RUSSIAN MARITIME REGISTER OF SHIPPING

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RULES

FOR THE CLASSIFICATION AND CONSTRUCTION OF SHIPS CARRYING LIQUEFIED GASES IN BULK

PART IV

CARGO CONTAINMENT

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RULES FOR THE CLASSIFICATION AND CONSTRUCTION OF SHIPS CARRYING LIQUEFIED GASES IN BULK

Rules for the Classification and Construction of Ships Carrying Liquefied Gases in Bulk of Russian Maritime Register of Shipping (RS, the Register) have been approved in accordance with the established approval procedure and come into force on 1 January 2023.

The present edition of the Rules is based on the 2022 edition taking into account the amendments developed immediately before publication.

The Rules establish requirements, which are specific for ships carrying liquefied gases in bulk, and supplement the Rules for the Classification and Construction of Sea-Going Ships and Rules for the Equipment of Sea-Going Ships of Russian Maritime Register of Shipping.

The Rules are published in the following parts:

Part I "Classification";
Part II "Ship Arrangement";
Part III "Stability. Subdivision. Freeboard";
Part IV "Cargo Containment";
Part V "Fire Protection";
Part VI "Systems and Piping";
Part VII "Electrical Equipment";
Part VIII "Instrumentation and Automation Systems";
Part IX "Materials and Welding";
Part X "Special Requirements".

The Annexes to the Rules are published separately.

REVISION HISTORY
(purely editorial amendments are not included in the Revision History)

For this version, there are no amendments to be included in the Revision History.

1 GENERAL

1.1 The goal of requirements specified in this Part of the Rules for the Classification and Construction of Ships Carrying Liquefied Gases in Bulk[1] is to ensure the safe containment of cargo under all design and operating conditions having regard to the nature of the cargo carried. This will include measures to:

provide strength to withstand defined loads;

maintain the cargo in a liquid state;

design for or protect the hull structure from low temperature exposure, and

prevent the ingress of water or air into the cargo containment system.

1.2 Definitions and explanations.

1.2.1 In addition to the definitions in 1.2, Part I "Classification", the definitions given in this Section shall apply throughout this Part.

Independent tanks are self-supporting tanks. They do not form part of the ship's hull and are not essential to the hull strength. There are three categories of independent tank, which are referred to in Sections 21 — 23.

Integral tanks are tanks that form a structural part of the hull and are influenced in the same manner by the loads that stress the adjacent hull structure. Integral tanks are covered in Section 25.

Wohler (*S* — *N*) curve[2] is a stress-cycle number dependence diagram where the fatigue material damage occurs at the given stress cycle number.

Membrane tanks are non-self-supporting tanks that consist of a thin liquid and gastight layer (membrane) supported through insulation by the adjacent hull structure. Membrane tanks are covered in Section 24.

Semi-membrane tanks are non-self-supporting tanks in the loaded condition and consist of a layer, parts of which are supported through insulation by the adjacent hull structure. Semi-membrane tanks are covered in Section 26.

Design temperature for selection of materials is the minimum temperature at which cargo may be loaded or transported in the cargo tanks.

Design vapour pressure P_0 is the maximum gauge pressure, at the top of the tank, to be used in the design of the tank.

A cold spot is a part of the hull or thermal insulation surface where a localized temperature decrease occurs with respect to the allowable minimum temperature of the hull or of its adjacent hull structure, or to design capabilities of cargo pressure/temperature control systems required in Section 4, Part VI "Systems and Piping".

[1] Hereinafter referred to as "the LG Rules".
[2] Additional provisions not included in the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (hereinafter referred to as "the Code").

2 APPLICATION

2.1 Unless otherwise specified in Sections 21 – 26, the requirements of Sections 1 – 20 shall apply to all types of tanks, including those covered in Section 27.

3 FUNCTIONAL REQUIREMENTS FOR CARGO CONTAINMENT

3.1 The design life of the cargo containment system shall not be less than the design life of the ship.

3.2 Cargo containment systems shall be designed for North Atlantic environmental conditions and relevant long-term sea state scatter diagrams for unrestricted navigation. Lesser environmental conditions, consistent with the expected usage, may be accepted according to a procedure agreed with the Register for cargo containment systems used exclusively for restricted navigation. Greater environmental conditions may be required for cargo containment systems operated in conditions more severe than the North Atlantic environment.

3.3 Cargo containment systems shall be designed with suitable safety margins:

.1 to withstand, in the intact condition, the environmental conditions anticipated for the cargo containment system's design life and the loading conditions appropriate for them, which include full homogeneous and partial load conditions, partial filling within defined limits and ballast voyage loads; and

.2 being appropriate for uncertainties in loads, structural modelling, fatigue, corrosion, thermal effects, material variability, ageing and construction tolerances.

3.4 The cargo containment system structural strength shall be assessed against failure modes, including but not limited to plastic deformation, buckling and fatigue. The specific design conditions which shall be considered for the design of each cargo containment system are given in Sections 21 — 26. There are three main categories of design conditions:

.1 ultimate design conditions — the cargo containment system structure and its structural components shall withstand loads liable to occur during its construction, testing and anticipated use in service, without loss of structural integrity. The design shall take into account proper combinations of the following loads:

internal pressure;
external pressure;
dynamic loads due to the motion of the ship;
thermal loads;
sloshing loads;
loads corresponding to ship deflections;
tank and cargo weight with the corresponding reaction in way of supports;
insulation weight;
loads in way of towers and other attachments; and
test loads.

.2 fatigue design conditions — the cargo containment system structure and its structural components shall not fail under accumulated cyclic loading;

.3 the cargo containment system shall meet the following criteria.

Collision — the cargo containment system shall be protectively located in accordance with 2.4, Part II "Ship Arrangement", and withstand the collision loads specified in 15.1 without deformation of the supports, or the tank structure in way of the supports, likely to endanger the tank structure.

Fire — the cargo containment systems shall sustain, without rupture, the rise in internal pressure specified in 3.19.1, Part VI "Systems and Piping", under the fire scenarios envisaged therein.

Flooded compartment causing buoyancy on tank — the anti-flotation arrangements shall sustain the upward force, specified in 15.2, and there shall be no endangering plastic deformation to the hull.

3.5 Measures shall be applied to ensure that scantlings required meet the structural strength provisions and be maintained throughout the design life. Measures may include, but are not limited to, material selection, coatings, corrosion additions, cathodic protection and inerting. Corrosion allowance need not be required in addition to the thickness resulting from the structural analysis. However, where there is no environmental control, such as inerting around the cargo tank, or where the cargo is of a corrosive nature, a suitable corrosion allowance shall be applied and agreed with the Register.

3.6 An inspection/survey plan for the cargo containment system shall be approved by the Register. The inspection/survey plan shall identify areas that need inspection during surveys throughout the cargo containment system's life and, in particular, all necessary in-service survey and maintenance that was assumed when selecting cargo containment system design parameters. Cargo containment systems shall be designed, constructed and equipped to provide adequate means of access to areas that need inspection as specified in the inspection/survey plan. Cargo containment systems, including all associated internal equipment, shall be designed and built to ensure safety during operations, inspection and maintenance (refer to Section 1, Part II "Ship Arrangement").

4 CARGO CONTAINMENT SAFETY PRINCIPLES

4.1 The containment systems shall be provided with a full secondary liquid-tight barrier capable of safely containing all potential leakages through the primary barrier and, in conjunction with the thermal insulation system, of preventing lowering of the temperature of the ship structure to an unsafe level.

4.2 The size and configuration or arrangement of the secondary barrier may be reduced where an equivalent level of safety is demonstrated in accordance with the requirements of 4.3 — 4.5, as applicable.

4.3 Cargo containment systems for which the probability for structural failures to develop into a critical state has been determined to be extremely low, but where the possibility of leakages through the primary barrier cannot be excluded, shall be equipped with a partial secondary barrier and small leak protection system capable of safely handling and disposing of the leakages. The arrangements shall comply with the following requirements:

.1 failure developments that can be reliably detected before reaching a critical state (e.g. by gas detection or inspection) shall have a sufficiently long development time for remedial actions to be taken; and

.2 failure developments that cannot be safely detected before reaching a critical state shall have a predicted development time that is much longer than the expected lifetime of the tank.

4.4 No secondary barrier is required for cargo containment systems, e.g. type C independent tanks, where the probability for structural failures and leakages through the primary barrier is extremely low and can be neglected.

4.5 No secondary barrier is required where the cargo temperature at atmospheric pressure is at or above –10 °C.

5 SECONDARY BARRIERS IN RELATION TO TANK TYPES

5.1 Secondary barriers in relation to the tank types defined in Sections 21 — 26 shall be provided in accordance with the Table 5.1.

Table 5.1

Cargo temperature at atmospheric pressure	–10 °C and above	Below –10 °C down to –55 °C	Below –55 °C
Basic tank type	No secondary barrier required	Hull may act as secondary barrier	Separate secondary barrier where required
Integral Membrane Semi-membrane Independent: type A type B type C		Tank type not normally allowed[1] Complete secondary barrier Complete secondary barrier[2] Complete secondary barrier Partial secondary barrier No secondary barrier required	

[1] A complete secondary barrier shall normally be required if cargoes with a temperature at atmospheric pressure below –10 °C are permitted in accordance with 25.1.
[2] In the case of semi-membrane tanks that comply in all respects with the requirements applicable to type B independent tanks, except for the manner of support, a partial secondary barrier may be accepted.

6 DESIGN OF SECONDARY BARRIERS

6.1 Where the cargo temperature at atmospheric pressure is not below –55 °C, the hull structure may act as a secondary barrier based on the following:

.1 the hull material shall be suitable for the cargo temperature at atmospheric pressure as required by 19.2.4; and

.2 the design shall be such that this temperature will not result in unacceptable hull stresses.

6.2 The design of the secondary barrier shall be such that:

.1 it is capable of containing any envisaged leakage of liquid cargo for a period of 15 days, unless different criteria apply for particular voyages, taking into account the load spectrum referred to in 18.3.6;

.2 physical, mechanical, or operational events within the cargo tank that could cause failure of the primary barrier shall not impair the due function of the secondary barrier, or vice versa;

.3 failure of a support or an attachment to the hull structure will not lead to loss of liquid tightness of both the primary and secondary barriers;

.4 it is capable of being periodically checked for its effectiveness by means acceptable to the Register. This may be by means of a visual inspection or a pressure/vacuum test or other suitable means carried out according to a documented procedure agreed with the Register;

.5 the methods required in 6.2.4 above shall be approved by the Register and shall include, where applicable to the test procedure:

details on the size of defect acceptable and the location within the secondary barrier, before its liquid- tight effectiveness is compromised;

accuracy and range of values of the proposed method for detecting defects specified above;

scaling factors to be used in determining the acceptance criteria, if full scale model testing is not undertaken; and

effects of thermal and mechanical cyclic loading on the effectiveness of the proposed test; and

.6 the secondary barrier shall fulfil its functional requirements at a static angle of heel of 30°.

7 PARTIAL SECONDARY BARRIERS AND PRIMARY BARRIER SMALL LEAK PROTECTION SYSTEM

7.1 Partial secondary barriers as permitted in 4.3 shall be used with a small leak protection system and meet all the requirements in 6.2. The small leak protection system shall include means to detect a leak in the primary barrier, provision such as a spray shield to deflect any liquid cargo down into the partial secondary barrier, and means to dispose of the liquid, which may be by natural evaporation.

