PART
3

CHAPTER 2 Hull Structures and Arrangements

APPENDIX 1 Calculation of Shear Stresses for Vessels Having Longitudinal Bulkheads

1 Methods of Calculation

The nominal total shear stress f_s in the side shell or longitudinal bulkhead plating is related to the shear flow N at that point, by the following equation:

f_s = N/t, kN/cm^2 (tf/cm^2, Ltf/in^2)

N = shear flow, kN/cm (tf/cm, Ltf/in.)

t = thickness of the plating, cm (in.)

3 Calculation of the Shear Flow Around Closed Sections

The shear flow of a closed and prismatic structure is expressed by the following equation.

N = $(Fm/I)+N_i$, kN/cm (tf/cm, Ltf/in.)

F = total shear force at the section under consideration, in kN(tf, Ltf)

m = first moment about the neutral axis of the section, in cm^3(in^3), of the area of the longitudinal material between the zero shear level and the vertical level, at which the shear stress is being calculated

m = $\int_o^p Zt \quad ds + \sum_{i=o}^{n} a_i z_i$ cm^3(in^3)

I = moment of inertia of the section, in cm^4(in^4)

N_i = constant shear flow around the cell regarded as an integration constant of unknown value arising from substituting the statically indeterminate structure by statically determinate one, in kN/cm (tf/cm, Ltf/in)

Z = distance from section neutral axis to a point in the girth, positive downward, in cm(in.)

a = equivalent sectional area of the stiffener or girder attached to the deck, shell and bulkhead plating, in cm^2(in^2)

s = length along girth and longitudinal bulkhead, in cm (in.)

5 Calculation of m

To calculate the value of m requires the knowledge or assumption of a zero shear point in the closed cell. As an example, in the case of a simplified tanker section, the deck point at the centerline is a known point of zero shear in the absence of the centerline girder. An arbitrary point may be chosen in the wing tank cell. Superposition of the constant N_i to the shear flow resulting from the assumption of zero shear point will yield to the correct shear flow around the wing cell.

7 Determination of N_i

N_i is determined by using Bredt's torsion formula, making use of the assumption that there is no twist in the cell section, i.e., the twist moment resulting from the shear flow around a closed cell should equal zero, or $\oint N\frac{ds}{t} = 0$. In a multicell structure of n number of cells, the formula can be written for the i^{th} cell as follows.

$$\oint N\frac{ds}{t} = \frac{F}{I}\oint_i m_i\frac{ds}{t} + N_{i-1}\int_{Div}\frac{ds}{t} + N_i\oint\frac{ds}{t} + N_{i+1}\int_{Div}\frac{ds}{t} = 0$$

Div = common division between cell i and the adjacent cells $i-1$ and $i+1$.

The first term represents twist moment around cell i at the assumed statically determined status. The m values are calculated upon arbitrary zero shear points in the cell i and the adjacent cells. The remaining terms in the equations represent the balancing twist moments around cell i and of those carried out by the common divisions in the adjacent cells $i-1$ and $i+1$.

To determine the constant shear flow in the cells N_1, N_2,. . . N_i,N_n,n number of similar equations are formed for each cell and are solved simultaneously.

PART

3

CHAPTER 2 Hull Structures and Arrangements

APPENDIX 2 Loading Manuals and Loading Instruments

Note: These requirements are intended to satisfy Regulation 10(1) of the International Convention on Load Lines, 1966 and are applicable for vessels with freeboard length, L_f, of 65 meters (213 feet) and above.

1 General

1.1 Application

The requirements in this Appendix apply to all classed cargo vessels 65 m (213 ft) and above in length that are contracted for construction on or after 1 July 1998.

Additional requirements in Appendix 3-2-A3 are applied to bulk carriers, ore carriers and combination carriers having a freeboard length (L_f) of 150 m (492 ft) and above. L_f is as defined in 3-1-1/3.3.

