Liquefied gas carriers with independent prismatic tanks of type A and B
FOREWORD

DNV GL class guidelines contain methods, technical requirements, principles and acceptance criteria related to classed objects as referred to from the rules.

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**CHANGES – CURRENT**

This document supersedes the April 2016 edition of DNVGL-CG-0133.
Changes in this document are highlighted in red colour. However, if the changes involve a whole chapter, section or sub-section, normally only the title will be in red colour.

**Changes July 2017**

- **Sec.4 Cargo tank and hull finite element analysis**
  - **Sec.4 Table 2, Sec.4 Table 3 and Sec.4 Table 4:** Number of design waves to be applied for various load cases has been increased. 30 degree heel condition has been categorized as an accidental load case.
  - **Sec.4 Table 5:** Terminology for allowable stress aligned with DNVGL-RU-SHIP Pt.3 (no change in allowable stress) and clarifying footnotes have been added.

- **Sec.5 Local structural strength analysis**
  - **Sec.5 Table 1:** Clarifications to standard locations and loads to be considered for fine mesh analysis.

- **Sec.6 Fatigue analysis**
  - **Sec.6 [3.1]:** Time in harbor applied in fatigue calculations has been aligned with DNVGL-RU-SHIP Pt.3.

**Editorial corrections**

In addition to the above stated changes, editorial corrections may have been made.
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SECTION 1 GENERAL

1 Introduction

1.1 Objective
This class guideline provides additional information to the main rule text in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 Design with independent prismatic tanks of type A and type B. Design and assessment procedures are given for hull, cargo tanks and supporting structures of IMO type A and B independent tanks, primarily constructed of plane surfaces, in accordance with the rules. The objectives are:
— to give a general description on material selection
— how to carry out relevant calculations and analyses.
In case of discrepancy between the rule DNVGL-RU-SHIP Pt.5 Ch.7 and this class guideline, the rule prevails. For ships used for offshore production and/or storage, additional requirements given by the Society and/or the shelf state may be applicable.

2 Stresses and strength members

2.1 Stress categories
The definitions of stress categories are primary and secondary stress, membrane, bending stress and shear stress are given in the rules DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [6.1.3].

2.2 Material strength definition
The following definitions are used:

\[ R_m = \text{The specified minimum tensile strength at room temperature, in N/mm}^2. \text{ For welded connections in aluminium alloys the tensile strength in annealed condition shall be used.} \]

\[ R_{eH} = \text{The specified minimum yield stress at room temperature, in N/mm}^2. \text{ If the stress-strain curve does not show a defined yield stress, the 0.2\% proof stress applies.} \]

\[ R_{eH,0.2} = \text{The specified minimum 0.2\% proof stress at room temperature, in N/mm}^2. \text{ For welded connections in aluminium alloys the 0.2\% proof stress in annealed condition shall be used.} \]

2.3 Strength members
Definition of strength member types is as follows:
— Primary members: supporting members such as webs, girders and stringers consisting of web plates, face plate and effective plating.
— Secondary members: stiffeners and beams, consisting of web plate, face plate (if any) and effective plating.
— Tertiary members: plates between stiffeners.
3 Symbols and abbreviations

3.1 Symbols
For symbols not defined in this document, see DNVGL-RU-SHIP Pt.3 Ch.1 Sec.4 and DNVGL-RU-SHIP Pt.5 Ch.7 Sec.1.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_A$</td>
<td>actual minimum draught in m, at any hold, loaded condition from loading manual</td>
</tr>
<tr>
<td>$T_{MIN}$</td>
<td>min. relevant seagoing draught in m, may be taken as $0.35 D$ if not known</td>
</tr>
<tr>
<td>$T_{DAM}$</td>
<td>damaged draught, in m, from damage stability calculation</td>
</tr>
<tr>
<td>$k$</td>
<td>material factor, see DNVGL-RU-SHIP Pt.3 Ch.3 Sec.1 [2]</td>
</tr>
<tr>
<td>$x$</td>
<td>X coordinate along longitudinal axis in m</td>
</tr>
<tr>
<td>$y$</td>
<td>Y coordinate along transverse axis in m</td>
</tr>
<tr>
<td>$z$</td>
<td>Z coordinate along vertical axis in m</td>
</tr>
<tr>
<td>$E$</td>
<td>Young's modulus, in N/mm$^2$</td>
</tr>
<tr>
<td>$2.06 \cdot 10^5$ N/mm$^2$ for steel</td>
<td></td>
</tr>
<tr>
<td>$7.00 \cdot 10^4$ N/mm$^2$ for aluminium</td>
<td></td>
</tr>
<tr>
<td>$\sigma$</td>
<td>normal stress in N/mm$^2$</td>
</tr>
<tr>
<td>$\tau$</td>
<td>shear stress in N/mm$^2$</td>
</tr>
<tr>
<td>$LT$</td>
<td>material grade intended for low temperature service</td>
</tr>
<tr>
<td>$\sigma_e$</td>
<td>equivalent von Mises stress, in N/mm$^2$, as defined in DNVGL-RU-SHIP Pt.3 Ch.1 Sec.7 [4.2]</td>
</tr>
<tr>
<td>$\tau_m$</td>
<td>mean shear stress over a net cross section in N/mm$^2$</td>
</tr>
<tr>
<td>$\eta$</td>
<td>usage factor with respect to yield or buckling</td>
</tr>
<tr>
<td>$\eta_S$</td>
<td>usage factor related to static loads (S)</td>
</tr>
<tr>
<td>$\eta_{S+D}$</td>
<td>usage factor related to static plus dynamic loads (S+D)</td>
</tr>
</tbody>
</table>

3.2 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALS</td>
<td>Accidental limit state, accidental design condition</td>
</tr>
<tr>
<td>FLS</td>
<td>Fatigue limit state, design condition related to repeated dynamic fatigue loads, $10^{-2}$ loads</td>
</tr>
<tr>
<td>LBF</td>
<td>Leak-before-failure</td>
</tr>
<tr>
<td>TWI</td>
<td>The Welding Institute</td>
</tr>
<tr>
<td>UDW</td>
<td>Ultimate design waves</td>
</tr>
<tr>
<td>ULS</td>
<td>Ultimate limit state, design condition related to static plus dynamic (S+D), $10^{-8}$ loads</td>
</tr>
</tbody>
</table>

4 Scope of work

4.1 Hull structure
Hull structure analysis of gas carriers with independent prismatic tanks are summarized in Table 1.
# Table 1 Overview – hull structure analysis

<table>
<thead>
<tr>
<th>Tank type</th>
<th>Classification requirements – hull structures</th>
<th>Task summary</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A, B</td>
<td>Damage stability and separation of cargo hold spaces</td>
<td>The ship shall comply with the requirements for ship type 2G. The calculation shall include all relevant loading conditions with partially filled tanks.</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.2 [1.1.2], DNVGL-RU-SHIP Pt.5 Ch.7 Sec.2 [6.1] and DNVGL-RU-SHIP Pt.5 Ch.7 Sec.2 [2.1]</td>
</tr>
<tr>
<td>A, B</td>
<td>Hull loads</td>
<td>Rule loads unless CSA notation is specified</td>
<td>DNVGL-RU-SHIP Pt.3 Ch.4</td>
</tr>
<tr>
<td>A, B</td>
<td>Hull girder strength</td>
<td>In general. Shear force correction for single side hull.</td>
<td>DNVGL-RU-SHIP Pt.3 Ch.5 and DNVGL-RU-SHIP Pt.5 Ch.1 Sec.5 [5.2.4]</td>
</tr>
<tr>
<td>A, B</td>
<td>Hull local strength</td>
<td>In general. Transverse side frame of single side hull.</td>
<td>DNVGL-RU-SHIP Pt.3 Ch.6 and DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [1.6]</td>
</tr>
<tr>
<td>A, B</td>
<td>Cargo hold analysis</td>
<td>A three dimensional integrated ship hull cargo hold and cargo tank model FE analysis shall be carried out for the midship region. For type A, additional analyses for the fore and/or aft cargo hold regions may have to be carried out depending on the actual tank/ship design configuration if fore and aft region deviates significantly from the midship region. For type B, fore and aft cargo hold FE analyses shall be conducted.</td>
<td>DNVGL-RU-SHIP Pt.3 Ch.7, DNVGL-CG-0127, DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [4] and Sec.4</td>
</tr>
<tr>
<td>A, B</td>
<td>Local structural fine mesh analysis</td>
<td>According to hull rule scope</td>
<td>DNVGL-RU-SHIP Pt.3 Ch.7 Sec.4, DNVGL-RU-SHIP Pt.5 Ch.7 Sec.5 and Sec.5</td>
</tr>
<tr>
<td>A, B</td>
<td>Hull fatigue strength</td>
<td>Fatigue strength assessment to be carried out for the hull structure. Design target life of minimum 25 years based on World wide operation (scatter diagram). Rule load to be applied, unless CSA notation is specified.</td>
<td>DNVGL-RU-SHIP Pt.3 Ch.9 and DNVGL-CG-0129</td>
</tr>
<tr>
<td>A, B</td>
<td>Fatigue strength of cargo area</td>
<td>Supports and associated structures. Other details where high stresses occur.</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [8] and Sec.7</td>
</tr>
<tr>
<td>A, B</td>
<td>Slamming calculation</td>
<td>A calculation of stern slamming and bottom slamming to be carried out, when applicable</td>
<td>DNVGL-RU-SHIP Pt.3 Ch.10 Sec.2 and DNVGL-RU-SHIP Pt.3 Ch.10 Sec.3</td>
</tr>
<tr>
<td>A, B</td>
<td>Temperature calculation</td>
<td>A temperature calculation shall be carried out for selection of hull material, similar reference designs may be used. For definition of ambient temperatures see Sec.2 [2.3] Table 1.</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [6]</td>
</tr>
</tbody>
</table>

1) Only for novel designs and/or tanks intended for cargo temperatures below -55 °C.
4.2 Cargo tanks and supporting structure in way of cargo tanks

Required analyses for approval of the cargo tanks and the supporting hull structure of carriers with independent prismatic tanks are summarized in Table 2.

Table 2 Overview – cargo tanks

<table>
<thead>
<tr>
<th>Tank type</th>
<th>Classification requirements</th>
<th>Task summary</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Design loads</td>
<td>— Rule loads. — Rule accelerations.</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [3] and DNVGL-RU-SHIP Pt.3 Ch.4</td>
</tr>
<tr>
<td>B</td>
<td>Design loads</td>
<td>A complete wave load analysis is required for cargo tanks of type B, loads defined at $10^{-8}$ probability level and based on North Atlantic wave scatter diagram</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [3]</td>
</tr>
<tr>
<td>A, B</td>
<td>Local strength of cargo tanks</td>
<td>Prescriptive design of plates and stiffeners</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [3] and Sec.3</td>
</tr>
<tr>
<td>A, B</td>
<td>FE stress analysis of cargo tanks</td>
<td>— A three dimensional FE cargo hold and tank analysis shall be carried out for midship region. — For A type, if the fore and/or aft region deviates significantly from the midship region, analysis of these areas may also be necessary. — For B type, cargo hold analyses of fore and aft region are mandatory.</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [4] and Sec.4</td>
</tr>
<tr>
<td>A, B</td>
<td>Local structural fine mesh analysis</td>
<td>Analysis of cargo tanks, tank supports and hull structure in way of supports (localised high stress yield control)</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [5] and Sec.5 [2] Table 1</td>
</tr>
<tr>
<td>A, B</td>
<td>Thermal analysis</td>
<td>Steady state temperature analysis and thermal stress analysis of the cargo hold area and the cargo tank shall be performed to — confirm the structural integrity of the cargo tank with respect to yield and buckling in partial and full load conditions. Transient thermally induced loads during cooling down periods to be considered for tanks intended for cargo temperatures below -55 °C. Results from similar reference design may be used.</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [6]</td>
</tr>
<tr>
<td>A, B</td>
<td>Sloshing calculation</td>
<td>— For tanks with size $l_{slh} &gt; 0.13 L$ or breadth $b_{slh} &gt; 0.56 B$ natural periods of liquid motions in the tank for each anticipated filling level to be documented and strength assessment for impact sloshing loads shall be carried out, see DNVGL-RU-SHIP Pt.3 Ch.10 Sec.4. — A simplified sloshing calculation as per DNVGL-RU-SHIP Pt.3 Ch.10 Sec.4 for inertia sloshing loads.</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [7], DNVGL-RU-SHIP Pt.3 Ch.10 Sec.4 and Sec.6</td>
</tr>
<tr>
<td>Tank type</td>
<td>Items</td>
<td>Task summary</td>
<td>Reference</td>
</tr>
<tr>
<td>-----------</td>
<td>-------</td>
<td>--------------</td>
<td>-----------</td>
</tr>
<tr>
<td>B</td>
<td>Sloshing analysis</td>
<td>Numerical sloshing analyses and/or model testing may be required by the Society</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [3.2.7]</td>
</tr>
<tr>
<td>(A)&lt;sup&gt;1&lt;/sup&gt;, B</td>
<td>Fatigue analysis</td>
<td>Cargo tanks covering areas of stress concentrations, e.g. tanks, supports, tank and hull structure in way of supports, supports of cargo piping and cargo pumps, and other local details where high stresses occur</td>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [4.3.3], DNVGL-RU-SHIP Pt.5 Ch.7 Sec.8 and DNVGL-CG-0129 and [6]</td>
</tr>
</tbody>
</table>
| B         | Crack propagation analysis | — A fatigue crack propagation analysis to be carried out for areas with high dynamic stresses. Propagation rates in parent material, weld metal and heat-affected zone shall be established.  
— The largest crack dimension at penetration shall be defined. The propagation of the through-thickness crack during a 15 day North Atlantic storm shall be determined as basis for estimation of leakage rates, and assessment of possible unstable crack behaviour. | DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [4.3.3], Sec.20 [9], [7], Sec.4 [2.2.3], Sec.4 [2.2.5], Sec.4 [2.5], Sec.20 [9.4] and [7] |
| B         | Leakage rate determination | Leak analysis to determine potential leakage rates as basis for design and dimensioning of the small leak protection system to be made | DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [2.2.6] and Sec.7 [7] |
| B         | Vibration analysis | — The potentially damaging effects of vibration on the cargo containment system shall be considered.  
— Determination of natural frequencies to be carried out.  
— Forced vibration analysis may be required to show that no harmful vibrations will be excited by the propulsion system or other machinery. Added mass of LNG to be considered as relevant. | DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [3.3.5] and Sec.8 |
| B         | Partial secondary barrier and primary barrier small leak protection system | — Insulation system for cargo containment system to be documented with respect to material and design.  
— Documentation of the suitability of the insulation system acting as a spray shield to deflect any liquid cargo down into the space between the primary and secondary barrier at low temperature.  
— An assessment to be performed to verify that any leaks are contained by the drip tray for at least 15 days and that the leaked gas can be disposed of in a safe way. | DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [5.1.3], DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [2.8], DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [2.1.2], DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [2.2.6], DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 Sec.20 [2.1.2] and Sec.7 [7.8] |

