CLASS GUIDELINE

DNVGL-CG-0138 Edition February 2016

Direct strength analysis of hull structures in passenger ships
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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This is a new document.
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SECTION 1 INTRODUCTION

1 Definitions

1.1 Symbols and units

Reference is made to RU SHIP Pt.3 Ch.1 Sec.4 [1].

2 General

In many contemporary passenger ship designs, the superstructure extends over most of the ship length and
the internal structure comprises of a large number of decks connected together with pillars and longitudinal
and transverse bulkheads. The structure, in general, has many discontinuities such as knuckle points,
recesses, non-continuous bulkheads and decks and geometric irregularities such as openings in decks and
bulkheads, as well as many side shell doors and windows. To evaluate the global stiffness of the structure,
establish the load path and to assess the global and local strength of the design, the use of direct analysis
methods is deemed necessary.

Strength analysis carried out in accordance with the procedure outlined in this class guideline will normally be
accepted as basis for class approval.

It is recommended that the designer provide the intended analysis procedure for review at an early stage of
the design process.

Where in the text it is referred to the rules, the references refer to the latest edition of “DNV GL Rules for
Classification of Ships”.

3 Objectives

The objective of this class guideline is to:

— Provide guidance for the hull structural design and assessment of passenger ships in accordance with the
rules when direct strength calculations are required
— Provide a general description on how to carry out the required calculations and analyses
— Provide guidance on other structural aspects, not necessarily being part of the scope of the rules, but
being important for passenger ship design, e.g. vibrations.

4 Methods of analysis

This class guideline describes the methods for performing direct strength calculations for passenger ships by
use of finite element methods. The calculation procedure is divided in two levels, global and local, defined in
Table 1 below.

Table 1 Analysis levels

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>The global model is used to evaluate the global strength of the entire hull girder accounting for the stiffness contribution of the superstructure.</td>
<td>To evaluate the global hull girder strength and perform yielding and buckling check of stiffened plates and pillars as required by the rules.</td>
</tr>
</tbody>
</table>
| Local  | Local finite element models of areas with geometric irregularities or discontinuities, e.g openings, etc. | — The peak stresses to be within acceptable limits given in RU SHIP Pt.5 Ch.4 Sec.2 [4.2]
|        |                                                                             | — Fatigue life > 25 years criterion                                                                  |
SECTION 2 DIRECT STRENGTH ASSESSMENT

1 Longitudinal strength analysis

1.1 General
The moment and shear force distributions used in the FEM analyses are to approximate the permissible bending moment curves as far as possible. Typical still water and wave bending moments are shown in Figure 1.

Figure 1 Typical still water and wave moment limit curves
Respective standard cases to be considered for longitudinal strength analysis are loading conditions with maximized vertical bending moments given in [1.2] and [1.3].

1.2 Maximum hogging (LC1)
This loading condition represents the maximum hogging vertical bending moment curve by combining:
— The permissible still water hogging moment envelope limit curve.
— The vertical wave bending moment curve for hogging, as defined in RU SHIP Pt.3 Ch.4 Sec.4 [3.1].
The maximum hogging condition will normally be decisive for the dimensioning of the following structural areas:
— Upper decks with respect to yielding criterion.
— Lower longitudinal bulkheads and side shell and bottom structure with respect to buckling criterion.
— Main continuous longitudinal structure with respect to shear stress
— Pillar loads induced by the global deformations. This is important assessment to identify pillars under tension loads.
— Peak stresses in areas with discontinuities or geometric irregularities, such as cut-outs and openings in upper sides, decks and bulkheads.

1.3 Maximum sagging (LC2)
This loading condition represents the maximum sagging vertical bending moment curve by combining:
— The permissible still water sagging or the minimum permissible still water hogging moment curve, whichever is applicable.
— The vertical wave bending moment curve for sagging, as defined in the rules RU SHIP Pt.3 Ch.4 Sec.4 [3.1].
This loading condition will normally be decisive for the dimensioning of the following structural areas:
— Upper decks, longitudinal bulkheads and side walls with respect to buckling.
— Pillar loads induced by the global deformations. This is important assessment to identify pillars under tension loads.

