.
- The design speed (see Section 3.6.2).

The environmental loads caused by wave action comprise several dynamic components, such as:

1. Wave cyclic loads:
    - Hydrodynamic pressure
    - Inertial loads due to ship motions
    - Hull girder vertical wave shear forces and bending moments
    - Hull girder horizontal wave shear forces and bending moments
    - Hull girder torsional moments
    - Springing loads, i.e., shear forces and bending moments caused by near resonant response of the hull girder to the predominant wave frequency
2. Impact loads:
    - Bottom slamming forward
    - Bow flare slamming
    - Side shell wave impact loads
    - Stern overhang wave impact loads
    - Sloshing loads on boundaries of partially filled tanks
    - Whipping loads, i.e., global hull girder shear forces and bending moments caused by slamming or bow flare impacts
    - Green seas

Springing and whipping loads are difficult to assess precisely within the format if simplified rule criteria and therefore many time accounted for in a non-explicit form, such as by using minimum scantlings in certain areas of the ship. The formulation of explicit springing and whipping loads are considered to be topics for future investigation. It is noted however, that advanced analytical tools are available for investigation should the need arise.

The rule formulations for dynamic load are typically based on hydrodynamic first principles analysis and calibrated using feed back from service experience and measurements.

To apply realistic combinations of simultaneously occurring environmental loads, information on the phasing of the various environmental load components is typically employed.

The bottom slamming impact loads are based on the minimum specified draught forward and the design speed. The characteristic values are based on the maximum probable load that can occur in a severe storm.

The bow or bow flare impact loads are based on the design speed. The characteristic value is based on the maximum probable load that can occur in a severe storm.

The formulations for impact loads are based on first principles analysis and are calibrated using feedback from service experience and measurements.

6.9 Characteristic Load Values

The general principles used to derive characteristic values are as follows:

- The application of load values is consistent for all similar load scenarios. Hence, the characteristic load value(s) have a common origin and derivation.

- The probability of occurrence is tailored to the purpose of application of the load and the selected structural assessment method (appropriate limit state design equations).

The characteristic value of a single load component is typically taken as the most severe value that can be expected during the design life of the ship, or as a fractile in the probability density function for the load.

6.10 Design Load Combinations

The design load combinations combine static loads, environmental loads, and other relevant loads to evaluate the overall strength of the ship and its structural components. The design load combinations accomplish the following:

- They reflect the probable combined load effects by considering the most unfavourable combination(s) for the particular structural component.

- They link the operating area of the ship with the magnitude of the dynamic and static loads, thereby separately identifying the operational risks in seagoing and harbour conditions. The magnitude of the applied dynamic loads in each design load scenario is taken to be consistent with the imposed risk.

7 STRENGTH ASSESSMENT

7.1 Structural member categorization

A ship hull is a large, complex structure and is composed of many structural elements. For practical strength assessment of the hull structure, a structural member categorization is usually made as shown in Table 7.1. In the strength assessment of each categorized structural members, the criticality of the structural members should be considered with respect to the consequences of the possible failure modes in the limit states to be assessed, see Table 7.2.

(1) Ship hull

When the whole ship structure is considered for the hull girder strength assessment, the ship hull is usually idealized by a single beam. This is the top level criticality of the hierarchy.

(2) Primary support members

Primary support members are parts of the ship hull assembling many structural components, which mean the assembled structures with many local support members. Primary support members also include the assembled large structures with many primary support members. The criticality of the primary support members is less than that of ship hull.

(3) Local support members

Local support members are smaller structural components constituting the ship hull, which are usually stiffened panels. The stiffened panels can be further classified into two, namely, plating between stiffeners and stiffeners for reinforcement of plating between primary support members. The criticality of the local support members is less than that of primary support member.

7.2 Structural strength categorization

In relation to the structural member categorization mentioned in Section 7.1, the structural strength categorization can be made for a practical strength assessment of ship hull. The structural strength is roughly classified into two groups, namely, global strength and local strength as shown in Table 7.1. The criticality of the structural strength should also be taken into account with respect to the consequences of the possible failure modes in the limit states to be assessed, see Table 7.2.

(1) Hull girder strength

Hull girder strength is defined as the strength of the ship’s hull and primary support members. The ship’s hull is usually idealized by a single beam and its strength is examined based on beam theory under the shear forces and bending moments. The latter is the three-dimensional strength of primary support members such as girders under external and internal pressures due to sea water and cargo / ballast loads. The global strength of primary support members is generally assessed by a combination of prescriptive requirements and direct strength calculations.