3 Definitions

3.1 Loading Guidance

Loading guidance is a generic term covering both loading manual and loading instrument, as defined below.

3.1.1 Loading Manual

A loading manual is a document containing sufficient information to assist the master of the vessel to arrange for the loading and ballasting of the vessel in such a way as to avoid the creation of any unacceptable stresses in the vessel's structure.

3.1.2 Loading Instrument

A loading instrument is an instrument designed to assess vessel's still water bending moments, shear forces and, where applicable, the still water torsional moments and lateral loads at the specified points along the length for the purpose not to exceed the specified values in any loaded or ballast condition.

3.3 Category I Vessels

Category I vessels are any of the following:

i) Vessels with large deck openings where combined stresses due to vertical and horizontal hull girder bending, torsional and lateral loads need be considered, such as container carriers.

ii) Vessels designed for non-homogeneous loading where the cargo and/or ballast may be unevenly distributed, except those belonging to 3-2-A2/3.5.iii. Examples of such vessel are bulk carriers, ore carriers and combination carriers.

iii) Vessels, such as oil carriers and fuel carriers, except those belonging to 3-2-A2/3.5.iii.

iv) Chemical carriers and gas carriers

3.5 Category II Vessels

Category II vessels are any of the following:

i) Vessels with such arrangements that only allow a small possibility for variation in cargo and ballast distribution, such as passenger ships.

ii) Vessels on regular and fixed trading pattern where the loading manual gives sufficient guidance, such as ro-ro ferries.

iii) Vessels less than 120 m (394 ft) in length, L, when their design takes into account the uneven distribution of cargo or ballast.

5 Loading Documents

5.1 Loading Manual

All vessels are to be provided with a loading manual reviewed and stamped by ABS in accordance with 3-2-A2/7, except for Category II vessels with deadweight not exceeding 30% of the displacement at the summer load line.

5.3 Modifications

Where modifications to the vessel or to the loading/trading pattern result in changes to the input information, a revised or new loading manual is to be submitted and a stamped copy is to be placed aboard the vessel to replace the existing manual. The loading instrument is to be verified in accordance with 3-2-A2/9.3 or newly installed and verified in such cases.

Where changes due to modification of the vessel are such that the still water bending moments and shear forces corresponding to the new loading conditions are within ±2% of the existing allowable values, the existing allowable values need not be modified.

7 Loading Manual

7.1 Required Information

The loading manual is to be based on the final data of the vessel and is to include at least the following information:

i) The loading conditions upon which the design of this vessel is approved.

ii) The results of the calculations of still water bending moments and shear forces.

iii) Permissible limits of still water bending moments and shear forces and, where applicable, limitations due to torsional and lateral loads.

iv) Maximum allowable local lower decks and double bottom loading.

v) If cargoes other than bulk cargoes are contemplated, such as different deck cargoes, they are to be listed together with any specific instructions for loading.

vi) Maximum allowable load on deck and hatch covers. If the vessel is not approved to carry load on deck or hatch covers, that fact is to be clearly stated in the loading manual.

vii) Information on the heavy ballast draft forward used for the fore-end strengthening required in 3-2-4/13.

7.3 Loading Conditions

The above information is to be based on the intended service conditions. See 3-2-A2/11 TABLE 1 for the selection of loading conditions.

7.5 Language

The loading manual is to be prepared in, or is to include, a language understood by the user. English may be considered to be a language understood by the user.

9 Loading Instrument

In addition to the loading manual indicated in 3-2-A2/5.1, Category I vessels of 100 m (328 ft) or more in length are to be provided with a loading instrument verified in accordance with 3-2-A2/9.

9.1 Type

A loading instrument is to be digital. A single point loading instrument is not acceptable.