7.2 The capacity of the partial secondary barrier shall be determined, based on the cargo leakage corresponding to the extent of failure resulting from the load spectrum referred to in 18.3.6, after the initial detection of a primary leak. Due account may be taken of liquid evaporation, rate of leakage, pumping capacity and other relevant factors.

7.3 The required liquid leakage detection may be by means of liquid sensors, or by an effective use of pressure, temperature or gas detection systems, or any combination thereof.

8 SUPPORTING ARRANGEMENTS

8.1 The cargo tanks shall be supported by the hull in a manner that prevents bodily movement of the tank under the static and dynamic loads defined in Sections 12 — 15, where applicable, while allowing contraction and expansion of the tank under temperature variations and hull deflections without undue stressing of the tank and the hull.

8.2 Anti-flotation arrangements shall be provided for independent tanks and capable of withstanding the loads defined in 15.2 without plastic deformation likely to endanger the hull structure.

8.3 Supports and supporting arrangements shall withstand the loads defined in 13.9 and Section 15, but these loads need not be combined with each other or with wave-induced loads.

9 ASSOCIATED STRUCTURE AND EQUIPMENT

9.1 Cargo containment systems shall be designed for the loads imposed by associated structure and equipment. This includes pump towers, cargo domes, cargo pumps and piping, stripping pumps and piping, nitrogen piping, access hatches, ladders, piping penetrations, liquid level gauges, independent level alarm gauges, spray nozzles, and instrumentation systems (such as pressure, temperature and strain gauges).

10 THERMAL INSULATION

10.1 Thermal insulation shall be provided, as required, to protect the hull from temperatures below those allowable (refer to 19.2) and limit the heat flux into the tank to the levels that can be maintained by the pressure and temperature control system applied in Section 4, Part VI "Systems and Piping".

10.2 In determining the insulation performance, due regard shall be given to the amount of the acceptable boil-off in association with the reliquefaction plant on board, main propulsion machinery or other temperature control system.

11 DESIGN LOADS. GENERAL

11.1 This Section and Sections 12 — 15 define the design loads to be considered with regard to the requirements in Sections 16 — 18. These include:

load categories (permanent, functional, environmental and accidental) and the description of the loads;

the extent to which these loads shall be considered depending on the type of tank, and is more fully detailed in the following paragraphs; and

tanks, together with their supporting structure and other fixtures, that shall be designed taking into account relevant combinations of the loads described below.

12 PERMANENT LOADS

12.1 Gravity loads.

12.1.1 The weight of tank, thermal insulation, loads caused by towers and other attachments shall be considered.

12.2 Permanent external loads.

12.2.1 Gravity loads of structures and equipment acting externally on the tank shall be considered.

13 FUNCTIONAL LOADS

13.1 Loads arising from the operational use of the tank system shall be classified as functional loads. All functional loads that are essential for ensuring the integrity of the tank system, during all design conditions, shall be considered. As a minimum, the effects from the following criteria, as applicable, shall be considered when establishing functional loads:
internal pressure;
external pressure;
thermally induced loads;
vibration;
interaction loads;
loads associated with construction and installation;
test loads;
static heel loads; and
weight of cargo.

13.2 Internal pressure.

13.2.1 In all cases, including 13.2.2, P_0 shall not be less than MARVS.

13.2.2 For cargo tanks, where there is no temperature control and where the pressure of the cargo is dictated only by the ambient temperature, P_0 shall not be less than the gauge vapour pressure of the cargo at a temperature of 45 °C except as follows:

.1 lower values of ambient temperature shall be agreed with the Register for ships operating in restricted areas. Conversely, higher values of ambient temperature may be required; and

.2 for ships on voyages of restricted duration, P_0 may be calculated based on the actual pressure rise during the voyage, and account may be taken of any thermal insulation of the tank.

13.2.3 Taking into account the calculations made in accordance with the agreed procedure and the limitations given in Sections 21 — 26, for the various tank types, a vapour pressure P_h higher than P_0 may be accepted for site specific conditions (harbour or other locations), where dynamic loads are reduced. Any relief valve setting resulting from this para shall be recorded in the International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk.

13.2.4 The internal pressure P_{eq} results from the vapour pressure P_0 or P_h plus the maximum associated dynamic liquid pressure P_{gd}, but not including the effects of liquid sloshing loads. Formula for associated dynamic liquid pressure P_{gd} is given in 28.1.

13.3 External pressure.

13.3.1 External design pressure loads shall be based on the difference between the minimum internal pressure and the maximum external pressure to which any portion of the tank may be simultaneously subjected.

13.4 Thermally induced loads.

13.4.1 Transient thermally induced loads during cooling down periods shall be considered for tanks intended for cargo temperatures below –55 °C.

13.4.2 Stationary thermally induced loads shall be considered for cargo containment systems where the design supporting arrangements or attachments and operating temperature may give rise to significant thermal stresses (refer to 4.1.3, Part VI "Systems and Piping").

13.5 Vibration.

13.5.1 The potentially damaging effects of vibration on the cargo containment system shall be considered.

13.6 Interaction loads.

13.6.1 The static component of loads resulting from interaction between cargo containment system and the hull structure, as well as loads from associated structure and equipment, shall be considered.

13.7 Loads associated with construction and installation.

13.7.1 Loads or conditions associated with construction and installation, e.g. lifting, shall be considered.

13.8 Test loads.

13.8.1 Account shall be taken of the loads corresponding to the testing of the cargo containment system referred to in Sections 21 — 26.

13.9 Static heel loads.

13.9.1 Loads corresponding to the most unfavourable static heel angle within the range 0° to 30° shall be considered.

13.10 Other loads.

13.10.1 Any other loads not specifically addressed, which could have an effect on the cargo containment system, shall be taken into account.

14 ENVIRONMENTAL LOADS

14.1 Environmental loads are defined as those loads on the cargo containment system that are caused by the surrounding environment and that are not otherwise classified as a permanent, functional or accidental load.

14.2 Loads due to ship motion.

14.2.1 The determination of dynamic loads shall take into account the long-term distribution of ship motion in irregular seas, which the ship will experience during its operating life. Account may be taken of the reduction in dynamic loads due to necessary speed reduction and variation of heading.

14.2.2 The ship's motion shall include surge, sway, heave, roll, pitch and yaw. The accelerations acting on tanks shall be estimated at their centre of gravity and include the following components:

.1 vertical acceleration: motion accelerations of heave, pitch and, possibly, roll (normal to the ship base);

.2 transverse acceleration: motion accelerations of sway, yaw and roll and gravity component of roll; and

.3 longitudinal acceleration: motion accelerations of surge and pitch and gravity component of pitch.

14.2.3 Methods to predict accelerations due to ship motion shall be proposed and approved by the Register.

14.2.4 Formulae for acceleration components are given in 28.2.

14.2.5 Loads for ships of restricted service may be specified in accordance with a procedure agreed with the Register.

14.3 Dynamic interaction loads.

14.3.1 Account shall be taken of the dynamic component of loads resulting from interaction between cargo containment systems and the hull structure, including loads from associated structures and equipment.

14.4 Sloshing loads.

14.4.1 The sloshing loads on a cargo containment system and internal components shall be evaluated based on allowable filling levels.

14.4.2 When significant sloshing-induced loads are expected to be present, special tests and calculations shall be required covering the full range of intended filling levels.

14.5 Snow and ice loads.

14.5.1 Snow and icing shall be considered, if relevant.

14.6 Loads due to navigation in ice.

14.6.1 Loads due to navigation in ice shall be considered for ships intended for such service.

15 ACCIDENTAL LOADS

15.1 Accidental loads are defined as loads that are imposed on a cargo containment system and its supporting arrangements under abnormal and unplanned conditions.

15.2 Collision loads.

15.2.1 The collision load shall be determined based on the cargo containment system under fully loaded condition with an inertial force corresponding to 0,5g in the forward direction and 0,25g in the aft direction, where "g" is gravitational acceleration.

15.3 Loads due to flooding on ship.

15.3.1 For independent tanks, loads caused by the buoyancy of an empty tank in a hold space flooded to the summer load draught shall be considered in the design of the anti-flotation chocks and the supporting hull structure.

16 STRUCTURAL INTEGRITY. GENERAL

16.1 The structural design shall ensure that tanks have an adequate capacity to sustain all relevant loads with an adequate margin of safety. This shall take into account the possibility of plastic deformation, buckling, fatigue and loss of liquid and gas tightness.

16.2 The structural integrity of cargo containment systems shall be demonstrated by compliance with Sections 21 — 26, as appropriate, for the cargo containment system type.

16.3 The structural integrity of cargo containment system types that are of novel design and differ significantly from those covered by Sections 21 — 26 shall be demonstrated by compliance with Section 27 to ensure that the overall level of safety provided in this Part is maintained.

17 STRUCTURAL ANALYSES

17.1 Analysis.

17.1.1 The design analyses shall be based on accepted principles of statics, dynamics and strength of materials.

17.1.2 Simplified methods or simplified analyses may be used to calculate the load effects, provided that they are conservative. Model tests may be used in combination with, or instead of, theoretical calculations. In cases where theoretical methods are inadequate, model or full-scale tests may be required.

17.1.3 When determining responses to dynamic loads, the dynamic effect shall be taken into account where it may affect structural integrity.

17.2 Load scenarios.

17.2.1 For each location or part of the cargo containment system to be considered and for each possible mode of failure to be analyzed, all relevant combinations of loads that may act simultaneously shall be considered.

17.2.2 The most unfavourable scenarios for all relevant phases during construction, handling, testing and in service, and conditions shall be considered.

17.2.3 When the static and dynamic stresses are calculated separately, and unless other methods of calculation are justified, the total stresses shall be calculated according to:

$$\sigma_x = \sigma_{x.st} \pm \sqrt{\Sigma(\sigma_{x.dyn})^2}; \quad (17.2.3\text{-}1)$$

$$\sigma_y = \sigma_{y.st} \pm \sqrt{\Sigma(\sigma_{y.dyn})^2}; \quad (17.2.3\text{-}2)$$

$$\sigma_z = \sigma_{z.st} \pm \sqrt{\Sigma(\sigma_{z.dyn})^2}; \quad (17.2.3\text{-}3)$$

$$\tau_{xy} = \tau_{xy.st} \pm \sqrt{\Sigma(\tau_{xy.dyn})^2}; \quad (17.2.3\text{-}4)$$

$$\tau_{xz} = \tau_{xz.st} \pm \sqrt{\Sigma(\tau_{xz.dyn})^2}; \quad (17.2.3\text{-}5)$$

$$\tau_{yz} = \tau_{yz.st} \pm \sqrt{\Sigma(\tau_{yz.dyn})^2}; \quad (17.2.3\text{-}6)$$

where $\sigma_{x.st}, \sigma_{y.st}, \sigma_{z.st}, \tau_{xy.st}, \tau_{xz.st}, \tau_{yz.st}$ are static stresses;
$\sigma_{x.dyn}, \sigma_{y.dyn}, \sigma_{z.dyn}, \tau_{xy.dyn}, \tau_{xz.dyn}, \tau_{yz.dyn}$ are dynamic stresses, determined separately from acceleration components and hull strain components due to deflection and torsion.

18 DESIGN CONDITIONS

18.1 All relevant failure modes shall be considered in the design for all relevant load scenarios and design conditions. The design conditions are given above in this Part, and the load scenarios are covered by 17.2.