2 Pillar analysis

2.1 Objective
The purpose of the pillar analysis using direct strength assessment methods, is to calculate the maximum axial force in compression and/or tension in each pillar, and verify that the structural strength of the pillars and surrounding structure is adequate.

2.2 Analysis procedure
When the still water loads are applied to the global FE model according to Sec.3 [4], Sec.3 [5] and Sec.3 [6], the forces in the pillars may be calculated according to the following procedure:
— Step 1: Calculate the pillar loads from the maximum hogging or maximum sagging load case (LC1 or LC2). This load case gives the combined pillar load due to global bending and deck loads, but includes local effects on the pillars due to the way the loads are applied and distributed in the model.
— Step 2: The same load case as in step 1, but with boundary conditions where transverse bulkheads are fixed in vertical direction from bottom to double bottom. This step enables to isolate the local effects on the pillars.
— Step 3: Calculate the pillar loads due to steel weight and design deck loads applying the rule envelope vertical acceleration defined in RU SHIP Pt.3 Ch.4 Sec.3 [3.3]. The same boundary conditions as in step 2 are applied. This step gives the pillar loads due to self weight and deck loads accelerations only.
— Step 4, sum: The total pillar load, including the effect of global deflection, may be calculated according to the following:
  Total pillar load = (Pillar load from step 1 – Pillar load from step 2) + Pillar load from step 3.

3 Bow impact analysis

3.1 General
The bow impact analysis will normally be decisive for the dimensioning of the following structural areas:
— Decks and longitudinal bulkheads in the fore ship with respect to compressive buckling stress.
3.2 FE model
The global model may be cut at the first full transverse bulkhead aft of collision bulkhead and fixed boundary conditions applied.

3.3 Load application
Pressure loads according to RU SHIP Pt.3 Ch.10 Sec.1 [3.3.4] to be applied to the bow structure. Load area is given by RU SHIP Pt.3 Ch.10 Sec.1 [1.1.3].
Alternative load application method is to represent the bow impact pressure loads as forces according to RU SHIP Pt.3 Ch.12 Sec.5 [2.4].

4 Docking analysis

4.1 Modelling and load application
When required, a separate docking analysis should be carried out using the global FE model based on the lightship weight and the docking plan.
Spring elements should be added as boundary conditions to model the docking blocks.

4.2 Critical structure
The docking analysis will often be decisive for the dimensioning of the following structural areas:
— Capacity of double bottom structure and support
— Shear buckling of floors and girders in the double bottom.

4.3 Aft structure
For vessels with extended flat bottom design in the aft structure, the docking analysis will provide a good overview of the vertical deflections. It may be necessary to add supporting pillars/docking blocks under the flat bottom during docking if the analysis shows significant deflections.

5 Direct wave load analysis
Direct wave load analysis shall be based on recognised software. As recognised software is considered all wave load programs that can show results to the satisfaction of the Society.
SECTION 3 GLOBAL FE STRENGTH ANALYSIS

1 Objectives
The objectives of the global analysis are to:
— determine the longitudinal hull girder stresses
— determine stresses in transverse structures due to racking
— obtain forces in pillars
— provide boundary conditions for the local analysis described in Sec.4.

2 Global finite element model

2.1 General
The main purpose for the global model is to represent the global stiffness satisfactorily with respect to the objective for the analysis. The effectiveness of the superstructure is dependent on its length, the flexibility of its supports, the integration with the hull girder at its ends, and the size and number of openings in side bulkheads and internal decks.

Global finite element modelling is described in DNVGL CG 0127 Sec.2 [2.1] to DNVGL CG 0127 Sec.2 [2.4]. In addition, some specific modelling considerations for passenger ship are given in this sub-section.

2.2 Modelling simplifications
It may not be practical to include all bulkheads and steps in their correct place. Bulkheads may be lumped to the nearest mesh-line in the global modelling. However, it is important to document the consequences when bulkheads are lumped. Figure 1 shows how the shear stress in the deck plate will be affected after bulkheads have been lumped.

Figure 1 Effect of bulkhead lumping
3 Boundary conditions

3.1 General
The boundary conditions are described in DNVGL CG 0127 Sec.2 [2.5]. In addition, some specific information for passenger ship are given in this sub-section.