9.3 Required Verifications

Before a loading instrument is accepted for the vessel, all relevant aspects of the instrument, including but not limited to, the following, are to be demonstrated to the Surveyor for his/her personal verification:

- That the instrument is type approved, where applicable
- That the instrument is based on the final data of the vessel
- That the number and position of read-out points are satisfactory
- That the relevant limits for all read-out points are satisfactory
- That the operation of the instrument after installation onboard, in accordance with the approved test conditions has been found satisfactory
- That approved test conditions are available onboard
- That an operational manual, which does not require approval, is available onboard for the instrument

9.5 Language

The operation manual and the instrument output are to be prepared in, or are to include, a language understood by the user. English may be considered to be a language understood by the user.

11 Annual Surveys

The requirements in 7-3-2/1.1.5 are to be complied with as follows:

At each Annual Survey, it is to be verified that the loading manual is onboard and, where applicable, a loading instrument is to be verified in working order. The operation manual for the loading instrument is also to be verified as being onboard.

TABLE 1
Loading Conditions in the Loading Manual

1.	The loading manual is to include at least	
1.1	full load conditions, for both departure and arrival conditions,	
1.2	ballast conditions, for both departure and arrival conditions (see also 1.5)	
1.3	any other critical loading conditions on which the design of the vessel is based.	
1.4	in-port conditions (see also 1.5.3)	
1.5	Intermediate conditions, including but not limited to	
	1.5.1	before and after any ballasting/deballasting during the voyage.
	1.5.2	ballast exchange and its sequence, where intended,

	1.5.3	during loading/unloading (for vessels in 2.1, 2.2 where applicable, and 2.5)
2.	The following conditions are to be considered for the particular type of vessel. The list does not preclude any loading conditions that are necessary for the particular service intended:	
2.1	Oil Carriers:	
	2.1.1	homogeneous cargo if consistent with the service of the vessel
	2.1.2	cargoes of typical densities within the expected range
	2.1.3	part loaded conditions
	2.1.4	short voyages (e.g. half bunker)
	2.1.5	tank cleaning conditions
	2.1.6	docking conditions afloat
2.2	Bulk Carriers, Ore Carriers, Container Carriers, Dry Cargo Vessels, Other Specialized Carriers:	
	2.2.1	homogeneous cargo if consistent with the service of the vessel
	2.2.2	cargoes of typical densities within the expected range
	2.2.3	heavy cargo with empty holds or non-homogeneous conditions
	2.2.4	short voyages (e.g. half bunker)
	2.2.5	deck cargoes
	2.2.6	docking conditions afloat
2.3	Liquefied Gas Carriers:	
	2.3.1	homogeneous loading for all approved cargoes
	2.3.2	with empty or partially filled tank(s)
	2.3.3	docking conditions afloat
2.4	Chemical Carriers:	
	2.4.1	conditions for oil carriers
	2.4.2	all approved high density cargoes
2.5	Combination Carriers	
	2.5.1	conditions as specified in 2.1 and 2.2 above.
2.6	Offshore Support Vessels	
	2.6.1	anchor handling operations
	2.6.2	pipe laying and/or seabed trenching
	2.6.3	outboard weights lifting either with use of heavy cranes or A-frames
	2.6.4	homogeneous cargo if consistent with the service of the vessel
	2.6.5	heavy deck cargo with empty holds and/or tanks or non-homogeneous conditions
	2.6.6	cargo deck and/or lower decks or inner bottom cargoes
	2.6.7	cargoes of typical densities within the expected range
	2.6.8	high densities cargoes
	2.6.9	part loaded conditions
	2.6.10	short voyages (e.g. half bunker)

2.6.11	tank cleaning conditions
2.6.12	docking conditions afloat

PART
3

CHAPTER 2 Hull Structures and Arrangements

APPENDIX 3 Loading Manuals and Loading Instruments: Additional Requirements for Bulk Carriers, Ore Carriers and Combination Carriers 150 Meters (492 Feet) and above in Length (L_f)

1 Application

The requirements in this Appendix apply to bulk carriers, ore carriers and combination carriers having a freeboard length (L_f), as defined in 3-1-1/3.3, of 150 m (492 ft) and above. Unless otherwise stated, these requirements are additional to those in Appendix 3-2-A2.