18.2 Ultimate design condition.

18.2.1 Structural capacity may be determined by testing, or by analysis, taking into account both the elastic and plastic material properties, by simplified linear elastic analysis or by the provisions of these Rules.

18.2.2 Plastic deformation and buckling shall be considered.

18.2.3 Analysis shall be based on characteristic load values as follows:

permanent loads — expected values;

functional loads — specified values;

environmental loads — for wave loads: most probable largest load encountered during 10^8 wave encounters.

18.2.4 For the purpose of ultimate strength assessment, the following material parameters apply:

.1.1 R_e= specified minimum yield stress at room temperature, in MPa. If the stress-strain curve does not show a defined yield stress, the 0,2 % proof stress applies;

.1.2 R_m = specified minimum tensile strength at room temperature, in MPa.

For welded connections where under-matched welds, i.e. where the weld metal has lower tensile strength than the parent metal, are unavoidable, such as in some aluminium alloys, the respective R_e and R_m of the welds, after any applied heat treatment, shall be used. In such cases, the transverse weld tensile strength shall not be less than the actual yield strength of the parent metal. If this cannot be achieved, welded structures made from such materials shall not be incorporated in cargo containment systems;

.2 the above properties shall correspond to the minimum specified mechanical properties of the material, including the weld metal in the as-fabricated condition. The enhanced yield stress and tensile strength at low temperature may be taken into account. The temperature on which the material properties are based shall be shown on the International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk.

18.2.5 The equivalent stress σ_C (von Mises, Huber) shall be determined by:

$$\sigma_C = \sqrt{\sigma_x^2 + \sigma_y^2 + \sigma_z^2 - \sigma_x\sigma_y - \sigma_x\sigma_z - \sigma_y\sigma_z + 3(\tau_{xy}^2 + \tau_{xz}^2 + \tau_{yz}^2)}, \qquad (18.2.5)$$

where σ_x = total normal stress in x-direction;
σ_y = total normal stress in y-direction;
σ_z= total normal stress in z-direction;
τ_{xy} = total shear stress in $x - y$ plane;
τ_{xz} = total shear stress in $x - z$ plane; and
τ_{yz} = total shear stress in $y - z$ plane.

The above values shall be calculated as described in 17.2.3.

18.2.6 Allowable stresses for materials other than those covered by Part IX "Materials and Welding" shall be subject to approval by the Register.

18.2.7 Stresses may be further limited by fatigue analysis, crack propagation analysis and buckling criteria.

18.3 Fatigue design condition.

18.3.1 The fatigue design condition is the design condition with respect to accumulated cyclic loading.

18.3.2 Where a fatigue analysis is required, the cumulative effect of the fatigue load shall comply with:

$$\Sigma\frac{n_i}{N_i}+\frac{n_{Loading}}{N_{Loading}}\leq C_w, \qquad (18.3.2)$$

where n_i = number of stress cycles at each stress level during the life of the tank;
N_i = number of cycles to fracture for the respective stress level according to the Wohler (S — N) curve;
$n_{Loading}$ = number of loading and unloading cycles during the life of the tank, not to be less than 1000 (normally corresponds to 20 years of operation). Loading and unloading cycles include a complete pressure and thermal cycle;
$N_{Loading}$ = number of cycles to fracture for the fatigue loads due to loading and unloading; and
C_w = maximum allowable cumulative fatigue damage ratio.

The fatigue damage shall be based on the design life of the tank but not less than 10^8 wave encounters.

18.3.3 Where required, the cargo containment system shall be subject to fatigue analysis, considering all fatigue loads and their appropriate combinations for the expected life of the cargo containment system. Consideration shall be given to various filling conditions.

18.3.4 Wohler (*S* — *N*) curves application.

18.3.4.1 Design *S* — *N* curves used in the analysis shall be applicable to the materials and weldments, construction details, fabrication procedures and applicable state of the stress envisioned.

18.3.4.2 The *S* — *N* curves shall be based on a 97.6 % probability of survival corresponding to the mean-minus-two-standard-deviation curves of relevant experimental data up to final failure. Use of *S* — *N* curves derived in a different way requires adjustments to the acceptable $C_w$values specified in 18.3.7 — 18.3.9.

18.3.5 Analysis shall be based on characteristic load values as follows:

permanent loads — expected values;

functional loads — specified values or specified history; environmental loads — expected load history, but not less than 10^8 cycles.

If simplified dynamic loading spectra are used for the estimation of the fatigue life, they shall be approved by the Register.

18.3.6 Fatigue crack propagation analysis.

18.3.6.1 Where the size of the secondary barrier is reduced, as is provided for in 4.3, fracture mechanics analyses of fatigue crack growth shall be carried out to determine:

.1 crack propagation paths in the structure;
.2 crack growth rate;
.3 the time required for a crack to propagate to cause a leakage from the tank;
.4 the size and shape of through thickness cracks; and
.5 the time required for detectable cracks to reach a critical state.

The fracture mechanics are, in general, based on crack growth data taken as a mean value plus two standard deviations of the test data.

18.3.6.2 In analyzing crack propagation, the largest initial crack not detectable by the inspection method applied shall be assumed, taking into account the allowable non-destructive testing and visual inspection criterion, as applicable.

18.3.6.3 Crack propagation analysis under the condition specified in 18.3.7: the simplified load distribution and sequence over a period of 15 days may be used. Such distributions may be obtained as indicated in Fig. 18.3.6.3. Load distribution and sequence for longer periods, such as in 18.3.8 and 18.3.9 shall be approved by the Register.

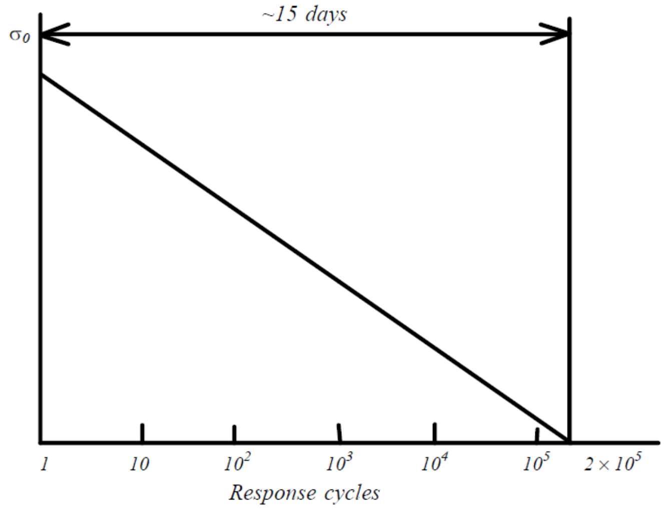

Fig. 18.3.6.3
Simplified load distribution
(σ_0 = most probable maximum stress over the life of the ship.
Response cycle scale is logarithmic. The value of 2×10^5 is given as an example of estimate)

18.3.6.4 The arrangements shall comply with 18.3.7 — 18.3.9, as applicable.

18.3.7 For failures that can be reliably detected by means of leakage detection:

C_w shall be less than or equal to 0,5.

Predicted remaining failure development time, from the point of detection of leakage till reaching a critical state, shall not be less than 15 days, unless different requirements apply for ships engaged in particular voyages.

18.3.8 For failures that cannot be detected by leakage but that can be reliably detected at the time of inservice inspections, C_w shall be less than or equal to 0,5.

Predicted remaining failure development time, from the largest crack not detectable by in-service inspection methods until reaching a critical state, shall not be less than three times the inspection interval.

18.3.9 In particular locations of the tank, where effective defect or crack development detection cannot be assured, the following, more stringent, fatigue acceptance criteria shall be applied as a minimum: C_w shall be less than or equal to 0,1.

Predicted remaining failure development time, from the assumed initial defect until reaching a critical state, shall not be less than three times the lifetime of the tank.

18.4 Accident design condition.

18.4.1 The accident design condition is a design condition for accidental loads with extremely low probability of occurrence.

18.4.2 Analysis shall be based on the characteristic values as follows:

permanent loads — expected values;

functional loads — specified values;

environmental loads — specified values;

accidental loads — specified values or expected values.

18.4.3 Loads mentioned in 13.9 and Section 15 need not be combined with each other or with waveinduced loads.

19 MATERIALS

19.1 The goal of the requirements specified in this Section is to ensure that the cargo containment system, primary and secondary barriers, the thermal insulation, adjacent ship structure and other materials in the cargo containment system are constructed from materials of suitable properties for the conditions they will experience, both in normal service and in the event of failure of the primary barrier, where applicable.

19.2 Materials forming ship structure.

19.2.1 To determine the grade of plate and sections used in the hull structure, a temperature calculation shall be performed for all tank types when the cargo temperature is below –10 °C. The following assumptions shall be made in this calculation:

.1 the primary barrier of all tanks shall be assumed to be at the cargo temperature;

.2 in addition to 19.2.1.1, where a complete or partial secondary barrier is required, it shall be assumed to be at the cargo temperature at atmospheric pressure for any one tank only;

.3 for worldwide service, ambient temperatures shall be taken as 5 °C for air and 0 °C for seawater. Higher values may be accepted for ships operating in restricted areas and, conversely, lower values may be accepted for ships trading to areas where lower temperatures are expected during the winter months. During temperature calculation and selection of a steel grade for hull structures adjacent to the cargo containment system but not coming into direct contact with the ambient air the ambient temperature is taken in accordance with the technical documentation submitted in the scope of the ship project review[1]. For ice-breakers and ice class ships, the ambient temperature shall not be taken to be above that specified in 1.2.3.3, Part II "Hull" of the Rules for the Classification and Construction of Sea-Going Ships[2];

.4 still air and seawater conditions shall be assumed, i.e. no adjustment for forced convection;

.5 degradation of the thermal insulation properties over the life of the ship due to factors such as thermal and mechanical ageing, compaction, ship motions and tank vibrations, as defined in 19.4.6 and 19.4.7, shall be assumed;

.6 the cooling effect of the rising boil-off vapour from the leaked cargo shall be taken into account, where applicable;

.7 credit for hull heating may be taken in accordance with 19.2.5, provided the heating arrangements are in compliance with 19.2.6;

.8 no credit shall be given for any means of heating, except as described in 19.2.5; and

.9 for members connecting inner and outer hulls, the mean temperature may be taken for determining the steel grade.

The ambient temperatures used in the design, described in this Section, shall be shown on the International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk.

19.2.2 The shell and deck plating of the ship and all stiffeners attached thereto shall be in accordance with recognized standards. If the calculated temperature of the material in the design condition is below –5 °C due to the influence of the cargo temperature, the material shall be in accordance with Table 2.1-5, Part IX "Materials and Welding".

19.2.3 The materials of all other hull structures for which the calculated temperature in the design condition is below 0 °C, due to the influence of cargo temperature and that do not form the secondary barrier, shall also be in accordance with Table 2.1-5, Part IX "Materials and Welding". This includes hull structure supporting the cargo tanks, inner bottom plating, longitudinal bulkhead plating, transverse bulkhead plating, floors, webs, stringers and all attached stiffening members.

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[1] Additional provisions not included in the Code.

[2] Hereinafter referred to as "the Rules for the Classification".

