STRENGTH ANALYSIS OF HULL STRUCTURES IN BULK CARRIERS

JUNE 1999
FOREWORD

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1. General

1.1 Introduction

1.1.1
The “Rules for Classification of Ships” require a direct structural analysis to be carried out in order to cope with the complexity in the loading of bulk carriers and the many possible loading conditions. The scope for the analysis is to verify that stresses in the girder structure are within specified limits when the structure is loaded in accordance with the specified design load conditions.

1.1.2
The structural analysis is generally related to primary strength members of the midship region of bulk carriers arranged with double bottom and single or double side and without separate longitudinal bulkheads. However, additional calculations may have to be carried out for foremost and almost holds as the hopper/top wing tank construction normally is changed significantly compared to the midship construction.

1.1.3
Where in the text it is referred to the Rules, the references refer to the July 1998 edition of “Rules for Classification of Ships”.

1.1.4
Any recognised calculation method or computer program may be applied provided the effects of bending, shear axial and torsional deformations are considered when relevant.

1.1.5
Strength analysis carried out in accordance with the procedure outlined in the Note will normally be accepted as basis for class approval.

"NAUTICUS HULL" is a computer program offered by DNV that is suitable for the calculations specified in this Classification Note.

1.2 Bulk Carriers

1.2.1
Bulk carriers are ships designed primarily for the transportation of solid bulk cargoes. Such cargoes are generally uniform in composition, and are loaded directly into the cargo space without any intermediate form of containment. The range of cargoes carried in bulk carriers is considerable. Leading bulk cargoes in the world trade are iron ore, coal, grain, bauxite/alumina and phosphate rock, along with substantial quantities of concentrates, petroleum coke, steel, ores, cement, sugar, quarts, salt, fertilisers, sulphur, scrap, aggregates and forestry products. Further, the receivers of bulk cargoes have very varied requirements for tonnage delivered per month or per year. The size of vessels that they choose to carry their cargoes and the frequency that such vessels are employed will be influenced by a variety of factors, including the receivers’ storage capacity, depth of water in the berth, regularity of the demand for the commodity and the financing of its purchase. This large variety in demand and the variety in pattern of international trade has created a versatile world fleet of very varied ship sizes. These may be categorised as follows:

Handy-size bulkers: This is the most common size of bulk carriers with a displacement of 25000-50000 tonnes and a draught less than 11.5m. The handy-sized bulker is so called because her comparatively modest dimensions permit her to enter a considerable number of ports, world-wide. Such vessels are used in many trades in which the loading or discharging port imposes a restriction upon the vessel’s size, or where the quantity of cargo to be transported requires only a ship able to carry 50000 tonnes or less.

Handymax bulkers: The trend is for each category of bulker to increase in size, and some commentators now consider the larger handy-sized bulkers, in the 35000-50000 tonnes range, to be a separate category, the handy-max bulker.

Panamax bulkers: Larger than the handy-sized vessel is the Panamax bulk carrier, so named because she is designed to the maximum dimensions (particularly the maximum breadth) which can pass through the Panama Canal. The limiting dimensions for canal transit are Loa 289.5m, extreme breadth 32.2m and maximum draught 12.04m. The typical tonnage range is 50000-100000 tonnes. Panamax bulkers are extensively employed in the transport of large volume bulk cargoes such as coal, grain, bauxite and iron ore in the longhaul trades.

Cape-sized bulkers: Cape-sized bulk carriers have dead weights in the range of 100000-180000 tonnes. While most lie within the range of 100000-140000 tonnes, new-building in recent years have been concentrated in the 140000-160000 tonnes range. Cape-sized vessels, with loaded draughts usually in excess of 17m can be accepted fully laden at only a small number of ports world-wide and are engaged in the longhaul iron ore and coal trades. The range of ports which they visit is increased by the use of two port discharges, the ship being only part laden on reaching the second discharge port.

Very Large Bulk Carriers (VLBCs): VLBCs are bulkers greater than 180000 tonnes dead weight. These are mainly employed on the Brazil/Europe and the Australia/Japan routes. A number of these largest vessels are special types such as ore carriers, crude oil carriers and OBOs, vessels which will not be specially considered in this Classification Note.

1.2.2
In light of the variety both in cargoes, vessel size, hold arrangement and not least the trading routes, including multi port loading and discharging it is evident that the masters and officers of such vessels, will be in great need of information about relevant loading limitations of the vessel, such as:
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- Maximum allowable/minimum required mass in each individual hold as a function of draught.
- Maximum allowable/minimum required mass in two (or more) adjacent holds. i.e. block loading as a function of draught.
- Maximum allowable mass in each individual hold as a function of angle of repose in case the bulkhead has not been designed for the cargo in question without filling restriction.
- Maximum allowable mass on deck and hatch cover loading.
- Allowable container loading arrangement both in holds and on deck/hatch cover.
- Maximum allowable tank top pressure (steel coil loading).
- Still water bending moment and shear force limitations.

In paragraph 1.2.3 and 1.2.4 the most important local load limitations and those most frequently not adhered to have been highlighted.

1.2.3

In order to exemplify the need for information about limitations related to the maximum allowable mass in each individual hold we have described below two situations in which the master may decide to place an excessive tonnage of cargo in a particular hold.

- Many bulk carriers load iron ore in ports, which are located within the tropical zone (Brazil, Australia, West Africa, India). When such vessels are loaded to tropical marks, and take only small quantities of bunkers, the total cargo tonnage carried will be substantially (5-10 per cent) larger than the standard loading shown in the loading manual. In this situation each alternately loaded hold is likely to be overloaded by tonnage approaching 5-10 per cent.
- When a ship is asked to load two or more different grades or consignments of ore (e.g. fines and pellets) it is sometimes necessary to juggle with the quantities in each hold, to take account of draught, trim and longitudinal strength at each stage in the voyage. In these circumstances it is easy to decide to load an excessive tonnage in one or several holds, if the maximum permitted tonnage is not prominently displayed and well known aboard ship.

1.2.4

In recent years there has been reported structural damages in which there are reason to believe that incorrect adjacent hold loading (block loading), has caused such structural damages. The reason for such maloperation is not easy to explain exactly, however, below we have indicated some arguments which should be sufficient to justify the need for proper instruction for such load limitations.

- A ship can be incorrectly block loaded without creating excessive hull girder shear forces or bending moments, so there is normally no evidence to warn the ship’s officer that his loading may cause damage.
- Adjacent hold loading (block loading) is likely to be considered as a method of loading when several grades of ore are to be loaded, or several consignments of cargo carried, and has recently been used increasingly, for a third reason.

In order to cope with the above need for information a procedure for calculating the necessary cargo hold load limitations is given in Chapter 7 of this Classification Note.

1.3 Procedure

This classification note describes methods for performing calculations with respect to structural strength of bulk carriers with conventional design. The calculations are based on requirements given in DNV’s Rules. For some vessels it is required that FEM analysis is carried out, while for other vessels beam analysis is acceptable. The flow chart in Figure 1.1 gives an overview of the applicable chapters depending on the method of calculation.

![Flowchart of applicable chapters in this Classification Note depending on calculation method](image-url)
The chapters are briefly described in the following:

Chapter 2. Design Loads, gives description or references to the applicable local loads, like sea pressure and pressure from cargo.

Chapter 3. Loading Conditions, gives a description of applicable loading conditions. The conditions described in detail here are normally covering all relevant conditions for a typical bulk carrier design. Some conditions represent the Rule minimum loading while others represent the extreme loading conditions as defined in the loading manual. Steel coil loading and container loading are to be evaluated separately.

Chapter 4. Cargo Hold Analysis, gives a description of an acceptable procedure for Finite Element Analysis for bulk carriers. It is here focused on extent of model, the structure that shall be included, boundary conditions, mesh topology and results that shall be evaluated.

Chapter 5. Local Structure Analysis gives a description of how to perform Finite Element Analysis of local structures of bulk carriers.

Chapter 6. Flooding Conditions, gives a description of additional requirements for vessels where this is applicable. These requirements are from unified rules given by IACS (International Association of Classification Societies) and are applicable to bulk carriers above 150 meters carrying heavy cargoes.

Chapter 7. Cargo Hold Limitations, gives a procedure for preparation of local load diagrams for individual holds and for any two adjacent holds. Such limitations do generally define maximum allowable and minimum required mass as a function of the vessel draught.

Chapter 8. Wave Torsion induced Bending Stresses in Crossdeck of Conventional Bulkcarriers, gives a method to calculate torsion induced bending stresses.

Chapter 9. Shear force correction, describes the method and background for shear force corrections.

Appendix A, Checklist for FE Analysis, gives checklists related to modelling of Finite Element Models. The checklists are suitable for verification of the model.

Appendix B, Beam Modelling, gives a description of acceptable methods for performing structural strength calculations by use of 2- or 3-dimensional beam models. For other types of bulk carriers, similar procedures should be followed. For open type bulk carriers, it is advised that additional calculations are carried out for the purpose of investigating the torsional effect of the structural elements.

1.4 Definitions

1.4.1

Symbols not mentioned in the following list are given in connection with relevant formulae. The general symbols may be repeated when additional definition is found necessary in connection with specific formulae.

\[ L = \text{Rule length in m.} * \]

\[ B = \text{Rule moulded breadth in m.} * \]

\[ D = \text{Moulded depth in m}^* \]

\[ T = \text{Mean moulded summer draught in m.} * \]

\[ C_b = \text{Block coefficient.} * \]

\[ \dot{V} = \text{Maximum service speed in knots on draught T.} \]

\[ h = \text{Cargo or ballast head in m.} \]

\[ h_{db} = \text{Height of double bottom in m.} \]

\[ E = \text{Modulus of elasticity} = 2.06 \times 10^5 \text{ N/mm}^2 \text{ for steel.} \]

\[ g = \text{Acceleration of gravity, } g_0 = 9.81 \text{ m/s}^2 \]

\[ C_w = \text{Wave coefficient.} ** \]

\[ a_v = \text{combined vertical acceleration in m/s}^2. ** \]

\[ a_t = \text{combined transverse acceleration in m/s}^2. ** \]

\[ \sigma = \text{Normal stress} \]

\[ \tau = \text{Shear stress} \]

* For details see the Rules Pt.3 Ch.1 Sec.1

** For details see the Rules Pt.3 Ch.1 Sec.4 B

\[ \rho, \rho_{ds}, \delta = \text{as given in the Rules Pt.5 Ch.2 Sec.5 B100.} \]

1.4.2

The structural terminology adopted in this Note is illustrated in Fig. 1.2, showing a typical structural arrangement of a bulk carrier in the midship area.
Figure 1.2 Typical nomenclature for bulk carrier sections in way of cargo hold and transverse bulkhead
2. Design Loads

2.1 General

2.1.1 Design pressure loads applied in direct calculations representing external sea pressure, liquid in tanks and cargo in holds, are to be taken as given in the Rules Pt.3 Ch.1 Sec.13. Loads from cargo in holds are further specified in 2.2-2.3 in the following.

2.2 Bulk cargo filling part of hold, (heavy cargo).

2.2.1 Design pressure: The design lateral pressures with bulk cargo in hold are in accordance with Rules Pt.3 Ch.1 Sec.13 to be taken as:

\[ P = \rho (g_e + 0.5 \alpha_h) K h_c \] (Kn/m²).

\[ K = \sin^2 \alpha \tan^2(45 - 0.5 \delta) + \cos^2 \alpha \]

\[ \alpha = \text{Angle between panel in question and the horizontal plane in degrees.} \]

\[ \delta = \text{Angle of repose. In general to be taken as 20 degrees for light bulk cargo (grain etc.), 25 degrees for cement cargo (associated cargo density 1.35t/m³) and 35 degrees for heavy bulk cargo.} \]

\[ h_c = \text{Assumed level of cargo surface in hold, ref. Rules Pt.5 Ch.2 Sec.5, see also Fig.2.1. To be taken as } 0.3H + 0.14 b_r \text{ within 60% of the hold length and breadth, and linearly reduced to a level } 0.3H \text{ at hold sides and to } 0.3H + 0.07 b_t \text{ at transverse bulkheads.} \]

\[ H = \text{Height of hold (including hatchway) above plane part of inner bottom in m.} \]

\[ b_r = \text{Breath of hold in m at level } 0.3H \text{ above inner bottom at hold midlength.} \]

\[ \rho = \frac{M_H}{V_{HR}} \text{ Assumed cargo density in t/m}^3 \]

\[ M_H = \text{Mass of cargo in hold, in (t), in accordance with the Rules Pt.5 Ch.2 Sec.5.} \]

\[ V_{HR} = \text{Defines volume of cargo hold below the level of } h_c. \text{ To be taken as } V_{HR} + 0.10267b_h^2 b_r \text{ for regularly shaped cargo holds. For irregularly shaped holds, } V_{HR} \text{ may be specially considered.} \]

\[ V_{RLH} = \text{Volume of hold in m}^3 \text{ below level } 0.3H \text{ above inner bottom.} \]

\[ l_h = \text{Length of hold above lower stool in m, measured to the middle of corrugation depth. See also Fig. 2.1.} \]

Figure 2.1 Cargo distribution filling part of cargo hold

2.2.2 Shear load: A design shear load, \( P_s \), has been added in order to obtain the correct total downward force in way of sloping elements i.e. transverse bulkhead struts and hopper tank construction, corresponding to the cargo mass, see also Fig.2.2. The shear load, \( P_s \), acting on sloping parts of bulkheads is to be taken as:

\[ P_s = \rho (g_e + 0.5 \alpha_h) (1 - K) h_c \tan \alpha \] (kN/m²).

\[ \rho, \alpha, K, h_c = \text{as given in 2.2.1.} \]

Figure 2.2 Cargo shear load on sloping elements

2.3 Bulk cargo expanded to fill hold

2.3.1 Design pressure: The below pressure distribution assumes that the hold is filled completely up to the top of hatch coaming with bulk cargo. The mass in the hold is then expanded giving a different definition of \( P \) compared with Chapter 2.2. The design lateral pressures are to be taken as:
\[ p = \rho (g_0 + 0.5\alpha_0) K h_c \ (Kn/m^2) \]

\[ K = \text{As defined in 2.2.1} \]

\[ h_c = \text{Vertical distance in m from the load point to the highest point of the hold including hatchway in general. For sloping hopper, lower stool, bulkhead and shipside plating the distance may be measured to the deck level only, unless the hatch coaming is in line with or close to the panel considered. (Note that sloping hopper, lower stool, bulkhead and shipside may be taken to be close to the hatch coaming when it is less than 10 degrees out of line from the vertical when measured from the deck, see also Fig. 2.3.)} \]

\[ \rho = M/V_H \text{ “Expanded” cargo density in t/m}^3 \]

\[ M = \text{Mass of cargo in hold (t). Defined as the mass, according to the loading manual, combined with the corresponding angle of repose that gives the largest nominal lateral pressure on the bulkhead. This is expressed by the largest effective lateral mass, } M_E, \text{ where } M_E = M \tan^2(45 - 0.5\alpha). \text{ } M_E \text{ is not to be less than } 0.43 V_H, \text{ which correspond to a cargo density of } 0.88 \text{ t/m}^3 \text{ and an angle of repose of } 20 \text{ deg. Ref Rules Pt.5 Ch.2 Sec.5} \]

\[ V_H = \text{Cargo hold volume including hatch in m}^3. \]

### 3. Loading Conditions

#### 3.1 General

In Table 1, applicable loading conditions given in the Rules Pt.5 Ch.2 Sec.5 are listed with indications regarding their applicability with respect to typical class notations, structural part and analysis.

These conditions are normally covering all relevant loading conditions for a typical bulk carrier design. These conditions also cover the Rule “minimum condition” in which the intention is to ensure sufficient flexibility of the vessel, independent of the specified loading conditions. The specified loading conditions for the vessel in question may however contain conditions not represented in Table 1, such as steel coils, containers, lumber etc. It is therefore of utmost importance that the loading manual is carefully reviewed prior to defining the final design conditions.

The structure in the loaded hold as well as in the empty holds are to be evaluated for all the relevant loading conditions.

#### 3.1.2 Flooding conditions applicable for vessels as described in 1.3 Procedure, are separately described in chapter 6. The structure is in general not dimensioned by direct calculations for such conditions.