3 Required Loading Guidance

3.1 Loading Manual

All vessels are to be provided with a Loading Manual, reviewed and stamped by ABS in accordance with 3-2-A3/5.

3.3 Loading Instrument

In addition to the loading manual, all vessels of Category I are to be provided with a loading instrument calibrated in accordance with 3-2-A3/7.

3.5 Modifications

Where modifications to the vessel or to the loading/trading pattern affect the required information, a revised or new loading manual is to be submitted and a stamped copy is to be placed aboard the vessel, replacing where applicable the invalidated manual. The loading instrument is to be re-calibrated or newly installed and calibrated in such cases.

Where the difference in the calculated still-water bending moments or shear forces is within ±2% of the allowable value, those values may be considered as not being affected.

5 Loading Manual

5.1 Required Information

5.1.1 Permissible Limits

In addition to 3-2-A2/7.1, the loading manual is to include the following information:

5.1.1(a) For single side skin bulk carriers,

i) The permissible limits of still water bending moments and shear forces in the hold flooded condition in accordance with 5C-3-3/3.1 and 5C-3-A5a/1.

ii) The still water bending moment limits are to be presented in the form of an envelope curve for all combinations of loading conditions and flooded holds.

5.1.1(b) The cargo hold(s) or combination of cargo holds that might be empty at full draft. If it is not permitted to have an empty cargo hold at full draft, this is to be clearly stated in the loading manual.

5.1.1(c) Maximum allowable and minimum required mass of contents of each cargo hold and double bottom space in way thereof, as a function of the draft at the mid length of the hold.

5.1.1(d) Maximum allowable and minimum required mass of contents of two cargo holds and double bottom spaces forward and aft of any cargo hold bulkhead, as a function of the mean draft. This mean draft may be taken as the average of the drafts at the mid-length of two holds.

5.1.2 Loading Rate and Sequence

5.1.2(a) The maximum rate of ballast change

5.1.2(b) An instruction that a loading plan is to be agreed with the terminal on the basis of the achievable rates of change of ballast.

5.1.2(c) Typical sequence of loading from commencement to full deadweight or any contemplated part load conditions. Where applicable, homogeneous conditions and alternate loading conditions are to be included. The typical loading sequences shall be developed with due attention being paid to the loading rate, the deballasting capacity and applicable strength limitations. The Annex to this Appendix and 3-2-A3/7.1.4 TABLE 2 contain, as guidance only, an example of a Loading Sequence Summary Form and aspects that may be considered in developing the sequence.

5.1.2(d) Typical sequences for change of ballast at sea, where applicable.

5.3 Loading Conditions

The above information is to be based on the intended service conditions. See 3-2-A3/7.1.4 TABLE 1 for the selection of loading conditions, which replaces 3-2-A2/11 TABLE 1 for the vessels covered by this Appendix.

7 Loading Instrument

7.1 Required Verifications

In addition to 3-2-A2/9.3, at least the following aspects are to be demonstrated to the Surveyor for his/her verification:

7.1.1

That the instrument can easily and quickly perform calculations to determine that the permissible values at the specified points along the vessel will not be exceeded in any loaded or ballast condition;

7.1.2

That the relevant limits for the mass of contents of each cargo hold and double bottom spaces in way thereof, as a function of the draft at the mid-hold position, are satisfactory;

7.1.3

That the relevant limits for the mass of contents of two cargo holds and double bottom spaces forward and aft of any cargo hold bulkhead, as a function of the mean draft in way of these holds, are satisfactory;

7.1.4

Where applicable for single side skin bulk carriers, that the relevant limits for the still water bending moments and shear forces in any one hold flooded conditions in accordance with 5C-3-3/3.1 and 5C-3-A5a/1 are satisfactory.