19.2.4 The hull material forming the secondary barrier shall be in accordance with Table 2.1-2, Part IX "Materials and Welding". Where the secondary barrier is formed by the deck or side shell plating, the material grade required by Table 2.1-2, Part IX "Materials and Welding" shall be carried into the adjacent deck or side shell plating, where applicable, to a suitable extent.

19.2.5 Means of heating structural materials may be used to ensure that the material temperature does not fall below the minimum allowed for the grade of material specified in Table 2.1-5, Part IX "Materials and Welding". In the calculations required in 19.2.1, credit for such heating may be taken in accordance with the following:

.1 for any transverse hull structure;

.2 for longitudinal hull structure referred to in 19.2.2 and 19.2.3 where colder ambient temperatures are specified, provided the material remains suitable for the ambient temperature conditions of 5 °C for air and 0 °C for seawater with no credit taken in the calculations for heating; and

.3 as an alternative to 19.2.5.2, for longitudinal bulkhead between cargo tanks, credit may be taken for heating, provided the material remain suitable for a minimum design temperature of –30 °C, or a temperature 30 °C lower than that determined by 19.2.1 with the heating considered, whichever is less. In this case, the ship's longitudinal strength shall comply with SOLAS regulation II-1/3-1 for both when those bulkhead(s) are considered effective and not.

19.2.6 The means of heating referred to in 19.2.5 shall comply with the following requirements[1]:

.1 the heating system shall be arranged so that, in case of a single failure of a mechanical or electrical component in any part of the system, its intact part could ensure at least 100 % design heat supply;

.2 the heating system shall be considered as an essential auxiliary; all electrical components of at least one of the systems provided in accordance with 19.2.5.1 (for any transverse hull structure) shall be supplied from emergency source, as specified in 6.1.4, Part VII "Electrical Equipment";

.3 where duplication of the primary source of heat, e.g. a boiler, in the system as specified above is not feasible, alternative solutions such as electric heaters capable of providing 100 % design heat supply shall be provided. The heaters shall be supplied in accordance with 6.1.5, Part VII "Electrical Equipment"; and

.4 the design and construction of the heating system shall be included in the approval of the containment system by the Register.

19.3 Materials of primary and secondary barriers.

19.3.1 Metallic materials used in the construction of primary and secondary barriers not forming the hull, shall be suitable for the design loads that they may be subjected to, and be in accordance with Tables 2.1-1 — 2.1-3, Part IX "Materials and Welding".

19.3.2 Materials, either non-metallic or metallic but not covered by Tables 2.1-1 — 2.1-3, Part IX "Materials and Welding", used in the primary and secondary barriers may be approved by the Register, considering the design loads that they may be subjected to, their properties and their intended use.

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[1] Updated in compliance with IACS UI GC23.

19.3.3 Where non-metallic materials, including composites, are used for, or incorporated in the primary or secondary barriers, they shall be tested for the following properties, as applicable, to ensure that they are adequate for the intended service:
.1 compatibility with the cargoes;
.2 ageing;
.3 mechanical properties;
.4 thermal expansion and contraction;
.5 abrasion;
.6 cohesion;
.7 resistance to vibrations;
.8 resistance to fire and flame spread; and
.9 resistance to fatigue failure and crack propagation.
19.3.4 The above properties, where applicable, shall be tested for the range between the expected maximum temperature in service and +5 °C below the minimum design temperature, but not lower than –196 °C.
19.3.5 Joining of the primary and secondary barriers.
19.3.5.1 Where non-metallic materials, including composites, are used for the primary and secondary barriers, the joining processes shall also be tested as described above.
19.3.5.2 Guidance on the use of non-metallic materials in the construction of primary and secondary barriers is provided in Annex 3.
19.3.6 Consideration may be given to the use of materials in the primary and secondary barrier, which are not resistant to fire and flame spread, provided they are protected by a suitable system such as a permanent inert gas environment, or are provided with a fire-retardant barrier.
19.4 Thermal insulation and other materials used in cargo containment systems.
19.4.1 Load-bearing thermal insulation and other materials used in cargo containment systems shall be suitable for the design loads.
19.4.2 Thermal insulation and other materials used in cargo containment systems shall have the following properties, as applicable, to ensure that they are adequate for the intended service:
.1 compatibility with the cargoes;
.2 solubility in the cargo;
.3 absorption of the cargo;
.4 shrinkage;
.5 ageing;
.6 closed cell content;
.7 density;
.8 mechanical properties, to the extent that they are subjected to cargo and other loading effects, thermal expansion and contraction;
.9 abrasion;
.10 cohesion;
.11 thermal conductivity;
.12 resistance to vibrations;
.13 resistance to fire and flame spread; and
.14 resistance to fatigue failure and crack propagation.
19.4.3 The above properties, where applicable, shall be tested for the range between the expected maximum temperature in service and 5 °C below the minimum design temperature, but not lower than –196 °C.

19.4.4 Due to location or environmental conditions, thermal insulation materials shall have suitable properties of resistance to fire and flame spread and shall be adequately protected against penetration of water vapour and mechanical damage. Where the thermal insulation is located on or above the exposed deck, and in way of tank cover penetrations, it shall have suitable fire resistance properties in accordance with recognized standards or be covered with a material having low flame-spread characteristics and forming an efficient approved vapour seal.

19.4.5 Thermal insulation that does not meet recognized standards for fire resistance may be used in hold spaces that are not kept permanently inerted, provided its surfaces are covered with material with low flame-spread characteristics and that forms an efficient approved vapour seal.

19.4.6 Testing for thermal conductivity of thermal insulation shall be carried out on suitably aged samples.

19.4.7 Where powder or granulated thermal insulation is used, measures shall be taken to reduce compaction in service and to maintain the required thermal conductivity and also prevent any undue increase of pressure on the cargo containment system.

20 CONSTRUCTION PROCESSES

20.1 The goal of this Section is to define suitable construction processes and test procedures in order to ensure, as far as reasonably practical, that the cargo containment system will perform satisfactorily in service in accordance with the assumptions made at the design stage.

20.2 Weld joint design.

20.2.1 The requirements apply to independent tanks of type A or type B, primarily constructed of plane surfaces. This includes the tank corners which are constructed using bend plating which is aligned with the tank surfaces and connected with in-plane welds[1]. All welded joints of the shells of independent tanks shall be of the in-plane butt weld full penetration type. For dome-to-shell connections only, tee welds of the full penetration type may be used depending on the results of the tests carried out at the approval of the welding procedure. Except for small penetrations on domes, nozzle welds shall also be designed with full penetration.

Welded corners (i.e. corners made of weld metal) shall not be used in the main tank shell construction, i.e. corners between shell side (sloped plane surfaces parallel to hopper or top side inclusive if any) and bottom or top of the tank, and between tank and transverse bulkheads and bottom, top or shell sides (sloped plane surfaces inclusive if any) of the tank. Instead, tank corners which are constructed using bent plating aligned with the tank surfaces and connected with in-plane welds shall be used.

Tee welds of full penetration type can be accepted for other localized constructions of the shell such as suction well, sump or dome.

20.2.2 Welding joint details for type C independent tanks including bi-lobe tanks, primarily constructed of curved surfaces fitted with a centerline bulkhead, and for the liquid-tight primary barriers of type B independent tanks primarily constructed of curved surfaces, shall be as follows[2]:

.1 all longitudinal and circumferential joints shall be of butt welded, full penetration, double vee or single vee type. Full penetration butt welds shall be obtained by double welding or by the use of backing rings. If used, backing rings shall be removed except from very small process pressure vessels. Other edge preparations may be permitted, depending on the results of the tests carried out at the approval of the welding procedure;

.2 the bevel preparation of the joints between the tank body and domes and between domes and relevant fittings shall be designed according to a procedure approved by the Register. All welds connecting nozzles, domes or other penetrations of the vessel and all welds connecting flanges to the vessel or nozzles shall be full penetration welds; and

.3 cruciform full penetration welded joints in bi-lobe tanks with centerline bulkhead can be accepted for the tank structure construction at tank centerline welds with bevel preparation subject to approval by the Register, based on the results of the tests carried out at the approval of the welding procedure.

20.2.3 Where applicable, all the construction processes and testing, except that specified in 20.4, shall be done in accordance with the applicable provisions of Part IX "Materials and Welding".

20.3 Design for gluing and other joining processes.

20.3.1 The design of the joint to be glued (or joined by some other process except welding) shall take account of the strength characteristics of the joining process.

[1] The requirements are added considering IACS UI GC20.
[2] The requirements are added considering IACS UI GC21.

20.4 Testing.

20.4.1 All cargo tanks and process pressure vessels shall be subjected to hydrostatic or hydropneumatic pressure testing in accordance with Sections 21 — 26, as applicable for the tank type.

20.4.2 All tanks shall be subject to a tightness test which may be performed in combination with the pressure test referred to in 20.4.1.

20.4.3 The requirements for inspection of secondary barriers shall be agreed with the Register, taking into account the accessibility of the barrier (refer to 6.2).

20.4.4 For ships fitted with novel type B independent tanks, or tanks designed according to Section 27, at least one prototype tank and its supporting structures shall be instrumented with strain gauges or other suitable equipment to confirm stress levels. Similar instrumentation is recommended for elements of the type C independent tank structure, depending on their configuration and on the arrangement of their support and attachments.

20.4.5 The overall performance of the cargo containment system shall be verified for compliance with the design parameters during the first full loading and discharging of the cargo, in accordance with the survey procedure, requirements in Section 5, Part I "Classification" and other applicable requirements of the Register. Records of the performance of the components and equipment essential to verify the design parameters, shall be maintained and be available to the surveyor to the Register.

20.4.6 Heating arrangements, if fitted in accordance with 19.2.5 and 19.2.6, shall be tested for required heat output and heat distribution.

20.4.7 The cargo containment system shall be inspected for cold spots during, or immediately following, the first loaded voyage. Inspection of the integrity of thermal insulation surfaces that cannot be visually checked shall be carried out in accordance with procedures approved by Register.

21 TYPE A INDEPENDENT TANKS

21.1 Design basis.

21.1.1 Type A independent tanks are tanks primarily designed using ship-structural analysis procedures approved by the Register. Where such tanks are primarily constructed of plane surfaces, the design vapour pressure P_0 shall be less than 0,07 MPa.

21.1.2 If the cargo temperature at atmospheric pressure is below –10 °C, a complete secondary barrier shall be provided as required in Section 5. The secondary barrier shall be designed in accordance with Section 6.

21.2 Structural analysis.

21.2.1 A structural analysis shall be performed taking into account the internal pressure as indicated in 13.2, and the interaction loads with the supporting and keying system as well as a reasonable part of the ship's hull.

21.2.2 For parts, such as supporting structures, not otherwise covered by the requirements of these Rules, stresses shall be determined by direct calculations, taking into account the loads referred to in Sections 12 — 15 as far as applicable, and the ship deflection in way of supporting structures.

21.2.3 The tanks with supports shall be designed for the accidental loads specified in Section 15. These loads need not be combined with each other or with environmental loads.

21.3 Ultimate design condition.

21.3.1 For tanks primarily constructed of plane surfaces, the nominal membrane stresses for primary and secondary members (stiffeners, web frames, stringers, girders), when calculated by classical analysis procedures, shall not exceed the lower of R_m/2,66 or R_e /1,33 for nickel steels, carbon-manganese steels, austenitic steels and aluminium alloys, where R_m and R_e are defined in 18.2.3. However, if detailed calculations are carried out for the primary members, the equivalent stress σ_C, as defined in 18.2.4, may be increased over that indicated above to a stress acceptable to the Register. Calculations shall take into account the effects of bending, shear, axial and torsional deformation as well as the hull/cargo tank interaction forces due to the deflection of the double bottom and cargo tank bottoms.