---

**Figure 2.3 Design load pressure height for cargo bulkhead**

2.3.2

**Design shear load:** The design shear load, \( p_s \), described in 2.2.2, is to be applied for sloping parts of bulkheads.
<table>
<thead>
<tr>
<th>LC</th>
<th>Description</th>
<th>Class notation</th>
<th>Application</th>
<th>Illustration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Specified full draught condition with empty hold, seagoing</td>
<td>Bulk Carrier HC/E</td>
<td>Double bottom structure and mainframes</td>
<td><img src="image1" alt="Diagram" /></td>
</tr>
<tr>
<td>2</td>
<td>Bulk cargo with empty holds “Rule minimum”, seagoing</td>
<td>Bulk Carrier HC</td>
<td>Double bottom structure and mainframes</td>
<td><img src="image2" alt="Diagram" /></td>
</tr>
<tr>
<td>3</td>
<td>Bulk cargo in two adjacent holds, seagoing</td>
<td>Bulk Carrier HC/E</td>
<td>Transverse bulkhead, transverse deck and double bottom strength</td>
<td><img src="image3" alt="Diagram" /></td>
</tr>
<tr>
<td>4</td>
<td>Two or more adjacent empty holds, seagoing or harbour</td>
<td>Bulk Carrier HC/E</td>
<td>Transverse bulkhead, transverse deck and double bottom strength</td>
<td><img src="image4" alt="Diagram" /></td>
</tr>
<tr>
<td>5</td>
<td>Bulk cargo with filled hold, seagoing</td>
<td>Bulk Carrier HC/E</td>
<td>Transverse bulkhead lateral strength</td>
<td><img src="image5" alt="Diagram" /></td>
</tr>
<tr>
<td>6</td>
<td>Water ballast in hold, heavy ballast condition, adjacent hold empty, seagoing</td>
<td>Bulk Carrier HC/E</td>
<td>Transverse bulkhead, top wing tank</td>
<td><img src="image6" alt="Diagram" /></td>
</tr>
<tr>
<td>7</td>
<td>Water ballast in hold, heavy ballast condition, adjacent hold empty, heeled condition, seagoing</td>
<td>Bulk Carrier HC/E</td>
<td>Top wing tank and hopper tank girders</td>
<td><img src="image7" alt="Diagram" /></td>
</tr>
<tr>
<td>8</td>
<td>Cargo on deck, seagoing</td>
<td>Bulk Carrier HC/E</td>
<td>Top wing tank, cross deck cantilevers, hatch end and side coamings</td>
<td><img src="image8" alt="Diagram" /></td>
</tr>
<tr>
<td>9</td>
<td>Watertight bulkhead loading</td>
<td>Bulk Carrier HC/E</td>
<td>Transverse bulkhead lateral strength</td>
<td><img src="image9" alt="Diagram" /></td>
</tr>
<tr>
<td>10</td>
<td>Ballast in top wing tank, seagoing</td>
<td>Bulk Carrier HC/E</td>
<td>Top wing tank construction</td>
<td><img src="image10" alt="Diagram" /></td>
</tr>
<tr>
<td>11</td>
<td>Ballast in top wing tank, heeled condition</td>
<td>Bulk Carrier HC/E</td>
<td>Top wing tank construction</td>
<td><img src="image11" alt="Diagram" /></td>
</tr>
<tr>
<td>12</td>
<td>Non-homogeneous loading at reduced draught</td>
<td>Bulk Carrier HC/E</td>
<td>Transverse bulkhead, transverse deck and double bottom strength</td>
<td><img src="image12" alt="Diagram" /></td>
</tr>
</tbody>
</table>
3.2 LC1: Specified maximum draught bulk cargo conditions with empty hold, seagoing

3.2.1
This condition is applicable for bulk carriers with the class notations Bulk Carrier HC/E or Bulk Carrier HC/EA, and represent typical "ore" loading conditions. The loading condition shall be in accordance with the specified loading condition with empty cargo hold at maximum draught. I.e. the loading manual should normally contain loading condition reflecting alternate loading with maximum cargo deadweight on maximum draught and without any ballast. For class notation Bulk Carrier HC/E this is mandatory while for Bulk Carrier HC/EA it may be considered non-mandatory. For Bulk Carrier HC/EA vessels, without any specified combination of empty holds, LC1 will be similar to LC2.

This loading condition is generally applied for the strength evaluation of the double bottom structure. However, it may also be decisive for the mainframe ends, if rotation of hopper/top wing tank construction becomes significant. It should be noted that for vessels with clearly defined combinations of empty holds on maximum draught, i.e. alternate loading, the double bottom strength may be evaluated with basis in a reduced still water bending moment. Ref. is made to Pt.5 Ch.2 Sec.5 C.

3.2.2
The bulk cargo pressure loads are to be taken with cargo mass in hold MH in accordance with the specified loading condition(s). Note that any fuel oil specified for the double bottom tank below the loaded cargo hold should be included in the consideration. Cargo pressure to be in accordance with Chapter 2.2.

3.2.3
The sea pressure load is to be in accordance with 2.1 at maximum draught, T.

3.3 LC2: Bulk cargo with empty holds “Rule minimum”, seagoing

3.3.1
This condition is applicable for bulk carriers with the class notations Bulk Carrier, Bulk Carrier HC, Bulk Carrier HC/E or Bulk Carrier HC/EA, and is generally applied for the double bottom structure such that any single hold is assumed filled with heavy cargo with adjacent cargo hold empty. This loading condition represent the “Rule minimum” and is intended to give the vessel sufficient flexibility, realising that “ore” holds may be empty and “empty” hold may be loaded.

If the loading manual contain loading conditions representing a higher net load on the double bottom construction than the “Rule minimum”, i.e. holds other than “ore” holds, LC2 shall be adjusted to comply with these conditions for the actual holds. The remaining holds shall comply with the "Rule minimum" requirements.

3.3.2
Cargo pressure is to be taken as given in Chapter 2.2 with cargo mass, MH, assumed in the loaded hold defined as follows:

\[ M_H = k \rho_{dc} V_H(t) \]

where:

- \( k = 1.0 \) for Bulk Carrier
- \( k = 1.25 \) for Bulk Carrier HC and Bulk Carrier HC/E
- \( k = 1.50 \) for Bulk Carrier HC/EA

\( \rho_{dc} = \frac{(Ship \ cargo \ deadweight \ capacity)}{(total \ cargo \ hold \ volume)} \), (t/m\(^3\))

- \( \rho_{dc} = 0.7 \) minimum

\( V_H = \) cargo hold volume including hatchway in m\(^3\).

3.3.3
Sea pressure load is to be taken as given in Chapter 2.1. The draught is to be taken as 0.6 T for Bulk Carrier, 0.8 T for Bulk Carrier HC and Bulk Carrier HC/E and 1.0 T for Bulk Carrier HC/EA. The double bottom strength shall be evaluated with basis in full still water bending moments.

3.4 LC3: Bulk cargo in two adjacent holds, seagoing

3.4.1
This condition is applicable for bulk carriers with class notations Bulk Carrier, Bulk Carrier HC, Bulk Carrier HC/E and Bulk Carrier HC/EA, and is generally to be applied as a “minimum” condition for any two adjacent cargo holds.

For bulk carriers where loading conditions with two adjacent holds have been specified with net load on the double bottom construction exceeding the “rule minimum”, LC12 are to be considered. The remaining “two adjacent holds” are to be checked as for the “minimum” condition as described below.

The condition may be decisive for the compression strength of the transverse deck structure between hatches and for the shear strength of the transverse bulkheads at the shipside.

3.4.2
The bulk cargo pressure loads are to be taken as given in Chapter 2.2. Both cargo holds are assumed filled with cargo with a mass, MH, defined as:

\[ M_H = k \rho_{dc} V_H(t) \]

where:

- \( k = 1.0 \) minimum for Bulk Carrier
- \( k = 1.125 \) minimum for Bulk Carrier HC and Bulk Carrier HC/E
- \( k = 1.25 \) minimum for Bulk Carrier HC/EA

\( \rho_{dc} = \frac{(Ship \ cargo \ deadweight \ capacity)}{(total \ cargo \ hold \ volume)} \), (t/m\(^3\))
3.4.3
Sea pressure load is to be taken as given in Chapter 2.1. The draught is to be taken as maximum draught, T.

3.5 LC4: Two or more adjacent empty holds, seagoing or harbour

3.5.1
In case the loading manual is specifying two or more adjacent holds empty at a specified draught, \( T_{\text{ACT}} \), exceeding the heavy ballast draught, \( T_{\text{HB}} \), this condition should be considered. Typical loading conditions are those representing multiport conditions. The sea pressure should reflect whether this is a sea going or harbour condition whichever is relevant. This condition may be decisive for the longitudinal girders in double bottom and for the tensile strength of the cross deck construction and the bulkhead shear strength.

This condition may be used as basis for specifying the minimum required mass in two adjacent holds when approaching maximum draught which are to be specified in the local load diagrams. See chapter 7 covering "Allowable Hold Load Limits". If such draught has not been specified it is proposed to use maximum draught as basis in order to estimate a draught corresponding to the bulkhead and or cross deck strength capacity.

3.6 LC5: Bulk cargo with filled hold, seagoing

3.6.1
This load condition is applicable for the transverse bulkhead structure including stool diaphragm plates and in-line shear plates inside double bottom and for focal design of the hopper tank.

3.6.2
The cargo pressure load is to be taken according to Chapter 2.3 and the sea pressure to be taken according to Chapter 2.1. The draught to be taken as maximum draught, T.

3.7 LC6: Water ballast in hold, (heavy ballast condition) adjacent hold empty, seagoing

3.7.1
This condition shall be considered if ballast in holds has been specified for the vessel. The condition may be decisive for the transverse bulkhead, hopper and top wing tank structures. For bulk carriers without the HC/E or HC/EA class notations, the condition may in addition be decisive for the double bottom structure of the ballast hold.

3.7.2
Water ballast tanks below the ballast hold may normally be assumed filled. Top wing ballast tank adjacent to the ballast hold shall be empty for checking the strength of the top wing tank construction.

3.7.3
The sea pressure loads are to be taken in accordance with 2.1, reflecting the actual heavy ballast draught, \( T_{\text{HB}} \). If data for the ballast draught are not available, the draught may be taken as 0.45 T. Load from ballast pressure acting on the hatch cover shall be included as appropriate.

3.8 LC7: Water ballast in hold, (heavy ballast condition) adjacent hold empty, heeled condition, seagoing

3.8.1
This condition is generally applicable for the top wing tank structure adjacent to the ballast hold, side structure and local scantlings of the transverse bulkhead.

3.8.2
The draught is to be as given in 3.7 and sea pressure as given in 2.1. Internal pressure from ballast is to be taken as described in Rules Pt.3 Ch.1 Sec.13 as for liquid in tanks, heeled condition. Load from ballast pressure acting on the hatch cover shall be included as appropriate. Top wing ballast tank adjacent to the ballast hold shall be empty for checking the strength of the top wing tank construction.

3.9 LC8: Cargo on deck, seagoing

3.9.1
This condition is applicable for bulk carriers with a distinct top wing tank arrangement, where a deck cargo loading capacity has been specified.

3.9.2
Forces due to specified cargo load on hatches should be included in the consideration. Ref. Rules Pt.3 Ch.1 Sec.4 C.

3.9.3
The external sea pressure load is to be in accordance with 2.1 at maximum draught, T. It should be noted that any combination of sea pressure and deck load is not considered necessary provided appropriate limitation is explicitly given in appendix to Classification Certificate. Ref. Pt.3 Ch.1 Sec. 4 C(10).

3.10 LC9: Watertight bulkhead loading

3.10.1
This loading condition is intended to ensure that the watertight subdivision is maintained in case of an emergency flooding and is applicable for watertight bulkhead structures including stool diaphragm plates and in-line shear plates inside double bottom. However, this condition is not applicable for vertical corrugated bulkheads being built in compliance with the requirements as given in Pt. 5 Ch. 2 Sec. 10 D (IACS Unified Requirements (URS18))
Internal pressure load is to be according to the Rules, Pt.3 Ch.1 Sec.9 B, with filling of the hold up to the damaged waterline.

3.10.2

The external pressure may be taken at a draught equal to the damaged waterline, $T_{DAM}$. Further design criteria are given in the Rules, Pt.3 Ch.1 Sec.9.

3.11 LC10: Ballast in top wing tank, seagoing

3.11.1

This condition is applicable for bulk carriers with top wing tanks. The intention with this condition is to check the topwing tank structure only. Consequently, application of a realistic pressure distribution on the double bottom construction is not necessary.

3.11.2

The internal pressure shall be applied in the top wing tank, and are to be taken in accordance with 2.1. The sea pressure loads may correspond to the heavy ballast draught, $T_{HB}$, when considered relevant or disregarded of reasons as mentioned in 3.11.1.

3.12 LC11: Ballast in top wing tank, heeled condition

3.12.1

The condition is similar to condition LC10 with modified internal and external pressure loads.

3.12.2

The internal pressure is to be taken according to the Rules Pt.3 Ch.1 Sec.13 as for liquid in tanks in heeled condition. The sea pressure loads may correspond to the heavy ballast draught, $T_{HB}$, when considered relevant or disregarded of reasons as mentioned in 3.11.1.

3.13 LC12: Non homogeneous loading at reduced draught

3.13.1

Special non-homogeneous loading condition given in the Loading Manual, i.e. with heavy cargo in a limited number of cargo holds at a reduced draught may have to be considered. Typical loading is multiport conditions. The principle will be the same as for LC3, or LC1 if this condition represent a single loaded hold with adjacent holds empty, except that the draught is reduced.

3.13.2

The bulk cargo pressure loads are to be taken as given in 2.2. The cargo mass, $M_H$, is to be taken from specified conditions for each of the holds considered.

3.13.3

Sea pressure load is to be taken as given in Chapter 2.1. The draught is to be taken as the actual mean draught, $T_{ACR}$.

4. Cargo Hold Analysis

4.1 General

4.1.1

This chapter gives guidance on how to perform finite element calculations for the girder system within the midship area of bulk carriers.

4.1.2

In general the finite element model shall provide results suitable for evaluating the strength of the girder system and for performing buckling analysis of plate flanges and girder webs. This may be done by using a 3D finite element model of the midship area. Several approaches may be applied; ranging from a detailed 3D-model of the cargo holds to a coarse mesh 3D-model, supported by finer mesh submodels. Coarse mesh models can be used for calculating deformations and stresses typically suited for buckling control. The deformations may be applied as boundary conditions on submodels for finding the stress level in more detail.

The same principles may normally be used on structures outside the midship area but within the cargo area, provided special precautions are taken regarding model extent and boundary conditions.

4.1.3

Figure 4.1 shows a typical 3D-model of a conventional bulk carrier. Whichever approach is used, the model or set of models applied shall give a proper presentation of the following structure:

- Typical web frames in hopper and top wing tanks, including floors and mainframes at midhold in midship area
- Typical corrugation section of transverse bulkhead with connection to upper and lower stool
- Transverse section in way of pipe duct in line with the lower transverse bulkhead stool side
- Typical longitudinal girder in double bottom.

In the model description and examples given in the following all these structures are included in one 3D-model of the cargo hold for evaluating the results in these areas directly. This implies that the "cargo hold analysis" and "frame and girder analysis", in the Rules Pt.3 Ch.1 Sec.13, are combined into one model.

4.1.4

In addition, analyses of local structure can be made for determining the detailed stress level in stiffeners subject to large relative support deflections. Such analyses are described in Chapter 5 "Local structure analysis".

It is emphasised that this represents one acceptable approach for performing such calculations, and that alternative methods may be equally applicable.
4.2 Model Extent

4.2.1 General: The extent of the model does in general depend on the structure and the loading conditions, and whether these are symmetric in the longitudinal and transverse direction.

The extent of the recommended model extent is visualized in Table 4.1.

4.2.2 Transverse extent: Normally the structure is symmetric in the transverse direction while the load pattern in the heeled condition, LC7, is not symmetric. This implies that a full breadth model should be made:

For vessels without symmetry about centreline with respect to structure or loads; the analysis model amidships should comprise full breadth of the model.

However, even for the heeled condition a half breadth model may be satisfactory if due concern is shown to boundary conditions and their influence of the results in the structure. In the examples in the following, a full breadth model is applied.

4.2.3 Longitudinal extent: Often the transverse bulkhead with upper and lower stools are not symmetric in the longitudinal direction. In order to represent this correctly the model must have an extent including one full length cargo hold:

For vessels without symmetry about the transverse bulkhead, the analysis model amidships should comprise two hold lengths (1/2 + 1 + 1/2).

For vessels with symmetry about the transverse bulkhead, the model may be limited to 1/2 + 1/2 hold models.

4.3 Modelling of geometry

4.3.1 General model identification: All main longitudinal and transverse geometry shall be included in the model. The scantlings shall, according to DNV Rules, be modelled with reduced scantlings; i.e. corrosion addition according to the Rules shall be deducted from the actual scantlings.

When reduced effectivity of curved flanges are not represented by the model formulation itself, the reduced effectivity shall be defined by assigning reduced thickness of plate elements or cross sectional areas of beam and rod elements. Such reduced effectivity may be calculated as given in Pt.3 Ch.7 Sec.3. Typical structures are:

- Curved plate flanges (e.g. bilge plating)
- Curved face plates on hopper tank web frame and top wing tank web frame.

Half thicknesses shall be applied on plates in symmetry planes on the boundaries of the model.