TABLE 1
Loading Conditions in the Loading Manual For Bulk Carriers, Ore Carriers and Combination Carriers 150 Meters (492 Feet) and above in Length (L_f)

1.	The loading manual is to include at least the following loading conditions, upon which the design of the vessel is based.
1.1	full load conditions, subdivided into departure and arrival conditions
	1.1.1 cargoes of typical densities within the expected range
	1.1.2 alternate heavy cargo loading condition (see notes 1 & 5 below)
	1.1.3 alternate light cargo loading condition (see notes 2 & 5 below)
	1.1.4 homogeneous heavy cargo loading (see notes 3 & 5 below)
	1.1.5 homogeneous light cargo loading (see notes 4 & 5 below)
	1.1.6 short voyages (e.g. half bunker)
	1.1.7 deck cargoes
1.2	multiple port loading/unloading conditions, subdivided into departure and arrival conditions (see note 5 below)
1.3	ballast conditions, subdivided into departure and arrival conditions
1.4	critical loading conditions
1.5	intermediate conditions, including but not limited to
	1.5.1 before and after any ballasting/deballasting during the voyage
	1.5.2 ballast exchange and its sequence {see 5.1.2(a), (b) and (d)}
1.6	in-port conditions
1.7	docking conditions afloat
2.	The following conditions are to be considered for combination carriers, in addition to the conditions as specified above. The list does not preclude any loading conditions that are necessary for the particular service intended:
2.1	part loaded conditions (see note 5 below)

Notes:

1 Heaviest cargo can be carried and the draft is corresponding to the summer load water line. Loaded holds may not be filled completely with cargo.

2 Lightest cargo can be carried at the summer load water line. Loaded holds may or may not be filled completely with cargo.

3 Heaviest cargo loaded in all cargo holds at the same filling ratio (cargo volume/hold cubic capacity) and at the draft corresponding to the summer load water line. All loaded holds may not be filled up with cargo.

4 Homogeneous loading condition. All cargo holds are filled completely with cargo and the draft is corresponding to the summer load water line.

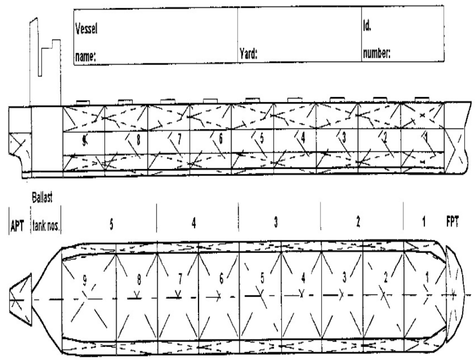
5 Conditions during loading/unloading are also to be included.

TABLE 2
Guidance on Loading/Unloading Sequences

1.	In addition to 3-2-A3/5.1.2(c), due attention is to be paid to the following items in the development of typical loading/unloading sequences being submitted for review.
2.	The typical sequences are to include, but not limited to, the following:
-	alternate hold light and heavy cargo condition
-	homogeneous light and heavy cargo condition
-	short voyage (full load with less than full fuel)
-	multiple port loading/unloading
-	deck cargo condition
-	block loading
3.	The sequences may be port specific if so desired.
4.	The sequence should include each and every stage from commencement to full deadweight or vice versa. Whenever the loading/unloading equipment moves to the next location, it constitutes the end of that stage. For each stage, longitudinal as well as local strength of double bottom are to be considered.
5.	for each stage, a summary highlighting the essential information such as the following is to be prepared:
-	the amount of cargo loaded/unloaded during that stage
-	the amount of ballast discharged/ballasted during that stage
-	the still-water bending moment and shearing forces at the end of the stage
-	trim and draft at the end of the stage

ANNEX Guidance on Loading Summary Sequence Form [see 3-2-A3/5.1.2(c)]

Vessel name:	Yard:	Id. number:



Port (specific or typical):	Condition at commencement of loading/discharging	
Total mass of cargo to be loaded/discharged:	Condition at end of loading/discharging	
Dock water density (t/m3):	Maximum Loading/discharging rate:	Average Loading/discharging rate:
Number of loaders/dischargers:	Maximum Ballasting/Deballasting rate:	Average Ballasting/Deballasting rate:

Volume of Hold, Vh (m3)									
Height of hold,h (m)									

Note: During each pour allowable limits for hull girder shear forces, bending moments and mass in holds are not to be exceeded.
Loading/discharging operations may have to be suspended temporarily to allow for ballasting/deballasting in order to keep actual values within limits.