21.3.2 Tank boundary scantlings shall meet the requirements of the Register for deep tanks taking into account the internal pressure as indicated in 13.2 and any corrosion allowance required by 3.5.

21.3.3 The cargo tank structure shall be reviewed against potential buckling.

21.4 Accident design condition.

21.4.1 The tanks and the tank supports shall be designed for the accidental loads and design conditions specified in 3.4.3 and Section 15, as relevant.

21.4.2 When subjected to the accidental loads specified in Section 15, the stress shall comply with the acceptance criteria specified in 21.3, modified as appropriate, taking into account their lower probability of occurrence.

21.5 Testing.

21.5.1 All type A independent tanks shall be subjected to a hydrostatic or hydropneumatic test. This test shall be performed such that the stresses approximate, as far as practicable, the design stresses, and that the pressure at the top of the tank corresponds at least to the MARVS. When a hydropneumatic test is performed, the conditions shall simulate, as far as practicable, the design loading of the tank and of its support structure, including dynamic components, while avoiding stress levels that could cause permanent deformation.

22 TYPE B INDEPENDENT TANKS

22.1 Design basis.

22.1.1 Type B independent tanks are tanks designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics. Where such tanks are primarily constructed of plane surfaces (prismatic tanks), the design vapour pressure P_0 shall be less than 0,07 MPa.

22.1.2 If the cargo temperature at atmospheric pressure is below –10 °C, a partial secondary barrier with a small leak protection system shall be provided as required in Section 5. The small leak protection system shall be designed according to Section 7.

22.2 Structural analysis.

22.2.1 The effects of all dynamic and static loads shall be used to determine the suitability of the structure with respect to:

.1 plastic deformation;
.2 buckling;
.3 fatigue failure; and
.4 crack propagation.

Finite element analysis or similar methods and fracture mechanics analysis, or an equivalent approach, shall be carried out.

22.2.2 A three-dimensional analysis shall be carried out to evaluate the stress levels, including interaction with the ship's hull. The model for this analysis shall include the cargo tank with its supporting and keying system, as well as a reasonable part of the hull.

22.2.3 A complete analysis of the particular ship accelerations and motions in irregular waves, and of the response of the ship and its cargo tanks to these forces and motions shall be performed, unless the data is available from similar ships.

22.3 Ultimate design condition.

22.3.1 Plastic deformation.

22.3.1.1 For type B independent tanks, primarily constructed of bodies of revolution, the allowable stresses shall not exceed:

$$\sigma_m \le f; \quad (22.3.1.1\text{-}1)$$

$$\sigma_L \le 1{,}5f; \quad (22.3.1.1\text{-}2)$$

$$\sigma_b \le 1{,}5F; \quad (22.3.1.1\text{-}3)$$

$$\sigma_L + \sigma_b \le 1{,}5F; \quad (22.3.1.1\text{-}4)$$

$$\sigma_m + \sigma_b \le 1{,}5F; \quad (22.3.1.1\text{-}5)$$

$$\sigma_m + \sigma_b + \sigma_g \le 3{,}0F; \quad (22.3.1.1\text{-}6)$$

$$\sigma_L + \sigma_b + \sigma_g \le 3{,}0F \quad (22.3.1.1\text{-}7)$$

where σ_m = equivalent primary general membrane stress;
σ_L = equivalent primary local membrane stress;
σ_b = equivalent primary bending stress;
σ_g = equivalent secondary stress;
f = the lesser of (R_m/A) or (R_e/B); and
F = the lesser of (R_m/C) or (R_e/D),

with R_m and R_e as defined in 18.2.4. With regard to the stresses σ_m, σ_L, σ_b and σ_g, the definitions of stress categories in 28.3 are referred. The values A and B shall be shown on the International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk and shall have at least the following minimum values as specified in Table 22.3.1.1.

Table 22.3.1.1

	Nickel steel and carbon manganese steels	Austenitic steels	Aluminium alloys
A	3	3,5	4
B	2	1,6	1,5
C	3	3	3
D	1,5	1,5	1,5

The above figures may be altered, taking into account the design condition considered, and shall be agreed with the Register.

22.3.1.2 For type B independent tanks, primarily constructed of plane surfaces, the allowable membrane equivalent stresses applied for finite element analysis shall not exceed:

.1 for nickel steels and carbon-manganese steels, the lesser of R_m /2 or R_e/1,2;

.2 for austenitic steels, the lesser of R_m/2,5 or R_e/1,2; and

.3 for aluminium alloys, the lesser of R_m /2,5 or R_e/1,2.

The above figures may be amended, taking into account the locality of the stress, stress analysis methods and design condition considered. The figures as amended shall be agreed with the Register.

22.3.1.3 The thickness of the skin plate and the size of the stiffener shall not be less than those required for type A independent tanks.

22.3.2 Buckling.

Buckling strength analyses of cargo tanks subject to external pressure and other loads causing compressive stresses shall be carried out in accordance with a procedure approved by the Register. The method shall adequately account for the difference in theoretical and actual buckling stress as a result of plate edge misalignment, lack of straightness or flatness, ovality and deviation from true circular form over a specified arc or chord length, as applicable.

22.4 Fatigue design condition.

22.4.1 Fatigue and crack propagation assessment shall be performed in accordance with 18.3. The acceptance criteria shall comply with 18.3.7 — 18.3.9, depending on the detectability of the defect.

22.4.2 Fatigue analysis shall consider construction tolerances.

22.4.3 Model tests are recommended to determine stress concentration factors and fatigue life of structural elements. The requirements for tests shall be agreed with the Register.

22.5 Accident design condition.

22.5.1 The tanks and the tank supports shall be designed for the accidental loads and design conditions specified in 3.4.3 and Section 15, as applicable.

22.5.2 When subjected to the accidental loads specified in Section 15, the stress shall comply with the acceptance criteria specified in 22.3, modified as appropriate, taking into account their lower probability of occurrence.

22.6 Testing.

22.6.1 Type B independent tanks shall be subjected to a hydrostatic or hydropneumatic test as follows:

.1 the test shall be performed as required in 21.5 for type A independent tanks; and

.2 in addition, the maximum primary membrane stress or maximum bending stress in primary members under test conditions shall not exceed 90 % of the yield strength of the material (as fabricated) at the test temperature. To ensure that this condition is satisfied, when calculations indicate that this stress exceeds 75 % of the yield strength, the prototype test shall be monitored by the use of strain gauges or other suitable equipment.

22.7 Marking.

22.7.1 Any marking of the pressure vessel shall be achieved by a method that does not cause unacceptable local stress raisers.

23 TYPE C INDEPENDENT TANKS

23.1 Design basis.

23.1.1 The design basis for type C independent tanks is based on pressure vessel criteria modified to include fracture mechanics and crack propagation criteria. The minimum design pressure defined in 23.1.2 is intended to ensure that the dynamic stress is sufficiently low, so that an initial surface flaw will not propagate more than half the thickness of the shell during the lifetime of the tank.

23.1.2 The design vapour pressure, in MPa, shall not be less than

$$P_0 = 0{,}2 + AC(\rho_r)^{1{,}5}, \quad (23.1.2\text{-}1)$$

where $A = 0{,}00185(\sigma_m/\Delta\sigma_A)^2$; (23.1.2-2)

σ_m = design primary membrane stress;

$\Delta\sigma_A$ = allowable dynamic membrane stress (double amplitude at probability level $Q = 10^{-8}$) and equal to:
55 MPa for ferritic-perlitic, martensitic and austenitic steel;
25 MPa for aluminium alloy (5083-O);

C = a characteristic tank dimension to be taken as the greatest of the following: h, 0,75b or 0,45l,

with h = height of tank (dimension in ship's vertical direction), in m;

b = width of tank (dimension in ship's transverse direction), in m;

l = length of tank (dimension in ship's longitudinal direction), in m;

ρ_r = the relative density of the cargo (ρ_r = 1 for fresh water) at the design temperature.

When a specified design life of the tank is longer than 10^8 wave encounters, $\Delta\sigma_A$ shall be modified to give equivalent crack propagation corresponding to the design life.

23.1.3 The Register may allocate a tank complying with the criteria of type C tank minimum design pressure as in 23.1.2, to a type A or type B, dependent on the configuration of the tank and the arrangement of its supports and attachments.

23.1.4 If the carriage of products not covered by the Code[1] and having the relative density above 1,0 is intended, it shall be verified that the double amplitude of the primary membrane stress $\Delta\sigma_m$ created by the maximum dynamic pressure differential ΔP does not exceed the allowable double amplitude of the dynamic membrane stress $\Delta\sigma_A$, as specified in 23.1.2, i.e.

$$\Delta\sigma_m \le \Delta\sigma_A. \quad (23.1.4\text{-}1)$$

The dynamic pressure differential ΔP, in MPa, shall be determined by the formula

$$\Delta P = \frac{\gamma}{1{,}02 \times 10^5}(\alpha_{\beta 1} Z_{\beta 1} - \alpha_{\beta 2} Z_{\beta 2}), \quad (23.1.4\text{-}2)$$

where γ — maximum liquid cargo density, in kg/m³, at the design temperature;

α_β, Z_β — refer to 28.1.2 and figure 23.1.4;

$\alpha_{\beta 1}, Z_{\beta 1}$ are the α_β and Z_β values giving the maximum liquid pressure $(P_{gd})_{\max}$, refer to 28.1;

$\alpha_{\beta 2}, Z_{\beta 2}$ are the α_β and Z_β values giving the minimum liquid pressure $(P_{gd})_{\min}$, refer to 28.1.

In order to evaluate the maximum pressure differential ΔP, pressure differentials shall be evaluated over the full range of the acceleration ellipse as shown in the sketch in Fig. 23.1.4.

[1] Additional provisions from IACS UI GC7.

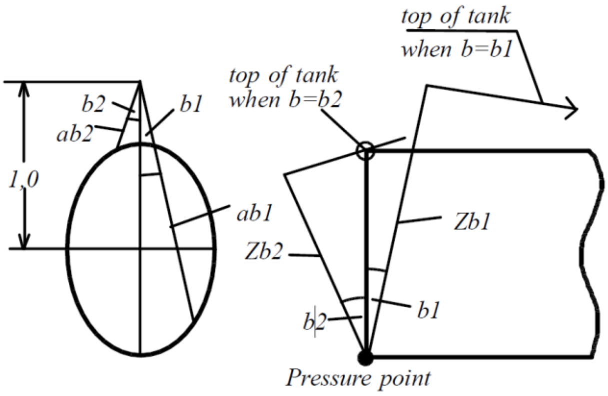

Fig. 23.1.4
Sketch for calculating a dynamic pressure differential

23.2 Shell thickness.

23.2.1 The shell thickness shall be as follows:

.1 for pressure vessels, the thickness calculated according to 23.2.4 shall be considered as a minimum thickness after forming, without any negative tolerance;

.2 for pressure vessels, the minimum thickness of shell and heads including corrosion allowance, after forming, shall not be less than 5 mm for carbon-manganese steels and nickel steels, 3 mm for austenitic steels or 7 mm for aluminium alloys;

.3 the welded joint efficiency factor to be used in the calculation according to 23.2.4 shall be 0,95 when the inspection and the non-destructive testing referred to in 3.9, Part IX "Materials and Welding" are carried out. This figure may be increased up to 1,0 when account is taken of other considerations, such as the material used, type of joints, welding procedure and type of loading. For process pressure vessels, partial non-destructive examinations may be accepted, but not less than those of 3.7, Part IX "Materials and Welding", depending on such factors as the material used, the design temperature, the nil-ductility transition temperature of the material, as fabricated, and the type of joint and welding procedure, but in this case an efficiency factor of not more than 0,85 shall be adopted. For special materials, the abovementioned factors shall be reduced, depending on the specified mechanical properties of the welded joint.