4.3.2 Girders

Free flanges of girders shall be included in the model:

In ship structures, openings in the girder webs will be present for access and pipe penetrations. If such cut-outs affect the overall force distribution or stiffness of the girder, the cut-out shall be reflected in the model. This may be done by either; reducing the thickness according to the formula below or by geometrical modelling of the cut-out. The mean girder web thickness may for the first approach be taken as follows:

![Figure 4.2 Mean girder web thickness](image)

\[
\ell_{\text{mean}} = \frac{h - h_{\text{co}}}{h} \ell_{\text{w}} \\
\text{where:}
\]

- \( \ell_{\text{w}} \) = web thickness
- \( \ell_{\text{co}} \) = \( \frac{l_{\text{co}}}{2.6(h - h_{\text{co}})} \)
- \( h_{\text{co}} \) = height of cut-out
- \( h \) = height of girder web
When $r_0$ is larger than 1.2, $(r_0 > 1.2)$, it is advised that the
out is included in the model in one of the two ways given
above. When $r_0$ is larger than 2, $(r_0 > 2)$, it is advised that
the cut out is geometrically included in the model.

Smaller openings for access and piping may be ignored.
However, when such openings are ignored this must be
considered when evaluating the results ref. Chapter 4.8.2.

4.3.3

Stiffeners: Continuous stiffeners oriented in the direction of
the girders contributes to the overall bending stiffness of the
girders and shall be included in the model in such a way that
the bending stiffness of the girder is correctly modelled.

Non-continuous stiffeners may be included in the model as
beam element with reduced effectivity. Sectional area of
such stiffeners may be calculated as follows:

- Sniped at both ends: 30% of actual area
- Sniped at one end: 70% of actual area
- Connected at both ends: 100% of actual area

Stiffeners on girders perpendicular to the flanges may be
included in the model when considered important,
alternatively by transferring them to the nearest nodes
instead of introducing additional nodes. Buckling stiffeners
considered less important for the stress distribution, as sniped
buckling stiffeners, may be ignored.

4.3.4

Corrugated bulkhead and stools: Corrugated bulkheads
shall be included in the model. Slanted plates (shadder
plates) shall, if present, be included in the model as they
transfer loads from the flange of the corrugations to the
opposite side of the stool.

Normally it is difficult to match the mesh from the
corrugations directly with the mesh from the stool, so a
practical approach is to adjust the mesh of the stools in to the
corrugations. The corrugations will then have their true
geometrical shape.

Diaphragms in the stools and vertical stiffeners on the stool
side plating are to be included in the model.

It is proposed to use one or two 4-noded element over the
depth of the corrugation web. This model formulation gives a
good representation of the response of the corrugated
bulkhead provided supporting brackets are fitted in line with
the corrugations. Modelling of these brackets do normally
not change the load transfer from the corrugations to the
stool significantly as the vertical flanges are well supported
by the vertical or slanted stool plate. Such brackets do
therefore not have to be included in a cargo hold analysis due
to the fact that finite elements tends to transmit forces more
than the real structure through the nodes shared by the
neighbouring elements.

The calculated response for designs without such brackets
should however be adjusted to represent the reduced
efficiency of the web. Alternatively, a model with a fine
element mesh, or a separate evaluation, may be used.

4.3.5

Main frames, supporting brackets and connected
longitudinals: The cargo hold model shall give a proper
representation of deflection of mainframes. In order to
achieve this, the mainframes, the supporting brackets in the
hopper tank and top wing tank and the connected
longitudinals must be represented in the model. A practical
approach is to include all the mainframes in the model. In
order to evaluate the mainframes, supporting bracket and
connected longitudinal, in detail, a fine mesh model must be
made.

4.3.6

Hatch coamings, hatch corners and hatches: The hatch
coamings shall be included in the model. When it is
necessary to evaluate the strength of hatch corners a separate
fine mesh model must be made. Hatch covers shall not be
included in the model. Unless load conditions including
torsional loading of the hull girder is included, the results in
these areas will be limited to stress concentrations mainly
caused by global hull girder forces. In such cases these forces
must be applied to the model.

4.4 Elements and Mesh Size

4.4.1

General: The performance of the model is closely linked to
the type-, shape- and aspect ratio of elements, and the mesh
topology that is used. The mesh described here is adequate
for representing the cargo hold model and frame and girder
model as defined in the Rules P.I.Ch.I Sec.13. The
following guidance on mesh size etc., is based on the
assumption that 4-noded shell or membrane elements in
combination with 2-noded beam or truss elements are used.

Higher order elements such as 8-noded or 6-noded elements
with a coarser mesh than described below may be used
provided that the structure and the load distribution are
properly described.

In general the mesh size should be decided on the basis of
proper stiffness representation and load distribution of tank
and sea pressure on shell- or membrane elements.

4.4.2

Plating: 4-noded shell or membrane elements may be used in
connection with mesh size as described below. 3-noded shell
or membrane elements with constant strain shall normally
not be used. It may however be used to a limited extent for
avoiding poor mesh transitions.
The element mesh should preferably represent the actual plate panels between stiffeners so that the stresses for the control of yield and buckling strength can be read and averaged from the results without interpolation or extrapolation.

In practise, the following may be applied:

- There should be minimum three elements over the height of girders. The mesh should in general and as far as practical follow the stiffener system on the girder. See Figure 4.3
- One, two or three elements between transverse girders. By using three elements it normally matches with the mainframes. However, some local stiffener bending will be included in the results. Ref. comments given in chapter 4.8.
- One element between longitudinals. See Figure 4.3. This contributes to a correct load transfer from the longitudinal to the transverse frame.
- Inside hopper tank and top wing areas the mesh are normally limited by the longitudinals in surrounding structures. The mesh should follow the stiffener system on transverse girder webs as far as practicable. The mesh should be fine enough to represent the shape of large openings in the web frame inside the hopper tank. See Figure 4.5.
- One element or more on each web and flange on the corrugations in corrugated bulkheads. This is satisfactory for determining the stress level in the bulkhead. An example of mesh on corrugated bulkheads is shown in Fig. 4.6. See also Chapter 4.3.4.
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4.4.3

**Longitudinals and stiffeners:** Longitudinals and other continuous stiffeners should be included in the model. These are preferably to be represented by 2-noded eccentric beam elements.

If the program used cannot consider eccentricity of profiles, precautions shall be taken so that the model gives the correct section modulus for double and single skin structures. However, axial area and shear area of such stiffeners should only represent the profile without the plate flange.

![Diagram](https://via.placeholder.com/150)

**Figure 4.7 Overlap of beam elements and shell elements**

Special attention should be paid when connecting a beam element to one node of a shell or membrane element. The end of the beam elements may then be assumed as hinged in the calculation. This will affect the load distribution. The mentioned effect may be avoided by an overlap between the beam and shell elements (see Figure 4.7).

Other stiffeners including buckling stiffeners and free flanges of girders may be modelled as 2-noded beam or truss elements with effective cross sectional areas calculated according to the Rules.

Curved flanges are to be represented with their true effectiveness in the model.

Stiffeners inside stools may in general be represented by beam elements or alternatively by shell or membrane elements.
4.5 Boundary Conditions

4.5.1 Boundary conditions for the application of local load

Symmetric boundary conditions are in general to be applied at the ends of the model. If half breadth models are used, symmetry shall be applied along the centreline of the model.

The model may be supported in vertical direction by applying vertical springs in the vertical direction at the line forming the intersection between side and transverse bulkhead. Bulk carriers with double side shall be supported by vertical springs or forces at the intersection between double side and transverse bulkheads. The spring constant may be calculated as follows, ignoring the effect of bending deflection:

\[ K = \frac{8 A_s E}{7.8 \cdot l_h} \]

Where:

- \( A_s \) = shear area for side (side and inner side for bulk carriers with double side).
- \( l_h \) = length of one cargo hold.

Alternatively, vertical forces applied in the same intersections may be applied. The model must then be restrained from rigid body translation in the vertical direction.

Boundary conditions for the application of local loads for bulk carriers of ordinary design are given in Table 4.1, applying symmetry conditions in one end and symmetry and linear dependency in the other end. These boundary conditions introduce a horizontal force applied at one of the ends. The purpose of this force is to compensate for the fictitious compression of the hull girder when the mid hold is empty and the holds fore and aft are full. In order to keep the nodes in “plane A” in one plane, the nodes must be linearly dependent in the longitudinal direction of the point (point c) where the force is applied. The magnitude of the force will vary on each loadcase but shall in general be equal to the net load on the transverse bulkhead.

Line C is defined as the intersection between the vertical part of the side shell and the transverse bulkhead. Point a is the point of intersection between the bottom, centreline and transverse bulkhead.

As an alternative, boundary conditions with pure symmetry at the ends (Plane A also fixed in the longitudinal direction) without a counteracting force may be applied. The longitudinal stresses should then be corrected for the mentioned fictitious compression.

### Table 4.1 Boundary conditions for an ordiary bulk carrier with unsymmetrical stoke structure

<table>
<thead>
<tr>
<th>Location</th>
<th>Displacement</th>
<th>Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plane A</td>
<td>( \delta x )</td>
<td>( \delta x )</td>
</tr>
<tr>
<td>Plane B</td>
<td>( X )</td>
<td>( X )</td>
</tr>
<tr>
<td>Line C</td>
<td>( X )</td>
<td>( S )</td>
</tr>
<tr>
<td>Point a</td>
<td>( F_v )</td>
<td></td>
</tr>
<tr>
<td>Point c</td>
<td>( F_h )</td>
<td></td>
</tr>
</tbody>
</table>

- \( X \) = Restricted from displacement or rotation
- \( L \) = Linearly dependent of point c
- \( \_ \) = Free
- \( S \) = Springs
- \( F_v \) = Vertical forces. When vertical forces are applied the model must in addition be restricted from translation in the vertical direction by fixing it in one node.
- \( F_h \) = Counteracting horizontal force
4.5.2 Boundary conditions for the application of hull girder loads

When hull girder loads, i.e. bending moment and shear forces, are intended applied to the model, it is advised that such loads are applied as separate load cases with separate boundary conditions. The resulting stresses may then be manually superimposed to the relevant stresses from the local load model. The described boundary conditions and load application are summarised in Table 4.2 and Table 4.3.

Bending moment - boundary conditions: One end should be restricted as shown in Table 4.2. The other end should be kept plane and the displacements of the plane should be as a rigid body. The latter is necessary to apply the hull girder bending moment. In order to keep the nodes in one plane they are to be linearly dependent of each other as a rigid body.

Symmetry conditions along the centreline of the model are to be applied for models covering a half breadth of the ship.

Application of hull girder bending moment: In general a bending moment shall be applied to the end of the model. The bending moment at the end may be applied as a force pair acting in the opposite direction applied at two points. The points should be positioned vertically above each other with one point in the deck and one point in bottom. The size of the bending moment shall be such that the vertical hull girder bending moment, as described in the rules, is achieved in the middle of the model. Some modifications to the size of this bending moment are however necessary. The background for this is that the allowable hull girder bending moment \((M_s + M_w)\) is based on gross scantlings. The FEM model is based on net scantlings (gross scantling reduced by \(t_k\)). It is therefore necessary to reduce the Hull girder bending moment by a factor of \(Z_{mod} / Z_{gross}\). Where \(Z_{mod}\) is the hull girder section modulus as modelled (i.e. gross scantling reduced by the corrosion addition, \(t_k\)) and \(Z_{gross}\), the hull girder section modulus based on actual scantlings. In addition to this bending moment the local loads will also set up a "semi-global hull girder bending moment" that may be compensated for when applying the bending moment. (It is advised that the loads are adjusted to match the acceptance criteria and not the opposite.)

The magnitude of the force pair will be as follows:

\[
F = \frac{M}{h}
\]

Where
\(F\) = Magnitude of force at points in deck and bottom
\(M\) = Modified bending moment as described above
\(h\) = Height from base line to point in deck

### Table 4.2 Boundary conditions for bulk carrier cargo hold analysis when hull girder bending moments are applied

<table>
<thead>
<tr>
<th>Location</th>
<th>Displacement</th>
<th>Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plane A</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Plane B</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Centreline (when applicable)</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Point a,b</td>
<td>Fixed.</td>
<td>Rigid body linearly dependent.</td>
</tr>
</tbody>
</table>

\(F_{a,b}\) Force according to the above. Forces acting in opposite direction at point a and b.
4.6 Loading Conditions

4.6.1 General: Normally the basic loading conditions as described in Pt.5 Ch.2 of the Rules, shall be considered. These loading conditions are further elaborated in Chapter 3 of this Classification Note. For some bulk carriers, depending on the length, class rating and arrangement of bottom longitudinal girders, additional loading condition as described in 4.6.2 may be necessary for the estimation of the fatigue life of the longitudinal strength elements.

The loading should be applied in the form of lateral pressure on shell elements, or line loads on membrane elements. Alternative load application may be specially considered.

4.6.2 Fatigue loads: For vessels subject to the class notation NAUTICUS(Newbuilding), ref. Rules Pt.5 Ch 2 Sec 5A, fatigue strength assessment are in general to be carried out for end structures of longitudinals in bottom, inner bottom, side, inner side and deck in the midship area. For that purpose any deformation of the said longitudinals caused by relative deformation by the supporting strength members may have to be considered. However, for conventional bulk carrier design the large number of bottom longitudinal girders will normally result in relative deformations not having any significant effect on the fatigue life and may thus be ignored.

It is emphasized that such deformations are to reflect dynamic loading only. The dynamic pressure loads are to be calculated according the Classification Note 30.7 "Fatigue Assessment of Ship Structure".

4.7 Presentation of input and results

4.7.1 The requirements given in DNV Rules Pt.3 Ch.1 Sec.13 regarding proper documentation of the model shall be followed. A practical guidance is given in the following. In appendix A, examples of checklists for internal verification of FEM analyses are given.

4.7.2 Presentation of input data: A reference to the set of drawings the model is meant to represent should be given. The modelled geometry is to be documented, preferably as an extract directly from the generated model. The following input shall be reflected:

- Plate thickness
- Free flange sectional area considering efficiency of curved flanges
- Beam section properties
- Boundary conditions
- Load cases

4.7.3 Presentation of results: The stress presentation should be based on element membrane stresses or gauss membrane stresses at the middle of element thickness, excluding plate bending stress, in the form of iso-stress contours in general. Numerical values should also be presented for highly stressed areas (e.g. areas where stress exceeds 60% of allowable limits or areas in way of openings not included in the model).
The following should be presented:

- Deformed shapes
- Transverse membrane stress of shell/plate elements in
  - Bottom plating
  - Inner bottom plating
  - Cross deck/upper stool plating
  - Hopper tank plating
  - Top wing tank bottom plating
  - Transverse floors and hopper and top wing tank web frames
- Vertical membrane stress of shell/plate elements in
  - Transverse bulkhead plating
  - Upper and lower stool plating
  - Side and inner side if double side skin construction
  - Mainframes
- Longitudinal membrane stress of shell/plate elements in
  - Bottom plating
  - Inner bottom plating
  - Longitudinal girders
  - Cross deck cantilever beams
- Shear stresses of shell/plate elements in
  - Transverse floors
  - Longitudinal girders
  - Longitudinal girders below bulkhead stool
  - Stool diaphragms
  - Lower/upper stools top and bottom plating
  - Transverse bulkhead plating in way of ship side, (inner side if relevant) hopper and top wing tank
  - Hopper plating and hopping girder adjacent to transverse bulkhead
  - Web frames inside hopper and top wing tank, mainframes, upper and lower bracket
  - Cross deck cantilever beams
- Axial stress of free flanges
- Deformations of supporting brackets for mainframes including longitudinals connected to these
- Deformation of supports for longitudinals subject to large relative deformation

4.8 Evaluation of results and applicable acceptance criteria

4.8.1

In the following procedures for handling results and applying acceptance criteria are described. Acceptance criteria are in general given in the Rules Pt.3 Ch.1 Sec.13 and Pt.5 Ch.2 Sec.14

4.8.2 Evaluation of results - Longitudinal stress: For buckling control the following longitudinal stresses may normally be considered:

\[
\sigma_L = \sigma_{DB} + \sigma_S + \sigma_W
\]

or

\[
\sigma_{LR} = \sigma_{DB} + \sigma_S + \sigma_{WR}
\]

where:

- \(\sigma_L\) = Sum of longitudinal stresses based on wave bending moment with a probability of \(10^{-8}\) of exceedance.
- \(\sigma_{LR}\) = Sum of longitudinal stresses based on wave bending moments with a probability of \(10^{-4}\) of exceedance.
- \(\sigma_{DB}\) = Longitudinal girder bending stresses resulting from bending of large stiffened panels between transverse bulkheads, due to local load on an individual cargo hold. These stresses are often referred to as double bottom stresses, as they are typical for double bottom structures, and may be taken as results from the cargo hold analysis.
- \(\sigma_S\) = Longitudinal hull girder bending stresses defined as \(M_S/Z_s\), where \(M_S\) is the still water bending moment and \(Z_s\) is the section modulus at the considered position (i) based on gross scantling. (No corrosion addition deducted). Maximum sagging or hogging moment to be applied as values for \(M_S\). \(M_S\) is defined in DNV Rules Pt.3 Ch.1 Sec.5/ Pt.5 Ch.2 Sec.5
- \(\sigma_W\) = Longitudinal hull girder bending stresses caused by wave bending moment \(M_W\), which correspond to a probability of exceedance of \(10^{-8}\). \(\sigma_W = M_W/Z_s\). \(M_W\) is defined in DNV Rules Pt.3 Ch.1 Sec.5
- \(\sigma_{WR}\) = Longitudinal hull girder bending stresses caused by reduced wave bending moment \(M_{WR}\), which corresponds to a probability level of exceedance of \(10^{-4}\). \(M_{WR} = 0.59M_W\).