3.2 Balancing of global FEM model
It is of great importance that the internal and external loads applied on the global FEM model are in balance with minimum of reaction forces at the fixation points. The size of the reaction forces will indicate how well the applied loads are balanced and also how realistically the loads are distributed along the hull girder in order to achieve the desired bending moment and shear force curves. None of the reaction forces should exceed 2% of the total weight of the structure.

3.3 Fixation points
The fixation points can be either individual nodes or a group of nodes. Preferably they should be “simply supported” in such a way for the global structural model to avoid rigid body movement. The fixation points should be located away from areas where the stress is of interest.
For the longitudinal strength assessment the boundary conditions can be applied as given in DNVGL CG 0127 Sec.2 [2.5.2].
For the transverse strength assessment (racking analysis) the fixation nodes can be placed at the intersection of the bulkhead deck to the side shell, and are normally to be fixed for the transverse displacement.

4 Load application

4.1 General
The global analysis model has to represent the actual mass distribution of the hull structure as well as other mass components with a reasonably good accuracy.

5 Stillwater loads application

5.1 Light ship weight
The weight of the structure is obtained by applying density to the applied steel material. In order to be able to tune the position of the centre of gravity and verify the weight distribution in a simple way, different material densities can be used along the hull length. The whole analysis model should be in compliance with the actual light ship weight distribution. This often requires an iteration process for tuning the mass distribution.
The remaining light ship weight should be represented by concentrated mass components at the centre of gravity of each component.
All masses must be attached to the surrounding structure.

5.2 Machinery and outfitting
All heavy machinery items (such as main engine, rudder, main generators etc.) should be modelled as point masses attached to the surrounding structure at their correct locations. The weight of a component may be divided into several mass points if the component is too large (for instance the main machinery).
5.3 Deadweight and passenger loads
Deadweight and passenger loads may be represented by concentrated mass components at the centre of gravity of each component or as distributed pressure to the relevant deck areas.

5.4 Tank loads
The liquid mass in tanks should be represented by pressure loads or point mass components which are distributed to the node points at the tank base or boundary. It is not necessary to include the local pressure distribution of the tanks in the global FEM analysis.

5.5 Buoyancy loads
The still water hydrostatic pressure load should be applied to the wet part of the hull.

6 Dynamic loads application

6.1 General
To achieve the required vertical wave bending moment, a pressure load to the shell elements of the wet surface of the hull may be applied. Since the rule wave bending distribution is actually an envelope curve it can be a challenge to achieve the exact form of the rule curve. Therefore the established practice has been either:

1) to obtain a bending moment curve by applying pressure load on the wet surface, that is actually larger than the required within 0.4L but approaching the required curve outside 0.4L, see Figure 2 for example.

![Figure 2 Rule limit curve and vertical wave bending moment based on surface pressure application on wet surface](image)

2) to calculate using appropriate mathematical algorithms (e.g. Fourier series analysis) a pressure distribution that satisfies the rule curve.
6.2 Correction factors

The distribution of actual achieved bending moments and shear forces obtained over the length of the model should be compared with the required design bending moment and shear force distributions. Plots showing the comparison between the applied bending moment and shear force with the design required values should be produced.

In practice, it will be not possible to satisfy with one load case the rule wave vertical bending moment and the rule wave vertical shear force curves. Hence, to satisfy the rule wave vertical shear force either a separate load case is used, or appropriate scaling factors for the shear stresses should be used but these should not exceed a scaling factor of 2. Scaling factors should also be used for the bending moment curve where there is significant deviation between obtained and actual curves. However for bending moment curve the scaling factor should not be more than ±1.2.

7 Simplified global strength assessment method

Alternative methods to achieve the required rule bending moment distribution may be considered. One alternative method to what is described in [5] and [6] above is to apply a parametric line load which will produce the total moment from both the still water and wave bending moments. To determine the loads to be applied to the global model, the total bending moment \((M_S + M_W)\) is differentiated twice. The first differentiation gives the shear force distribution \((Q = d(M_S + M_W)/dx)\), while a second differentiation gives a line load \((q = dQ/dx)\). This line load may be either applied in the ship’s side as shearing load or as point/nodal forces in the ship’s bottom structure at every web frame.