1) See Table 1
SECTION 2 HULL MATERIAL SELECTION

1 Hull temperature

1.1 Temperature calculation
The presence of the cold cargo will cause a low temperature for parts of the hull steel structure. The temperature for hull structures shall be calculated in accordance with DNVGL-RU-SHIP Pt.5 Ch.7 Sec.6 [8]. The calculation is normally to be based on empty ballast tanks if this assumption will cause the lowest steel temperature. Further guidance is given DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [6].

1.2 Ambient temperature
Design ambient temperatures for the analysis are given in Table 1.

Table 1 Ambient temperature for temperature calculation

<table>
<thead>
<tr>
<th>Regulations</th>
<th>Still sea water temperature (°C)</th>
<th>Air temperature (°C)</th>
<th>Wind speed (knots)</th>
<th>Applicable areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [5.1.1]</td>
<td>0.0</td>
<td>+5.0</td>
<td>0.0</td>
<td>All hull structure in cargo area</td>
</tr>
<tr>
<td>USCG requirements, except Alaskan water Sec.9 [1]</td>
<td>0.0</td>
<td>-18.0</td>
<td>5.0</td>
<td>Inner hull structure and members connected to inner hull in cargo area</td>
</tr>
<tr>
<td>USCG requirements, Alaskan water Sec.9 [1]</td>
<td>-2.0</td>
<td>-29.0</td>
<td>5.0</td>
<td>Inner hull structure and members connected to inner hull in cargo area</td>
</tr>
</tbody>
</table>

For ships intended for trading in cold areas, other ambient temperature may be required by port authorities or flag states.

2 Hull materials selection for A-tanks designs

2.1 Temperature range
The information in the following relates to type A-tanks with cargo temperature between -10°C and -55°C.

2.2 Extent of secondary barrier
The strip of deck plating between the top wing tanks in side, defined by the intersection between the deck plate and a line at a static heel angle of ±30 degrees is regarded to be outside the secondary barrier. Steel grade E may therefore be used for this deck strip.

Low temperature steel grade shall be applied to the secondary barrier and shall be extended $d = 500$ mm toward the centreline from the above mentioned intersection, and also extended inside the top wing tank and hoppertank, see Figure 1.
2.3 Hull temperatures

For structural members connecting inner and outer hull, the mean temperature may be taken for selection of steel grade. When the inner hull functions as the secondary barrier, for a cargo temperature not below \(-55^\circ\text{C}\), the material grade of web frames or girders with large openings, attached to the secondary barrier, shall be of the same as the secondary barrier itself. The same may apply to stiffeners attached to web frames or girders. Some examples are shown in Figure 2 – Figure 5 below assuming a cargo temperature of \(-50^\circ\text{C}\).
Figure 2 Typical temperature and steel grades for hopper tank

Figure 3 Typical temperature and steel grades for top side tank for cargo temperature -50°C

Engine room temperature of 5°C and fore peak tank of 0°C is assumed as shown below. It is further assumed that heating coil in fuel oil tanks are inactive.
Figure 4 Typical temperature of engine room and fore body for cargo temperature -50°C

Steel grade of longitudinal secondary members beyond aft most and foremost cargo hold bulkheads may be acceptable for the main class material grades as defined in DNVGL-RU-SHIP Pt.3 Ch.3.
Two cases should be considered for the material grade of the vertical/horizontal girders on transverse bulkhead forming a secondary barrier:

- When the aft/fore space of aft/fore most cargo hold bulkhead forming a secondary barrier is exposed to engine room space or ballast tank, DH or E grade may be acceptable.
- When the aft/fore space of aft/fore most cargo hold bulkhead forming a secondary barrier is enclosed between the bulkhead and engine room space or ballast tank, i.e cofferdam or F.O. tank, LT grade or E/DH grade shall be used. It shall be extended at least 500 mm when LT grade is used and at least one web frame space when E or DH grade is used.

As for type A-tanks it is normally assumed that the engine room temperature is 5°C and that heating coils in the fuel oil tanks are inactive.

2.4 Material for hull outfitting

Due considerations should be taken when selecting materials for hull outfitting details attached to hull structures in the cargo area. Temperature in the outfitting details should be considered, due to low temperature for the part of the outer hull that forms a secondary barrier. Materials for hull outfitting attached to the secondary barrier are generally to be of LT grade.

For hull outfittings attached to the secondary barrier by doubler plates, the material of the outfittings can be selected based on the temperature of the space where it is located, but the doubler plate shall be of LT grade.
3 Materials selection for type B-tanks

3.1 Material of cargo tank and hull structures

Specification of materials in cargo tank shall be submitted for approval, see DNVGL-RU-SHIP Pt.5 Ch.7 Sec.1 [4.1.2]. For certain materials, subject to special consideration by the Society, enhanced yield strength and tensile strength at design temperatures below -105°C, see DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [4.1.2] may be applied. Materials for cargo tanks and hull structures shall comply with the minimum requirements given in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [5.1].

3.2 Outer hull structures

The outer hull structure includes hull envelope and deck plating of the ship and all the attached stiffeners. The material of the outer hull structure shall be in accordance with DNVGL-RU-SHIP Pt.3 Ch.3 Sec.1, unless the calculated temperature of the material in the design condition is below -5°C due to the effect of low temperature cargo. In this case the material shall be in accordance with the rules DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [5.1]. Additional USCG requirements apply to hull plating along the length of the cargo area as follows, see Sec.9 [1]:

— deck stringer and sheer strake shall be at least grade E steel
— bilge strake at the turn of the bilge shall be of grade D or grade E.

3.3 Inner hull structures

The inner hull structure includes inner bottom plating, longitudinal bulkhead plating, transverse bulkhead plating, floors, webs, stringers and all stiffeners attached thereto. For ships intended for trading in areas where the ambient temperatures differ from those in Table 1, the lower ambient temperatures shall be used for the temperature calculation.

The loading condition giving the lowest draft among the loading conditions with two tanks empty and the other tanks full may be used for the temperature calculations.

Steel grade of load carrying stiffeners, e.g. deck longitudinals or bulkhead stiffeners, shall be the same as the plating to which the stiffener is attached. This also applies to structural members where direct loads are not applied, e.g. brackets, top stiffeners, ribs, lugs attached to web frames, floors and girders.

For structural members connecting inner and outer hull, possibly containing small openings, the mean temperature may be taken for selection of steel grade as given in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [5.1.1].
SECTION 3 LOCAL STRENGTH OF CARGO TANKS

1 Requirements for scantlings

1.1 Minimum thickness
The minimum rule requirements for the thickness of plating, stiffeners/tripping bracket and primary support members are given in DNVGL-RU-SHIP Pt.3 Ch.6 Sec.3.

1.2 Local scantling
The prescriptive requirements of plates and stiffeners are given in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [3.2].

1.3 Corrosion addition
For independent tank, no corrosion addition is in general required for tank boundary and internal members.

2 Longitudinal bulkhead
The cargo tank is normally divided by a liquid tight centre line bulkhead with opening in way of liquid dome area forming a common gas phase. The same filling height at both sides of centreline longitudinal bulkhead is assumed for sea going conditions. If divided by a liquid tight centreline bulkhead the centreline longitudinal bulkhead is normally to be designed for one side filling in harbour.

3 Swash bulkheads
Transverse swash bulkhead is normally arranged in the middle of a cargo tank to prevent sloshing impact loads in the tank. Resonance sloshing with high impact loads may occur if motion periods (e.g. roll or pitch) coincide with natural sloshing periods. Examples of swash bulkhead design are shown in Figure 1.

Figure 1 Arrangements of swash bulkhead
4 Wood and dam plates

4.1 General

Strength of wood and dam plate should carefully be checked in view of compressive strength and shear
strength. The acceptance criteria in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [5.5] of the rules apply.
The wood and the dam plate may be evaluated by the simplified approach outlined in [4.2] to [4.4]. The
compressive and shear strength of the resin shall be higher than the values for the wood.

4.2 Compressive strength

Figure 2 shows assumption of force transmission to wood if applied from the support. It is assumed that
the reaction force from a support will be transmitted through the top plate of the supports with angle of 90
degrees. The compressive strength at wood may be checked as follows:

\[
\sigma_r = \frac{F_z}{A} \leq \frac{R_{c-wood}}{\gamma_{SF}}
\]

where:
- \(F_z\) = load on the support normal to the support surface, see Sec.5 Table 1, in N
- \(\gamma_{SF}\) = safety factor for wood, DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [5.5]
- \(A\) = loaded area due to transmitted vertical force, in mm\(^2\)
- \(R_{c-wood}\) = minimum compressive strength of wood, in N/mm\(^2\)

Figure 2 Assumption of force transmitted

4.3 Shear strength

Shear strength of wood shall be checked using the friction force due to the maximum normal force applied
the support to be considered. Thus, the shear strength for wood shall be satisfied as follows:

\[
\tau_r = \frac{F_f}{A_w} \leq \frac{R_{s-wood}}{\gamma_{SF}}
\]
where:

\[ F_f = \text{friction force at support, in N} \]
\[ = \mu F_z \]
\[ \mu = \text{friction coefficient} \]
\[ \gamma_{SF} = \text{see [4.2]} \]
\[ A_w = \text{shear area of wood in mm}^2 \]
\[ R_{s-wood} = \text{minimum shear strength of wood in N/mm}^2 \]

### 4.4 Dam plate

Dam plates shall be fitted to secure the wood and shall be designed to withstand 10% of the maximum force applied to the support considered, assuming adhesive and resin strength is damaged. The shear area of dam plates shall satisfy the following:

\[ A_d \geq \frac{0.1 \cdot F_f}{\tau_{allow}} \]

where:

\[ \tau_{allow} = \text{allowable shear stress of dam plate, N/mm}^2 \]
\[ = 0.95 \frac{R_{eH}s}{\sqrt{3}} \kappa \]
\[ \kappa = \text{coefficient as defined in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [4.3.4]} \]

A small size bracket may be fitted to prevent yielding of the dam plate, if dam plate area is not sufficient.

![Figure 3 Force applied to the dam plate](image)

**Figure 3 Force applied to the dam plate**

The bending strength of the dam plate shall be designed based on 10% of the maximum force applied to the considered support, and satisfying the maximum allowable stress as specified in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [5.5].
SECTION 4 CARGO TANK AND HULL FINITE ELEMENT ANALYSIS

1 General
Finite element analysis requirements are given in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [4]. A flow diagram showing the minimum requirement to finite element analysis is shown in Figure 1.

Figure 1 Minimum requirement on finite element analysis

2 Structural idealization

2.1 General
Modelling of hull and tank structure shall unless defined otherwise follow DNVGL-RU-SHIP Pt.3 Ch.7 of the rules and DNVGL-CG-0127. This covers, but is not limited to, the following items:
— geometric modelling of hull and tank structure in general
— element types and mesh size
— boundary conditions for 3 hold models
— load application.

Tank supports will normally transfer compressive loads (and friction loads). This effect need to be accounted for in the modelling. A linearisation around the static equilibrium will normally be sufficient. An example of a cargo hold model of the midship area of an A-tank design is shown in Figure 2.
2.2 Interaction forces between tanks and hull

An important issue for the strength analysis is determining the interaction forces acting between the cargo tanks and the ship hull. For this purpose an integrated cargo hold models need to be made as described in [2.1] and [2.3].

The deformation of the double bottom due to cargo tank loads, lateral sea pressure and hull girder bending causes vertical deformation of the double bottom and horizontal shortening/elongation of the inner bottom. The cargo tank is in most cases rather stiff and will resist the imposed deformation from the inner bottom. This will influence the vertical force distribution at the vertical supports and also create transverse and longitudinal forces in the supports. The flexibility of the vertical supports will also play a role in determining these support forces.

The load effects necessary for determining the interaction forces are included in the rule based EDWs and the UDWs from wave load analysis as simultaneously acting loads, i.e. bending moments, accelerations and sea pressure, are included in the applied equivalent design waves.