(2) Local strength

Local strength is defined as the strength for local support members such as plating and stiffened panels under the bending stresses due to out-of-plane loads and the in-plane stresses influenced by global strength. The local strength can often be examined by prescriptive rule formulae based on appropriate idealized models such as a beam or a simply supported rectangular plate, as appropriate.

Table 7.1 Categorization of structural members and structural strength

Strength categorization	Global strength		Local strength	
Structural member categorization	Ship hull	Primary support members	Local support members	
			Stiffened panels	Plating
Examples of structural members	-	Bottom girder, transverse floors, deck transverse web frames. Also includes assembly of elements such as double bottom structure, deck structure, double side structure etc.	Deck stiffened panel, bottom stiffened panel, etc.	Deck plating, bottom plating, inner bottom plating etc.

7.3 Characteristic value of material and geometrical properties

The material properties of structural members such as yield stress, tensile stress (breaking stress), and Young's modulus are influenced by temperature, steel specification, steel making condition etc. The characteristic values of the material properties should be determined by considering the uncertainties due to the variation of the material properties. In the assessment of structural strength, the characteristic values are specified as a lower limit of the property variations, derived from a fractile in the probability density distribution for the property.

For the geometrical properties, the variations from the specified scantlings should also be taken into account. Usually the geometrical variation can be considered small and the effect on the structural strength negligible. The characteristic values of the geometrical properties are therefore usually taken as the specified dimensions. The variation of geometrical properties is then controlled by specified construction tolerances.

7.4 Failure modes to be assessed

The relevant possible failure modes in ship structures are to be considered for the assessment of ship structural safety with the relation to the limit states as shown in Table 7.2. Usually the main failure modes for ship structures can be classified as follows:

(1) Yielding

The yielding failure mode is the mode in which plastic strain locally occurs in the structural members to be considered under combined in-plane and normal stresses.

Local plastic strain is controlled in SLS, ULS and ALS by checking that the stresses caused in the structural members remains below a permissible value.

(2) Plastic collapse

The plastic collapse failure mode usually appears in the local structural members under large lateral impact pressure. In this failure mode, permanent lateral deflection in the local structural members will occur, but does not influence the global strength. This mode is controlled in ULS and ALS by using conventional plastic design method.

(3) Buckling

The buckling failure mode is the instability phenomena of structural members under compressive loads. When the stress in structural members just attains the elastic buckling stress, elastic (reversible) buckling occurs during the compressive load. This buckling failure mode is controlled in SLS. By further increasing the compressive load, stress redistribution occurs due to buckling of the weakest structural member and the stress in some structural members will reach the yield stress. This buckling failure mode with large elastic deflection is controlled in ULS or ALS. When compression is unloaded, no consequence of failure due to buckling is seen.

On the other hand, plastic (irreversible) buckling occurs when the stress in structural members exceeds the yield stress. As the result, the substantial permanent deflections due to plastic buckling will appear. This irreversible buckling failure mode is controlled only in ULS or ALS for global hull girder strength.

(4) Rupture

The rupture failure mode is the mode in which breaking occurs in the structural members to be considered under large tensile stress beyond the yield stress of the material. This failure mode is controlled in ULS or ALS, but the assessment of this failure mode will be covered by controlling the yielding failure.

(5) Brittle fracture

Brittle fracture occurs with very little plastic deformation under tensile stresses less than the yield stress of the material when small cracks are contained in the structural members due to undesirable material properties. The failure mode of brittle fracture is basically different from ductile fracture. The consequence of this failure mode is directed to the overall collapse of the ship hull. Brittle fracture is depending on the material tensile strength, temperature and thickness. Therefore, this mode is controlled by the material rule requirement of steel grade based on the impact test and addresses all limit states except FLS.

(6) Fatigue cracking

This failure mode is different from the failure modes mentioned above and is controlled in FLS alone.

Table 7.2 Failure modes in the relation to the limit states to be considered

Possible failure modes to be considered	Limit states			
	ULS	SLS	ALS	FLS
Yielding	√	√	√	
Plastic collapse	√		√	
Buckling	√	√	√	
Rupture	√		√	
Brittle fracture	√	√	√	
Fatigue cracking				√

7.5 Structural response assessment

Structural response assessment is carried out to derive the reference stresses to be used for the strength assessment. The rules should specify acceptable methods for the structural response assessment. The method used for the response assessment is to be selected based on the complexity and the criticality of the structural member considered. The general principle should be that analytical solutions based on beam theory or plate theory may be used for simple and less critical structures. For more complex and critical structures, direct response assessment using Finite Element Methods (FEM) is often necessary.