23.2.2 The design liquid pressure defined in 13.2 shall be taken into account in the internal pressure calculations.

23.2.3 The design external pressure P_e , in MPa, used for verifying the buckling of the pressure vessels, shall not be less than that given by:

$$P_e = P_1 + P_2 + P_3 + P_4, \qquad (23.2.3)$$

where P_1 = setting value of vacuum relief valves. For vessels not fitted with vacuum relief valves, P_1 is determined by the procedure agreed with the Register, but shall not, in general, be taken as less than 0,025 MPa;

P_2 = the set pressure of the pressure relief valves (PRVs) for completely closed spaces containing pressure vessels or parts of pressure vessels; elsewhere P_2 = 0;

P_3 = compressive actions in or on the shell due to the weight and contraction of thermal insulation, weight of shell including corrosion allowance and other miscellaneous external pressure loads to which the pressure vessel may be subjected. These include, but are not limited to, weight of domes, weight of towers and piping, effect of product in the partially filled condition, accelerations and hull deflection. In addition, the local effect of external or internal pressures or both shall be taken into account; and

P_4 = external pressure due to head of water for pressure vessels or part of pressure vessels on exposed decks; elsewhere P_4 = 0.

23.2.4 Scantlings based on internal pressure shall be calculated as follows: the thickness and form of pressure-containing parts of pressure vessels, under internal pressure, as defined in 13.2, including flanges, shall be determined. These calculations shall in all cases be based on accepted pressure vessel design theory. Openings in pressure-containing parts of pressure vessels shall be reinforced.

23.2.5 Stress analysis in respect of static and dynamic loads shall be performed as follows:

.1 pressure vessel scantlings shall be determined in accordance with 23.2.1 — 23.2.4 and 23.3;

.2 calculations of the loads and stresses in way of the supports and the shell attachment of the support shall be made. Loads referred to in Sections 12 — 15 shall be used, as applicable. Stresses in way of the supporting structures shall be determined by the procedure agreed by the Register. A fatigue analysis may be required;

.3 secondary stresses and thermal stresses shall be considered.

23.3 Ultimate design condition.

23.3.1 Plastic deformation

For type C independent tanks, the allowable stresses shall not exceed:

$$\sigma_m \le f; \quad (23.3.1\text{-}1)$$

$$\sigma_L \le 1{,}5f; \quad (23.3.1\text{-}2)$$

$$\sigma_b \le 1{,}5f; \quad (23.3.1\text{-}3)$$

$$\sigma_L + \sigma_b \le 1{,}5f; \quad (23.3.1\text{-}4)$$

$$\sigma_m + \sigma_b \le 1{,}5f; \quad (23.3.1\text{-}5)$$

$$\sigma_m + \sigma_b + \sigma_g \le 3{,}0f; \quad (23.3.1\text{-}6)$$

$$\sigma_L + \sigma_b + \sigma_g \le 3{,}0f \quad (23.3.1\text{-}7)$$

where σ_m = equivalent primary general membrane stress;
σ_L = equivalent primary local membrane stress;
σ_b = equivalent primary bending stress;
σ_g = equivalent secondary stress; and
f = the lesser of (R_m/A) or (R_e/B),

with R_m and R_e as defined in 18.2.4. With regard to the stresses σ_m, σ_L , σ_b и σ_g, the definition of stress categories in 28.3 are referred. The values A and B shall be shown on the International Certificate of Fitness for the Carriage of Liquefied Gases in Bulk and shall have at least as mentioned in Table 23.3.1.

Table 23.3.1

	Nickel steel and carbon manganese steels	Austenitic steels	Aluminium alloys
A	3	3,5	4
B	1,5	1,5	1,5

23.3.2 Buckling criteria shall be as follows: the thickness and form of pressure vessels subject to external pressure and other loads causing compressive stresses shall be based on calculations using pressure vessel buckling theory approved by the Register and shall adequately account for the difference in theoretical and actual buckling stress as a result of plate edge misalignment, ovality and deviation from true circular form over a specified arc or chord length.

23.3.3 Permissible stresses in stiffening rings[1].

For horizontal cylindrical tanks made of C-Mn steel supported in saddles, the equivalent stress in the stiffening rings shall not exceed the following values if calculated using finite element method:

$$\sigma_e \leq \sigma_{all}, \quad (23.3.3\text{-}1)$$

where $\sigma_{all} = \min(0{,}57R_m;\ 0{,}85R_e)$, (23.3.3-2)

$$\sigma_e = \sqrt{(\sigma_n + \sigma_b)^2 + 3\tau^2}, \quad (23.3.3\text{-}3)$$

σ_e = von Mises equivalent stress, in MPa;
σ_n = normal stress, in MPa, in the circumferential direction of the stiffening ring;
σ_b = bending stress, in MPa, in the circumferential direction of the stiffening ring; and
τ = shear stress, in MPa, in the stiffening ring; and
with R_m and R_e as defined in 18.2.4.

Equivalent stress values σ_e shall be calculated over the full extent of the stiffening ring by a procedure with a sufficient number of load cases agreed with the Register.

23.3.4 Assumptions made for the stiffening rings.

The stiffening ring shall be considered as a circumferential beam formed by web, face plate, doubler plate, if any, and associated shell plating.

The effective width of the associated plating shall be taken as follows.

.1 For cylindrical shells:

an effective width, in mm, not greater than $0{,}78\sqrt{rt}$ on each side of the web,

where r = mean radius of the cylindrical shell, in mm, and t = shell thickness, in mm.

A doubler plate, if any, may be included within that distance;

.2 For longitudinal bulkheads (in the case of lobe tanks):

the effective width shall be determined according to established standards. A value of $20t_b$ on each side may be taken as a guidance value, where t_b = bulkhead thickness, in mm.

The stiffening ring shall be loaded with circumferential forces, on each side of the ring, due to the shear stress, determined by the bi-dimensional shear flow theory from the shear force of the tank.

23.3.5 For calculation of reaction forces at the supports, the following factors shall be taken into account:

elasticity of support material (intermediate layer of wood or similar material);

change in contact surface between tank and support, and of the relevant reactions, due to thermal shrinkage of tank, elastic deformations of tank and support material.

The final distribution of the reaction forces at the supports shall not show any tensile forces.

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[1] Additional provisions not included in the Code.

23.3.6 The buckling strength of the stiffening rings shall be examined.

23.4 Fatigue design condition.

23.4.1 For large type C independent tanks, where the cargo at atmospheric pressure is below –55 °C, the Register may require additional verification to check their compliance with 23.1.1 regarding static and dynamic stress.

23.5 Accident design condition.

23.5.1 The tanks and the tank supporting structures shall be designed for the accidental loads and design conditions specified in 3.4.3 and Section 15, as applicable.

23.5.2 When subjected to the accidental loads specified in Section 15, the stress shall comply with the acceptance criteria specified in 23.3.1, modified as appropriate taking into account their lower probability of occurrence.

23.6 Testing.

23.6.1 Each pressure vessel shall be subjected to a hydrostatic test at a pressure measured at the top of the tanks, of not less than 1,5P_0. In no case during the pressure test shall the calculated primary membrane stress at any point exceed 90 % of the yield stress of the material. Where calculations indicate that this stress will exceed 0,75 times the yield strength, the prototype test shall be monitored by the use of strain gauges or other suitable equipment in pressure vessels other than simple cylindrical and spherical pressure vessels.

23.6.2 The temperature of the water used for the test shall be at least 30 °C above the nil-ductility transition temperature of the material, as fabricated.

23.6.3 The pressure shall be held for 2 h per 25 mm of thickness, but in no case less than 2 h.

23.6.4 Where necessary for cargo pressure vessels, a hydropneumatic test may be carried out under the conditions prescribed in 23.6.1 — 23.6.3.

23.6.5 The conditions for the testing of tanks in which higher allowable stresses are used, may be amended depending on service temperature. The conditions as amended shall be approved by the Register. However, the requirements of 23.6.1 shall be fully complied with.

23.6.6 After completion and assembly, each pressure vessel and its related fittings shall be subjected to an adequate tightness test which may be performed in combination with the pressure testing referred to in 23.6.1.

23.6.7 Pneumatic testing of pressure vessels other than cargo tanks shall be agreed by the Register. Such testing shall only be permitted for those vessels designed or supported such that they cannot be safely filled with water, or for those vessels that cannot be dried and shall be used in a service where traces of the testing medium cannot be tolerated.

23.7 Marking.

23.7.1 The required marking of the pressure vessel shall be achieved by a method that does not cause unacceptable local stress raisers.

24 MEMBRANE TANKS

24.1 Design basis.

24.1.1 The design basis for membrane containment systems is that thermal and other expansion or contraction is compensated for without undue risk of losing the tightness of the membrane.

24.1.2 A systematic approach based on analysis and testing shall be used to demonstrate that the system will provide its intended function in consideration of the events identified in service as specified in 24.2.1.

24.1.3 If the cargo temperature at atmospheric pressure is below –10 °C, a complete secondary barrier shall be provided as required in Section 5. The secondary barrier shall be designed according to Section 6.

24.1.4 The design vapour pressure P_0 shall not normally exceed 0,025 MPa. If the hull scantlings are increased accordingly and consideration is given, where appropriate, to the strength of the supporting thermal insulation, P_0 may be increased to a higher value, but less than 0,07 MPa.

24.1.5 The definition of membrane tanks does not exclude designs such as those in which non-metallic membranes are used or where membranes are included or incorporated into the thermal insulation.

24.1.6 The thickness of the membranes shall not normally exceed 10 mm.

24.1.7 The circulation of inert gas throughout the primary insulation space and the secondary insulation space, in accordance with 6.2.1, Part VI "Systems and Piping", shall be sufficient to allow for effective means of gas detection.

24.2 Design considerations.

24.2.1 Potential incidents that could lead to loss of fluid tightness over the life of the membranes shall be evaluated. These include, but are not limited to:

.1 ultimate design events:
tensile failure of membranes;
compressive collapse of thermal insulation;
thermal ageing;
loss of attachment between thermal insulation and hull structure;
loss of attachment of membranes to thermal insulation system;
structural integrity of internal structures and their supporting structures; and
failure of the supporting hull structure;

.2 fatigue design events:
fatigue of membranes including joints and attachments to hull structure;
fatigue cracking of thermal insulation;
fatigue of internal structures and their supporting structures; and
fatigue cracking of inner hull leading to ballast water ingress;

.3 accident design events:
accidental mechanical damage (such as dropped objects inside the tank while in service);
accidental overpressurization of thermal insulation spaces;
accidental vacuum in the tank; and
water ingress through the inner hull structure.