2.3 Modelling of supports

Vertical supports, anti-rolling/pitching supports and anti-floatation supports may be idealized by shell elements. The supports on hull and cargo tank may be interconnected with solid elements or beam/spring elements representing the support blocks. If linear analysis is employed, it is recommended to use spring elements with only axial stiffness for the connection of vertical supports and anti-rolling/pitching supports. When the length of connection element in the model is different from the actual design due to resin and/or other reason, the properties of the element should be adjusted to obtain a stiffness close to the actual condition.

The connection elements of the vertical supports shall be disconnected when they are in tension, i.e. no contact. An iterative procedure may be required, supports in tension shall be disconnected and the FE model rerun until all active supports are in compression. However, for the transverse anti-roll supports and longitudinal anti-pitch supports simplifications may be made if those simplifications are considered to have negligible impact on the stress levels in the cargo tanks and the supporting hull structure, see [4].
The friction forces on vertical supports are be considered in the estimation of reaction forces on transverse/longitudinal supports. The procedure described in this section is the simplified method which is considered sufficient for cargo hold analysis. For reference, the full iterative approach is described in App.A.

The supports with associated parts of the tanks and the hull structure in way of the supports shall be analysed with fine mesh models as shown in Sec.5. The cargo tanks are supported by the following supports:

— vertical supports in global Z direction (vertical, positive upwards)
— anti-rolling keys in global Y direction (transverse, positive to port side)
— anti-pitch/anti-collision keys in global X direction (longitudinal, positive forward)
— anti-flotation keys in global Z direction.

Standard modelling of supports are further described in Sec.5 [4]. Unless otherwise documented, friction coefficients for the analyses of the supports are shown in Table 1.

**Table 1 Friction coefficients**

<table>
<thead>
<tr>
<th>Surface material 1</th>
<th>Surface material 2</th>
<th>Maximum friction coefficient ($\mu_{\text{max}}$)</th>
<th>Minimum friction coefficient ($\mu_{\text{min}}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>Wood</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Steel</td>
<td>Synthetic Resin</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Steel</td>
<td>Steel (Dry)</td>
<td>0.78</td>
<td>0.42</td>
</tr>
<tr>
<td>Steel</td>
<td>Steel (Greasy)</td>
<td>0.17</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Typical lay-outs of tank supports are shown in Figure 3 and Figure 4 for A-tanks and B-tanks respectively.
Figure 3 Support arrangement of prismatic tank type A
3 Design application of load cases and loading conditions

3.1 General
As a minimum requirement the following loads are to be applied for accelerations, dynamic pressures and dynamic hull girder loads:

— rule loads for hull and cargo tanks to be applied to type A-tanks
— rule loads for hull and directly calculated loads for the cargo tanks for type B-tanks
— dynamic ULS loads shall refer to $10^{-8}$ probability level in North Atlantic environment unless special design conditions have been accepted by the Society, see DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [2.1.2]
— temperature loads to be applied as relevant.

Primary members shall be designed considering the loading conditions and load cases summarized in Table 2. However, other load cases not mentioned may need to be reviewed depending on the configuration of the actual design.

3.2 Shear force correction
Shear force correction is supposed to be done naturally in the FE model. It is therefore important to use shear force values without correction in FE calculation to avoid double correction.
3.3 Loading conditions

It should be noted that the loading conditions given in Table 2 are a minimum set of loading conditions. If more severe loading conditions, e.g. two adjacent cargo tanks empty or full, etc. are given in the loading manual, these conditions shall also be taken into account.

3.4 Load combinations

The following load cases shall be applied:

— LC 1-4: static load cases for hull, tank and supports design
— LC 5-7: seagoing load cases for hull, tank and supports design
— LC 8-13: accidental load cases for tank and supports design.

For LC 8 and 9 an inclination angle of 30 degrees with static tank and sea pressure shall be used, DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [3.3.9] and DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [2.4.2.6]. The internal pressure in the cargo tank shall be based on the combined effect of gravity $g$ and the transverse component of gravity that amounts to

$$g \cdot \sin 30^\circ = 0.5 g$$

For the damaged condition, load case 13, the double bottom ballast tank and the cargo hold is assumed punctured resulting of water ingress into the hold space between the hull and the cargo tank. The maximum static pressure from the damaged waterline shall be applied to the transverse bulkhead. However, the vertical distance shall not be less than up to the actual damage waterline in way of centerline. It is assumed that the cargo tank is intact without any cargo leakage into the void space.

The load cases and loading conditions shown in Table 2 shall be applied for evaluation of the midship tank(s). Similar load cases need to be applied for other tanks if the calculation is considered to be necessary. For foremost cargo hold, the load cases and the loading patterns to be considered are shown in Table 3. And Table 4 can be used for aftmost cargo hold. Reference to dynamic load cases given in DNVGL-RU-SHIP Pt.3 Ch.4 Sec.2.

Based on operational limitations, e.g. if surrounding ballast tanks in way of an empty cargo tank are always filled, the standard load cases shown in Table 2, Table 3 and Table 4 may be modified.

### Table 2 Design load combinations for cargo hold analysis in midship area

<table>
<thead>
<tr>
<th>No.</th>
<th>Application</th>
<th>Loading pattern</th>
<th>Draught</th>
<th>% of perm. SWBM</th>
<th>% of perm. SWSF</th>
<th>Dynamic load cases/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Static load cases (S), ULS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC1</td>
<td>Hull, tank and supports</td>
<td>![Image of loading pattern]</td>
<td>$T_{SC}$</td>
<td>100% (hog.)</td>
<td>≤ 100%</td>
<td>Static only (S)</td>
</tr>
<tr>
<td>No.</td>
<td>Application</td>
<td>Loading pattern</td>
<td>% of perm. ( T_{SC} )</td>
<td>% of perm. ( T_{SC} )</td>
<td>Dynamic load cases/comments</td>
<td></td>
</tr>
<tr>
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<td></td>
</tr>
<tr>
<td>LC 2</td>
<td>Hull</td>
<td><img src="image1" alt="Hull LC2" /></td>
<td>100% (hog.)</td>
<td>Static only (S)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC 3</td>
<td>Hull, tank and</td>
<td><img src="image2" alt="Hull LC3" /></td>
<td>100% (sag.)</td>
<td>Static only (S)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>supports</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC 4</td>
<td>Tank</td>
<td><img src="image3" alt="Tank LC4" /></td>
<td>≤ 100%</td>
<td>Static only (S).</td>
<td>Hydrostatic plus vapour</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>pressure, ( P_0 ) in both</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>empty and loaded tanks.</td>
<td></td>
</tr>
<tr>
<td>LC 5</td>
<td>Hull, tank and</td>
<td><img src="image4" alt="Hull LC5" /></td>
<td>100% (hog.)</td>
<td>HSM-2, FSM-2, BSR-2P,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>supports</td>
<td></td>
<td></td>
<td>BSP-1P, BSP-2P, OST-1P,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>OST-2P, OSA-1P, OSA-2P.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Application</td>
<td>Loading pattern</td>
<td>Draught</td>
<td>% of perm. SWBM</td>
<td>% of perm. SWSF</td>
<td>Dynamic load cases/comments</td>
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<td>-----------------</td>
<td>--------------------------</td>
</tr>
<tr>
<td>LC 6</td>
<td>Hull</td>
<td>![Hull Loading Pattern]</td>
<td>$T_{Sc}^{1)$}</td>
<td>100% (hog.)</td>
<td>100% max SFLC $^{4)(5)(6)}$</td>
<td>HSM-2, FSM-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$\leq 100%$</td>
<td>BSR-1P, BSP-1P, OSA-1P$^{9)}$</td>
</tr>
</tbody>
</table>

| LC 7$^{11)}$ | Hull, tank and supports | ![Hull, Tank, and Supports Loading Pattern] | $T_{A}^{2)$} | 100% (sag.) | 100% max SFLC $^{4)(5)(6)}$ | HSM-1, FSM-1 |
|             |             |                   |         |                 | $\leq 100\%$ | HSA-1, BSR-1P, BSR-2P, BSP-1P, OST-1P, OSA-1P, OSA-2P$^{9)}$ |

**Accidental load cases (A), ALS**

| LC 8 | Tank and supports | ![Tank and Supports Loading Pattern] | $T_{Sc}$ | $\leq 100\%$ | $\leq 100\%$ | Static only (S). Inclination of 30° with tank pressure corresponding to $g$ and a transverse component equal to $g \cdot \sin30° = 0.5 \ g \ (S)$. Inclined static sea pressure (S). |

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*Class guideline — DNVGL-CG-0133. Edition July 2017*
<table>
<thead>
<tr>
<th>No.</th>
<th>Application</th>
<th>Loading pattern</th>
<th>Draught</th>
<th>% of perm. SWBM</th>
<th>% of perm. SWSF</th>
<th>Dynamic load cases/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tank and supports</td>
<td><img src="image1" alt="Diagram" /></td>
<td>$T_A^{(2,3)}$</td>
<td>$\leq 100%$</td>
<td>$\leq 100%$</td>
<td>Static only (S). Inclination of $30^\circ$ with tank pressure corresponding to $g$ and a transverse component equal to $g \cdot \sin 30^\circ = 0.5g$ (S). Inclined static sea pressure (S).</td>
</tr>
<tr>
<td></td>
<td>Tank and supports</td>
<td><img src="image2" alt="Diagram" /></td>
<td>$T_{SC}$</td>
<td>$\leq 100%$</td>
<td>$\leq 100%$</td>
<td>Collision case - forward. Static only (S). Tank load. (A) Acceleration $a_x = 0.5g$ forward combined with gravity $g$.</td>
</tr>
<tr>
<td>No.</td>
<td>Application</td>
<td>Loading pattern</td>
<td>Draught</td>
<td>% of perm. SWBM</td>
<td>% of perm. SWSF</td>
<td>Dynamic load cases/comments</td>
</tr>
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<td>---------------------------</td>
</tr>
<tr>
<td></td>
<td><strong>LC 11</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tank and supports</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Collision case - aftward. Static only (S). Tank Load (A). Acceleration $a_x = 0.25 , g$ aftward combined with gravity $g$. LC 14 will normally be governing.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$T_{SC}$</td>
<td>$\leq 100%$</td>
<td>$\leq 100%$</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>LC 12</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hull and supports</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Flooded one tank empty condition. Static only (S).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>$T_{SC}$</td>
<td>$\leq 100%$</td>
<td>$\leq 100%$</td>
<td></td>
</tr>
<tr>
<td>No.</td>
<td>Application</td>
<td>Loading pattern</td>
<td>Draught</td>
<td>% of perm. SWBM</td>
<td>% of perm. SWSF</td>
<td>Dynamic load cases/comments</td>
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<td>-----------------------------</td>
</tr>
</tbody>
</table>
| LC 13 | Hull | ![Loading pattern image] | $T_{DAM}$ | $\leq 100\%$ | $\leq 100\%$ | Damaged condition.  
Static only (S).  
Heeled damage waterline to be applied to the transverse bulkhead. The vertical distance shall not be less than actual damage draught at C.L.  
Inclined internal and sea pressure. |

Notes:

1) Maximum draft with one cargo tank empty may be used instead of scantling draft $T_{SC}$, if this is stated as an operational information in the loading manual.
2) Actual minimum draught at any cargo tank loaded condition from the loading manual.
3) Draught not to be taken greater than minimum of $2 + 0.02L$ and the minimum ballast draught.
4) For the mid-hold where $x_{b-aft} < 0.5L$ and $x_{b-fwd} > 0.5L$, the shear force shall be adjusted to target value at aft bulkhead of the midhold.
5) For the mid-hold where $x_{b-aft} < 0.5L$ and $x_{b-fwd} > 0.5L$, the shear force shall be adjusted to target value at forward bulkhead of the midhold. Otherwise this load combination may be omitted.
6) This load combination shall be considered only for the mid-hold where $x_{b-aft} > 0.5L$ or $x_{b-fwd} < 0.5L$.
7) The shear force shall be adjusted to target value at aft bulkhead of the midhold.
8) The shear force shall be adjusted to target value at forward bulkhead of the midhold.
9) The beam sea and oblique sea dynamic load cases calculated for port and starboard are to be applied on the model to obtain the results for both model sides. Alternatively, for ship structure symmetrical about the centreline, the beam sea and oblique sea dynamic load cases calculated for port side may be applied only to the model (i.e. starboard may be omitted) provided the results (maximum stress and buckling) are mirrored.
10) Anti-floatation support and hull structures in way of anti-floatation support.
11) For B type tank, ultimate design waves (UDW) from direct hydrodynamic analysis to be applied.
### Table 3 Design load cases for cargo hold analysis for foremost cargo hold

<table>
<thead>
<tr>
<th>No.</th>
<th>Application</th>
<th>Loading pattern</th>
<th>Draft</th>
<th>% of perm. SWBM</th>
<th>% of perm. SWSF</th>
<th>Dynamic load cases/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$T_{SC}$</td>
<td>100% (sag.)</td>
<td>$\leq 100%$</td>
<td>Static only (S)</td>
</tr>
<tr>
<td>LC1</td>
<td>Hull, tank and supports</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

|      | Hull                             |                 | $T_{SC}^{1)}$ | 100% (sag.)    | $100\%$ max SFLC$^{4)}$ | Static only (S)             |
| LC 2 |                                  |                 |        |                |                |                             |