8 Equivalent design wave (EDW) method

8.1 General

Equivalent design waves are determined by a direct wave load analysis and they can be used to calculate hull girder forces and moments corresponding to the rule requirements. Because of the direct analysis, the wave pressure loads, and accelerations have the same phase and this ensures a more realistic superposition of the different hull girder load components.

8.2 Load application for longitudinal strength assessment

As an alternative to [6], the EDW method can be used to study the global strength of the hull structure by selecting the corresponding EDW that produce the highest wave vertical bending moment for sagging and hogging. The advantages of using the EDW pressures and accelerations, are that the required vertical bending moment and shear forces are achieved with the vessel in balance hence there is no need to add additional external loads to balance the model.

With the direct wave load analysis the inertia loads and external pressures are to be in equilibrium and keeping the reaction forces at a minimum. The sum of local loads along the hull needs to give the correct global response as well as local response for further stress evaluation. This enables to analyse several critical structural components at the same time, without the need for different load cases. E.g. the global hull girder strength, pillars and primary supporting structure of decks, side shell and bottom can be checked against yield and buckling criteria under one load combination.
SECTION 4 LOCAL FE STRENGTH ASSESSMENT

1 Application

Local models, in addition to the global model, may be required for passenger ships as given in RU SHIP Pt.5 Ch.4, where there are large hull openings, discontinuities or other highly stressed areas. The location and number of models required will be evaluated based on results from the global calculation.

2 Peak stress control

In order to control the size of the plasticity zones in way of openings in highly stressed areas, local models with fine mesh need to be evaluated. Because of the geometric irregularities and the high average stresses, the local stresses in way of openings will exceed the yield strength of the material and this may cause permanent plastic deformation.

In reality the peak stresses will be much lower than the ones predicted from the linear elastic analysis because of the re-distribution of the stresses in the adjacent area, after the material has reached its yield capacity. The condition for this is that the plasticity zone is limited in extent, hence the allowable peak stress criteria in the rules are valid for an 50 × 50 element size. In practice, a peak stress value more than yield represents a permanent strain in the material after the load has been removed. Since this local permanent strain does not represent ultimate failure of the hull girder, it can be accepted under extreme loads, provided its extent is limited.

3 Shear stress control

It is important to evaluate the shear capacity of highly stressed areas with many openings. Especially, in main supporting longitudinal structure, such as longitudinal walls and side superstructure walls. This will ensure better control of openings and cut-outs such as cable, piping and ventilation penetrations in the bulkheads. Normally, designers indicates areas on the structural drawings where openings are not allowed or the percentage of allowed area reduction due to shear capacity limitations.
SECTION 5 FATIGUE

1 Method and application

With reference to RU SHIP Pt.5 Ch.4 Sec.2 [5], FE analysis by local FE or hot spot models may be required for a number of structural details. If required, [2] is relevant.

2 Fatigue capacity and strength representation

2.1 General

Reference is made to RU SHIP Pt.5 Ch.4 Sec.2 [5], RU SHIP Pt.3 Ch.9 and DNVGL CG 0129 Sec.2 and DNVGL CG 0129 Sec.3. The following sub-sections describe assumptions relevant for the fatigue assessment.

2.2 Loading condition for dynamic stress range

The vertical wave bending moment contributes the most to the stress range at free plate edges associated with corners of openings and cut-outs in the longitudinal bulkheads and decks.

2.3 Corrosive environment

For the structural details considered relevant in the upper part of the structure the time in corrosive environment as part of the minimum design life, $T_{C2S}$, can be set to zero, i.e. the structural details are regarded as in air-environment during the whole life time.

2.4 Mean stress, $f_{mean}$

For passenger vessels, the majority of the critical details for fatigue is located above the hull girder neutral axis. These vessels are usually exposed to hogging stillwater moments only. The critical details will therefore be exposed to a mean stress level in tension, and a mean stress factor, $f_{mean} = 1.0$ should be applied.

2.5 Thickness effect, $f_{thick}$ and S-N curves

For free plate edge, $f_{thick}$ can be set to 1.0. S-N curve C should be used. In case of edge treatment B or B2 can be used.