Relevant stress components related to hull girder, girders, and stiffeners are defined in Figure 4.8.

Fictitious longitudinal stresses may occur in the model due to assumptions made for the boundary conditions:

- Ordinary bulk carriers have longitudinal girders in the double bottom. It is advised that the fictitious compression force when the mid hold is empty is eliminated by applying boundary conditions as described in Table 4.1. An alternative may be done by manual corrections after the calculation.
- The effect of the "semi global moment" depends on the distance between the supports. For an ordinary bulk carrier the holds are relatively short and this effect may normally be neglected. It is however recommended that the magnitude of the effect is checked.

It should also be noted that the stiffener bending stress is not a part of the girder bending stresses. The magnitude of the stiffener bending stress included in the stress results depends on the mesh division and the element type that is used. This is shown in Figure 4.9 where the stiffener bending stress, as
Figure 4.8 Stresses identified as hull girder bending stresses, double bottom bending stresses and stiffener bending stresses, $\sigma_{it} = \sigma_i + \sigma_{in}$, Ref DNV Rules

calculated by the FE-model, is shown depending on the mesh size (valid for 4-noded shell elements). One element between floors results in zero stiffener bending. Two elements between floors result in a linear distribution with approximately zero bending in the middle of the elements. When a relatively fine mesh is used in the longitudinal direction the effect of stiffener bending stresses should be isolated from the girder bending stresses when buckling and stress level is checked for the plate flange.

4.8.3

Mean shear stress: The mean shear stress, $\tau_{mean}$, is to be used for the capacity check of a plate. This may be defined as the shear force divided on the effective shear area. For results from finite element methods the mean shear stress may be taken as the average shear stress in elements located within the actual plate field, and corrected with a factor describing the actual shear area compared to the modelled shear area when this is relevant. For a plate field with $n$ elements the following apply:

$$\tau_{mean} = \frac{\sum \tau_i \cdot A_i}{A_w}$$

Where

- $A_i = \text{effective shear area of element } i$
- $\tau_i = \text{shear stress of element } i$
- $A_w = \text{effective shear area as of the real structure. To be taken in accordance with DNV Rules Pt.3 Ch.1 Sec.3}$

Figure 4.9 Normal stress caused by local load on the stiffener, depending on number of elements along the stiffener
4.8.4 Shear stress in the hull girder: It is not necessary to consider hull girder shear stresses in longitudinal bulkheads and ship side unless special boundary conditions as well as loads are applied. The shear strength of the hull girder may normally be evaluated in accordance with the Rules Pt.3 Ch.1 Sec.5.

4.8.5 Buckling control and related acceptance criteria: Table 4.3 gives examples of areas to be checked for buckling and the applicable method and accept criteria. In case of any differences in the acceptance criteria given here compared with those given in the Rules for Ships, the latter shall apply.

Table 4.3 Examples of areas to be checked and procedure to be used related to buckling control

<table>
<thead>
<tr>
<th>Item</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| Buckling of girder plate flanges in: | 1) Uniaxial buckling in transverse direction to be analysed based on mean transverse compressive stress with $\psi = 1$ and allowable usage factor, $\eta = 0.8$  
2) Uniaxial buckling in longitudinal direction to be analysed according to Sec.14 based on hull girder stress $\sigma_{hl} = \sigma_b + \sigma_w$.  
3) Bi-axial buckling to be analysed based on longitudinal stress and mean transverse stress. When the longitudinal stresses are obtained from hull girder loads on a probability of exceedance of $10^{-4}$, usage factors $\eta = 0.85$ shall be used. For a probability of exceedance of $10^{-8}$, usage factors $\eta = 1.0$ shall be used. |
| • Double bottom (including bottom and inner bottom)  
• Side plating (including inner side when relevant)  
• Deck  
• Hopper structure  
• Top wing tank structure  
• Cross deck structure incl. stools |  

Comment:  
Mean transverse compressive stress is to be calculated from a group of elements representing one plate field between stiffeners.  
Longitudinal stress are to be taken as described in 4.8.2 |
| Buckling of girder plate flanges in: | 1) Buckling to be analysed based on mean compressive stress with $\psi = 1$ and allowable usage factor, $\eta = 0.8$.  
2) Bi-axial buckling to be checked when relevant. |
| • Upper and lower stools and the web of these girders |  

Comment:  
Mean compressive stress are to be calculated from a group of elements representing one plate field between stiffeners. |
| Buckling of corrugated bulkheads | 1. Buckling to be analysed based on mean compressive stress with $k_3 = 5$ (Pt.3 Ch.1 Sec.14) and allowable usage factor, $\eta = 0.8$. |
| Buckling of girder webs in: |  

Buckling of girder webs with one plate flange:  
1) Buckling to be calculated as for girder plate flanges  
2) Buckling to be analysed based on mean shear stress with allowable usage factor, $\eta = 0.85$.  
3) Bi-axial buckling with shear.  

Buckling of girder webs with two plate flanges:  
1) Buckling to be analysed based on mean shear stress with allowable usage factor, $\eta = 0.85$.  
2) Buckling caused by compression loads from sea and cargo, alternatively together with shear, to be checked when relevant. |
| • Double bottom  
• Double side (when relevant)  
• Deck  
• Hopper tank  
• Topwing tank  
• Stools |  

Comment:  
Mean shear stress to be taken as described in 4.8.3, representing one plate field between stiffeners. |
4.8.6

**Stress control and related acceptance criteria:** Table 4.4 gives examples of areas where the stress level shall be controlled, together with the applicable method and accept criteria. In case of any differences in the acceptance criteria given here compared with those given in the Rules, the latter shall apply.

### Table 4.4 Examples of areas to be checked and procedure to be used related to control of nominal membrane stresses. All stresses in N/mm²

<table>
<thead>
<tr>
<th>Item</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| Stresses in longitudinal girders | 1) Allowable reduced longitudinal nominal stress, \( \sigma = 190f_1 \). Based on a probability of exceedance of \( 10^{-4} \). (Reduced longitudinal stress, \( \sigma_{LR} = \sigma_{lw} + \sigma_t + \sigma_{wz} < 190 f_1 \), Ref 4.8.2)  
2) Allowable mean shear stress \( \tau = 90f_1 \) (sea) and \( \tau = 100f_1 \) (harbour) for girders with one plate flange, and \( \tau = 100f_1 \) (sea) and \( \tau = 110f_1 \) (harbour) for girders with two plate flanges. Shear stress in way of openings not included in the calculation to be evaluated in terms of mean shear stress Ref. 4.8.3. |
| Stresses in transverse and vertical girders with two plate flanges (Double skin constructions) like:  
- Double bottom  
- Double side | 1) Allowable nominal normal stress in flanges of girders \( \sigma = 160f_1 \) (sea) and \( \sigma = 180f_1 \) (harbour) in general.  
2) Allowable mean shear stress of girder webs, \( \tau = 100f_1 \) (sea) and \( \tau = 110f_1 \) (harbour). Shear stress in way of openings not included in the calculation to be evaluated in terms of mean shear stress Ref. 4.8.3.  
3) Allowable equivalent stress, \( \sigma_e = 180f_1 \) for seagoing conditions and \( \sigma_e = 200f_1 \) for harbour conditions. |
| Stresses in transverse and vertical girders with one plate flange (Single skin constructions) like:  
- Main frames  
- Top wing tank web frame  
- Hopper tank web frame | 1) Allowable nominal normal stress, \( \sigma = 160f_1 \) (sea) and \( \sigma = 180f_1 \) (harbour) in general  
2) Allowable mean shear stress \( \tau = 90f_1 \) (sea) and \( 100f_1 \) (harbour). Shear stress in way of openings not included in the calculation to be evaluated in terms of mean shear stress Ref. 4.8.3.  
3) Allowable equivalent stress, \( \sigma_e = 180f_1 \) for seagoing conditions and \( \sigma_e = 200f_1 \) for harbour conditions  
4) Allowable nominal normal stress in flooded condition, \( \sigma = 220f_1 \) (Not applicable for mainframes) |

### 5. Local Structure Analysis

#### 5.1 General

Local structure analysis may be used to analyse local nominal stresses in laterally loaded local stiffeners and their connecting brackets, subjected to relative deformations between supports. See Figure 5.1. The model and analysis described in the following are suitable for calculating:

- Nominal stresses in stiffeners.
- Nominal stresses in longitudinals supporting main frames.

These models may be included in the 3D cargo hold analysis model, or run separately as submodels with prescribed boundary deformations from a 3D-analysis. Local pressure loads must be applied to the local models.

#### 5.2 Stiffeners subject to large deformations

##### 5.2.1 General:

Relative deformations between stiffener supports may give rise to high stresses in local areas. Typical areas to be considered are, longitudinals in double bottom towards transverse bulkheads or partial girders, and longitudinals connected to main frame supporting brackets. A method for the first example is shown in the following.

![Figure 5.1 Main frames, connecting brackets and longitudinals](https://example.com/image.png)
5.2.2 Model extent: In general, the model of a longitudinal in double bottom towards transverse bulkheads or partial girder is recommended to have the following extent:

- The stiffener model shall extend to a stiffener support at least two frame spacings outside the area subject to the study.
- The width of the model shall be at least \( \frac{1}{2} + \frac{1}{2} \) stiffener spacing. See Figure 5.3.

Figure 5.2 shows the extent of a model of an inner bottom longitudinal and bottom longitudinal. Here the extent covering the full length is used for checking both sides of the unsymmetrical stools simultaneously.

5.2.3 Elements and element mesh: Normally three (3) 4-noded elements are to be used over the web height of the stiffeners. Corresponding sizes are to be used for the plate flanges. The face plate shall normally be modelled with 2-noded beam elements. Effective flange in curved areas should however be represented properly. An example of a model as described is shown in Figure 5.3 and 5.4. Generally, the element fineness along the stiffener shall be fine enough for providing a good aspect ratio of the elements.

The two last elements towards the point of interest shall not be larger than 2\% of the stiffener’s span length if the results are to be used directly. However, the elements may be up to 8\% of the span length if extrapolation of the results towards the point of interest is carried out. A method for extrapolation is given in chapter 5.4.

5.2.4 Boundary conditions: If the model is run separately, prescribed displacements or forces are to be taken from the cargo hold analysis (or frame and girder analysis when relevant). These displacements or forces are to be applied to the boundaries of the local structure model in points where the results from the global model are representative. See Table 5.1.

<table>
<thead>
<tr>
<th>Location</th>
<th>Displacement</th>
<th>Rotation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free edge of plate flanges</td>
<td>0x 0y 0z</td>
<td>X X</td>
</tr>
<tr>
<td>forming the bottom, inner</td>
<td></td>
<td></td>
</tr>
<tr>
<td>bottom and stool sides</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free edges of:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double bottom floors</td>
<td>D D D</td>
<td>D D D</td>
</tr>
<tr>
<td>Top of stool</td>
<td>D D D</td>
<td>D D D</td>
</tr>
<tr>
<td>Double bottom floors in line</td>
<td>D D</td>
<td>D D</td>
</tr>
<tr>
<td>with stool</td>
<td></td>
<td></td>
</tr>
<tr>
<td>X Restricted from displacement or rotation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D Displacements transferred from cargo tank model or frame and girder model</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5.3 Other fine mesh models.
Other fine mesh models may be made for the study of critical details. If the accept criteria are based on maximum allowable nominal stresses the modelling principles described above should be followed.
5.4 Documentation and result presentation
When extrapolation of results is required, ref. 5.2.3, this shall normally be based on the results in the two last elements towards the point of interest. The results in the Gauss point in the middle of the element representing the flange of the longitudinal shall be used for the extrapolation. The extrapolation method is indicated in Figure 5.5.

![Figure 5.5 Extrapolation towards point of interest based on results in elements representing the flange](image)

Documentation and result presentation is to follow the principles given in chapter 4.7.

The following stresses shall be given.

a) Normal stresses and shear stresses of plate/membrane elements.

b) Axial stress of truss/beam elements.

5.5 Acceptance Criteria
Acceptance criteria for stress results from local structure analysis are given in the Rules Pt.3 Ch.1 Sec.13 and in Pt.5 Ch.2.

6. Additional requirements considering flooding
6.1 General
6.1.1 Generally the Rules require that damage stability calculations are carried out to control that the ship has sufficient residual stability for given damage scenarios without reference to the ship's actual loading conditions and without controlling the ships overall strength for such damage conditions.

However, for vessels subject to the requirements as given in Pt.5 Ch.2 Sec.5 A102 Table 1, the ships overall strength (hull girder shear and bending strength) are to be controlled for flooding of each cargo hold for all actual seagoing cargo and ballast conditions, i.e., the loading conditions given in the loading manual and those evaluated by the loading instrument only. The determination of the mass of water ingress should reflect the damaged waterline. A permeability of 0.3 for the volume occupied by cargo may be used. For the remaining flooded volume in the loaded hold and for empty holds a permeability of 0.95 to be used. For the loaded holds a permeability of 0.9 for the whole volume below the damaged waterline may be used as an alternative to the above. Realistic data for the cargo mass volume and density to be applied.

6.2 Global Bending Moment and Shear Force Limitation

6.2.1 Generally the maximum allowable still water bending moment in a flooded condition, \( M_{sf} \), is described by below formula, provided adequate uni-axial buckling capacity of the cross section is available. Ref. Rules Pt.3 Ch.1 Sec.14.

\[
M_{sf} = 175 f_{t} Z - 0.8 M_{w}
\]

Where:

- \( Z_{s} \) = Hull girder section modulus at the considered position.
- \( M_{w} \) = Wave loading moment according to DNV Rules.

When the hull girder capacity is fully utilised, the maximum allowable still water bending moment at the considered section, in flooded condition, \( M_{sf} \), is described by:

\[
M_{sf} = M_{s} + 0.2 M_{w}
\]

Where:

- \( M_{s} \) = Allowable still water bending moment according to DNV Rules in intact condition.

6.2.2 It should be noted that there is only one limitation curve in a flooded condition, irrespective of possible reduced bending moment limits applied in an alternate intact condition.

6.2.3 The three typical bending moment limits are given in the illustration figure 6.1 following.

![Figure 6.1 Typical bending moment limitation curves for intact and flooded conditions](image)
6.2.4 The maximum allowable shear force capacity at the considered section in flooding condition, $Q_{sr}$, is described by:

$$Q_{sr} = Q_s + 0.2 Q_w$$

Where:

$Q_s$ = Allowable still water shear force according to DNV Rules in intact condition. Ref. also 9.4.

$Q_w$ = Maximum vertical wave shear force according to DNV Rules

6.3 Transverse Bulkhead Strength

6.3.1 Generally the Rules require that the strength of transverse bulkhead structure subjected to flooding loads have been controlled using a pressure head corresponding to the deepest equilibrium waterline in the damage condition, and pressure load from water alone only.

6.3.2 For vessels subject to the requirements as given in the Rules Pt.5 Ch.2 Sec.10 D. The pressure loads in this case reflects the effect of mixed cargo and water.

The following loadcases may be applied:

- water alone
- filled cargo hold to deck at side with mass corresponding to the hold's maximum allowable mass
- cargo hold filled to a level corresponding to its max. allowable mass and applying cargo density of 1.78 t/m$^3$
- cargo hold filled to a level corresponding to its max. allowable mass and applying cargo density of 3.0 t/m$^3$

Flooding head to be as required in above referred Rules and an angle of repose of 35 degrees may be applied.

6.4 Diaphragm and shear plates in double bottom below bulkhead stool, considering flooding. Evaluation of the effectiveness.