<p>|      | Hull, tank and supports          |                 | $T_{A}^{2)}3^{3)}$ | 100% (hog.)    | $100%$ max SFLC$^{5)}$ | Sea press (S)                |
| LC 3 |                                  |                 |        |                |                |                             |</p>
<table>
<thead>
<tr>
<th>No.</th>
<th>Application</th>
<th>Loading pattern</th>
<th>Draught</th>
<th>% of perm. SWBM</th>
<th>% of perm. SWSF</th>
<th>Dynamic load cases/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC 4</td>
<td>Tank</td>
<td></td>
<td>0.5 $T_{SC}$</td>
<td>$\leq 100%$</td>
<td>$\leq 100%$</td>
<td>Static only (S). Hydrostatic plus vapour pressure, $P_0$ in both empty and loaded tanks.</td>
</tr>
</tbody>
</table>

### Seagoing load cases (S+D), ULS

<table>
<thead>
<tr>
<th>No.</th>
<th>Application</th>
<th>Loading pattern</th>
<th>Draught</th>
<th>% of perm. SWBM</th>
<th>% of perm. SWSF</th>
<th>Dynamic load cases/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC 5</td>
<td>Hull, tank and supports</td>
<td></td>
<td>$T_{SC}$</td>
<td>100% (sag.)</td>
<td>$\leq 100%$</td>
<td>HSM-1, FSM-1, HSA-1, BSR-1P, BSR-2P, BSP-1P, BSP-2P, OST-1P, OST-2P, OSA-1P, OSA-2P $^{(5)}$</td>
</tr>
<tr>
<td>LC 6</td>
<td>Hull</td>
<td></td>
<td>$T_{SC}^{(1)}$</td>
<td>100% max SFLC</td>
<td>HSM-1, FSM-1</td>
<td>≤ 100% HSA-1, BSR-1P, BSR-2P, BSP-1P, BSP-2P, OST-1P, OST-2P, OSA-1P, OSA-2P $^{(5)}$</td>
</tr>
<tr>
<td>LC 7</td>
<td>Hull, tank and supports</td>
<td></td>
<td>$T_{A}^{(2)}$</td>
<td>0% (sag.)</td>
<td>100% max SFLC</td>
<td>HSM-2, FSM-2, HSA-2, BSR-1P, BSR-2P, BSP-1P, BSP-2P, OST-1P, OST-2P, OSA-1P, OSA-2P $^{(5)}$</td>
</tr>
<tr>
<td>No.</td>
<td>Application</td>
<td>Loading pattern</td>
<td>Draught</td>
<td>% of perm. SWBM</td>
<td>% of perm. SWSF</td>
<td>Dynamic load cases/comments</td>
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<td>---------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>T_{SC}</td>
<td>≤ 100%</td>
<td>≤ 100%</td>
<td>Static only (S). Inclination of 30° with tank pressure corresponding to $g$ and a transverse component equal to $g \cdot \sin 30° = 0.5g$ (S). Inclined static sea pressure (S).</td>
</tr>
<tr>
<td>LC 8</td>
<td>Tank and supports</td>
<td>[Diagram]</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LC 9</td>
<td>Tank and supports</td>
<td>[Diagram]</td>
<td>$T_A^{233}$</td>
<td>≤ 100%</td>
<td>≤ 100%</td>
<td>Static only (S). Inclination of 30° with tank pressure corresponding to $g$ and a transverse component equal to $g \cdot \sin 30° = 0.5g$ (S). Inclined static sea pressure (S).</td>
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</tr>
<tr>
<td>No.</td>
<td>Application</td>
<td>Loading pattern</td>
<td>Draught</td>
<td>% of perm. SWBM</td>
<td>% of perm. SWSF</td>
<td>Dynamic load cases/comments</td>
</tr>
<tr>
<td>-----</td>
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<td>-----------------------------</td>
</tr>
<tr>
<td>LC 10</td>
<td>Tank and supports</td>
<td><img src="image1" alt="Tank and supports" /></td>
<td>$T_{SC}$</td>
<td>$\leq 100%$</td>
<td>$\leq 100%$</td>
<td>Collision case - forward. Static only (S). Tank load. (A). Acceleration $a_x = 0.5 , g$ forward combined with gravity $g_0$.</td>
</tr>
<tr>
<td>LC 11</td>
<td>Tank and supports</td>
<td><img src="image2" alt="Tank and supports" /></td>
<td>$T_{SC}$</td>
<td>$\leq 100%$</td>
<td>$\leq 100%$</td>
<td>Collision case - aftward. Static only (S). Tank load (A). Acceleration $a_x = 0.25 , g$ aftward combined with gravity $g$. LC 14 will normally be governing.</td>
</tr>
<tr>
<td>No.</td>
<td>Application</td>
<td>Loading pattern</td>
<td>Draught</td>
<td>% of perm. SWBM</td>
<td>% of perm. SWSF</td>
<td>Dynamic load cases/comments</td>
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<td>-----------------------------------------------------------------</td>
</tr>
<tr>
<td>LC 12</td>
<td>Hull and supports (7)</td>
<td>[Diagram]</td>
<td>$T_{SC}$</td>
<td>≤ 100%</td>
<td>≤ 100%</td>
<td>Flooded one tank empty condition. Static only (S).</td>
</tr>
<tr>
<td>LC 13</td>
<td>Hull</td>
<td>[Diagram]</td>
<td>$T_{DAM}$</td>
<td>≤ 100%</td>
<td>≤ 100%</td>
<td>Damaged condition. Static only (S). Heeled damage waterline to be applied to the transverse bulkhead. The vertical distance shall not be less than actual damage draught at C.L. Inclined internal and sea pressure.</td>
</tr>
<tr>
<td>No.</td>
<td>Application</td>
<td>Loading pattern</td>
<td>Draught</td>
<td>% of perm. SWBM</td>
<td>% of perm. SWSF</td>
<td>Dynamic load cases/comments</td>
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</tr>
</tbody>
</table>

Notes:

1) Maximum draft with cargo tank no.1 empty may be used instead of scantling draft $T_{SC}$, if this is stated as an operational information in the loading manual.
2) Actual minimum draught at any cargo tank no.1 loaded from the loading manual.
3) Draught not to be taken greater than minimum of $2 + 0.02L$ and the minimum ballast draught.
4) The shear force shall be adjusted to target value at aft bulkhead of the foremost hold.
5) The shear force shall be adjusted to target value at forward bulkhead of the foremost hold.
6) The beam sea and oblique sea dynamic load cases calculated for port and starboard are to be applied on the model to obtain the results for both model sides. Alternatively, for ship structure symmetrical about the centreline, the beam sea and oblique sea dynamic load cases calculated for P may be applied only to the model (i.e. starboard may be omitted) provided the results (maximum stress and buckling) are mirrored.
7) Anti-floatation support and hull structures in way of anti-floatation support.
8) For B type tank, UDW from direct hydrodynamic analysis to be applied.

Table 4 Design load cases for cargo hold analysis for aftmost cargo hold

<table>
<thead>
<tr>
<th>No.</th>
<th>Application</th>
<th>Loading pattern</th>
<th>Draught</th>
<th>% of perm. SWBM</th>
<th>% of perm. SWSF</th>
<th>Dynamic load cases/comments</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LC1</th>
<th>Hull, tank and supports</th>
<th>$T_{SC}$</th>
<th>100% (hog.)</th>
<th>≤ 100%</th>
<th>Static only (S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.</td>
<td>Application</td>
<td>Loading pattern</td>
<td>% of perm. SWBM</td>
<td>% of perm. SWSF</td>
<td>Dynamic load cases/comments</td>
</tr>
<tr>
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<td>-----------------------------</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>% of perm. SWBM</td>
<td>% of perm. SWSF</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100% max SFLC&lt;sup&gt;4)&lt;/sup&gt;</td>
<td>Static only (S)&lt;sup&gt;5)&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100% max SFLC&lt;sup&gt;4)&lt;/sup&gt;</td>
<td>Static only (S)&lt;sup&gt;5)&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>100% max SFLC&lt;sup&gt;4)&lt;/sup&gt;</td>
<td>Static only (S)&lt;sup&gt;5)&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>≤ 100%</td>
<td>≤ 100%</td>
<td>Static only (S). Hydrostatic plus vapour pressure, (P_0) in empty and loaded tanks.</td>
</tr>
</tbody>
</table>

Seagoing load cases (S+D), ULS

| LC 5<sup>8)</sup> | Hull, tank and supports | \(T_{SC}\) | 100% max SFLC<sup>4)</sup> | ≤ 100% | HSM-2, FSM-2, HSA-2, BSR-1P, BSR-2P, BSP-1P, BSP-2P, OST-1P, OST-2P, OSA-1P, OSA-2P<sup>6)</sup>

---

<sup>1)</sup> \(T_{SC}\) = static condition

<sup>2)</sup> \(T_{SA}\) = seakeeping condition

<sup>3)</sup> \(T_{SC}\) = seakeeping condition

<sup>4)</sup> \(SFLC\) = static load condition

<sup>5)</sup> Static only (S)

<sup>6)</sup> \(P_0\) in empty and loaded tanks
<table>
<thead>
<tr>
<th>No.</th>
<th>Application</th>
<th>Loading pattern</th>
<th>% of perm. SWBM</th>
<th>% of perm. SWSF</th>
<th>Dynamic load cases/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC 6</td>
<td>Hull</td>
<td>T&lt;sub&gt;SC&lt;/sub&gt;&lt;sup&gt;1&lt;/sup&gt;</td>
<td>100% (hog.)</td>
<td>100% max SFLC</td>
<td>HSM-2, FSM-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0%</td>
<td>100% max SFLC</td>
<td>HSM-1, FSM-1</td>
</tr>
<tr>
<td>LC 7&lt;sup&gt;8&lt;/sup&gt;</td>
<td>Hull, tank and supports</td>
<td>T&lt;sub&gt;A&lt;/sub&gt;&lt;sup&gt;2&lt;/sup&gt;</td>
<td>100% (hog.)</td>
<td>100% max SFLC</td>
<td>HSM-2, FSM-2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0%</td>
<td>100% max SFLC</td>
<td>HSM-1, FSM-1</td>
</tr>
</tbody>
</table>

Accidental conditiona (A), ALS

<table>
<thead>
<tr>
<th>LC 8</th>
<th>Tank and supports</th>
<th>T&lt;sub&gt;SC&lt;/sub&gt;</th>
<th>≤ 100%</th>
<th>≤ 100%</th>
</tr>
</thead>
</table>

Static only (S). Inclination of 30° with tank pressure corresponding to g and a transverse component equal to \( g \cdot \sin 30° \approx 0.5 \ g \) (S). Inclined static sea pressure (S).
<table>
<thead>
<tr>
<th>No.</th>
<th>Application</th>
<th>Loading pattern</th>
<th>Draught</th>
<th>% of perm. SWBM</th>
<th>% of perm. SWSF</th>
<th>Dynamic load cases/comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>LC 9</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><img src="image" alt="Tank and supports" /></td>
<td>(T_A^{2,3)})</td>
<td>(\leq 100%)</td>
<td>(\leq 100%)</td>
<td>Static only (S). Inclination of 30° with tank pressure corresponding to (g) and a transverse component equal to (g \cdot \sin30° = 0.5 \cdot g) (S). Inclined static sea pressure (S).</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>LC 10</strong></td>
</tr>
<tr>
<td></td>
<td></td>
<td><img src="image" alt="Tank and supports" /></td>
<td>(T_{SC})</td>
<td>(\leq 100%)</td>
<td>(\leq 100%)</td>
<td>Collision case - forward. Static only (S). Tank load (A). Acceleration (a_x = 0.5 \cdot g) forward combined with gravity (g).</td>
</tr>
<tr>
<td>No.</td>
<td>Application</td>
<td>Loading pattern</td>
<td>Draught</td>
<td>% of perm. SWBM</td>
<td>% of perm. SWSF</td>
<td>Dynamic load cases/comments</td>
</tr>
<tr>
<td>-----</td>
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<td>-----------------</td>
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<td>-----------------</td>
<td>-----------------</td>
<td>--------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>LC 11</td>
<td>Tank and supports</td>
<td>![Tank and supports diagram]</td>
<td>$T_{SC}$</td>
<td>$\leq 100%$</td>
<td>$\leq 100%$</td>
<td>Collision case - aftward. Static only (S). Tank load (A). Acceleration $a_x = 0.25 , g$ aftward combined with gravity $g$. LC 14 will normally be governing.</td>
</tr>
<tr>
<td>LC 12</td>
<td>Hull and supports 7)</td>
<td>![Hull and supports diagram]</td>
<td>$T_{SC}$</td>
<td>$\leq 100%$</td>
<td>$\leq 100%$</td>
<td>Flooded one tank empty condition. Static only (S).</td>
</tr>
</tbody>
</table>
### 4 Analysis procedure for assessment of supports

#### 4.1 Vertical supports

Various types of vertical supports are used. Figure 5 shows an example of a vertical support. Normally wood mounted on resin will contribute to levelling of vertical supports in a cargo hold. Dam plates are fitted to avoid movement of wood in case of damages in the resin or the bond between resin and the top plate of a vertical support.
The load cases as given in this section includes load cases which maximize the vertical acceleration. The maximum reaction force on each support may however be found in other load cases such as 30° heel or HSM wave condition due to double bottom deformation. Therefore all load cases in Table 2 shall be considered in the evaluation of maximum vertical reaction force.