Designs where a single internal event could cause simultaneous or cascading failure of both membranes are unacceptable.

24.2.2 The necessary physical properties (mechanical, thermal, chemical, etc.) of the materials used in the construction of the cargo containment system shall be established during the design development in accordance with 24.1.2.

24.3 Loads and load combinations.

24.3.1 Particular consideration shall be given to the possible loss of tank integrity due to either an overpressure in the interbarrier space, a possible vacuum in the cargo tank, the sloshing effects, hull vibration effects, or any combination of these events.

24.3.2 Methodology to determine dynamic design loads on the walls of a membrane cargo tank at its partial filling due to the sloshing effects[1] shall comply with the following minimum functional requirements:

.1 methodology shall contain the data on source specifications describing the operation during the whole ship's service life, including

the ship's main particulars;

geometry of cargo tanks at the primary barrier level, arrangement of cargo containments over the full breadth and length;

density and kinematic viscosity values;

selected design levels for tank filling;

the ship speed and distribution law of heading;

characteristics of ship's loading conditions (the centre of gravity and centre of buoyancy position, metacentric height);

statistics on irregular sea parameters (the provisions of IACS Recommendation No. 34 shall be met);

special service conditions, if available (ice class);

.2 in general, the loads shall be determined for all the cargo tanks where the partial filling is provided. In case of the available tanks identical in terms of geometrical features, it is allowed to determine the loads for those tanks where the maximum sloshing loads are expected. In addition, the methodology shall contain substantiation for the tanks selected for calculation regarding

geometrical features and shapes of the tanks;

arrangement of tanks over the full breadth and length of the ship relative to the centre of gravity;

.3 methodology shall contain the ship's rolling calculations. As a result of the calculation, the characteristics of oscillating movements shall be obtained for all types of rolling at irregular seas applicable to all selected operating conditions (amplitude versus frequency response characteristics or implementation on a time scale).During the rolling calculation, the methods may be applied based on the three-dimensional potential theory and other pitching and rolling calculation methods agreed with the Register;

.4 methodology shall contain the results of model sloshing tests in design cargo tanks. The model test program shall comply with the following minimum requirements:

all the main assumptions shall be specified when used during model tests;

description of the used test bench and equipment used for measuring and processing the measurement results shall be given;

substantiation for the value of scaling load factor shall be given;

the ship's oscillating movement at irregular seas shall be modelled (ship's motion characteristics can be scaled in the model test based on the Froude similarity criterion);

duration of each model test and scope of parameters characterizing each test shall be substantiated;

.5 methodology shall include description of statistical analysis of model test results. The statistical method description shall be given when used for short-term as well as long-term distribution of sloshing loads required to determine the maximum design loads on the walls of a cargo tank;

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[1] Additional provisions not included in the Code.

.6 when determining the maximum design loads, the results of model tests performed for sister ships with similar main dimensions and geometrical features of cargo tanks may be used. Feasible use of the results of earlier tests shall be justified considering the review of the compliance degree of, at least, the following characteristics:
the selected initial technical data;
the selected design cargo tanks;
the rolling and pitching calculation results; and
the main assumptions used during model tests.

24.4 Structural analyses.

24.4.1 Structural analyses and/or testing for the purpose of determining the ultimate strength and fatigue assessments of the cargo containment and associated structures, e.g. structures as defined in Section 9, shall be performed. The structural analysis shall provide the data required to assess each failure mode that has been identified as critical for the cargo containment system.

24.4.2 Structural analyses of the hull shall take into account the internal pressure as indicated in 13.2. Special attention shall be paid to deflections of the hull and their compatibility with the membrane and associated thermal insulation.

24.4.3 The analyses referred to in 24.4.1 and 24.4.2 shall be based on the particular motions, accelerations and response of ships and cargo containment systems.

24.5 Ultimate design condition.

24.5.1 The structural resistance of every critical component, subsystem or assembly shall be established, in accordance with 24.1.2, for in-service conditions.

24.5.2 The choice of strength acceptance criteria for the failure modes of the cargo containment system, its attachments to the hull structure and internal tank structures, shall reflect the consequences associated with the considered mode of failure.

24.5.3 The inner hull scantlings shall meet the requirements for deep tanks, taking into account the internal pressure as indicated in 13.2 and the specified appropriate requirements for sloshing load as defined in 14.3.

24.6 Fatigue design condition.

24.6.1 Fatigue analysis shall be carried out for structures inside the tank, i.e. pump towers, and for parts of membrane and pump tower attachments, where failure development cannot be reliably detected by continuous monitoring.

24.6.2 The fatigue calculations shall be carried out in accordance with 18.3, with relevant requirements depending on:

.1 the significance of the structural components with respect to structural integrity; and

.2 availability for inspection.

24.6.3 For structural elements for which it can be demonstrated by tests and/or analyses that a crack will not develop to cause simultaneous or cascading failure of both membranes, C_w shall be less than or equal to 0,5.

24.6.4 Structural elements subject to periodic inspection, and where an unattended fatigue crack can develop to cause simultaneous or cascading failure of both membranes, shall satisfy the fatigue and fracture mechanics requirements stated in 18.3.8.

24.6.5 Structural element not accessible for in-service inspection, and where a fatigue crack can develop without warning to cause simultaneous or cascading failure of both membranes, shall satisfy the fatigue and fracture mechanics requirements stated in 18.3.9.

24.7 Accident design condition.

24.7.1 The containment system and the supporting hull structure shall be designed for the accidental loads specified in Section 15. These loads need not be combined with each other or with environmental loads.

24.7.2 Additional relevant accident scenarios shall be determined based on a risk analysis. Particular attention shall be paid to securing devices inside tanks.

24.8 Design development testing.

24.8.1 The design development testing required in 24.1.2 shall include a series of analytical and physical models of both the primary and secondary barriers, including corners and joints, tested to verify that they will withstand the expected combined strains due to static, dynamic and thermal loads. This will culminate in the construction of a prototype-scaled model of the complete cargo containment system. Testing conditions considered in the analytical and physical models shall represent the most extreme service conditions the cargo containment system will be likely to encounter over its life. Proposed acceptance criteria for periodic testing of secondary barriers required in 6.2 may be based on the results of testing carried out on the prototype-scaled model.

24.8.2 The fatigue performance of the membrane materials and representative welded or bonded joints in the membranes shall be determined by tests. The ultimate strength and fatigue performance of arrangements for securing the thermal insulation system to the hull structure shall be determined by analyses or tests.

24.9 Testing.

24.9.1 In ships fitted with membrane cargo containment systems, all tanks and other spaces that may normally contain liquid and are adjacent to the hull structure supporting the membrane, shall be hydrostatically tested.

24.9.2 All hold structures supporting the membrane shall be tested for tightness before installation of the cargo containment system.

24.9.3 Pipe tunnels and other compartments that do not normally contain liquid need not be hydrostatically tested.

25 INTEGRAL TANKS

25.1 Design basis.

25.1.1 Integral tanks that form a structural part of the hull and are affected by the loads that stress the adjacent hull structure shall comply with the following:

.1 the design vapour pressure P_0 as defined in 1.2 shall not normally exceed 0,025 MPa. If the hull scantlings are increased accordingly, P_0 may be increased to a higher value, but less than 0,07 MPa;

.2 integral tanks may be used for products, provided the boiling point of the cargo is not below –10 °C. A lower temperature may be accepted, but in such cases a complete secondary barrier shall be provided; and

.3 products required by Annex 1 to be carried in type **1G** ships shall not be carried in integral tanks.

25.2 Structural analysis.

25.2.1 The structural analysis of integral tanks shall be in accordance with the procedure approved by the Register.

25.3 Ultimate design condition.

25.3.1 The tank boundary scantlings shall meet the requirements for deep tanks, taking into account the internal pressure as indicated in 13.2.

25.3.2 For integral tanks, allowable stresses shall normally be those given for hull structure in the RS Rules requirements.

25.4 Accident design condition.

25.4.1 The tanks and the tank supports shall be designed for the accidental loads specified in 3.4.3 and Section 15, as relevant.

25.4.2 When subjected to the accidental loads specified in Section 15, the stress shall comply with the acceptance criteria specified in 25.3, modified as appropriate, taking into account their lower probability of occurrence.

25.5 Testing.

25.5.1 All integral tanks shall be hydrostatically or hydropneumatically tested. The test shall be performed so that the stresses approximate, as far as practicable, to the design stresses and that the pressure at the top of the tank corresponds at least to the MARVS.

26 SEMI-MEMBRANE TANKS

26.1 Design basis.

26.1.1 Semi-membrane tanks are non-self-supporting tanks when in the loaded condition and consist of a layer, parts of which are supported through thermal insulation by the adjacent hull structure, whereas the rounded parts of this layer connecting the above-mentioned supported parts are designed also to accommodate the thermal and other expansion or contraction.

26.1.2 The design vapour pressure P_0 shall not normally exceed 0,025 MPa. If the hull scantlings are increased accordingly, and consideration is given, where appropriate, to the strength of the supporting thermal insulation, P_0 may be increased to a higher value, but less than 0,07 MPa.

26.1.3 For semi-membrane tanks the relevant requirements of this Part for independent tanks or for membrane tanks shall be applied as appropriate.

26.1.4 In the case of semi-membrane tanks that comply in all respects with the requirements applicable to type B independent tanks, except for the manner of support, the use of a partial secondary barrier may be accepted.

27 LIMIT STATE DESIGN FOR NOVEL CONCEPTS OF CARGO CONTAINMENT SYSTEMS

27.1 Cargo containment systems that are of a novel configuration that cannot be designed using Sections 21 — 26 shall be designed using this Section and Sections 3 — 15, and also Sections 16 — 20, as applicable. Cargo containment system design according to this Section shall be based on the principles of limit state design which is an approach to structural design that can be applied to established design solutions as well as novel designs. This more generic approach maintains a level of safety similar to that achieved for known containment systems as designed using Sections 21— 26.

27.2 **Limit state categories.**

27.2.1 The limit state design is a systematic approach where each structural element is evaluated with respect to possible failure modes related to the design conditions identified in 3.4. A limit state can be defined as a condition beyond which the structure, or part of a structure, no longer satisfies the requirements.

27.2.2 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. The limit states are divided into the three following categories:

.1 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;

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

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

27.3 The procedure and relevant design parameters of the limit state design shall comply with the Standards for the Use of Limit State Methodologies in the Design of Cargo Containment Systems of Novel Configuration (LSD Standard), as set out in Annex 4.

28 ADDITIONAL PROVISIONS FOR PART IV

28.1 Guidance to detailed calculation of internal pressure for static design purpose.

28.1.1 This Section provides guidance for the calculation of the associated dynamic liquid pressure for the purpose of static design calculations. This pressure may be used for determining the internal pressure referred to in 13.2.4, where:

.1 $(P_{gd})_{\max}$ is the associated liquid pressure, in MPa, determined using the maximum design accelerations;

.2 $(P_{gd}\ site)_{\max}$ is the associated liquid pressure, in MPa, determined using site specific accelerations.