6.4.1 The shear strength of diaphragm - and shear plates is to be checked with respect to the bending moment, $M_{LS}$, from the lower stool as given by:

$$M_{LS} = \frac{(Z_{10} \sigma_{\alpha,\beta} 10^{-3} + Q h_{LS})}{s_i} + \frac{h_{LS}^3}{3 (P_{c,t} + P_{c,fb})} (kN\text{m})$$

$Z_{10}$ = as given in the Rules Pt.5 Ch.2 Sec. 10 D303

$\sigma_{\alpha,\beta}$ = as given in the Rules Pt.5 Ch.2 Sec. 10 D305

$Q$ = as given in the Rules Pt.5 Ch.2 Sec. 10 D209

$s_i, h_{LS}$ = as given in the Rules Pt.5 Ch.2 Sec. 10 D203

$P_{c,t}$ = $P_{c,t}$ as given in the Rules Pt.5 Ch.2 Sec. 10 D204 with $h_1 = d_1 - h_{DB}$

$P_{c,fb}$ = $P_{c,t}$ as given in the Rules Pt.5 Ch.2 Sec. 10 D204 with $h_1 = d_1 - (h_{DB} + h_{LS})$

$d_{11, h_{DB}}$ = as given in the Rules Pt. 5 Ch. 2 sec. 10.D203.

$\tau_r$ = $\sigma_r / \sqrt{3}$

$\sigma_r$ = minimum upper yield stress

The shear moment capacity, $M_s$, of longitudinal double bottom girders and shear plates below the lower bulkhead stool, are within a load breadth of each longitudinal double bottom girder, $b_1$ generally given by:

$$M_s = M_{LS} b_1$$

The shear moment capacity, $M_s$, may generally be determined as follows:

$$M_s = M_{CL} + M_{CS}$$

$M_{CL}$ = $h_s \left( \frac{\tau_r (d_1 - 2) h_{DB} - h_{a}}{2} \right) + \tau_r (d_1 - 2) (h_{DB} - h_{a}) / 2$

$n$ = number of effective shear plates including longitudinal double bottom girders within the load breadth $b_1$.

6.4.2 For the determination of $M_{CS}$ smaller size access holes in the shear plates within the length of the lower stool may generally be disregarded.
Access holes etc. in shear plates and double bottom girder webs below the lower bulkhead stool are assumed to be arranged with effective edge stiffening.

**Figure 6.2 Diaphragm and shear plates in double bottom below bulkhead stool and longitudinal girder**

### 6.5 Limit to Hold Loading, Considering Flooding

**6.5.1**
Generally the Rules require that the strength of the double bottom construction is based on the most unfavorable loading conditions as given in the loading manual and the minimum loading as given in the Rules. The individual holds net loading (shear) and/or the most unfavorable combination of net loading and bending moment (hulling, longitudinals) will then decide the scantling. When first the extreme loading have been checked they serve as basis for the Local Strength Diagrams giving the maximum allowable/minimum required mass as a function of the draught. See Ch. 7.0 for further details. Typical for this approach is that it is based on intact loading only.

**6.5.2**
However, for vessels subjected to the requirements as given in Pt.5 Ch.2 Sec.5 Table A1, the double bottom shear strength are also to be checked for above loads in flooding condition. Ref. Pt. 5 Ch. 2 Sec.10 subsection E. It should be noted that the rule check program "Allowable Hold Loading" in the NAUTICUS HULL package may be used for this purpose.

Further, the highest cargo density will give the strictest requirement and a cargo density of 3.0 t/m³ should generally serve as the extreme condition in combination with permeability of 0.3 for the volume occupied by the cargo.

### 7. Cargo Hold Load Limitations

#### 7.1 General

**7.1.1**
The design load conditions of the ship as defined in the loading manual, ref. 3.2, and normally also reflecting class notations such as HC, HC/E or HC/EA, ref. 3.3, refer to a given draught. These design conditions are, in addition to being used for scantling check, also utilised to define limits to the cargo mass of holds for other draughts.

**7.1.2**
Generally the allowable mass of cargo in a given hold is related to the net loading on the double bottom of the considered hold. This implies that the allowable mass of cargo in the hold will vary linearly with the buoyancy pressure acting on the bottom of the ship. Typical Local Strength Diagrams for the allowable mass of cargo of a cargo hold are shown in Fig. 7.2.1.

With reference to 3.4 the Rules also specify minimum limits to the mass of cargo in any two adjacent cargo holds at maximum draught. The limit to the mass of cargo in two adjacent holds is given by the compression strength of the cross-deck, and the vertical shear strength of the bulkhead between the cargo holds. This implies that the allowable mass of cargo in two adjacent holds varies linearly with the buoyancy force acting on the double bottom of the same holds. Typical Local Strength Diagrams for the allowable mass of cargo of two adjacent cargo holds are shown in Fig. 7.2.1.

#### 7.2 Procedure for preparation of Local Strength Diagrams

**7.2.1**
The procedures for determining limits to the loading of cargo holds given in the following are applicable for ships with additional class notation HC, HC/E or HC/EA, but may also be considered for bulk carriers without such additional class notation. The procedures have been based on the assumption that the structure comply with class requirements for the ship's design load conditions but not necessarily utilising any strength margin, in particular at reduced draughts. In case such strength margin(s) exist, the local strength diagrams may alternatively be based on the stress response from the direct strength calculations reflecting the design mass and relevant draught.

**7.2.2**
It should be noted that the local strength diagrams generally do not apply for the carriage of ballast in the ballast hold.
Limit to mass of cargo in cargo hold: The limit to the mass of cargo in hold is primarily related to the shear response of the double bottom floors and girders, and is largely given by the net pressure load exerted by cargo, other deadweight and buoyancy on the double bottom structure.

For seagoing cargo conditions the maximum allowable mass of cargo, \( M \), in tonnes at draught \( T_A \) in a given cargo hold and in the associated double bottom tank(s), may generally be taken as the larger of \( M_1 \) and \( M_2 \), which are given as follows:

\[
M_1 = M_R + 1.025 A_H (T_A - T_R + \alpha_T) \\
M_2 = M_D + 1.025 A_H (T_A - T_D + \alpha_T) \\
M_R = \text{Rule minimum limit for allowable mass of cargo in hold} \\
M_D = \text{maximum} \\
\rho_A = \text{the homogeneous bulk cargo density in tonnes per m}^3 \\
T_R = \text{Rule draught in m associated with cargo mass } M_R \\
T_D = \text{vessel scantling draught in m} \\
M_D = \text{specified maximum mass of cargo in hold, e.g. for loaded holds in the specified empty hold condition} \\
T = \text{vessel scantling draught in m} \\
T_D = \text{vessel draught in m associated with cargo mass } M_D \text{ normally = scantling draught} \\
A_H = V_H / h_{IN} \\
\alpha_T = \text{trim allowance} \\
\alpha_T = 0.005 \left| x_H - L/2 \right| \\
x_H = \text{distance from A.P to middle of considered hold}
\]

\[ V_H = \text{hold volume in m}^3 \text{ including volume of hatch} \]
\[ V_{MW} = \text{hold volume in m}^3 \text{ to deck level} \]
\[ h_{IN} = \text{hold height from inner bottom to deck at centre line} \]

For ships with notation HOLDS ........ EMPTY, where a reduced bending moment limit has been assigned for the condition(s) with empty cargo hold(s) at maximum draught, both limits to the mass of cargo in the loaded hold(s) should be included in the local strength diagrams.

The higher allowable mass limit may then only be applied if the still water bending moments within the considered loaded hold and the adjacent empty hold(s) do not exceed the reduced still water bending moment limits. For intermediate still water bending moment values (between the two bending moment limits), the allowable mass of cargo in the loaded hold may be taken as:

\[ M = M_1 + (M_1 - M_2) \cdot (M_{SC} - M_{SR}) / (M_{SF} - M_{SR}) \]

\[ M_{SC} = \text{Maximum calculated still water bending moment within the length of the considered hold and adjacent empty cargo hold(s).} \]
\[ M_{SF} = \text{Allowable still water bending moment at the location of } M_{SC}. \]
\[ M_{SR} = \text{Allowable reduced still water bending moment at the location of } M_{SC}. \]

The maximum allowable mass in tonnes of a cargo hold and the associated double bottom tank(s), \( M_H \), in harbour condition may generally be taken as:

\[ M_H = 1.15 M \]

For all cargo holds of bulk carriers with no additional class notation, with additional class notation HC, and for the loaded holds of the alternate condition(s) in bulk carriers with additional class notation HC/E, the required minimum mass of cargo, \( M_M \), in tonnes in seagoing conditions is given by:

\[ M_M = 1.025 A_H (T_A - T_R) \]

\[ = 0. \text{ minimum} \]

For the empty holds of ships with additional class notation HC/E where a reduced still water bending moment limit has been specified for the alternate load condition, the required minimum mass of cargo, \( M_M \), in tonnes in seagoing conditions is given by:

\[ \text{DET NORSKE VERITAS} \]
$M_M = 1,025 A_H \left( T_A - T + \left( T - T_R \right) \left( M_{SC} - M_{SR} \right) / \left( M_{SF} - M_{SR} \right) \right)$

$M_M$ may be taken = 0 for all values less than $1,025 A_H \left( T_A - T_R \right) / 5$

For ships with additional class notation HC, HC/E or HC/EA no minimum mass of cargo is required for any cargo hold in harbour conditions, i.e. any cargo hold may be empty at maximum draught. For bulk carriers without additional class notation the minimum mass of cargo, $M_{MH}$, of any hold in harbour condition is given by:

$M_{MH} = 1,025 A_H \left( T_A - T_R \right) / 1,2$

= 0. Minimum

7.2.4

Limit to mass of cargo in two adjacent cargo holds: The limit to the mass of cargo in two adjacent holds is primarily related to the shear response of the transverse bulkhead at its attachment to the side structure, and to the normal stress response of the cross deck structure (mainly) at centre line. Both responses are governed by the net vertical force exerted by weight of cargo and other deadweight (mass in double side tanks excluded) and by the vertical buoyancy force within the considered hold lengths. Note that the formulas given in the following do not apply for conditions where the mass considered include ballast water carried in a ballast hold.

7.2.5

For seagoing conditions the allowable combined mass of cargo, $M_C$, in tonnes at draught $T_A$, of two adjacent cargo holds may generally be taken as the larger of $M_{CI}$ and $M_{CII}$, which are given as follows:

$M_{CI} = M_R + 1,025 / b \left( T_A - T + \alpha_T \right)$
$= M_R$ maximum

$M_{CII} = M_D + 1,025 / b \left( T_A - T_D + \alpha_T \right)$
$= M_D$ maximum

$M_R$ = Rule minimum limit for allowable mass of cargo in the considered adjacent holds

= undefined if no additional class notation

= 1,125 $\rho_{DE} V_H$ for additional class notations HC and HC/E

= 1,250 $\rho_{DE} V_H$ for additional class notation HC/EA

$l$ = length of the considered adjacent holds in m. See Fig. 7.1.

$b$ = mean breadth of the two considered cargo holds in m at the level of the top of the hopper tank. See fig. 7.1.

$M_D$ = specified maximum mass of cargo of the considered adjacent holds.

The maximum allowable mass in tonnes of a cargo hold and the associated double bottom tank(s), $M_{CH}$, in harbour condition may generally be taken as:

$M_{CH} = 1,15 M_C$
$= M_{CH(max)}$ maximum

Unless a direct calculation of the bulkhead strength in the two adjacent hold empty condition is carried out, the required minimum mass of cargo, $M_{CM}$, in tonnes of adjacent cargo holds in seagoing conditions may be taken as:

$M_{CM} = 1,025 / b \left( T_A - T_B \right)$
$= 0$ minimum

$T_B$ = The largest design ballast draught in m.

The required minimum mass of cargo, $M_{CMH}$, in tonnes of adjacent cargo holds in harbour conditions is given by:

$M_{CMH} = M_{CM} / 1,20$
7.3 Local Tank Top Loading

7.3.1

Bulk Carriers are often designed to carry general cargo on inner bottom, e.g. steel coils, aluminum ingots etc., in addition to the normal homogeneous, alternate and block-loading mode. For that reason owners may have specified a maximum tank top pressure without specifying the purpose. If such tank top pressure is used as basis for calculating the maximum mass in the holds, ref. formula given in Pt.5 Ch.2 Sec.5 A200, this maximum mass may exceed the maximum mass applied for the different loading conditions in the loading manual.

For the purpose of handling such cases the following procedure may be applied:

1) For girdle strength control the hold maximum mass should reflect the extreme loading conditions as given in the loading manual. Ref. Chapter 3 in this Note.

2) Inner bottom plating and stiffeners are to be designed for the specified maximum tank top pressure. The latter assume that this pressure is greater than pressure caused by the cargo mass given in the loading manual.

Regarding loading of slabs and ingots such cargoes is normally stowed on dunnage and the amount of such cargoes is rarely specified. However, if strength calculations or load limitations are requested, such strength calculations should be based on the actual footprint loading.

If steel coil loading has been specified the requirement to thickness of inner bottom plating and stiffeners will be related to the mass, breadth, the number of tiers of steel coils and the number of dunnages arranged beneath each coil.

All above load limitations are to be clearly stated in the appendix to class certificate.
HC/E (ore hold)
The upper line is the limitation when the hold is loaded with ore $M_D$ and a reduced allowable still water bending moment has been assigned.

The lower limitation covers the limitation when the hold is loaded with rule minimum mass $M_R$ and combined with full rule still water bending moment.

HC/E (empty hold)
Typical local strength diagram for an empty hold.

HC and HC/E (two adjacent holds)
Typical local strength diagram for two adjacent holds.

Figure 7.2 Typical local strength diagram
8. Wave Torsion induced Stresses in Crossdeck of Conventional Bulkcarriers.

8.1 General

8.1.1

For bulkcarriers of conventional type, the torsional stiffness of the hull is mainly related to the effective St Venant's moment of inertia of the hull, which is greatly increased compared to that of the typically open ship, as a consequence of the rigid cross deck structure.

8.1.2

The torsional deformation of a hull structure with large hatch openings is primarily characterized by an in plane deformation of the deck, giving rise to large horizontal shear forces and bending moments in the crossdeck structures.

8.2 Stress of crossdeck

8.2.1

The normal stress, \( \sigma \), of the crossdeck structure should generally be considered for critical sections within the breadth of the hatch opening. It is generally determined according to the following formula:

\[
\sigma = \sigma_D + \sigma_T \quad (\text{N/mm}^2).
\]

\( \sigma_D \) = normal stress in crossdeck due to load case caused by maximum vertical bending of bulkhead at the position considered. Ref. load cases LC1, LC3, LC4 or LC12 as applicable. Alternatively, as calculated according to B.5.5 of B.5 for maximum bending moment \( M_{BD} \) in the transverse bulkhead at the section considered according to the double bottom (or equivalent) calculation, see B.1-B.4.

\( \sigma_T \) = torsional induced stress in crossdeck at section considered. Alternatively, as calculated according to 8.2.2 for conventional bulkcarriers.

8.2.2

For a conventional bulkcarrier, the bending stress of crossdeck induced by the torsional deformation, \( \sigma_T \), may be related to the rate of twist of the hull, \( \phi_T \), by the following equation:

\[
\sigma_T = \frac{12 f_t}{Z_{CD}} \frac{E I_{CD} (Z_s + D)(1 + \delta_w) \phi_T}{Z_{CD} b_T^3 (t + \alpha_t)}
\]

\( f_t = \frac{2 I_{CP} b_t (1 + \alpha_t)}{2 I_{SD} b_t (1 + \alpha_t) + I_{CP} h (1 + \alpha_t)} \)

\( G \) = material shear modulus.

\( I_{CD} \) = (mean) moment of inertia of crossdeck about vertical axis. The hatch end coaming and hatch end beam may generally be included in the inertia calculation.

\( I_{SD} \) = moment of inertia of upper deck outside of hatches about vertical axis. The hatch side coaming, top wing tank plating vertical strake and ship side within the half height of the to wing tank may be included in the inertia calculations.

\( t_s \) = thickness of upper deck plating at side.

\( y \) = distance from central line to considered section on crossdeck.

\( Z_{CD} \) = section modulus of crossdeck about vertical axis with respect to considered section.

\( \sigma_1 = \frac{12 E I_{CD}}{b_T^3 G A_{CD}} \)

\( \sigma_2 = \frac{12 E I_{SD}}{b_T^3 G A_{SD}} \left( \frac{1}{b_T} + \frac{b_T}{b_{bd} b_{td} t_s} \right) \)

\( \delta_w = \frac{2 \Omega t_s}{(B - b_{bd}) b_T (Z_s + D)} \)

\( \Omega \) = unit warping of the deck at the hatch side coaming according to shear flow analysis of hull cross-section.

\( A_{CD} \) = horizontal shear area of crossdeck, generally deck plating only.

\( A_{SD} \) = horizontal shear area of upper deck plating outside of hatches.