The support chocks can be modelled either by springs or contact elements (no tension) with only axial stiffness. In case the vertical force in any of the elements representing the support blocks should be in tension, it will be necessary that the model is modified by disconnecting the vertical elements in tension. This means that springs/contact elements in tension are removed (stiffness set to zero or a very small value) and the analysis repeated until all active vertical supports are in compression. Usually, all vertical supports are in compression when the tank is loaded. However, removing elements in tension is necessary when the tank is empty.

In cargo hold analysis, friction forces on vertical supports shall be considered for LC8-10. The friction force acting on the contact surfaces shall be applied to both parts of the supports, as coupling forces, with a magnitude of the minimum friction coefficient ($\mu_{\text{min}}$) times the vertical force acting on each individual vertical support. It means two analyses are necessary to be made for those load cases LC8, LC9 and LC10. The first analysis finds the vertical forces acting on each individual vertical support at each load case and second analysis is done applying friction coupling forces. The reason for using minimum friction coefficient ($\mu_{\text{min}}$) is to consider the minimum friction on vertical support and estimate the maximum reaction forces on anti-roll and anti-pitch supports. The minimum friction coefficient can, if not otherwise specified, be according to Table 1. For other load cases such as all EDW cases and LC11 it is considered acceptable not to take the friction force into account for cargo hold analysis which means all horizontal forces are taken in anti-roll or anti-pitch supports.

In the fine mesh analysis of vertical supports, friction force based on maximum friction coefficient ($\mu_{\text{max}}$) shall be considered together with vertical reaction force. Both directions, longitudinal and transverse, should be considered separately for friction force application in the fine mesh analysis.

4.2 Transverse anti-roll supports

Examples of transverse anti-roll supports are given in Figure 6 and Figure 7. The anti-roll supports are designed based on the EDW load cases that transverse acceleration is maximized and the heeled load cases LC 8-9 in Table 2. In these load cases some of the transverse force is carried by friction in the vertical supports and the rest is taken by the upper and lower anti roll supports.
Figure 6 Example of a combined type of vertical and lower roll supports

Figure 7 Example of upper roll support
Figure 8 Modelling of anti-roll and anti-pitch supports

The effect of intentional clearances between support surfaces should be included if this is expected to significantly affect the distribution of forces between the upper and the lower roll supports. The support chocks can be modelled as spring or contact element with only axial stiffness at both sides of the support as shown in Figure 8. The connection element in tension side (i.e. no contact) shall be disconnected/removed and need to be rerun until all active connection elements are in compression. Friction forces in the longitudinal direction on the transverse anti-roll supports are not considered in the cargo hold analysis. These forces will be set up due to double bottom bending, hull girder bending and lateral loads at boundaries of the tank and shall be considered when local fine mesh analyses are performed for the transverse anti-roll supports. For the load cases generating maximum transverse force on anti-roll support, the amount of longitudinal friction force on anti-roll support is expected to be small. Therefore, friction forces based on the minimum friction coefficient ($\mu_{\text{min}}$) times the maximum transverse force acting on the support is considered acceptable.
4.3 Longitudinal anti-pitch supports

The support chocks can be modelled similarly as the transverse anti-roll supports described in [4.2]. The ULS assessment of the anti-pitch supports is based on the collision load cases LC10 and 11. Normally LC 10 will be governing. Like the anti-roll supports, some of the loads in the longitudinal direction will be taken by the friction in vertical supports and the rest will be taken by the anti-pitch supports. Like the transverse anti-roll support, friction force in the transverse direction shall be considered when local fine mesh analysis is performed for the longitudinal anti-pitch supports. Friction force may be calculated with a magnitude of the minimum friction coefficient ($\mu_{\text{min}}$) times the maximum longitudinal force acting on the support.

![Figure 9 Example of anti-pitch support](image)

4.4 Anti-floatation supports

These supports are analysed similarly as the vertical supports by using spring elements. In the fine mesh analysis, deformations of the local models are taken from the cargo hold model analysed with the flooding condition LC 12. The friction forces are to be calculated with a magnitude equal to the maximum friction coefficient ($\mu_{\text{max}}$) times the lateral force acting on the support. The direction of these forces is found from the cargo hold analysis. Both directions, longitudinal and transverse parallel to the surface of the support, should be considered separately for friction force application in the fine mesh analysis.
5 Acceptance criteria for ultimate and accidental strength

5.1 General
The tanks with supports directly attached to the tanks and the tank support areas shall be designed according to the principles in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4. Scantlings of the transverse and longitudinal primary cargo tank structures shall be determined according to the general yield and buckling criteria given in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [4.3.4].

5.2 Buckling
Buckling check procedures in DNVGL-CG-0128 are to be applied. In case of highly irregular geometries and/or boundary conditions, nonlinear FE analyses may have to be carried out in order to determine the buckling strength of specific areas. In such cases special considerations with respect to modelling (mesh fineness), imperfection levels/modes and acceptance levels is required.

5.3 Acceptance criteria for each load case
Table 5 below summarizes the acceptance criteria for FE analysis cargo hold analyses of hull and cargo tanks per load case with reference to the relevant rule sections.
Table 5 Acceptance criteria for cargo hold - FE analysis

<table>
<thead>
<tr>
<th>LC</th>
<th>Design cond.</th>
<th>Hull, type A and B&lt;sup&gt;1)3)&lt;/sup&gt;</th>
<th>Permissible usage factors for cargo tanks and supports&lt;sup&gt;5)&lt;/sup&gt;</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Yield</td>
<td>Buckling</td>
<td>Yield (η&lt;sub&gt;all&lt;/sub&gt;)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>λ&lt;sub&gt;perm&lt;/sub&gt;</td>
<td>σ&lt;sub&gt;all&lt;/sub&gt;</td>
<td>η&lt;sub&gt;all&lt;/sub&gt;</td>
</tr>
<tr>
<td>LC 1-4</td>
<td>ULS (S)</td>
<td>0.8</td>
<td>λ&lt;sub&gt;perm&lt;/sub&gt;R&lt;sub&gt;y&lt;/sub&gt;</td>
<td>0.8</td>
</tr>
<tr>
<td>LC 5-7</td>
<td>ULS (S+D)</td>
<td>1.0</td>
<td>λ&lt;sub&gt;perm&lt;/sub&gt;R&lt;sub&gt;y&lt;/sub&gt;</td>
<td>1.0</td>
</tr>
<tr>
<td>LC 8-11</td>
<td>ALS (A)</td>
<td>N.A</td>
<td>N.A</td>
<td>N.A</td>
</tr>
<tr>
<td>LC 12&lt;sup&gt;5)&lt;/sup&gt;</td>
<td>ALS (A)</td>
<td>1.0</td>
<td>λ&lt;sub&gt;perm&lt;/sub&gt;R&lt;sub&gt;y&lt;/sub&gt;</td>
<td>1.0</td>
</tr>
<tr>
<td>LC 13&lt;sup&gt;5)&lt;/sup&gt;</td>
<td>ALS (A)</td>
<td>1.0</td>
<td>λ&lt;sub&gt;perm&lt;/sub&gt;R&lt;sub&gt;y&lt;/sub&gt;</td>
<td>1.0</td>
</tr>
</tbody>
</table>

1) See DNVGL-RU-SHIP Pt.3 Ch.7 Sec.3 [4] for yield and DNVGL-RU-SHIP Pt.3 Ch.8 Sec.1 [3] for buckling.

2) See DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [4.3.4] and DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [4.3.5] for yield and buckling respectively. The κ factor for tank materials accounts for the relationship between tensile strength and yield strength for alternative tank materials.

3) Hull structures in way of supports are inclusive.

4) LC4 shall evaluate longitudinal bulkhead of cargo tank and it's neighboring tank structures.

5) LC12 shall evaluate anti-floatation support and hull structures in way of anti-floatation support.

6) LC13 shall evaluate hull transverse bulkhead and it's neighboring hull structure.
SECTION 5 LOCAL STRUCTURAL STRENGTH ANALYSIS

1 General

Modelling for fine mesh analysis shall follow the general requirements in DNVGL-CG-0127. The extensions of the local FE support models described below refers to the borders of the sub-models where tapering from the cargo hold mesh to where the 50 mm × 50 mm fine mesh starts. The support models shall not only cover the support itself with the associated parts of the tank, but also the associated area of the hull structure in way of the supports. If different designs of each support type are used, separate models for each design shall be made.

The fine mesh models shall be based on gross scantlings according to DNVGL-RU-SHIP Pt.3 Ch.3 Sec.2 Table 1. The most critically loaded designs of each of the types below shall be considered for fine mesh analysis:

— vertical supports
— transverse anti-roll supports
— longitudinal ant-pitch supports
— anti-floating supports.

The Society may exempt fine mesh analyses of the supports if low cycle and/or high cycle fatigue analyses is considered more appropriate for the actual detail, DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [5.1.1]. Fine mesh modelling shall be carried out according to the principles in [4.1], [4.2], [4.3] and [4.4].

2 Locations and loads to be considered

The locations given in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [5.2.1] shall be verified by local fine mesh analysis. The following areas shown in Table 1 in the midship cargo region shall be investigated with fine mesh analysis. Based on screening results from the cargo hold analysis the most critical location can be selected. The screening method is according to DNVGL-CG-0127 Sec.4 [3]. Additional locations may be required for fine mesh analysis in case the results of cargo hold analysis is not sufficient to judge the area due to the poor shape of element. The application of loads in each local fine mesh model is as given in Table 1.

Table 1: Standard locations and loads to be considered for fine mesh analysis

<table>
<thead>
<tr>
<th>Locations to check</th>
<th>Applied loads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cargo tanks and tank supports including adjacent hull or tank structures</td>
<td>Maximum vertical reaction force from cargo hold analysis: maximum vertical reaction force among all load cases in Sec.4 Table 2 to be combined with horizontal friction force. Vertical reaction force + transverse friction force: $F_v$, $F_{t,f}$ Vertical reaction force + longitudinal friction force: $F_v$, $F_{l,f}$.</td>
</tr>
<tr>
<td>Vertical supports (including bottom stiffeners at end of tank, if relevant)</td>
<td>$F_v = F_{v,CH}$</td>
</tr>
<tr>
<td></td>
<td>$F_{v,CH}$: is maximum vertical reaction force from cargo hold analysis</td>
</tr>
<tr>
<td></td>
<td>$F_{t,f}$, $F_{l,f}$ = $μ_{max} \times F_v$</td>
</tr>
<tr>
<td></td>
<td>$F_{t,f}$, $F_{l,f}$: is transverse and longitudinal friction force respectively, in N</td>
</tr>
<tr>
<td></td>
<td>$μ_{max}$: maximum friction coefficient according to Sec.4 Table 1 if not otherwise documented</td>
</tr>
<tr>
<td></td>
<td>Each representative support design to be assessed.</td>
</tr>
</tbody>
</table>
### Locations to check

<table>
<thead>
<tr>
<th>Applied loads</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transverse support</strong></td>
</tr>
<tr>
<td>— Maximum transverse reaction force from cargo hold analysis among all seagoing load cases and 30° heel load cases (LC 8-9) in Sec.4 Table 2 to be combined with longitudinal friction force.</td>
</tr>
<tr>
<td>— For lower anti-roll support:</td>
</tr>
<tr>
<td>— transverse reaction force + longitudinal friction force: $F_{t,CH}, F_{t,f}$.</td>
</tr>
<tr>
<td>$F_t = F_{t,CH}$</td>
</tr>
<tr>
<td>$F_{t,CH}$: maximum transverse reaction force from cargo hold analysis, in N</td>
</tr>
<tr>
<td>$F_{t,f} = \mu_{min} \times F_t$</td>
</tr>
<tr>
<td>$F_{t,f}$: longitudinal friction force, in N</td>
</tr>
<tr>
<td>$\mu_{min}$: minimum friction coefficient from Sec.4 Table 1 if not otherwise documented by the designer</td>
</tr>
<tr>
<td>— For upper anti-roll support:</td>
</tr>
<tr>
<td>— transverse reaction force + longitudinal friction force: $F_t, F_{t,f}$, in N.</td>
</tr>
<tr>
<td>$F_t = F_{t,CH}$</td>
</tr>
<tr>
<td>$F_{t,f} = \mu_{min} \times F_t$</td>
</tr>
<tr>
<td>— Each representative support design to be assessed.</td>
</tr>
<tr>
<td><strong>Longitudinal support</strong></td>
</tr>
<tr>
<td>— For anti-pitch support, maximum reaction force from cargo hold analysis, collision load cases (LC 10 and 11), Sec.4 Table 2 to be combined with transverse friction force. If the design is symmetrical longitudinally, aft-ward collision case (LC 11) can be omitted.</td>
</tr>
<tr>
<td>— Longitudinal reaction force + transverse friction force: $F_l, F_{t,f}$, in N.</td>
</tr>
<tr>
<td>$F_l = F_{l,CH}$</td>
</tr>
<tr>
<td>$F_{l,CH}$: maximum longitudinal reaction force from cargo hold analysis</td>
</tr>
<tr>
<td>$F_{t,f} = \mu_{min} \times F_l$</td>
</tr>
<tr>
<td>$F_{t,f}$: transverse friction force, in N</td>
</tr>
<tr>
<td>$\mu_{min}$: minimum friction coefficient according to Sec.4 Table 1 if not otherwise documented</td>
</tr>
<tr>
<td>— Each representative support design to be assessed.</td>
</tr>
<tr>
<td><strong>Anti-floatation supports</strong></td>
</tr>
<tr>
<td>— Reaction force from cargo hold analysis (LC 12), in Sec.4 Table 2 to be applied together with friction force.</td>
</tr>
<tr>
<td>— The friction forces based on maximum friction coefficient ($\mu_{max}$) shall be considered.</td>
</tr>
<tr>
<td>— The direction of friction force can be found from the cargo hold analysis.</td>
</tr>
<tr>
<td>— Each representative support design to be assessed.</td>
</tr>
</tbody>
</table>
### 3 Fine mesh model of hull

#### 3.1 Double hull longitudinals subjected to relative deformations

Relative deformations between longitudinal stiffener supports may give rise to high stresses in local areas. Typical areas to be considered are:

- longitudinal in double bottom and adjoining vertical bulkhead members.