In case of manual cutting, S-N curve C2 should be used. In case of edge treatment the S-N curve can be improved to C1. For welded details the thickness effect, $f_{thickw}$ can be set to 1.0, and the hot spot S-N curve D (FAT 90) should be used.

2.6 Scantling approach factor, $f_c$

The FE models (global, local and hot spot) can be based on gross scantlings and the $f_c$ should be set to 1.0.

2.7 Post weld treatment, $f_w$

Post-weld treatment of welded details should not be accounted for and $f_w$ should be set to 1.0.

2.8 Environmental factor, $f_e$

For world wide operation, $f_e = 0.8$, should be applied.
2.9 Fatigue damage calculation procedure

Based on the previous sub-sections, the step-wise fatigue assessment procedure is outlined below. In this procedure, the maximum allowed peak stress range for fatigue is found based on the selected S-N curve. The peak stresses obtained from the local FE models for the free plate edges can be used to calculate the usage factor against the allowable peak stress calculated as:

\[
\text{usage factor} = \frac{\text{Peak stress FE}}{\text{Allowed peak stress}}
\]

The usage factor of every opening/cut-out can then be plotted, giving a good representation of fatigue strength.

The method can be summarised by the following steps:

1) Calculate the total number of stress cycles, \( N_D \):

\[
N_D = \frac{31.557 \cdot 10^6}{4 \log(L)} \cdot f_0 \cdot T_{DF}
\]

\( N_D \) = Total number of stress cycles experienced by ship during the design fatigue life, where \((4 \log(L))\) is assumed as the zero up-crossing frequency

\( f_0 \) = Fraction of time at sea

\( T_{DF} \) = Design fatigue life. Minimum to be taken as 25 years.

2) Calculate the correction factor from 10\(^{-8}\) to 10\(^{-2}\) probability level, \( f_p \), for the vertical wave bending moment, according to RU SHIP Pt.3 Ch.4 Sec.4 [3].

3) Calculate the corresponding Weibull shape parameter, \( \xi^* = \log_{10}(0.25)/\log_{10}(f_p) \).

4) Interpolate from DNVGL CG 0129 App.C Table 4 for the Weibull shape parameter \( \xi^* \) and the stress cycles calculated above, to find the permissible stress range, \( \Delta\sigma_{FS} \), at 10\(^{-8}\) probability level, for the C S-N curve without edge treatment.

5) Calculate the allowable stress range, \( \Delta\sigma_{perm} \), at 10\(^{-8}\) probability level as:

\[
\Delta\sigma_{perm} = \frac{\Delta\sigma_{FS}}{f_{\text{mean}} \cdot f_{\text{thick}} \cdot f_{\text{material}} \cdot f_w \cdot f_c \cdot f_e}
\]

6) If only FE stress results from the maximum hogging load case are available, a correction factor for the stress range should be calculated according to \( K = (-M_{wv-s} + M_{wv-h})/(M_{sw-h} + M_{wv-h}) \). The permissible stress is then \( \Delta\sigma_{perm}/K \).

\( M_{wv-s} \) = The vertical wave bending moment in sagging according to RU SHIP Pt.3 Ch.4 Sec.4 [3], without non-linear adjustments, i.e. \( f_{nl-vs} = 1.0 \).

\( M_{wv-h} \) = The vertical wave bending moment in hogging according to RU SHIP Pt.3 Ch.4 Sec.4 [3].

\( M_{sw-h} \) = The vertical stillwater bending moment in hogging.

7) Fatigue criteria for FE screening is then \( \Delta\sigma_{FEM} < \Delta\sigma_{perm}/K \)

For a different class of S-N curve than C or B2, a numerical solution for the stress range \( \Delta\sigma \) can be found by setting \( D = 1.0 \) in the closed form expression of the damage using a two slope S-N curve given in DNVGL CG 0129 App.C [2.3]. Care should be used in the definition of the Gamma functions, which are software dependent, i.e. the numbers in DNVGL CG 0129 App.C Table 4 should first be reproduced for known input values.
CHANGES – HISTORIC

There are currently no historical changes for this document.
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