Stresses for strength assessment can be derived by modelling the hull and performing direct structural response analysis as described below:

(1) Modelling the hull

Considerations are to be given to the extent of the model, support and boundary conditions of the model, element types and its discretization method so that adequate accuracy of reference stresses are obtained depending on the strength assessment.

(2) Application of load

With regard to the application of design loads in the structural model, consideration should be given to the load types such as distributed loads, linear loads, concentrated loads and the load bearing point according to the structural model so that the mechanisms of loads transfer of the hull are adequately reproduced.

(3) Reference stresses

Appropriate values of reference stresses are to be selected to represent mainly the influence factors of mechanisms in the failure mode, such as buckling or cracks.

The reference stress for the strength assessment in yielding and buckling modes is to be taken as the nominal stress that represents the structural response of structural members for design loads. It should combine the severest stress components in each member during the design life of the ship. In this case, the local structural discontinuities may be ignored, but the increase in stress due to overall structural discontinuities is to be considered. The reference stress for fatigue strength assessment is to be assumed as a long-term distribution of local stresses representing local structural responses over the service life of the ship. In this case, the increase in stress due to local structural discontinuities is to be considered in addition to overall structural discontinuities.

8 CAPACITY ASSESSMENT

The possible failure modes are controlled by appropriate capacity assessment methods using relevant capacity models. The capacity assessment method should be capable of analyzing the failure mode in question to the required degree of accuracy. The method may be different for each of the limit states even for the same failure mode, as the degree of utilization of the ultimate capacity is different.

In order to select appropriate capacity models to control the failure modes, it is necessary to consider the following aspect:

a. The criticality class of the structural members to be assessed. This will primarily have impact on the assessment criteria, but needs to be considered in conjunction with selection of methodology for structural assessment.

b. A simplified capacity model where some of the stress components are ignored should give conservative results.

c. Determine appropriate methodology to assess the failure mode.

d. The load level defined by the limit state.

e. Capability of response calculations to represent the physical behaviour of the structure up to the given load level.

f. Complexity of structure and loads.

The capacity models are based on a net thickness approach with corresponding scantling requirements given as net thickness values.

Any additional thicknesses specified by the owner (as owner extras) are not included in the assessment. The actual scantlings proposed by the builder are used for the assessment, and the approved net scantling values will be fixed for the life of the ship. Hence, it will not be allowed to change the distribution of net thickness to match the actual corrosion pattern after 15 years or so in service.

In general, the overall hull girder structure and local members are evaluated taking into account openings that affect stress levels. Examples of such openings are cargo access trunks, ladder openings, and access openings in floors and webs.

Small openings in the structure (such as pipe penetrations and drainage holes) are generally not considered in the strength calculations, provided they do not lead to high stress levels.

8.1 Capacity models for yielding

Since ship structures are very complex, the resulting stress distribution in structural members is also complex. It is not straightforward how to determine the exact yielding criteria under complex stress distributions. Some typical theories for yielding criteria for ship structures may be considered as follows:

a. Maximum principal stress theory

b. Maximum shearing stress theory

c. Shearing strain energy theory

Because of good agreements with experiment results, Von-Mises yielding criteria based on theory c, has been widely used for an appropriate capacity model for yielding.

8.2 Capacity models for buckling

(1) Assessment Methods

The capacity model for buckling failure mode should be determined considering the limit state and the structural members to be assessed. Some typical assessment methods for simulating buckling behaviour are as follows:

a. When the buckling failure mode in reversible SLS is assessed, linear elastic stability calculation can be used.

b. When the buckling failure mode with stress redistribution in reversible SLS, ULS or ALS is assessed, non-linear geometrical behaviour should be accounted for.

c. When the buckling (collapse) failure mode with yielding for global strength in ULS or ALS is assessed, both non-linear geometrical and material effects need to be accounted for. In the analysis, an appropriate strain hardening rate should be considered.

Regarding assessment methods, closed-form or direct assessment methods can be used.

(2) Imperfections, boundary conditions, etc.

Buckling strength is largely influenced by initial imperfections and boundary conditions. Regarding initial imperfection effects, the initial deflections due to welding should be considered. In the determination of the initial deflections, the uncertainties of initial deflections should be taken into account as far as possible. The maximum amplitude of the initial deflection is to be determined considering shipbuilding tolerances.