The model is recommended to have the following extent:

- the stiffener model shall extend longitudinally at least two web frame spaces for both sides from the area under investigation
- transversely two stiffener spaces on each side of the stiffener.

*Figure 1 to Figure 2* shows examples of fine mesh models of hull details double bottom longitudinals.
3.2 Side frame

Typical areas to be considered are:
— side frame in the middle of cargo hold
— upper and lower ends of side frame for single side hold.

The model shall have the following extent:
— the model shall extend longitudinally at least one web frame spacing for both sides from the considered area
— transversely to include the whole hopper and wing tank.

*Figure 2* shows examples of fine mesh models of side frame.
Figure 2 Example of side frame fine mesh model

4 Fine mesh model of supports

4.1 Modelling of vertical supports
— the local model should extend one web frame spacing forward and aft of the vertical support in the longitudinal direction
— in the transverse direction, the model should in general include the neighbouring primary supporting structures.
4.2 Modelling of transverse supports

— The transverse extension of the local model should in general be as for the vertical supports.
— In the longitudinal direction, the extension is required to be two web frame spaces, i.e. one web frame spacing forward and one spacing aft of the support.
— Upper and lower supports shall be modelled.
4.3 Modelling of longitudinal supports

- Longitudinal extension of the model may be two web frame spaces, i.e. forward and aft of the support.
- In the transverse direction, symmetry may be considered and the extension of the model should normally be one longitudinal space from the edge of the support.

**Figure 4 Examples of transverse anti-roll support fine mesh models**

a) Lower support

b) Upper support
— One anti-pitch support of each design to be modelled.

**Figure 5 Example of longitudinal anti-pitch support fine mesh model**

### 4.4 Modelling of anti-floatation chocks

— one typical support of each design should be modelled
— the model shall extend to the next web frame forward and aft from its target frame and shall include the necessary surrounding hull and cargo tank structure in way of the support in order to provide proper boundary conditions for the fine mesh sub-model.

**Figure 6 Example of anti-floating support FE fine mesh model**
5 Load cases

The fine mesh analysis in way of cargo tanks and tank supports shall be carried out for the load cases specified in Sec.4 Table 2 for the locations outlined in Table 1. However, not all the load cases listed in Sec.4 Table 2 may be governing. The actual tank design and support configuration may vary and the applicable load cases will have to be selected accordingly.

6 Acceptance criteria

Acceptance criteria given in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [5.4] and DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [5.5] shall be complied with for local fine mesh analysis.
SECTION 6 FATIGUE ANALYSIS

1 General

1.1 Introduction

Fatigue analysis for independent tank type A will normally not be required for the cargo tank and tank support structure. However, with design cargo temperature below -55°C, fatigue analysis is required.

For independent B-tanks wave load calculations shall be carried out in compliance with DNVGL-RU-SHIP Pt.3 Ch.9, DNVGL-RU-SHIP Pt.5 Ch.7 and DNVGL-CG-0129. Rule loads are applicable unless otherwise specified, or if the voluntary notation CSA is specified.

1.2 Finite element models

The determination of nominal stress ranges for use with S-N curves and stress concentration factors may be based on cargo hold model meshes or fine mesh analysis models dependent on the suitability for use with the actual detail to be analysed. Alternatively, stresses can be extrapolated to the hot spot from a very fine mesh FE analysis ($t \times t$). Modelling requirements for very fine mesh FE models and stress extrapolation procedures are described in DNVGL-CG-0129.

1.3 Modelling of supports

It is assumed that $10^{-2}$ level of fatigue loads from cargo tanks are taken by vertical support in friction. Therefore, the connection of vertical supports shall be modelled with solid/shell or beam elements so that full connection is obtained both for vertical and horizontal forces. It is considered acceptable not to model the connection of anti-roll and anti-pitch supports.

For ballast condition, the connection elements of vertical supports shall be disconnected or changed to flexible springs so that the stiffness of cargo tank is not accounted for in the deformation of the double bottom structure.

1.4 Locations to be considered

Required scope of fatigue assessment is given in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [8]. The locations given in Table 1 shall be taken into consideration.
### Table 1 Locations to be considered for FE fatigue assessment

<table>
<thead>
<tr>
<th>Structure/member</th>
<th>Structural detail</th>
<th>Load type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hull structures, DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20</td>
<td>— Hull girder wave bending.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— Dynamic sea pressure load.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— Dynamic ballast pressure load.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— Dynamic cargo loads.</td>
</tr>
<tr>
<td>Hopper knuckles</td>
<td>— Lower hopper.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>— Upper hopper (type B tank).</td>
<td></td>
</tr>
<tr>
<td>Deck openings</td>
<td>Cargo tank dome openings and liquid dome coaming connection to deck (type B tank)</td>
<td>— Hull girder wave bending.</td>
</tr>
<tr>
<td>cargo tank dome</td>
<td></td>
<td>— Support deformation.</td>
</tr>
<tr>
<td>Double bottom</td>
<td>— Bottom girder connection to transverse bulkheads (type B tank).</td>
<td>— Hull girder wave bending.</td>
</tr>
<tr>
<td>longitudinal</td>
<td></td>
<td>— Dynamic sea pressure load.</td>
</tr>
<tr>
<td>girders and</td>
<td>— Side girder connection to transverse bulkheads (type B tank).</td>
<td>— Dynamic ballast pressure load.</td>
</tr>
<tr>
<td>side stringers</td>
<td></td>
<td>— Dynamic cargo loads.</td>
</tr>
<tr>
<td>Cargo tanks</td>
<td>— Vertical supports.</td>
<td>— Hull girder wave bending.</td>
</tr>
<tr>
<td></td>
<td>— Fwd and aft end secondary stiffeners.</td>
<td>— Internal pressure due to.</td>
</tr>
<tr>
<td></td>
<td>— High stressed tank structure in way of supports.</td>
<td>— vertical acceleration.</td>
</tr>
<tr>
<td></td>
<td>— Bracket ends.</td>
<td>— transverse acceleration.</td>
</tr>
<tr>
<td></td>
<td>— End connection of stiffeners.</td>
<td>— longitudinal acceleration.</td>
</tr>
<tr>
<td></td>
<td>— Outer shell plate to stiffeners and frames/girders.</td>
<td>— Dynamic sea pressure.</td>
</tr>
<tr>
<td>Cargo pump</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cargo riser</td>
<td>Supports</td>
<td>— Internal inertia pressure due to</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— vertical acceleration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— transverse acceleration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— longitudinal acceleration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>— Sloshing forces.</td>
</tr>
</tbody>
</table>

**Note:**

1) Tank supports includes the part of the tank structure in way of supports, he support structure welded to tank and hull, and adjacent hull structure where the stress mainly originates from the presence of the tank.

2) Applicable for A type tank when the cargo temperature is below 55°C.

3) Several methods for fatigue analyses are available, simplified beam approach, component spectral (stochastic) analysis and full spectral (stochastic) analysis, see DNVGL-CG-0129.

### 1.5 Acceptance criteria

Fatigue analysis shall be evaluated against the fatigue acceptance criteria in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [8.5.1].
2 Fatigue damage accumulation

2.1 General
The long term distributions of stresses at the critical welds shall be determined for the loaded, part load and ballast conditions. The combined effect for the fatigue analysis can be determined as outlined below considering the operational profile of the vessel. The operational profile is defining the fraction of the total lifetime spent in the actual loading conditions, as full load, ballast and partly loaded conditions at various heading angles.

By establishing a resulting long term Weibull stress distribution representative for the expected operation of the vessel over its life time. This can be done by combining the long term stress distributions for all the load cases as a weighted sum according to the operational profile for the vessel. Fatigue analysis on this basis shall be compared to the total design lifetime.

2.2 Total fatigue damage
The fatigue analysis shall be based on wave loads corresponding 25 years of operation, $10^8$ design wave cycles, in North Atlantic wave environment unless special design conditions have been accepted by the Society, see DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [2.1.2]. The stresses shall in most cases be determined by the use of finite element models. The total fatigue damage, i.e. low cycle and high cycle fatigue, may be obtained for cargo tanks as follows:

$$D = \sum_{i=1}^{k} \left( \frac{n_i}{N_i} \right) + \frac{n_{\text{loading}}}{N_{\text{loading}}} \leq C_w$$

or

$$D = \sum_{i=1}^{k} n_i (\Delta\sigma_i)^m + \frac{n_{\text{loading}}}{N_{\text{loading}}} \leq C_w$$

where:

- $D$ = accumulated fatigue damage ratio
- $n_i$ = number of cycles in stress block $i$
- $N_i$ = number of cycles to failure at constant stress range $\Delta\sigma$ as determined by an appropriate S-N curve
- $n_{\text{loading}}$ = number of loading and unloading cycles covering the complete pressure and temperature range during the lifetime of the vessel, to be taken as 1000 for trading carriers
- $N_{\text{loading}}$ = number of load cycles to failure for fatigue loads due to variable fillings, loading and unloading
- $k$ = number of stress blocks, $\geq 8$
- $\bar{a}, m$ = parameters defining the fatigue S-N curve
- $\Delta\sigma_i$ = stress range in stress block $i$
- $C_w$ = acceptable accumulated fatigue damage levels as given in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [4.3.3]

The first term in the damage equations above may be determined by the alternative formulation in DNVGL-CG-0129 using a gamma function and a long term weibull load distribution with a shape parameter $h = 1.0$. 
3 Operating profile

3.1 Typical trading profile
The ship loading conditions to be used in the fatigue and fracture mechanics analyses are given in DNVGL-RU-SHIP Pt.3 Ch.9 Sec.4 [4.3] for a normal trading pattern, i.e. trading with full load on entire laden voyage and in ballast for the return leg. 15% of the life time is assumed in harbour on sheltered water.

3.2 Other operating profiles
Other distributions of time fractions (exposure times) may be applied for trades that require the ship to operate more of the time in part load conditions.
The design loading conditions and exposure times giving basis for the fatigue calculations will be stated in the appendix to the class certificate.
For cargo piping, cargo pump and the supporting structure shall be assessed with respect to sloshing loads. A fatigue assessment for a fraction of time in part load conditions of not less than 5% to be considered.

4 Loads

4.1 Equivalent design waves for fatigue
Equivalent fatigue design waves shall be applied according to
— DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [8.4.1] for the hull
— DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [8.4.2] for the tanks and the support structure.

4.2 Load combinations
For hull structures see DNVGL-RU-SHIP Pt.3 Ch.9 Sec.4 [4.3]. Load cases and loading conditions for fatigue calculation of tank and supports are defined in Table 2.
### Table 2 Fatigue design load cases for midship area

<table>
<thead>
<tr>
<th>Load combinations</th>
<th>Application</th>
<th>Loading pattern</th>
<th>Draught</th>
<th>% of perm. SWBM</th>
<th>% of perm. SWSF</th>
<th>Dynamic load case/comments</th>
</tr>
</thead>
</table>
| Full              | Tank and support | $T_{FULL}$ | According to loading manual | $\leq 100\%$ | A-tanks$^2$: HSM, FSM, BSR-P, BSR-S, BSP-P, BSP-S, OST-P, OST-S. 
B-tanks: Fatigue design wave (FDW) from direct hydrodynamic analysis to be used. |
| Ballast           | Tank and support | $T_{BAL}$ | According to loading manual | $\leq 100\%$ | A-tanks$^2$: HSM, FSM, BSR-P, BSR-S, BSP-P, BSP-S, OST-P, OST-S. 
B-tanks: Fatigue design wave (FDW) from direct hydrodynamic analysis to be applied. |

1) The port (P) or starboard (S) versions shall be selected based on the geometry/symmetry of the construction and which load case gives the largest stress in the area under investigation (unsymmetric construction). Alternatively, if symmetric geometry load cases for only one side (P) can be used.

2) For type A tank, when fatigue assessment of tanks and supports is required, the load cases to be considered are the same as for fatigue assessment of hull structure.

### 5 Fatigue assessment of cargo tanks and supports

#### 5.1 Global structural analysis

Global and/or cargo hold structural analysis shall be performed to identify fatigue prone areas by fatigue screening and serve as basis for the local finite element analyses. Fatigue screening analyses shall be performed based on 25 years operation in North Atlantic environment with exposure times $f_0$ defined in DNVGL-RU-SHIP Pt.3 Ch.9 Sec.4 Table 2. The calculations shall be based on the S-N curves for welded joints in air for the actual material used. The fatigue screening uses nominal membrane stresses from a cargo hold type mesh, e.g. from a cargo hold type model.
5.2 Stress range distribution and reference stress range for fatigue analysis

The probability range below $10^{-4}$ is the part of the long term stress range distribution that contribute most to the (high cycle) fatigue damage. Probability level $10^{-2}$ has been found to be the most contributing area of the distribution. Hence, $10^{-2}$ has been selected in the rules as reference stress for fatigue analysis, DNVGL-RU-SHIP Pt.3 Ch.9 and DNVGL-CG-0129. This implies that:

— the upper part (above $10^{-6}$) of the long term distribution where modifications of the long term stress distribution could have been necessary due to sliding effects (lower stress range) can conservatively be disregarded
— the fatigue analysis can be carried out assuming no sliding at the support blocks.