For further definition of terms, see Fig. 8.1
8.2.3
The wave torsion induced shear response in the cross deck should generally be considered in combination with the shear stress response due to lateral bulkhead loading and still water torsion loading as applicable. The wave torsion induced shear stress in cross decks may in addition have to be considered with respect to the fatigue life in way of stress concentration areas such as access openings. The shear stress, $\tau_T$, in the crossdeck induced by the torsional deformation may be related to the rate of twist by the following equation:

$$\tau_T = \frac{12f_e E I_{CD}(r_e + D)(1 + \delta_w)}{AcD b_f^2 (1 + \alpha_f)} \phi'$$

8.2.4
The rate of twist of the hull, $\phi'$, is related conservatively to the hull girder torsional moment, $M_T$, by the following equation:

$$\phi' = \frac{k M_T}{R_D}$$

$k$ = fraction of the torsional moment that is supported through St. Venant's response of the model.

$R_D$ = 0.8 by the order of magnitude when related to the maximum wave torsional moment for conventional bulk carriers.

$M_T$ = maximum value for the wave torsional moment as given in the Rules Pt.3 Ch.1 Sec.5 B206 at probability of exceedance $10^{-8}$. (Note if the water plane area coefficient, $C_{swp}$, of the vessel is not known for the determination of $M_T$, the calculated value may generally be based on an assumed value for $C_{swp} = 0.9$.)

For definition of remaining terms it is referred to 8.2.2.

9. Shear force correction

9.1 General

9.1.1
For ships with several shear carrying elements such as single/double side and longitudinal bottom girders, the nominal shear force distribution among these elements may normally be decided based on "Shear Flow Calculation". The typical shear force distribution factors for the main shear carrying members of the hull, for various type of the vessel can be found from the Table D1 of the Rules Pt.3 Ch.1 Sec.5.

However, for ships covered by this Classification Note, the actual shear force distribution of the ship side structure for various loading conditions will be different from those calculated by "Shear Flow Calculation", where the 3-D effect of the load distribution on bottom structure is not considered. Therefore, for a correct shear strength evaluation, the corrected shear force has to be calculated taking into account the local load distribution. The Rule Pt.3 Ch.1 Sec.5 D200 describe the principle of this shear force correction.

This part of the note will provide the background and/or additional information to the Rules.

9.2 Definitions

9.2.1 Symbols

$I_N$ = moment of inertia in cm$^4$ about the transverse neutral axis

$S_N$ = first moment of area in cm$^3$ of the longitudinal material above or below the horizontal neutral axis, taken about this axis

$I_N/S_N$ = refer to neutral axis and is calculated in the program "Section Scantlings" or may be taken as 90D

$Q_s$ = conventional (not corrected distribution of local load in hold(s)) stillwater shear force in kN

$\Delta Q_s$ = shear force correction due to distribution of local loads in hold(s)

$Q_W$ = rule wave shear force in kN as given in Pt.3 Ch.1 Sec.5 B200

$\phi$ = shear force distribution factor for the effective longitudinal shear carrying elements in the hull girder, see Pt.3 Ch.1 Sec.5 D103

$t$ = thickness of effective longitudinal shear carrying element

$\tau$ = allowable shear stress, the lesser of $(1.1f'_1$ and $0.9\tau_{cu}$ (buckling stress))

![Figure 8.1 Bulk carrier deck / hatch arrangement](image-url)
9.3 Rule Requirement

9.3.1

The rule requirement to thickness of ship side or double side as given in Pt.3 Ch.1 Sec.5 D103 of the Rules may be reformulated as follows:

\[ Q_s = \frac{t \cdot I_N}{\phi 100} S_N - Q_w \]

The right hand side of the equation may be considered to express the still water shear force capacity \( Q_{allowable} \) of the hull in way of the considered section. The method for establishing allowable shear force curves is described in chapter 9.4.

The left hand side express the actual "Corrected Shear Force" which could be further simplified into \( Q_s \pm (K_Pc) \).

The procedure to determine \( (K_Pc) \) is described in chapter 9.5.

9.4 Allowable Shear Force

9.4.1 Seagoing condition

With reference to the formula above the allowable still water shear force can be expressed as follows

\[ Q_{allowable} = \frac{t \cdot I_N}{\phi 100} S_N - Q_w \]

where

\( t \) is the smallest thickness as described in the text below. Other symbols are as given in 9.2.

In the following a description is given for deciding the thickness, \( t \), to be used in the above formula.

9.4.2 Harbour condition

The allowable still water shear force in harbour conditions will be obtained according to the same formula and principles as given in 9.4.1 except that the wave shear force, \( Q_w \), is reduced to 50% for the sections in question.

9.5 Corrected Shear Force

9.5.1 General

With reference to the formula in 9.3 the corrected shear force, \( Q_{S,C} \), can be expressed as follows

\[ Q_{S,C} = Q_S \pm (K_Pc) \]

where

\( Q_S \) is the uncorrected shear force or the shear force normally found in the loading manual. The sign convention for \( Q_S \) and \( Q_{S,C} \) is as described in our rules Pt.3 Ch.1 Sec.5 B100 (weight of hull aft of considered section exceeding buoyancy \( \rightarrow \) positive), "+" applies for the corrected shear force at fore end of the hold, and "-" applies to the corrected shear force at aft end of the hold.

The shear force correction, \( (K_Pc) \), will be further described below for typical Bulk Carrier construction, i.e. single and double side construction.

9.5.2 Bulk Carriers, single/double side construction

The correction, \( (K_Pc) \), to the nominal shear force may be expressed as follows:

\[ t_1, t_2 \] are the thickness of the ship side as indicated in Figure 9.1

\( t_{30} \) are situated above D/2 for the ship. Due to the reduction in shear stress value when moving above D/2, the plate thickness above D/2 may be corrected as shown below.

\[ t_{KPC} = \frac{t_1}{0.9 + 0.1 \cdot (0.5D - y)} \]

\( y \) vertical distance from D/2, see Fig. 9.1

Double side Bulk Carrier:

The thickness to be used in the formula for \( Q_{allowable} \) for double side Bulk Carriers should be substituted by the sum of side and inner side plate thickness. The allowable stress, \( \tau \), should be as defined in 9.2, noting that the critical buckling stress refers to the individual plate thickness.

9.5.2 Bulk Carriers, single/double side construction

The correction, \( (K_Pc) \), to the nominal shear force may be expressed as follows:

\[ t_1, t_2 \] are the thickness of the ship side as indicated in Figure 9.1

\( t_{30} \) are situated above D/2 for the ship. Due to the reduction in shear stress value when moving above D/2, the plate thickness above D/2 may be corrected as shown below.

\[ t_{KPC} = \frac{t_1}{0.9 + 0.1 \cdot (0.5D - y)} \]

\( y \) vertical distance from D/2, see Fig. 9.1

Double side Bulk Carrier:

The thickness to be used in the formula for \( Q_{allowable} \) for double side Bulk Carriers should be substituted by the sum of side and inner side plate thickness. The allowable stress, \( \tau \), should be as defined in 9.2, noting that the critical buckling stress refers to the individual plate thickness.

9.5 Corrected Shear Force

9.5.1 General

With reference to the formula in 9.3 the corrected shear force, \( Q_{S,C} \), can be expressed as follows

\[ Q_{S,C} = Q_S \pm (K_Pc) \]

where

\( Q_S \) is the uncorrected shear force or the shear force normally found in the loading manual. The sign convention for \( Q_S \) and \( Q_{S,C} \) is as described in our rules Pt.3 Ch.1 Sec.5 B100 (weight of hull aft of considered section exceeding buoyancy \( \rightarrow \) positive), "+" applies for the corrected shear force at fore end of the hold, and "-" applies to the corrected shear force at aft end of the hold.

The shear force correction, \( (K_Pc) \), will be further described below for typical Bulk Carrier construction, i.e. single and double side construction.

The calculated \( (K_Pc) \)-value should be considered in connection with the peak values of the conventional shear force curve at the transverse cargo hold bulkheads.

9.5.2 Bulk Carriers, single/double side construction

The correction, \( (K_Pc) \), to the nominal shear force may be expressed as follows:

\[ t_1, t_2 \] are the thickness of the ship side as indicated in Figure 9.1

\( t_{30} \) are situated above D/2 for the ship. Due to the reduction in shear stress value when moving above D/2, the plate thickness above D/2 may be corrected as shown below.

\[ t_{KPC} = \frac{t_1}{0.9 + 0.1 \cdot (0.5D - y)} \]

\( y \) vertical distance from D/2, see Fig. 9.1

Double side Bulk Carrier:

The thickness to be used in the formula for \( Q_{allowable} \) for double side Bulk Carriers should be substituted by the sum of side and inner side plate thickness. The allowable stress, \( \tau \), should be as defined in 9.2, noting that the critical buckling stress refers to the individual plate thickness.
The \((KP_c)\)-value is always to be deducted from the peak-values of the conventional shear force curve in way of loaded hold between empty holds or empty hold between loaded holds.

For practical purposes \(C_p\) and \(C_0\) may be taken as constants independent of cargo filling height and draught respectively.

The following values may be used:

\[
C_p = \frac{(9.81 \, C \, B_{DB} \, L_H \, H)}{V_H} \quad (\text{kN/t})
\]

\[
C_0 = \frac{10 \, C \, B_{DB} \, L_H}{(\text{kN/m})}
\]

\[
C = \frac{B/(2.2 \, (B + L_H))}{\text{(for conventional designs)}}
\]

\[
B_{DB} = \text{breadth of the flat part of the double bottom in m.}
\]

\[
L_H = \text{length of hold in m.}
\]
Appendix A. Checklist for Finite Element Analysis

A.1 Guidelines for use of checklist for FE analysis

A.1.1

The checklist is developed as an aid to ensure a satisfactory level of technical quality of work for analysis performed by the FE method. The checklist may also function as guidance for the process of completing FE analysis.

It is recommended that the checklist is used for self-checking by the one performing the analysis, and preferably by those performing independent verification.

### CHECKLIST FOR GEOMETRY, MESH AND ELEMENT PROPERTIES

**STRUCTURAL PART:**

Reference drawings:

Directory:

Input and model file names:

FEM file name:

**Units (have been checked):**

<table>
<thead>
<tr>
<th>Length</th>
<th>Mass</th>
<th>Time</th>
<th>Force</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>[mm]</td>
<td>[t]</td>
<td>[s]</td>
<td>[N]</td>
<td>[N/mm²]</td>
</tr>
</tbody>
</table>

**Constants (have been checked):**

<table>
<thead>
<tr>
<th>Gravity</th>
<th>Density (steel)</th>
<th>Young's mod.</th>
<th>Thermal exp. coeff.</th>
<th>Poisson's ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>9810 [mm²/s²]</td>
<td>7.85E10⁻⁹ [l/mm³]</td>
<td>2.1E10⁻⁶ [N/mm²]</td>
<td>0.0</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Scantlings:**

Net scantlings applied/ not applied

**Check of nodes:**

Spot checks of coordinates for key-nodes and nodes at border lines have been performed.

**Check of elements:**

Elements have been checked for having correct material.

Elements have been checked for having correct thickness ( membrane/shell) or cross section properties (truss/beam).

Truss/beam elements have been checked for having correct eccentricity.

Free flange sectional area has been checked for efficiency of curved flanges.

Secondary elements ( buckling stiffeners) have been checked for having correct efficiency according to end connection (sniped/welded).

**Boundary conditions:**

The boundary conditions given ( fixations) have been checked.

Spring constants calculated according to prevailing Class Note used/ not used.

**Loads:**

Load directions are found to be correct.

**Plots:**

Plots of element mesh with thickness (colour plots or by numerical value on elements) and boundary conditions are submitted with the checklists.

There is conformance between drawings and plots.

Structural part accepted: ____________________________ date: ____________________________ sign.
### CHECKLIST FOR LOADS

<table>
<thead>
<tr>
<th>Structural part:</th>
<th>Controlled by / date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loads:</td>
<td></td>
</tr>
<tr>
<td>Hand calculations or other program calculation for each basic load case are compared with the results from data check performed by the solver.</td>
<td></td>
</tr>
<tr>
<td>Load directions are found to be correct.</td>
<td></td>
</tr>
<tr>
<td>The sum of loads from data check are checked.</td>
<td></td>
</tr>
<tr>
<td>Super-elements are/are not mirrored or rotated.</td>
<td></td>
</tr>
<tr>
<td>Loads are checked for mirrored and rotated super-elements.</td>
<td></td>
</tr>
<tr>
<td>Prints with data check of all load cases is submitted with the checklists.</td>
<td></td>
</tr>
</tbody>
</table>

Loads and load application are accepted: date: ____________ sign.

### CHECKLIST FOR LOAD COMBINATIONS AND RESULTS PRESENTATION

<table>
<thead>
<tr>
<th>Structural Part:</th>
<th>Controlled by / date:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plots:</td>
<td></td>
</tr>
<tr>
<td>Plots of structural part with <em>deformed shape</em> in proper scale are submitted with the checklists.</td>
<td></td>
</tr>
<tr>
<td>Plots of <em>transverse membrane stresses</em> of shell elements for relevant structural parts are submitted with the checklists (contour plots and/or plots with numerical values).</td>
<td></td>
</tr>
<tr>
<td>Plots of <em>shear stresses</em> for relevant structural parts are submitted with the checklists (contour plots and/or plots with numerical values).</td>
<td></td>
</tr>
<tr>
<td>Plots of <em>in-plane stresses</em> for relevant structural parts are submitted with the checklists (contour plots and/or plots with numerical values).</td>
<td></td>
</tr>
<tr>
<td>Plots of <em>equivalent (von-Mises)</em> stresses for relevant structural parts are submitted with the checklists (contour plots and/or plots with numerical values).</td>
<td></td>
</tr>
<tr>
<td>Plots of <em>axial stress</em> of free flange for relevant structural parts are submitted with the checklists (contour plots and/or plots with numerical values).</td>
<td></td>
</tr>
</tbody>
</table>

**Stresses / forces:**

Spot checks of the calculated stresses have been compared to values calculated by simplified methods.

Plots have been used to identify peak stresses.

Cross sectional forces and moments have been checked with simplified methods.

**Code checks / acceptance criteria:**

*Yield check of main structure performed based on relevant load cases and stresses. Hull girder stresses* added/not added manually.

*Yield check of secondary structure performed based on relevant load cases and stresses. Local bending has been taken into account.*

*Buckling check of transverse elements performed based on relevant load cases and stresses.*

*Buckling check of longitudinal elements performed based on relevant load cases and stresses. Hull girder stresses* added/not added manually.

*Fatigue check performed based on relevant load cases, stresses and available stress concentration factors.*

Analysis accepted: date: ____________
Appendix B. Beam Modelling

B.1 Beam modelling, general.

B.1.1
The 2-dimensional beam models, which may be applied for conventional bulk carriers, are as follows:

a) Transverse bulkhead structure, which is modelled as a framework model subjected to in plane loading, ref. B.2.

b) Double bottom structure, which is modelled as a grillage model, subjected to lateral loading, ref. B.3. Note that this calculation may utilize stiffness data and loads as calculated for the transverse bulkhead calculation mentioned under a) above. Alternatively, load and stiffness data for the bulkhead may be based on approximate formulae.

c) Top wing tank structure, which for ships without specified deck cargo, is calculated by a framework model of the top wing tank web frame subjected to in plane loading, ref. B.4.

B.1.2
Three-dimensional modelling may be applied instead of some or all of the 2-dimensional models referred above. It may be mentioned that 3-dimensional modelling for the double bottom structure may be utilised for improved description of the hopper and main frame region of conventional bulk carriers.

B.1.3
Three-dimensional models representing the total cargo hold structure of one or more cargo holds, should preferably be carried out as finite element models.

B.1.4
The symbols used in model sketches are described in Figure B.1.

B.1.5
For the formulae given in this section, consistent units are assumed used. The actual units to be applied, however, may depend on the structural analysis program used in each case.

B.1.6
The models should represent the "net" structure; i.e. the corrosion additions as specified in the Rules Pt.3 Ch.1 Sec.2 are to be deducted from the given scantlings.

B.1.7
Beam- and bar elements representing the stiffness of flanges are generally to be adjusted for effective width in accordance with the Rules Pt.3 Ch.1 Sec.3 C400.

For grillage type double skin structures, however, such as double bottoms stiffened by floors and longitudinal girders, full flange effectivity may normally be assumed for the elements representing the girders of the grillage.

B.1.8
The increased stiffness of girder elements with bracketed ends is to be properly taken into account by the modelling. The rigid length of beam elements in way of bracket regions, \( l_e \), may normally be taken as:

\[
\begin{align*}
  l_e &= l - d - l_n, \text{ see also Fig.B.2.} \\
  &= 0, \text{ minimum.} \\
  d &= \text{as given in Fig. B.2.} \\
  l_n &= \text{represents the shear induced bending flexibility of the bracket.} \\
  &= 0 \text{ in general} \\
  &= \frac{2.6}{A} \frac{l}{I}, \text{ if considered element is } l \text{ to all other elements representing the bracket region, and the } l_n \text{ of these elements are taken } = 0 \text{.} \\
  l &= \text{moment of inertia of considered girder element.} \\
  A &= \text{area of the bracket region including adjacent girder webs.} \\
  t &= \text{thickness (mean) of bracket and adjacent girder webs.}
\end{align*}
\]

B.1.9
The additional girder bending flexibility associated with the shear deformation of girder webs in nonbracketed corners and corners with limited size softening brackets only should normally be included in the models as applicable.