.3 P_{eq}, in MPa, should be the greater of P_{eq1}, in MPa, and P_{eq2}, in MPa, calculated as follows:

$$P_{eq1} = P_0 + (P_{gd})_{\max}; \quad (28.1.1.3\text{-}1)$$

$$P_{eq2} = P_0 + (P_{gd}\ site)_{\max}. \quad (28.1.1.3\text{-}2)$$

28.1.2 The internal liquid pressures are those created by the resulting acceleration of the centre of gravity of the cargo due to the motions of the ship referred to in 14.1. The value of internal liquid pressure P_{gd}, in MPa, resulting from combined effects of gravity and dynamic accelerations should be calculated as follows:

$$P_{gd} = \alpha_\beta Z_\beta \frac{\rho}{1{,}02\times10^5}, \quad (28.1.2\text{-}1)$$

where α_β = dimensionless acceleration (i.e. relative to the acceleration of gravity), resulting from gravitational and dynamic loads, in an arbitrary direction β (refer to Fig. 28.1.2-1).
For large tanks, an acceleration ellipsoid taking account of transverse vertical and longitudinal accelerations, should be used.

Z_β = largest liquid height, in m, above the point where the pressure shall be determined measured from the tank shell in the β direction (refer to Fig. 28.1.2-2).

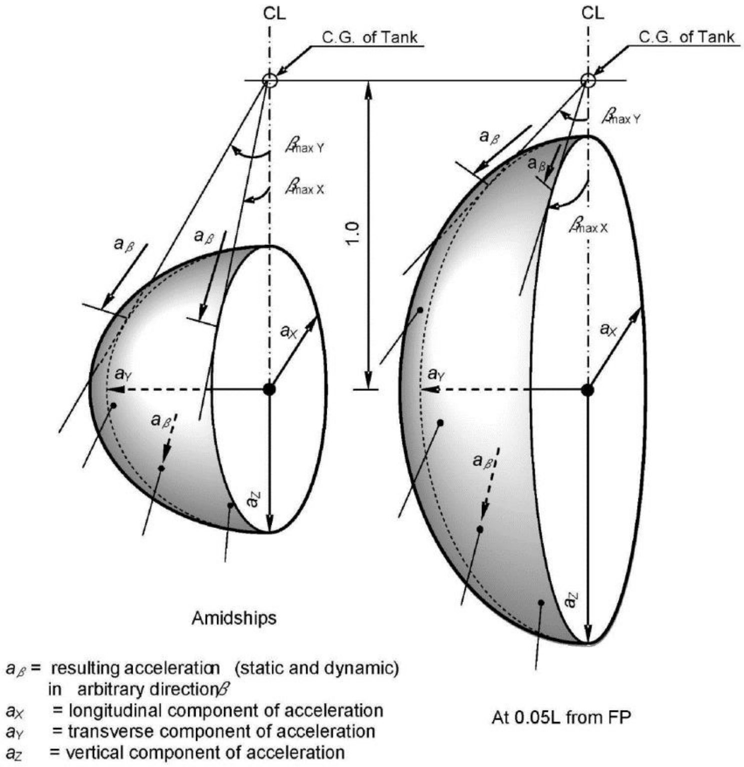

Fig. 28.1.2-1
Acceleration ellipsoid

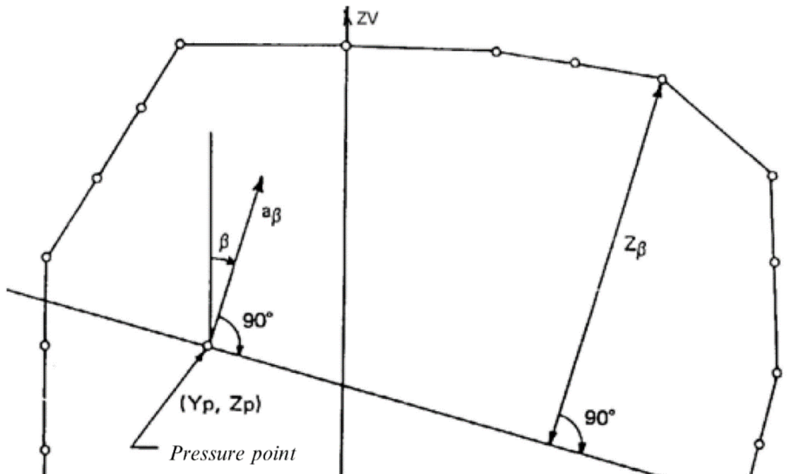

Fig. 28.1.2-2
Determination of internal pressure heads

Tank domes considered to be part of the accepted total tank volume shall be taken into account when determining Z_β, unless the total volume of tank domes V_d does not exceed the following value:

$$V_d = V_t \left(\frac{100-FL}{FL}\right), \tag{28.1.2-2}$$

with: V_t — tank volume without any domes; and
FL — filling limit according to 3.20, Part VI "Systems and Piping";
ρ — maximum cargo density, in kg/m³, at the design temperature.

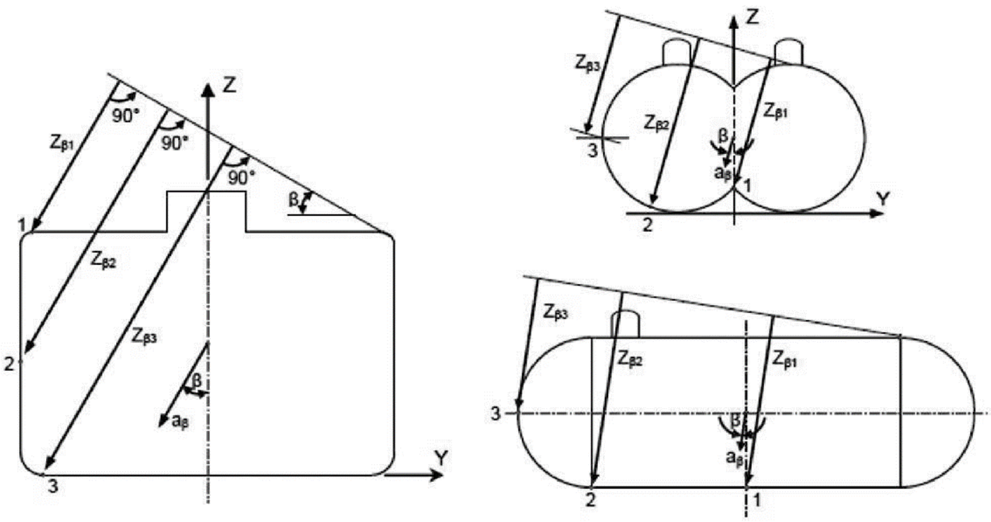

Fig. 28.1.2-3
Determination of liquid height Z_β for points *1*, *2* and *3*

The direction that gives the maximum value $(P_{gd})_{\max}$ or $(P_{gd}\ site)_{\max}$ shall be considered. The above formula applies only to full tanks.

28.1.3 Equivalent calculation procedures may be applied.

28.2 Guidance formulae for acceleration components.

28.2.1 The following formulae are given as guidance for the components of acceleration due to ship's motions corresponding to a probability level of 10⁻⁸ in the North Atlantic and apply to ships with a length exceeding 50 m and at or near their service speed:

vertical acceleration, as defined in 14.1:

$$a_z = \pm a_0 \sqrt{1 + \left(5{,}3 - \frac{45}{L_0}\right)^2 \left(\frac{x}{L_0} + 0{,}05\right)^2 \left(\frac{0{,}6}{C_b}\right)^2 + \left(\frac{0{,}6 y K^{1{,}5}}{B}\right)^2}; \tag{28.2.1-1}$$

transverse acceleration, as defined in 14.1:

$$a_y = \pm a_0 \sqrt{0{,}6 + 2{,}5\left(\frac{x}{L_0} + 0{,}05\right)^2 + K\left(1 + 0{,}6K\frac{z}{B}\right)^2}; \tag{28.2.1-2}$$

longitudinal acceleration, as defined in 14.1:

$$a_x = \pm a_0 \sqrt{0{,}06 + A^2 - 0{,}25A} \tag{28.2.1-3}$$

where

$$a_0 = 0{,}2\,\frac{V}{\sqrt{L_0}} + \frac{34-\frac{600}{L_0}}{L_0}; \qquad (28.2.1\text{-}4)$$

L_0 = length of the ship, in m (see Part II "Hull" of the Rules for the Classification);
C_B = block coefficient;
B = greatest moulded breadth of the ship, in m;
x = longitudinal distance, in m, from amidships to the centre of gravity of the tank with contents; x is positive forward of amidships, negative aft of amidships;
y = transverse distance, in m, from centreline to the centre of gravity of the tank with contents;
z = vertical distance, in m, from the ship's actual waterline to the centre of gravity of tank with contents; z is positive above and negative below the waterline;
K = 1 in general. For particular loading conditions and hull forms, determination of K according to the following formula may be necessary:

$$K = 13GM/B \qquad (28.2.1\text{-}5)$$

where $K \geq 1$ and GM = metacentric height (m);

$$A = \left(0{,}7-\frac{L_0}{1200} + \frac{5z}{L_0}\right)\left(\frac{0{,}6}{C_b}\right); \qquad (28.2.1\text{-}6)$$

V = service speed (knots);
a_x, a_y, a_z = maximum dimensionless accelerations (i.e. relative to the acceleration of gravity) in the respective directions. They are considered as acting separately for calculation purposes, and a_z does not include the component due to the static weight, a_y includes the component due to the static weight in the transverse direction due to rolling and a_x includes the component due to the static weight in the longitudinal direction due to pitching. The accelerations derived from the above formulae are applicable only to ships at or near their service speed, not while at anchor or otherwise near stationary in exposed locations.

28.3 Stress categories.

28.3.1 For the purpose of stress evaluation, stress categories are defined in this Section as follows. Normal stress is the component of stress normal to the plane of reference.

Membrane stress is the component of normal stress that is uniformly distributed and equal to the average value of the stress across the thickness of the section under consideration.

Bending stress is the variable stress across the thickness of the section under consideration, after the subtraction of the membrane stress.

Shear stress is the component of the stress acting in the plane of reference.

Primary stress is a stress produced by the imposed loading, which is necessary to balance the external forces and moments. The basic characteristic of a primary stress is that it is not self-limiting. Primary stresses that considerably exceed the yield strength will result in failure or at least in gross deformations.

Primary general membrane stress is a primary membrane stress that is so distributed in the structure that no redistribution of load occurs as a result of yielding.

Primary local membrane stress arises where a membrane stress produced by pressure or other mechanical loading and associated with a primary or a discontinuity effect produces excessive distortion in the transfer of loads for other portions of the structure. Such a stress is classified as a primary local membrane stress, although it has some characteristics of a secondary stress. A stress region may be considered as local, if:

$$S_1 \leq 0{,}5\sqrt{Rt}; \qquad (28.3.1\text{-}1)$$

$$S_1 \geq 2{,}5\sqrt{Rt}, \qquad (28.3.1\text{-}2)$$

where S_1 = distance in the meridional direction over which the equivalent stress exceeds $1{,}1f$;
S_2 = distance in the meridional direction to another region where the limits for primary general membrane stress are exceeded;
R = mean radius of the vessel;
t = wall thickness of the vessel at the location where the primary general membrane stress limit is exceeded; and
f = allowable primary general membrane stress.

Secondary stress is a normal stress or shear stress developed by constraints of adjacent parts or by self-constraint of a structure. The basic characteristic of a secondary stress is that it is self-limiting. Local yielding and minor distortions can satisfy the conditions that cause the stress to occur.

Russian Maritime Register of Shipping

Rules for the Classification and Construction of Ships Carrying Liquefied Gases in Bulk
Part IV
Cargo Containment

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