5.3 Internal pressure for fatigue assessment of centreline longitudinal bulkhead

The fatigue strength of plates and stiffeners in the upper part of the centreline cargo tank bulkhead shall be checked for sea going condition.

5.4 Vertical supports

Dynamic stresses in the vertical supports are caused by the following dynamic loads:

— vertical acceleration
— horizontal acceleration
— sea pressure
— double bottom bending
— hull girder bending.

These load components are taken into account according to the combinations defined for each equivalent design wave assigned in Table 2. The evaluation has to consider each support type considering maximum lateral support force.

5.5 Transverse supports

The total transverse forces acting on the cargo tanks will be supported by upper and lower transverse supports and friction forces in the vertical supports. The distribution of the supporting forces between friction force in the vertical supports and forces in the transverse supports will vary depending on the magnitude of the transverse dynamic force.

The dynamic loads used for fatigue calculations ($10^{-2}$ probability level) are mainly taken by friction within vertical supports. Only a relative small portion of the transverse loads are taken by transverse supports. Fatigue analysis of the transverse supports is therefore normally not required.

5.6 Longitudinal supports

The longitudinal supports normally not subject to fatigue analysis as the longitudinal acceleration is relatively small in normal ship operation and the longitudinal load is absorbed by the friction in the vertical supports.

5.7 Anti-floatation supports

The anti-floatation supports are supports designed to prevent the tank in an accidental cargo hold flooding situation to float up and need therefore not be subject to fatigue calculations.
SECTION 7 CRACK PROPAGATION ANALYSIS

1 Introduction

Typical weld connections to be considered are:

a) Plate connections to stiffeners, frames and girders in outer tank shell.
b) High stress areas at stiffener transitions through web frames and girders and stiffeners subjected large relative deformations, where failure developments has potential to propagate into the outer shell before being detected.
c) Tank structure in way of supports and tower foundation.

In case of a), the leakage rates shall be determined according to [7], and the small leak protection system shall be dimensioned accordingly. This demonstrates compliance with the leak-before-failure (LBF) requirements as outlined in the rules DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [2.2.6], and can be considered detectable by leakage detection. On the other hand, if a crack cannot be shown to penetrate the shell thickness before reaching a critical state (condition b) above) and LBF does not apply, the stricter requirements in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [8.5.1] in the rules have to be applied.

For details of the internal girder/frame structure away from the shell, and where failure detection by leakage is not an option, the analyses shall be used to determine crack propagation paths and the time until the failure development reaches a critical state where it can compromise the integrity of the tank. Requirements are given in the rules DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [8.5.1], and shall be selected considering whether or not detection by inspection is applicable.

Dynamic stresses are driving fatigue crack growth, whereas the rupture of a fatigue crack of a given size is governed by a maximum ULS load amplitude. The primary load effect governing final rupture of a fatigue crack of a certain size is the most probable largest one time stress amplitude (static plus dynamic amplitude) during $10^8$ cycles in the North Atlantic.

The most convenient approach shall establish the total fatigue load stress range spectrum for fracture mechanics (crack propagation) analyses from the most probable largest load spectrum the ship will experience during $10^8$ wave encounters in the North Atlantic applying a Weibull slope parameter of $h = 1$.

2 Fracture mechanics analysis

2.1 General

An unstable crack means either spontaneous crack growth with no additional input of driving strain energy (brittle fracture) or a plastic tearing needing only marginal input of strain energy for the crack to propagate. If leak-before-failure cannot be proven, enhanced fatigue and fracture mechanics requirements apply depending on possibilities to inspect (access) and the inspection period, the rules DNVGL-RU-SHIP Pt.5 Ch.7 Sec.4 [4.3.3].

2.2 Items to be considered

The start of the analyses is from an initial semi-elliptical crack of length $2c$ and depth $a$ that will at least be of the maximum defect size that will not be discovered with NDT inspections. The initial crack sizes shall not be taken less than the values given in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [9.2.1] in the rules. The following analyses will normally have to be carried out:

a) The estimated number of cycles/years before a leakage, i.e. the number of cycles to propagate through the thickness enabling gas detection of the leakage, or to reach a critical size shall be calculated. The stress spectrum to be used for this case is illustrated in a normalized form in Figure 2. Here, 30 stress blocks are used to define the load spectrum.

b) Further propagation of the penetrated crack shall then be calculated as a through-thickness crack for the worst 15 day North Atlantic storm, Figure 1.
c) If the crack is stable up to 15 days, and beyond, leakage calculations shall be carried out to estimate liquid leakage rates, [7] below.

d) If failure monitoring based on gas detection cannot be safely applied the predicted failure development time shall, if reliable in-service inspection is possible, be 3 times the inspection interval, otherwise 3 times the design lifetime of the tank, DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [8.5.1].

2.3 Crack growth calculation

Both the crack propagation and the critical crack size calculations can be performed using the software program Crackwise from The Welding Institute (TWI). The critical flaw calculations can be carried out based on the level 2B calculations defined in BS 7910, Sec.9 [1]. The crack growth can be calculated by stepwise integration of the Paris’ equation:

\[ \frac{da}{dN} = C(\Delta K)^m, \quad \Delta K = Y \cdot \Delta \sigma \sqrt{\pi a} \]

where:

\( da/dN \) = the crack growth per load cycle

\( m \) and \( C \) = the crack growth constants, determined from experiment

\( \Delta K \) = the stress intensity factor range in N/mm\(^2\)

\( \Delta \sigma \) = the stress range in N/mm\(^2\)

\( Y \) = is a correction factor depending on geometry

\( a \) = the crack depth in mm

The additional bending stress from eccentricities can be calculated directly from the FE analyses or from suitable stress concentration formulas as given in DNVGL-CG-0129. If the welds are ground flush the local stress concentration factor due to weld, \( M_k \), can be set equal to 1.0, otherwise the \( M_k \) definition in the Crackwise program can be applied if relevant for the actual geometry.

3 Crack propagation data for fracture mechanics analysis

The design crack propagation data shall be based on the mean-plus-two-standard-deviation of the test data. For the cargo tank, crack propagation data (\( C \) and \( m \) in Paris’ equation) and fracture toughness data, \( J \)-values or CTOD values, need to be determined for the tank material and its welded joins for relevant service conditions. Documented test data for both room temperature and cryogenic temperature should be available, see Sec.9 [1].

4 Welding residual stresses

In the critical flaw size calculations, the residual stress from welding is assumed equal to the yield stress.

5 Stress range spectra

5.1 Long term wave-induced stress range spectrum

For design against leakage the load spectrum is taken as the most probable largest load spectrum the ship will experience during \( 10^8 \) wave encounters in the North Atlantic. The normalized stress range on probability level \( 10^{-8} \) can be set equal to 1 to facilitate easy scaling to any stress level. The long term wave-induced stress range spectrum (\( 10^8 \) cycles) is given in Figure 2 using 30 stress blocks and assuming a Weibull shape parameter of \( h = 1.0 \). If no better estimate for \( h \) is available this is the normal assumption.
However, in the direct wave load analysis procedure which is required for independent tanks of type B the Weibull shape parameter can be determined. Hence, the shape of the stress distributions in Figure 2 and Figure 1 can be modified as follows:

\[
\frac{\Delta \sigma}{\Delta \sigma_0} = \left(1 - \frac{\log n}{\log n_0}\right)^{1/h}
\]

where:

- \(\Delta \sigma_0\) = reference stress value at the local detail exceeded once in \(n_0\) cycles (shown normalized to 1.0), in N/mm\(^2\)
- \(n_0\) = total number of cycles associated with the stress range level \(\Delta \sigma_0\) (here \(10^8\))
- \(h\) = the Weibull slope parameter.

**Figure 1 Short term (15 days of storm) wave-induced stress range spectrum**

### 5.2 Stress range spectrum for 15 days of storm

For analysing crack propagation of a through-thickness crack the stress range spectrum representing 15 days in the worst \(10^8\) storm condition in the North Atlantic is used. The stress range spectrum at 15 days (\(2 \times 10^5\) cycles) of storm is shown in Figure 1 using 30 stress blocks.
5.3 Failure criterion for ductile material

The dynamic stress range is the driving force for crack propagation. For through thickness analysis the $10^8$ cycles stress spectrum shall be used, Figure 2. When a through thickness crack has developed, the 15 day spectrum in the most severe storm (same extreme stress value as for the $10^8$ spectrum) shall be used and the crack length at day 15 determined.

The materials normally used for tank type B construction, aluminium 5083-0 and 9% Ni-steel, has been shown to be very ductile and no critical crack length can be precisely defined, see Sec.9 [1]. The value of the CTOD parameter can therefore during the through thickness crack propagation phase be set to a fairly large value (e.g. = 1000). The analysis should then be carried out well beyond the 15 day duration (up to about $3 \times 15$ days) in order to trace the through thickness crack growth curve (crack length vs. cycles). If the curve shows an accelerated crack growth this indicates an imminent plate failure (rupture). The driving stress range can based on the results of the investigations reported in Sec.9 [1] be set to

$$\Delta \sigma = \Delta \sigma_{dm} + \frac{\Delta \sigma_{db}}{m}$$

where:

- $\Delta \sigma_{dm}$ = dynamic membrane stress range in N/mm$^2$
- $\Delta \sigma_{db}$ = dynamic bending stress range in N/mm$^2$
- $m$ = dynamic bending reduction factor
The value of the dynamic bending factor \( m \) can be taken as 3. The strain energy associated with the compressive side of the bending stress distribution will not contribute to open the crack, but the tension side might. Hence, as a conservative measure 1/3 of the surface bending stress range can be included.

### 6 Stress combination for fracture mechanics analysis

In order to evaluate residual fracture of fatigue cracks over the lifetime of the vessel fracture mechanics analysis should be referred to the ULS stress range to be compatible with the total ULS stress amplitude that governs potential fatigue crack rupture. The fatigue stress range can preferably be determined at a \( Q = 10^{-2} \) probability level as for the S-N fatigue approach and extrapolated to the ULS stress range level using the long term Weibull stress distribution. For a Weibull shape parameter \( h = 1 \) this means multiplying the \( 10^{-2} \) stress range with 4 to arrive at the \( 10^{-8} \) stress range. For use in the fracture mechanics analysis the principal stresses determined for S-N curve fatigue analysis shall be further processed as given below:

- **a)** In order to correctly evaluate crack propagation, the static value plus the dynamic design life ULS amplitude of the principal surface stresses shall be calculated in addition to the dynamic stress ranges.
- **b)** Based on the inside and outside values of the principal surface stresses, the stresses shall be split into membrane and bending parts separately for dynamic stress ranges and for static plus ULS amplitude values. This is essential for the fracture mechanics analyses but is not necessary for the S-N fatigue analyses.
- **c)** Select the largest membrane stress for the analysis. This will give the fastest crack growth through the thickness and probably the shortest fatigue life. However, in some cases it might be necessary also to check the maximum bending combination in which the crack will grow faster in length than in depth.

### 7 Leakage calculation

#### 7.1 Purpose of calculation

It is important to estimate the leakage rate through a crack of given size in order to establish whether the concentration of leaked gas is sufficient to be detected before the crack becomes of unstable, e.g. by experiencing an accelerating crack propagation rate.

In practice it shall be established that the crack between the time of detection and the end of the voyage does not reach the critical crack length. For the possibility of detecting a leak the worst case would be one in which the leakage is detected soon after the start of the voyage.

In this context a conservative leakage estimate is one that underestimates the leakage for a given crack size. A calculation that overestimates the leakage will indicate that the leakage will be detected earlier than in reality.

On the other hand, a larger LNG liquid leakage will be conservative for the dimensioning of the capacity of the small leak protection system (the reduced secondary barrier drip tray).

#### 7.2 Cases to consider

The leakage may be of vapour from the region above the liquid surface or of liquid from the lower region of the tank. In practice it is considered sufficient to consider two cases:

1) Through-thickness cracks in the outer primary shell plate in the lower parts of the tank, e.g. in way of supports and tower foundation. The largest liquid leak rate will be when the tank is full, i.e. has the largest liquid pressure head at the position of the crack.

2) A through-thickness crack in the primary shell plate in the upper part of the tank, which may be above or below the liquid surface.
7.3 Form and dimensions of crack

The development of a fatigue crack in the tank shell may be considered to consist of three stages as shown in Figure 3 and described below:

I. The crack starts to grow from a defect at one surface (the initiation side). It grows in both the in-plane direction and the thickness direction until it reaches the opposite face of the plate (the penetration side).

II. The length of the crack at the initiation side is given by the fracture mechanics analysis when the crack has propagated through the thickness. The crack shape will be semi-elliptic with axes equal to the crack length at the initiation side and the smaller half axis equal to the plate thickness.

III. The crack will grow as a trough thickness crack. The length of the crack at the penetration side can be calculated assuming the same elliptic shape (the same ratio between the half axes) as in Stage II throughout the through thickness crack growth. This approach gives similar crack shapes as those found during the fracture and leakage testing, see Sec.9 [1] and Sec.9 [1].

![Figure 3 Three stages of crack growth](image)

7.4 The crack length at the penetration side

1) Calculate the crack propagation through the plate thickness starting from the defects given in DNVGL-RU-SHIP Pt.5 Ch.7 Sec.20 [9.2.1] by fracture mechanics analysis, e.g. by Crackwise. The crack length at the initiation side is then obtained from the analysis as the length when the crack penetrates the thickness.