The bilge region of transverse girders of open type bulk carriers and longitudinal double bottom girders supporting transverse bulkhead represent typical cases where the web shear deformation of the corner region may be of significance to the total girder bending response, see also Fig. B.3. The additional flexibility may be included in the model by introducing a rotational spring, \( K_{RC} \), between the vertical bulkhead elements and the attached nodes in the double bottom, or alternatively by introducing beam elements of a short length, \( l' \), and with cross-sectional moment of inertia, \( I \), as given by the following expressions:

\[
K_{RC} = b_1 b_2 t G
\]

\[
l' = \frac{b_1 b_2 t I G}{E}
\]
B.1.10

It is important to use a short element with above properties as this approach assumes constant moment over the element length. The modelling shall generally take into consideration relevant effects due to variation in element web height over its length as applicable. Unless special beam elements with varying web height are available, members with varying height should preferably be represented by a grid as shown in Fig. B.4, which shows a typical bulkhead lower stools.

The proposed meshes are appropriate for stools, which are stiffened by diaphragm plates with varying sized lightening holes. The purpose of the horizontal system lines is to connect the elements representing the stool side plating and stiffeners (flange effect) with the elements representing the web plating of the stool to form an integrated structural system. The horizontal elements should be made rigid compared to the vertical elements representing the web plating, but should not have excessive shear area and moment of inertia (in order to avoid numerical problems in the solution process).

The necessary number of rigid horizontal elements depends on the shape of the structure. Normally, however, 4-5 horizontal elements as indicated in Fig. B.4 should be enough for a satisfactory model representation.

B.1.11

In simplified two-dimensional modelling, possible three-dimensional effects caused by supporting girders etc. are normally represented by springs.

The spring stiffness, $K_G$, of axial springs representing supporting girders may normally be given by the following formula:

$$K_G = \frac{\epsilon_1 EI_{sm}}{l^2 \left(1 + \frac{c_1 l^2}{A_s} \right)}$$

$\epsilon_1 = \frac{c_1 E I_{sm}}{l^2 \left(1 + \frac{c_1 l^2}{A_s} \right)}$

$I = \frac{1}{2} \frac{c_2 I_{sm}}{l^2}$

$L = \frac{1}{2} \frac{s_m}{l^2}$

$A_s = \frac{1}{2} \frac{I_{sm}}{l^2}$

$c_1 = 76.8$ for simple end condition for supporting girder.

$c_2 = 384$ for fixed end condition for supporting girder.

$c_2 = 50$ for simple support condition for supporting girder.

$c_2 = 250$ for fixed end condition for supporting girder.

B.1.12

In beam models the torsional stiffness of box structures is normally represented by beam element torsional stiffness, and in case of three-dimensional modelling sometimes by shear elements representing the various panels constituting the box structure. Typical examples where shear elements have been used are shown in Fig. B.7(a), while a conventional beam element torsional stiffness has been applied in Fig. B.7(b).

The torsional moment of inertia, $I_T$, of a torsion box may generally be determined according to the following formula, see also Fig. B.5.

$$I_T = \frac{\sum_{i=1}^{m} l_i s_i}{\sum_{i=1}^{m} s_i t_i}$$

$m = \text{no. of panels of which the torsion box is composed.}$

$l_i = \text{thickness of panel no. } i.$

$s_i = \text{breadth of panel no. } i.$

$t_i = \text{distance from panel no. } i \text{ to the centre of rotation for the torsion box. Note the centre of rotation must be determined with due regard to the restraining effect of major supporting panels (such as ship side and double bottom) of the box structure.}$

B.1.13

In two-dimensional modelling, the three-dimensional effect of supporting torsion boxes is normally represented by rotational springs or by axial springs representing the stiffness of the various panels of the box.

The spring stiffness, $K_T$, of a rotational spring representing a supporting torsion box is normally given by the following expression:

$$K_T = \frac{6G_{sm} I_T}{l^2}$$

$s_m = \text{breath assumed for two-dimensional model.}$

$l = \text{length of torsion box between supports.}$

$I_T = \text{as given in B.1.12}$

B.1.14

The rotational restraint by torsion boxes (e.g. top wing tank) may be represented by axial springs as indicated in Fig. B.6. The stiffness of the axial spring(s) is generally given by the following formula:

$$K_S = \frac{4G_{t b s_m}}{l^2}$$
\[
\begin{align*}
    l &= \text{length of torsion box between supports.} \\
    b &= \text{breadth of panel represented by spring considered.} \\
    t &= \text{thickness of panel.} \\
    s_{n} &= \text{breadth assumed for two-dimensional model.}
\end{align*}
\]

In case the axial spring direction may not be correctly defined in the program applied, the spring should be replaced by an area element of the equivalent cross-sectional area and extending in the desired spring direction to a fixed support. The cross-sectional area, \( A \), of the area element is generally given by:

\[
A = \frac{K_{S}}{l}
\]

\[
\begin{align*}
    l &= \text{length of area element.}
\end{align*}
\]

---

**Figure B.1 Symbols**

- **Elements between Nodes**
- **Rigid End of Elements**
- **Rigid Elements**
- **Element Termed at Node**
- **Fixed Node**
- **Node with Fixed in Plane Rotation and X-Movement, Free Y-Movement**
- **Node with Fixed X- and Y-Movement, Free In Plane Rotation**
- **Node with Fixed Y-Movement, Free In Plane Rotation and X-Movement**
- **Node with Linear in Plane Restraint (Linear Spring)**
- **Node with Rotational In Plane Restraint (Rotational Spring)**
Figure B.2 Rigid end lengths of beam elements

Figure B.3 Nonbracketed corner model
Figure B.4  Element mesh representing tapering member (bulkhead stool)

Figure B.5  Torsional stiffness of box structure

Figure B.6  Spring modelling of supporting panels of torsion boxes
Figure B.7

(a)

3-D beam element model covering double bottom structure, hopper region represented by shear panels, bulkhead and deck between hatch structure. Lumped main frames

(b)

3-D beam element model covering double bottom structure, hopper region, bulkhead and deck between holds. Lumped main frames
B.2 Transverse bulkhead structures.

B.2.1
The transverse bulkhead is normally modelled as a two-dimensional structure. In such case the model normally represents the corrugation at centreline. Three-dimensional modelling including also the deck structure may be advisable in order to determine the variation in the support stresses of the bulkhead corrugation at the lower and upper stool over the breadth of the hold, or for instance to represent special load conditions including such as the moment exerted by a crane pedestal and or deck loads.

B.2.2
Fig. B.8 shows a sketch of a typical transverse bulkhead design and the corresponding two-dimensional beam model. For calculation of the watertight bulkhead loading, LC9, the fixed support condition should generally be assumed at the lower bulkhead support at the inner bottom. For consideration of bulkhead strength for cargo load as given by load case LC5, the rotational displacement obtained for the double bottom calculation should be applied at the lower bulkhead support.

B.2.3
The element mesh pattern of the stool should generally be made in accordance with B.1.10. Note that in the regions where each stool side is supported by separate webs, the sloping system lines should represent the complete stiffness of the webs including the plate flanges.

B.2.4
As indicated in Fig. B.8, it is normally sufficient to represent the bulkhead support at the deck by a simply supported node. Note, however, that the deck support should in principle be positioned in the shear centre position of the crossdeck structure, which in cases with a high hatch end coamings or a large upper stool tends to be below the deck level. If the shear centre position of the crossdeck is not known, a support position at deck level is generally acceptable.

It should be noted that when an upper stool has been arranged, the torsional stiffness of the stool structure may be included as a rotational spring, $K_T$, as given in B.1.13, see also Fig. B.9.

The support by the hatch end coamings and transverse beam may be represented as axial springs as indicated in Fig. B.9, $K_B$, which according to B.1.11 for the corrugation at centreline (assuming simple support at the hatch side coaming) may be expressed as:

$$K_B = \frac{77EIs_m}{b_f\left(1+\frac{501}{b_f^2A_b}\right)}$$

$K_B$ = rotational stiffness at hatch end coaming, $E$ = modulus of elasticity, $I$ = moment of inertia of hatch coaming about horizontal axis, $b_f$ = hatchway breadth, $A_b$ = vertical shear area of hatch end coaming, $s_m$ = model breadth.

B.2.5
The two-dimensional bulkhead model is normally taken at the ship's centreline. The required model breadth will depend on the actual design in each case. It may be convenient to choose the breadth corresponding to the longitudinal bottom girder spacing. Note that the stiffness of corrugated bulkhead above the stool is in this case to be taken as a multiple of the stiffness of one corrugation.

B.2.6
The bulkhead calculation may be utilised in order to determine stiffness- and force data for the bulkhead to be applied for the double bottom grillage calculation. In this case the supporting moment at the lower support, $M_{RB}$, may be applied in the double bottom grillage calculation as a moment, $M_{RB}$, per double bottom girder as follows:

$$M_{RB} = \frac{M_{RB}s_g}{s_m}$$

$s_g$ = effective breadth of the double bottom side girder considered, $s_m$ = model breadth of bulkhead model.

The rotational constraining stiffness exerted by the bulkhead on the double bottom may be determined by subjecting the lower bulkhead support to a rotational displacement, $\theta$, as a separate load case. The rotation spring stiffness exerted by the bulkhead is then determined from the calculated supporting moment, $M$, by the formula:

$$K_{RB} = \frac{M_{s_g}}{\theta s_m}$$

B.2.7
If three-dimensional modelling is used, the transverse bulkhead model should be joined to the double bottom grillage model described in B.3 following. In such case short bending elements representing the shear flexibility of longitudinal double bottom girders below the bulkhead (stool) should be considered introduced as described in principle in B.1.9.
In the longitudinal direction the model should extend at least from the middle of one hold to the middle of the adjacent hold. Symmetry is assumed at both model ends.

In cases where the considered holds are unsymmetrical, due to an unsymmetrical lower stool, or due to an unsymmetrical floor arrangement, an increased model length extending over one complete hold and two half hold lengths should be considered. Alternatively, if a model extending over 2 half hold lengths is used, care should be exerted to ensure that longitudinal double bottom girders are modelled with their true effective span length between bulkhead corrugations. This may be obtained by modelling the bulkhead lower stool as an equivalent symmetrical structure, or by rearranging the floor spacing such that the midspan position is located at a floor or midway between two floors.

The vertical model support(s) is generally assumed at the transverse bulkhead(s) in the shear centre position of the half cross-section of the hull. The shear centre position of the half cross-section may be determined by a shear flow analysis.

For bulk carriers of conventional arrangement the distance of the support position outside of the side shell, $y_s$, is given approximately by the following expression:

$$y_s = \frac{B - b_1}{16}$$

where:
- $b_1 = \text{breadth of hatch opening (m)}$.

For open type double skin bulk carriers, the support point may be assumed at the mid-breadth of the wing tank.

**B.3 Double bottom structure.**

**B.3.1**

The double bottom structure is normally modelled as a grillage or as a part of a three-dimensional model covering the hopper and/or the transverse bulkhead and deck, in addition to the double bottom structure.

Three-dimensional modelling is preferable, and should generally be used for the hopper region unless the hopper tank is small. Similarly the inclusion of the transverse bulkhead structure into the double bottom model may be important for the correct assessment of shear forces in double bottom longitudinal girders and for the bulkhead member shear and bending response.

**B.3.2**

Fig. B.10 shows a typical double bottom grillage element mesh with the hopper tank modelled as a three dimensional structure. The model is to extend athwartships from the ship side to the centreline, where symmetry is assumed for relevant load conditions.

The vertical model support(s) is generally assumed at the transverse bulkhead(s) in the shear centre position of the half cross-section of the hull. The shear centre position of the half cross-section may be determined by a shear flow analysis.

For bulk carriers of conventional arrangement the distance of the support position outside of the side shell, $y_s$, is given approximately by the following expression:

$$y_s = \frac{B - b_1}{16}$$

where:
- $b_1 = \text{breadth of hatch opening (m)}$.

For open type double skin bulk carriers, the support point may be assumed at the mid-breadth of the wing tank.
B.3.5
Adjacent floor elements of the grillage model are assumed to be separated halfway between floors. The floors in line with stool sides have not been included in the model.

B.3.6
Transverse elements in way of pipe tunnels with separate bottom and inner bottom stiffening may be modelled as the other floor elements, except for the effective shear area, $A_s$, which should be taken as:

$$A_s = \frac{2.6}{l^2 + \sum_{1}^{2.6} \Sigma A_s}$$

where:

- \( l \) = span of transverse stiffeners in pipe tunnel.
- \( \Sigma J \) = sum of moments of inertia of bottom and inner bottom transverse stiffeners within the floor flange breadth.
- \( \Sigma A_s \) = sum of shear areas of bottom and inner bottom transverse stiffeners within the floor flange breadth.

B.3.7
The transverse bulkhead elements should represent the shear and bending stiffness of the bulkhead and the torsional stiffness of the lower stool and that part of the inner bottom below and adjacent to the stool which is not represented by the neighbouring floor elements.

The cross-sectional properties of the transverse bulkhead elements should generally be based on an assumed effective flange width for bottom, inner bottom and deck which does not exceed 20% of the vessel breadth. For corrugated bulkheads with a lower stool structure, the element moment of inertia and shear area of the transverse bulkhead may be determined according to B.5.4.

The torsional moment of inertia, $I_T$, of the bulkhead elements representing the lower stool should (in agreement with B.1.12) be determined according to the following formula, see also Fig. B.11.

$$I_T = \left( \sum_{i=1}^{6} \frac{\Sigma_{j=1}^{6} \Sigma_k}{} \right)$$

B.3.8
Adjacent longitudinal double bottom elements are assumed to be separated halfway between the girder webs. The sloping hopper side plate and the bottom plating outside of the hopper side girder should be disregarded when the hopper side girder element cross-sectional properties are determined.

The bending stiffness contribution of the bottom-and inner bottom longitudinals may be included by increasing the longitudinal girder web thickness as follows:

$$\Delta t_w = \frac{3(A_N + A_{it})}{2h_n} \left(1 - \frac{2h_n}{h_n}ight)$$

where:

- $A_N$ = sum of net cross-sectional area of bottom longitudinals within flange breadth of girder (corrosion margin deducted).
- $A_{it}$ = sum of net cross-sectional area of inner bottom longitudinals within flange breadth of girder (corrosion margin deducted).
- $h_n$ = distance from bottom plating to neutral axis of bottom longitudinals (plate flange disregarded).
- $h_{it}$ = distance from inner bottom plating to neutral axis of inner bottom longitudinals (plate flange disregarded).

The correct effective shear area for the girder is obtained by multiplying the element shear effectivity factor (if available) by:

$$\frac{t_w}{t_w + \Delta t_w}$$

B.3.9
For the elements representing the ship side and hopper region, an element with bending and shear stiffness in accordance with the half hull girder cross-section may be used. The torsional moment of inertia of the hopper tank, $I_T$, should be determined in accordance with B.1.12.

B.3.10
The stiffness and load effects from the side frames acting on the double bottom structure may be represented by rotational springs and nodal forces and moments described for the nodes representing the hopper webs at the hopper top.

B.3.11
In general, a 3-dimensional modelling of the web frames of hopper region should be applied. The torsional stiffness of the hopper tank should then be represented by shear elements (elements with large bending rigidity) with shear area equal to the cross-sectional area of the hopper side plate. The local axis of these elements should be defined in the plane of the hopper side.

B.3.12
The rotational spring stiffness representing the transverse bulkhead, $K_{rb}$, in accordance with B.2.6, may for each longitudinal girder be determined from the transverse bulkhead calculation.
B.3.13

The moment and the forces are to be applied for each longitudinal girder due to the lateral pressure by cargo on the transverse bulkhead may be determined from the transverse bulkhead calculation.

Figure B.10 Double bottom grillage element mesh
The two-dimensional modelling may be less well suited for bulkcarrier designs intended for cargo on deck and hatch where the hatch cover load is supported on the hatch end coaming structure, and in particular if the deck structure between hatches is also utilised for support of a deck crane pedestal. The two-dimensional model may also be insufficient when calculating the load cases LC6 and LC7 considering ballast in the ballast hold. In these cases it is advised that the deck structure including top wing tank is modelled as a three-dimensional structure.

B.4.4
In addition, the two-dimensional modelling may be insufficient in such cases where the hull girder bending gives rise to significant local bending and/or shear stresses in longitudinal deck members. Important in such respect could be designs where high hatch side coamings are combined with deep hatch side coaming girder brackets at transverse bulkheads for effective support of deck cargo loads etc.