Inherently, welding induced residual stress should be considered appropriately in the capacity model. However, due to large uncertainties in the estimation of welding residual stress effect, this effect may be implicitly considered in the capacity model by using a simple, practical procedure, such as decreasing the yield stress, or similar.

Boundary conditions should be considered so as to represent the real structural behaviour appropriately. In this regards, relevant model extent should be considered in the estimation of each structural member.

(3) Combined load cases

All loads acting on the structural members should be considered. In ship structure bi-axial in-plane compressive and shear membrane loads and lateral pressure are to be considered simultaneously. Lateral pressure is to be applied first to generate deformation in the structural model. If a simplified capacity model considering the reduced load components is used, the combined load effect due to the simplification should be considered in the model.

8.3 Capacity models for plastic collapse

When large lateral impact pressures are loaded on local structural members, the bending stress due to lateral pressure may locally exceed the yield stress of the structural member.

However, structural collapse does not occur because of the stress redistribution after local yielding. Further increasing lateral pressure, local yielding is widely spreading in the structural member and plastic collapse occurs. To assess this collapse behaviour, both closed form and direct calculation methods can be used.

As a practical closed form approach, plastic design methods have been widely used in some structural areas. Non-linear static FEA can be also available to simulate plastic collapse behaviour as a refined direct calculation method.

(1) Areas of application

The plastic collapse failure mode should be considered especially in the local structural members subjected to large lateral pressure. In ship structure, the following areas may be assessed by using relevant capacity model for plastic collapse.

a. Bow and bottom structures subjected to slamming impact pressure and bow flare impact pressure (ULS).

b. Exposed deck structures subjected to green sea water load (ULS).

c. Tank boundary structures subjected to sloshing impact pressure (ULS).

d. Transverse bulkhead structures in assumed flooding conditions (ALS).

e. Plating subjected to ice loads (ULS).

(2) Collapse of a plating

Generally, when out-of-plane loads act on stiffened panels and deflection increases, membrane forces occur. Due to the occurrence of the membrane forces, the plate panel can resist even out-of-plane loads that exceed the yielding point. In view of the above, the plastic design method has been used conventionally as a standard method for design of maximum out-of-plane load.

The maximum load on the plate panel is determined by assuming the positions where plastic hinge lines occur in the panel, the work done at the plastic hinge lines (internal work) is taken as being equal to the work done by out-of-plane load (external work). The out-of-plane load at this stage is assumed to be the maximum load.

(3) Collapse of a stiffener

In the case of the assessment of a stiffener, the stiffener can be idealized as a beam and the plastic collapse strength of the beam studied. After calculating the plastic moment of the beam, the collapse mode is assumed, and the maximum load based on appropriate boundary conditions is calculated based on the same theory mentioned above.

When the in-plane stress is not negligible compared with the bending stress due to lateral pressure, the effect of in-plane stress should be considered in the plastic collapse capacity model of both plating and a stiffener.

9 MATERIALS, WELDING AND FABRICATION

9.1 General

Rule requirements are developed on the basis that the material and welds have a certain quality and certain minimum properties. To ensure that these assumptions are valid, specific requirements to materials, welding and fabrication need to be included in the rules.

While some of the aspects discussed in the following may be included in the hull structural rules, other may be covered by separate material rules.

The rule requirements should be in compliance with the relevant IACS Unified Requirements, such as UR S, UR W and UR Z.

9.2 Material

Rule requirements are to be included covering the choice of materials used for the construction. Of particular importance is the material strength and grade.

Special attention should be given to steel castings or forgings that are used for stern frames, rudder frames, rudder stocks, propeller shaft brackets, and other major structural items, covered in IACS UR W7 and UR W8.

9.2.1 Material manufacturing

Requirements to the material manufacturing methods and the chemical composition of the materials are necessary to ensure that the material properties are at least as good as assumed when developing the rule requirements. Manufacturing requirements are covered in UR W11.

Requirements to mechanical testing should be specified in the rules, to ensure that the material properties are above the minimum standard. This is specified in UR W11.

9.2.2 Material strength

The material strength is characterized by the specified minimum yield stress, and is related to the amount of stress that can be carried without suffering permanent deformations. Usually steel having a specified minimum yield stress of 235 N/mm^2 is regarded as normal strength steel, while steel with a higher specified minimum yield stress is regarded as high strength steel.

The strength criteria in the rules should be expressed as a function of the yield stress, or a high strength steel factor. Criteria for the use of high tensile steel are given in IACS UR S4.