2) Staring from the crack length on the initiation side carry out a crack growth calculation of the through-thickness crack and determine the crack length on the initiation side after 15 days in the most severe storm using a load spectrum as shown in Figure 1.

3) The corresponding crack length at the penetration side can then be estimated as:

\[ a_p^2 = a_i^2 - \left(\frac{t_0}{t} \right)^2 t^2 \]

where:

- \( a_p \) = half crack length at penetrations side after 15 days storm, in mm
- \( a_i \) = half crack length at initiation side after 15 days storm, in mm
- \( a_{i0} \) = half crack length at initiation side at penetration of the shell plate thickness, in mm
- \( t \) = shell plate thickness, in mm
- \( t_0 \) = depth of crack corresponding to \( a_{i0} \) as returned by Crackwise, in mm

Due to the numerical solution procedure used in Crackwise \( t_0 \) will normally be slightly less than \( t \). It will, however, be conservative to put \( t_0 = t \).
7.5 Effective crack opening stress

Compression will close the crack and no leakage will occur. The integrated mean tension stress over a dynamic cycle will be the opening crack stress in terms of leakage. The effective crack opening stress can be taken as

\[
\sigma_{eqt} = \sigma_{sm} + \frac{\sigma_{db}}{m} \quad \text{for} \quad \sigma_{sm} > \sigma_{dm} \tag{a}
\]

\[
\sigma_{eqt} = \sigma_{sm} + \frac{(\sigma_{dm} - \sigma_{sm})}{2} + \frac{\sigma_{db}}{m} \quad \text{for} \quad \sigma_{sm} \leq \sigma_{dm} \tag{b}
\]

where:

\[
\sigma_{sm} = \text{static membrane stress in N/mm}^2
\]

\[
\sigma_{dm} = \text{dynamic membrane stress amplitude in N/mm}^2
\]

\[
\sigma_{db} = \text{dynamic bending stress in N/mm}^2
\]

\[
m = \text{dynamic bending reduction factor}
\]

For the sake of conservatism a \((1/m)\) fraction of the dynamic bending stress has been included with a value of \(m\) equal to 3, [5.3].

For the purpose of average crack opening for leakage calculations the average effective tension stress will contribute to open the crack.

a) If the static membrane tension stress is larger than the dynamic membrane stress amplitude the net effect of the dynamic stress will be zero, eq. (a).

b) On the other hand, if the static membrane tension stress is less than the dynamic membrane stress amplitude the average effect of the difference should be included, eq. (b).

7.6 Effective crack opening area

For a case of a pure tension stress, \(\sigma_t\), it may be assumed that the shape of the opening in stage III is an ellipse whose major axis length is the crack length, \(2a_p\), and whose minor axis length is equal to the maximum crack opening displacement \(2d\). The area of the opening in mm\(^2\) is then given by

\[
A = \pi a_p \delta
\]

where:

\[
\delta = \frac{2\sigma_{eqt} a_p}{E}
\]

Thus

\[
A = \frac{2\pi a_p^2 \sigma_{eqt}}{E}
\]
For cases with combined bending and tension, the crack opening and also the crack length will vary through the thickness.

7.7 Leakage rate
The flow of liquefied gas through a fatigue crack is assumed to be an orifice flow of the liquid. The liquid volume in litres/h can be assessed by the following equation:

\[
Q = 3.6 C_{orifice} A \sqrt{2gh + 100 \left( \frac{P_1 - P_2}{\gamma} \right)}
\]

where:
- \( C_{orifice} \) = an orifice coefficient (= 0.1)
- \( A \) = crack opening area in mm\(^2\)
- \( h \) = the head of liquid inside the tank at the crack location, in m
- \( \gamma \) = the specific weight of the leaking fluid, in t/m\(^3\)
- \( P_1, P_2 \) = the pressures inside and outside the tank, respectively in N/mm\(^2\), respectively

Here \( A \) is the crack opening area on the penetration side as outlined above. The orifice coefficient has been derived from in-house tests carried out by DNV GL, see Sec.9 [1] and Sec.9 [1]. A value of 0.1 for the orifice coefficient has been found to give good results compared with the test data.

7.8 The size of the secondary drip tray
The inner bottom in way of cargo tanks shall be protected against liquid cargo. Away from (clear of) the partial secondary barrier, provisions need to be made to deflect any liquid cargo down into the space between the primary and secondary barriers and to keep the temperature of the hull structure at a safe level (spray-shield).

The secondary drip tray has to be dimensioned with a reasonable margin to be able to contain the leakage at day 15 in the worst expected storm. The total leakage over a given period of time is obtained by integrating the leakage rate with respect to time, taking account of the crack growth. For determining the necessary size of the partial secondary barrier (drip tray) due account has to be taken of liquid evaporation, rate of leakage, pumping capacity and other relevant factors.
SECTION 8 VIBRATION ANALYSIS

1 General

Vibration levels on LNG ships will depend on the design of the vessel with regard to structure and excitation sources. Thus it is difficult to establish general guidelines for this type of ship. The risk of unwanted vibration levels in the cargo containment system has therefore to be investigated case by case either by experience from similar vessels and/or by vibration studies. Normally unwanted vibration levels of structure at some distance from the excitation sources are associated with resonance of the structure. The risk for resonances is larger for a full or partially filled tank than for an empty tank due to the lower natural frequencies caused by the added mass of liquid.

The risk of unwanted vibration levels will also depend on the type of excitation sources on the vessel. Turbine driven ships and ships with diesel-electrical propulsion system comprising medium speed resiliently mounted diesel engines will have smaller risk of unwanted vibrations than ships propelled by large bore slow speed engine(s). However, similar ships with different excitation frequencies (number of propeller blades/number of cylinders) may perform differently.

The main aim should be to avoid that natural frequencies of the tank system to coincide with the excitation frequencies from relevant sources. The risk of unwanted vibration is in that case low. However, even at resonance the vibration levels may be acceptable. A forced vibration analysis may prove whether acceptable vibration levels are expected.

2 Analysis procedures

2.1 Excitation sources and frequencies

An LNG vessel may be equipped with different types of propulsion units giving rise to forces which may excite vibration in the tank system. The following excitation sources shall be considered for different types of propulsion units:

<table>
<thead>
<tr>
<th>Excitation sources</th>
<th>Frequencies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine and reduction gear</td>
<td></td>
</tr>
<tr>
<td>Diesel-electric propulsion with resiliently mounted diesel engines (speed above 500 RPM)</td>
<td>Blade passing frequency from main propeller(s)</td>
</tr>
<tr>
<td>Geared propulsion units with resiliently mounted diesel engines (speed above 500 RPM)</td>
<td></td>
</tr>
<tr>
<td>Slow speed engines (speed below some 200 RPM)</td>
<td>Blade passing frequency from main propeller(s). Main excitation frequencies from the diesel engine(s) (free moments/guide force moments).</td>
</tr>
</tbody>
</table>

2.2 Natural frequencies of the tank system

Global natural frequencies of the tank system can be determined by a FE analysis using the global stress model of the tank. Lateral vibration of panels can be determined separately paying due consideration to the effect of added mass due to liquid filling.
2.3 Forced response analyses

The safest way to achieve acceptable vibration levels of the tank system is to keep the natural frequencies away from the relevant excitation frequencies. However, the actual vibration levels of a structure will depend on the transfer function from the sources to the structure. Thus it may be acceptable to allow natural frequencies in actual speed ranges of the vessel if it can be demonstrated that acceptable vibration levels are achieved. This may be shown by means of a forced vibration analysis of the vessel. The vibration analysis should be performed according to following guidelines:

1) The finite element model shall comprise a full 3-dimensional model of the whole ship.
2) Self weight of hull and equipment and cargo to be modelled.
3) Added mass effects from the cargo and the seawater to be included.
4) Full load, ballast and possible part load condition should be analysed.
5) The supporting structure of the tank shall be modelled in such a detail that the dynamic behaviour is represented.
6) The tank and cargo riser/pump should be included.
7) The excitation forces from the propeller(s) shall be applied as:
   — pressure forces acting on the hull
   — shaft forces acting in relevant bearings.
8) The excitation forces from slow speed main engine(s) shall be applied to a rough model of the main engine including its top staying.
9) The excitation forces shall correspond to 100% MCR.
10) The frequency range to be applied for the relevant excitation forces shall correspond to the excitation frequency at 100% MCR +20% /- 30%.
11) The excitation forces are to be kept constant corresponding to 100% MCR for the above frequency range.
12) For twin screw vessels the forced response shall be calculated for two excitation modes:
   — propellers/main engines acting in phase
   — propellers/main engines acting in opposite phase.
13) The highest response of the two excitation modes shall be considered.
14) The damping applied may be proportional to frequency, but not exceeding 2% of critical damping.
15) The maximum calculated vibration level in a frequency range corresponding to 100% MCR + 15% and 90% MCR – 15% shall be considered to be excited at full speed.
16) The calculated vibration levels for each of the applied excitation sources may be evaluated separately.

2.4 Acceptance levels

Based on experience from full scale measurements a vibration level above some 20 mm/s may result in risk of fatigue cracks in aluminium structures. In order to account for uncertainties in the analyses and a safety margin, it is considered that calculated vibrations below some 10 mm/s are acceptable for the tower/tank structure.
### SECTION 9 REFERENCES

#### 1 References

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<th>Title</th>
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</tr>
</tbody>
</table>
APPENDIX A ITERATIVE ULS ANALYSIS STRATEGY FOR SUPPORTS

1 Preamble
Due to lift-off and friction sliding effects the iterative solution strategy described in this appendix is considered to be the most correct approach to determine the interaction forces between the tanks, supports and the supporting hull structure. Only changes of the text in Sec.4 [4] due to the iteration procedure are included in the following. See Sec.4 [4] for modelling of the wood support chocks, illustrations and descriptions of the supports.

2 Vertical supports
See Figure 1 and Sec.4 [4.1].

Figure 1 Modelling of a vertical support
The support chocks can be modelled in several ways, either by solid elements combined with contact elements or modelled as beams with representative axial, bending and shear stiffness. In the event that the vertical force on the support blocks is in tension, it will be important that the model correctly removes the vertical load on supports in tension. This means that beams/contact elements in tension are removed (the vertical stiffness set to zero or a very small value) and the analysis repeated until all active vertical supports are in compression.

If the combined longitudinal and transverse force exceeds the friction force limit based on the minimum friction coefficient, horizontal sliding occurs and the shear and bending stiffness has to be removed for the connection elements and the calculation rerun. The friction force acting on the interfacing surfaces must be applied as force couple acting on the upper and lower parts of the support with a magnitude equal to the minimum friction coefficient ($\mu_{min}$) times the vertical force acting on each individual support. The friction coefficients can, if not otherwise specified by the designer, be according to Sec.4 Table 1.
3 Transverse anti-roll supports

See Sec.4 Figure 8 thru Sec.4 Figure 10, as well as Sec.4 [4.2]. In order to be able to predict the distribution of forces between the upper and lower anti-roll supports a refined cargo hold analysis procedure should be used. This is based on an iterative approach.

1) All vertical supports are initially modelled with actual axial, shear and bending stiffness of the wood chocks.
2) Transverse supports are modelled in only one side (compression side) with only axial stiffness of chock.
3) The transverse forces in each of the vertical supports are calculated.
4) If the transverse force at the vertical supports exceeds the friction force based on the minimum friction coefficient, the shear and bending stiffness of the support chocks, e.g. the vertical beam element model of the support chocks, are set to zero and the friction force is applied as a force couple.
5) The analysis shall be repeated to determine the new distribution of horizontal support forces.

This procedure shall be repeated until all the transverse forces on the vertical supports are less or equal to the friction force based on the minimum friction coefficient. The friction couple force is calculated as the minimum friction coefficient ($\mu_{\text{min}}$) times the vertical force acting on each individual support. If not otherwise documented by the maker of the wood blocks, a friction coefficient according to Sec.4 Table 1 can be used. These friction forces shall be applied as force couples on the interfacing surfaces of the vertical supports. Effects of intentional clearances between support surfaces should be included if this is expected to significantly affect the distribution of forces between the upper and the lower roll supports.

4 Longitudinal anti-pitch supports

See Sec.4 Figure 9 and Sec.4 [4.3]. The ULS assessment of the anti-pitch supports is based on the collision load cases LC 10 and LC 11. Normally LC 10 will be governing. As for the anti-roll supports, some of the load in the longitudinal direction will be taken by the friction in vertical supports and the rest will be taken by the anti-pitch supports.

The same iterative approach as described for the transverse anti-roll supports should be utilized. If sliding occurs (the longitudinal force exceeds the friction force based on the minimum friction coefficient), the analysis should be rerun with applied dynamic friction force couples based on the minimum friction coefficient.

5 Anti-floatation supports

See Sec.4 Figure 10 and Sec.4 [4.4]. These supports are analysed similarly as the vertical supports. Deformations of the local models are taken from the cargo hold model analysed with the flooding condition, LC 12. The friction forces are to be calculated and applied in the fine mesh analysis as described in Sec.4 [4.4].
CHANGES – HISTORIC

October 2015 edition
This is a new document.

Amendments April 2016

• Sec.1 General
  — Sec.1 Table 1: Error in rule references corrected.

• Sec.5 Local structural strength analysis
  — Sec.5 Table 1: Clarification on locations for fine mesh analysis.
About DNV GL
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