B.4.5
Three-dimensional models of the top wing tank and deck structure should normally extend over minimum two half cargo hold lengths, and from the ship side to the centreline. The model should in addition include the side main frames and the transverse bulkhead structure at least as supporting springs. A finite element model is generally preferable, but beam formulations may also be utilised. When a beam model is used, it is important that the torsional stiffness of supporting panels of the top wing tank and bulkhead upper stool are properly included in the model in terms of element torsional moment of inertia as given in B.1.12 or by shear elements.

B.5 Stiffness Properties of Transverse Bulkhead Elements, including effect of Lower Stool.

B.5.1
The following gives an approximate formula for the determination of cross-sectional data for transverse corrugated bulkheads including the effect of the lower stool structure.

B.5.2
For the corrugated part, the cross-sectional moment of inertia, $I_B$, and the effective shear area, $A_B$, may be obtained as follows:

$$ I_B = \frac{H^2}{12} \frac{A_D A_L}{A_D + A_L} $$

$$ A_B = \frac{H b_2}{b_c} $$

$A_D$ = cross-sectional area of deck part.

$A_L$ = cross-sectional area of lower stool and bottom part.
\( H = \) distance between neutral axis of deck part and lower stool and bottom part.

\( t_c = \) mean thickness of bulkhead corrugation.

\( b_e = \) breadth of corrugation.

\( b_c = \) breadth of corrugation measured along the corrugation profile.

**B.5.3**

For the stool and bottom part, see Fig. B.12, the cross-sectional properties, \( I_s \) and \( A_s \), should be determined as normal. Based on the above, a correction factor, \( K \), may be determined by the formula:

\[
K = 1 + \frac{I_s}{I_B} \left( 1 + \frac{1001B}{A_B B^2} \right) = \frac{I}{I_B} \left( 1 + \frac{1001s}{A_s s^2} \right)
\]

**B.5.4**

By applying this factor, the cross-sectional moment of inertia, \( I \), and shear area, \( A \), of the transverse bulkhead as a whole are calculated to:

\[
I = K I_B
\]

\[
A = K A_B
\]

**B.5.5**

The normal stress in the upper deck, \( \sigma_D \), due to the bulkhead bending may be determined according to the following formula:

\[
\sigma_D = \frac{M_{SHD}}{K H A_D}
\]

**B.5.6**

Similarly the normal stress in the lower stool, \( \sigma_S \), due to the bulkhead bending may be determined according to the following formula:

\[
\sigma_S = \frac{M_{SHD}}{K} \left( \frac{1}{HA_L} + \frac{k_s (K - 1)}{Z_{LS}} \right)
\]

\( Z_{LS} = \) section modulus of lower stool with respect to position considered.

\( k_s = \) 1.0 for position below neutral axis of lower stool and bottom part.

\( = \) -1.0 for position above neutral axis of lower stool and bottom part.

![Figure B.12 Bulkhead double bottom grillage element definition](image-url)
B.6 Stress Analysis, general.

B.6.1
The analysis procedures described in the following refer to beam calculations carried out in accordance with B.1-B.4.

B.6.2
The described stress analyses generally refer to allowable stress limits given in the Rules. In addition compressive normal stresses and shear stresses shall be considered with respect to buckling in accordance with Pt.3 Ch.1 Sec.14 of the Rules, also for cases where no special reference to buckling control has been included in the text following.

B.6.3
In the following calculated forces and moments are assumed given in N and Nmm, and material scantlings referred in formulae are assumed to be net scantlings, i.e. corrosion additions as stated in the Rules Pt.3 Ch.1 Sec.2 D400 deducted.

B.7 Double bottom bending strength.

B.7.1
Allowable normal girder stresses as given in the Rules Pt.3 Ch.1 Sec.13 B400 and buckling requirements given in Pt.3 Ch.1 Sec.14 B200 and B400 are generally to be complied with. For the sum of longitudinal normal stress due to hull girder bending and longitudinal double bottom stress in nonhomogeneous loading conditions (Rule allowable stress = 190f; N/mm²), the still water hull girder stress may generally be based on the mean still water bending moment value, \( M_{SM} \), which for the middle of hold position is given by:

\[
M_{SM} = \frac{M_{S1} + M_{S2}}{2}
\]

\( M_{S1}, M_{S2} \) denote still water hull girder bending moments calculated for the aft and forward transverse bulkhead positions of the cargo hold for the loading condition being considered.

B.7.2
The transverse axial force of the double bottom structure due to external sea pressure on the sides need not be considered when the bottom panel is evaluated with respect to biaxial buckling in accordance with Pt.3 Ch.1 Sec.14B of the Rules, provided the inner bottom structure is able to effectively support the external sea pressure load.

B.8 Pipe tunnel strength.

B.8.1
The modelling technique applied normally reflects the transverse stiffness of the combined bottom and inner bottom structure in the pipe tunnel. Consequently, special stress analysis will be required to determine the local stress response.

B.8.2
The shear area of the pipe tunnel transverse members may normally be expressed as follows:

**Inner bottom transverse member:**

\[
\tau = \frac{2(F_1 - k)}{200A_1} \text{ (N/mm}^2\text{).}
\]

**Bottom transverse member:**

\[
\tau = \frac{2F_k + 1000p_s t_i}{200A_E} \text{ (N/mm}^2\text{).}
\]

\( F = \) mean calculated shear force (N) in floor in way of pipe tunnel.

\( \frac{F_k + E_J}{2s_F} = \) for pipe tunnels in the ships' centerline.

\( k = \) \( \frac{I_n}{I_E + I_I} \)

\( s = \) spacing in m of transverse stiffening members of in pipe tunnel.

\( s_F = \) mean spacing in m of double bottom floors in way of the considered transverse tunnel members.

\( t = \) span of transverse pipe tunnel members in m.

\( I_n, I_1 \) denote moment of inertia of stiffeners including plate flange in cm⁴.

\( A_E, A_1 \) denote shear area of stiffeners in cm².

Other symbols are illustrated in Fig. B.13.

Note the allowable shear stress is to be taken according to the Rules Pt.3 Ch.1 Sec.13 D400 (= 90 f; N/mm²).

B.8.3
The total normal stress of pipe tunnel transverse members may normally be determined according to the following formula:

**Inner bottom transverse member:**

\[
\sigma = \frac{F_1(t - k)}{Z_t} \frac{p_s t_i^2 10^3}{12} + \frac{c_{ab}(h_{ab} - 2h_b)}{h_{ab}} \text{ (N/mm}^2\text{).}
\]

**Bottom transverse member:**

\[
\sigma = \frac{F_k + p_s t_i^2 10^3}{Z_t} \frac{c_{ab}(h_{ab} - 2h_b)}{h_{ab}} \text{ (N/mm}^2\text{).}
\]
\( F_{ir} \) = as given in B.8.2

\( \sigma_{hb} \) = transverse stress (N/mm\(^2\)) in inner bottom in way of pipe tunnel according to double bottom calculation.

\( \sigma_{h} \) = transverse stress (N/mm\(^2\)) in bottom in way of pipe tunnel according to double bottom calculation.

\( h_{sb} \) = height in m of transverse inner bottom pipe tunnel member.

\( h_{b} \) = height in m of transverse bottom pipe tunnel member.

\( h_{db} \) = height of double bottom at pipe tunnel in m.

\( p_{c} \) = internal pressure from cargo as given in the Rules Pt.3 Ch.1 Sec.4 C400 for the load case considered.

\( p_{e} \) = external lateral sea pressure according to the load case considered.

\( Z_{b}, Z_{f} \) = section modulus of pipe tunnel members (cm\(^3\)).

Other symbols are defined under B.8.2 and in Fig. B.13.

Note the allowable normal stress is to be taken according to the Rules Pt.3 Ch.1 Sec.13 B400 (= 60 \( f_{t} \) N/mm\(^2\) in general).

---

**B.9 Strength of double bottom below transverse bulkhead stool.**

**B.9.1**

When vertically corrugated transverse bulkheads are subjected to lateral load, large support forces, \( P_{p} \), occurs by the bulkhead bending at the lower stool side or the corrugation flange (if no lower stool is fitted) attachment to the double bottom as illustrated in Fig. B.14.

The force, \( P_{p} \), may be determined from the calculated bending moment of the transverse bulkhead at the inner bottom, \( M_{b} \) (Nmm), as follows:

\[
P_{p} = \frac{M_{b}}{b_{s}} \quad \text{(N)}.
\]

\( b_{s} \) = breadth (mm) of stool at inner bottom.

For wide stools the force \( P_{p} \) will be balanced by the shear forces, \( F_{s1} \) and \( F_{s2} \), in the adjoining longitudinal bottom girder. For narrow stools the vertical stool side force may become very large giving rise to high shear stress in the web area below the stool. The nominal shear stress in the web may normally be determined as the larger of:

\[
\tau = \frac{P}{100 A_{s}} = \frac{P b_{s}}{100 h_{db} A_{h}} \quad \text{(N/mm\(^2\))}.
\]

\( P \) = \((2 P_{t} - (F_{s1} + F_{s2} + l_{p}) l_{b})/2 \quad \text{(N)}
\]

\( A_{s} \) = the (vertical) shear area of the longitudinal girder below stool in cm\(^2\).

\( = 10 (b_{sb} - b_{v}) \quad \text{cm}^{2} \).

\( A_{h} \) = the (horizontal) shear area of the longitudinal girder below the stool in cm\(^2\).

\( = 10 (b_{h} - b_{v}) \quad \text{cm}^{2} \).

\( h_{sb} \) = as given in B.8.3.

\( h_{v} \) = height in m of lightening hole arranged in double bottom girder below stool.

\( b_{v} \) = breadth in m of lightening hole arranged in double bottom girder below stool.

\( t \) = thickness of longitudinal double bottom girder below stool in mm.

\( F_{s1} \) and \( F_{s2} \) denote shear forces (N) of the longitudinal girder at the bulkhead stool, taken from the double bottom grillage calculation.
The allowable nominal shear stress is to be taken in accordance with the Rules Pt.3 Ch.1 Sec.13 B400 (\(= 100 f_1 \) N/mm\(^2\)).

**B.9.2**

Where the floors below the stool side are discontinuous, e.g. at pipe tunnels, large stress concentrations may occur when the normal force, \(P\), is transmitted from the stool to the double bottom. With reference to Fig. B.15, the nominal normal stress of the stool side, \(\sigma\), at inner bottom may be calculated to:

\[
\sigma = \frac{(b_h - b_w) P}{2 b_h b_w} \quad \text{(N/mm}^2)\]

\(b_h\) = breadth of stool side in mm corresponding to longitudinal girder.

\[
= \frac{b_h + b_w}{2}
\]

\(b_w\) = effective breadth considering continuity.

\(t_s\) = thickness of stool side plating in mm.

\(t_w\) = thickness of diaphragm plate in stool in line with considered longitudinal double bottom girder.

\(P_F\) = as given in B.9.1

The allowable normal stress may be taken in accordance with the Rules Pt.3 Ch.1 Sec.13 B400 (\(= 160 f_1 \) N/mm\(^2\)).

The nominal shear stress, \(\tau\), at the intersection between floor and longitudinal girder may be calculated to:

\[
\tau = \frac{P_F}{100 (A_{S1} + A_{S2})} \quad \text{(N/mm}^2)\]

\(A_{S1}\), \(A_{S2}\) denotes shear areas as indicated in Fig. B.15.

The allowable nominal shear stress may be taken in accordance with the Rules Pt.3 Ch.1 Sec.13 B400 (\(= 90 f_1 \) N/mm\(^2\)).
B.10 Shear strength of webs with cutouts.

B.10.1
The nominal shear stress, \( \tau \), in webs in way of scallops and holes may in general be calculated as:

\[
\tau = \frac{F_S}{100 A_s} \text{ (N/mm}^2\text{).}
\]

\( F_S \) = calculated shear force in N at section considered.

The allowable nominal shear stress for double bottom webs is to be taken in accordance with the Rules Pt.3 Ch.1 Sec.13 B400 (= 100 \( f_t \) N/mm\(^2\)).

B.10.2
For floor panels, a section parallel to the element axis may be decisive for the design shear stress. With reference to Fig. B.16 the nominal shear stress for the horizontal sections at neutral axis and bottom / resp. inner bottom may be calculated according to the following formulae:

\[
\tau = \text{nominal shear stress between stiffeners at neutral axis.}
\]

\[
= \frac{s F_S}{100 h_{db} A_{s1}} \text{ (N/mm}^2\text{).}
\]

\( s \) = effective thickness of bulkhead plating.

\( h_{db} \) = thickness of corrugation in way of corrugated part of bulkhead.

\( A_{s1} \) = plate thickness of diaphragm plate in the top wing tank.

\( h_{t1} \) = height of top wing tank in way of considered section.

\( f_t \) = effective thickness of bulkhead plating.

\( t \) = plate thickness of diaphragm plate in the top wing tank.

\( A_{s2} \) = critical horizontal sections of shear

\[
\tau = \text{nominal shear stress between stiffeners at bottom (or at inner bottom).}
\]

\[
= \frac{0.9 s F_S}{100 h_{db} A_{s2}} \text{ (N/mm}^2\text{).}
\]

The allowable nominal shear stress is to be taken as given in B.10.1.

Figure B.16 Shear stress analysis of girder webs with cutouts

B.11 Strength of transverse bulkhead.

B.11.1
The shear connection of the transverse bulkhead structure to the side shell, and compressive / tensile stresses in the transverse deck structure are matters of importance when the overall strength of the transverse bulkhead is evaluated. Both are of particular interest when the bulkhead is of the vertically corrugated type, and when special load conditions with two adjacent holds empty on a large draught or with two adjacent holds loaded (combined with one or more of remaining holds empty) have been specified.

Such load conditions have been calculated with respect to the double bottom strength as described in the following. The consideration of the bulkhead strength with respect to these load cases may therefore be based on the double bottom calculation results.

B.11.2
The nominal shear stress of transverse bulkheads (above the lower stool) is generally given by:

\[
\tau = \frac{F_{BHD}}{100 K (D - h_{db} - h_s) t} \text{ (N/mm}^2\text{)}
\]

\( F_{BHD} \) = maximum calculated shear force in the transverse bulkhead at the section considered according to the double bottom (or equivalent) calculation, see B1-B.4.

\( K \) = as given in B.5.

\( h_s \) = height of lower stool (m).

\( t \) = effective thickness of bulkhead plating.

\( h_{db} \) = height of double bottom as described in the following.

\( h_{t1} \) = height of top wing tank in way of considered section.

\( h_l \) = height of lightening holes in diaphragm plate in way of considered section.

The allowable nominal shear stress is to be taken in accordance with the Rules Pt.3 Ch.1 Sec.13 B400 (= 90 \( f_t \) N/mm\(^2\)). Within the top wing tank (above the top wing tank bottom), the nominal shear stress as calculated according to the above formula may generally be reduced by a factor = 1.5, by consideration of the partial support exerted by the top wing tank bottom panel.
B.11.3
The strength of the bulkhead corrugation in way of its attachment to the lower stool shall generally be considered in accordance with the Rules Pt.3 Ch.1 Sec.9 C 305. For stools with sloping stool top plate note in addition that the bending moment applicable for the control of stresses in way of the attachment of the corrugation to the stool need generally only be related to the bending moment at the level of the top of the sloped stool top plate.

B.11.4
The stress of the stool side plate at the attachment to the bulkhead corrugation may generally be determined based on the following formula:

\[ \sigma_{\text{stool}} = \frac{\sigma_{\text{corr}}}{t_{\text{stool}} \cos \beta} \]

- \( \sigma_{\text{corr}} \) = nominal bending stress in bulkhead corrugation at attachment to stool.
- \( t_{\text{corr}} \) = thickness of bulkhead corrugation, corrosion margin \( t_k \) deducted.
- \( t_{\text{stool}} \) = thickness of stool side plate, corrosion addition \( t_k \) deducted.
- \( \beta \) = angle of stool side plate with the vertical.

Generally the \( \sigma_{\text{stool}} \) should not exceed 1.2\( \sigma \), where \( \sigma \) denotes the allowable stress given in the Rules Pt.3 Ch.1 Sec.9 C 302.

B.12 Strength of main frames.

B.12.1
Generally the main frames of bulkcarriers are to comply with section modulus requirements as given in the Rules Pt.5 Ch.2 Sec.10 B. For ships with long cargo holds, the main frames will normally be subjected to considerable prescribed deformation caused by the rotational deformation of the hopper and top wing tanks. Such prescribed deformation occurs in particular for the empty holds and the ore holds in bulkcarriers in the alternate loading condition and for the condition with ballast cargo hold filled.

B.12.2
Main frames subjected to prescribed deformations shall comply with the allowable stress given in Pt.3 Ch.1 Sec.13 B400. The occurring stresses may be determined by including the main frames in the double bottom- or wing tank models described in B.1-B.4, or by separate direct calculation.