9.2.3 Material grade

The rules should include requirements to material grade. The material grade is related to ductility, and should be chosen so as to avoid brittle fracture. The required material grade at a certain location will depend on the thickness, temperature, criticality and stress level at the considered location. Requirements for material grade are given in IACS UR S6.

When tee or cruciform connections employ partial or full penetration welds, and the plate material is subject to significant tensile strain in a direction perpendicular to the rolled surfaces, consideration is to be given to the use of special material with specified through thickness properties (Z type steel). This is covered by UR W14.

9.3 Fabrication

The rule requirements are developed under the assumption that the structural fabrication is carried out with an adequate standard. It should therefore be a rule requirement that the fabrication is carried out according to a recognized fabrication standard. The rules should specify a list of recognized fabrication standards, or specify requirements to the minimum amount of information that must be included in the standard.

The fabrication plant should have suitable equipment and facilities to enable proper handling of the materials, fabrication process, structural components, etc. The personnel should have the necessary qualifications.

Guidance on shipbuilding quality standards for the hull structure during new construction is currently given in IACS Recommendation No. 47. Requirements for hull survey for new construction are given in UR Z23.

9.4 Welding

The rules should include requirements to weld type, size and material. The requirements should be based on consideration of joint type, criticality, stresses in the joint, material properties, and weld gap size.

Welding is to be carried out by welders qualified according to approved and qualified welding procedures.

Material imperfections in the form of residual stress are developed as a result of heat input during welding. These imperfections normally need to be accounted for in the ULS assessment of stiffened panels.

Requirements for welding consumables are given in IACS UR W17. Requirements for welding procedure qualification test are given in IACS UR W28.

10 SHIP IN OPERATION REQUIREMENTS

In order to provide a direct link between the thickness used for strength calculations during the new building stage and the minimum thickness accepted during the operational phase, as described in Section 3.5 Net Thickness Approach, the rules are to include information defining the permissible degradation limits for the structural components. During the operational phase, thickness measurements shall be used to assess the ship's structure against the specified renewal criteria.

It is to be noted that the Ship in Operation criteria should apply only to ships in operation that are designed and built in accordance with the same rules.

APPENDIX

Below is a summary table relating GBS Tier II requirements to individual sections in the guideline.

TIER II (FUNCTIONAL REQUIREMENTS) <from MSC 82/WP.5, 6 Dec 2006>	**IACS guideline for ship structural rule development** Associated Reference
DESIGN	
II.1 Design life The specified design life is not to be less than 25 years.	3. Rule Principles (3.6)
II.2 Environmental conditions Ships should be designed in accordance with North Atlantic environmental conditions and relevant long-term sea state scatter diagrams.	3. Rule Principles (3.6)
II.3 Structural strength Ships should be designed with suitable safety margins: .1 to withstand, at net scantlings**, in the intact condition, the environmental conditions anticipated for the ship's design life and the loading conditions appropriate for them, which should include full homogeneous and alternate loads, partial loads, multi-port and ballast voyage, and ballast management condition loads and occasional overruns/overloads during loading/unloading operations, as applicable to the class designation; and .2 appropriate for all design parameters whose calculation involves a degree of uncertainty, including loads, structural modelling, fatigue, corrosion, material imperfections, construction workmanship errors, buckling and residual strength.	3. Rule Principles 4. Rule Format
The structural strength should be assessed against excessive deflection and failure modes, including but not limited to buckling, yielding and fatigue. Ultimate strength calculations should include ultimate hull girder capacity and ultimate strength of plates and	7. Strength Assessment 8. Capacity Assessment

TIER II (FUNCTIONAL REQUIREMENTS) <from MSC 82/WP.5, 6 Dec 2006>	**IACS guideline for ship structural rule development** Associated Reference
stiffeners. The ship's structural members should be of a design that is compatible with the purpose of the space and ensures a degree of structural continuity. The structural members of ships should be designed to facilitate load/discharge for all contemplated cargoes to avoid damage by loading/discharging equipment which may compromise the safety of the structure. ** The net scantlings should provide the structural strength required to sustain the design loads, assuming the structure in intact condition and excluding any addition for corrosion.	
II.4 Fatigue life The design fatigue life should not be less than the ship's design life and should be based on the environmental conditions in II.2.	5. Application of rule principles (5.3)
II.5 Residual strength Ships should be designed to have sufficient strength to withstand the wave and internal loads in specified damaged conditions such as collision, grounding or flooding. Residual strength calculations should take into account the ultimate reserve capacity of the hull girder, including permanent deformation and post-buckling behaviour. Actual foreseeable scenarios should be investigated in this regard as far as is reasonably practicable.	5. Application of rule principles (5.4)
II.6 Protection against corrosion Measures are to be applied to ensure that net scantlings required to meet structural strength provisions are maintained throughout the specified design life. Measures include, but are not limited to, coatings, corrosion additions, cathodic protection, impressed current systems, etc.	3. Rule principles (3.4)
II.6.1 Coating life Coatings should be applied and maintained in accordance with manufacturers' specifications concerning surface preparation, coating selection, application and maintenance. Where coating is	3. Rule principles (3.4)

TIER II (FUNCTIONAL REQUIREMENTS) <from MSC 82/WP.5, 6 Dec 2006>	**IACS guideline for ship structural rule development** Associated Reference
required to be applied, the design coating life is to be specified. The actual coating life may be longer or shorter than the design coating life, depending on the actual conditions and maintenance of the ship. Coatings should be selected as a function of the intended use of the compartment, materials and application of other corrosion prevention systems, e.g. cathodic protection or other alternatives.	
II.6.2 Corrosion addition The corrosion addition should be added to the net scantling and should be adequate for the specified design life. The corrosion addition should be determined on the basis of exposure to corrosive agents such as water, cargo or corrosive atmosphere, or mechanical wear, and whether the structure is protected by corrosion prevention systems, e.g. coating, cathodic protection or by alternative means. The design corrosion rates (mm/year) should be evaluated in accordance with statistical information established from service experience and/or accelerated model tests. The actual corrosion rate may be greater or smaller than the design corrosion rate, depending on the actual conditions and maintenance of the ship.	3. Rule principles (3.5)
II.7 Structural redundancy Ships should be of redundant design and construction so that localized damage of any one structural member will not lead to immediate consequential failure of other structural elements leading to loss of structural and watertight integrity of the ship.	3. Rule principles
II.8 Watertight and weathertight integrity Ships should be designed to have adequate watertight and weathertight integrity for the intended service of the ship and adequate strength and redundancy of the associated securing devices of hull openings.	3. Rule principles (3.3)

TIER II (FUNCTIONAL REQUIREMENTS) <from MSC 82/WP.5, 6 Dec 2006>	**IACS guideline for ship structural rule development** Associated Reference
II.9 Human element considerations Ships should be designed and built using ergonomic design principles to ensure safety during operations, inspection and maintenance of ship's structures. These considerations should include stairs, vertical ladders, ramps, walkways and standing platforms used for permanent means of access, the work environment and inspection and maintenance considerations.	3. Rule principles (3.3)
II.10 Design transparency Ships should be designed under a reliable, controlled and transparent process made accessible to the extent necessary to confirm the safety of the new as-built ship, with due consideration to intellectual property rights. Readily available documentation should include the main goal-based parameters and all relevant design parameters that may limit the operation of the ship.	2. Rule development
CONSTRUCTION	
II.11 Construction quality procedures Ships should be built in accordance with controlled and transparent quality production standards with due regard to intellectual property rights. The ship construction quality procedures should include, but not be limited to, specifications for material, manufacturing, alignment, assembling, joining and welding procedures, surface preparation and coating.	9. Materials, welding and fabrication
II.12 Survey A survey plan should be developed for the construction phase of the ship, taking into account the ship type and design. The survey plan should contain a set of requirements, including specifying the extent and scope of the construction survey(s) and identifying areas that need special attention during the survey(s), to ensure compliance of construction with mandatory ship construction standards.	2. Rule development

TIER II (FUNCTIONAL REQUIREMENTS) <from MSC 82/WP.5, 6 Dec 2006>	**IACS guideline for ship structural rule development** Associated Reference
IN-SERVICE CONSIDERATIONS	
II.13 Survey and Maintenance Ships should be designed and constructed to facilitate ease of survey and maintenance, in particular avoiding the creation of spaces too confined to allow for adequate survey and maintenance activities. The survey plan in II.11 should also identify areas that need special attention during surveys throughout the ship's life and in particular all necessary in-service survey and maintenance that was assumed when selecting ship design parameters.	3. Rule principles (3.3)
II.14 Structural accessibility The ship should be designed, constructed and equipped to provide adequate means of access to all internal structures to facilitate overall and close-up inspections and thickness measurements.	3. Rule principles (3.3)
RECYCLING CONSIDERATIONS	
II.15 Recycling Ships should be designed and constructed of materials for environmentally acceptable recycling without compromising the safety and operational efficiency of the ship.	

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