	Hold content at commencement of loading/discharging								
Cargo mass									
Density (t/m3)									
Grade									

Ballast content at commencement of loading/discharging									
Wings or peaks	APT	Ball. no. 5	Ball. no. 4	Hold no. 6	Ball. no. 3	Hold no. 4	Ball. no. 2	Ball. no.1	FPT
Upper									
Lower/Peaks									

Commencement of loading/discharging (sea)				
d aft	Trim	d fwd	Maximum	
(m)	(m)	(m)	S.F. (%)	B.M. (%)

	CARGO OPERATIONS								
Pour no. /grade	Hold 9	Hold 8	Hold 7	Hold 6	Hold 5	Hold 4	Hold 3	Hold 2	Hold 1
1									
2									
3									
4									
5									
6									
7									
8									
..									
Draft Survey (for loading):	Total cargo onboard (t):			Remaining cargo to be loaded (t):					
n-1									
n									

BALLAST OPERATIONS									
Upper / Lower/Peak	APT	Ballast tank no. 5	Ballast tank no.4	No.6 Ballast hold	Ballast tank no.3	No. 4 Ballast hold	Ballast tank no.2	Ballast tank no.1	FPT
Upper (1)									
Lower/Peak (1)									
Upper (2)									
Lower/Peak (2)									
Upper (3)									
Lower/Peak (3)									
Upper (4)									
Lower/Peak (4)									
Upper (5)									
Lower/Peak (5)									
Upper (6)									
Lower/Peak (6)									
Upper (7)									
Lower/Peak (7)									
Upper (8)									
Lower/Peak (8)									
Upper (..)									
Lower/Peak (..)									
Total amount of bunkers onboard (t):									
Upper (n-1)									
Lower/Peak (n-1)									
Upper (n)									
Lower/Peak (n)									

Values at end of pour (from harbour to sea)				
d fwd	Trim	d fwd	Maximum	
(m)	(m)	(m)	S.F. (%)	B.M. (%)

	Hold content at end of loading/discharging								
Cargo mass									
Total mass loaded/discharged (t)									

Ballast content at end of loading/discharging									
Wings or peaks	APT	Ball. no. 5	Ball. no. 4	No. 6 hold	Ball. no. 3	No. 4 hold	Ball. no. 2	Ball. no.1	FPT
Upper									
Lower/Peaks									

Values at end of loading/discharging (sea)				
d aft	Trim	d fwd	Maximum	
(m)	(m)	(m)	S.F. (%)	B.M. (%)

Approved by:

PART
3

CHAPTER **2** **Hull Structures and Arrangements**

APPENDIX **4** **Buckling Strength of Longitudinal Strength Members for Vessels Over 61 m (200 ft) in Length**

1 Application

These requirements apply to plate panels and longitudinals subject to hull girder bending and shear stresses.

3 Elastic Buckling Stresses

3.1 Elastic Buckling of Plates

3.1.1 Compression

The ideal elastic buckling stress is given by:

$$\sigma_E = 0.9mE\left(\frac{t_b}{s}\right)^2 \qquad \mathrm{N/mm^2}(\mathrm{kgf/mm^2}, \mathrm{psi})$$

For plating with longitudinal stiffeners (parallel to compressive stress):

$$m = \frac{8.4}{\Psi + 1.1} \quad \text{for} \quad (0 \le \Psi \le 1)$$

For plating with transverse stiffeners (perpendicular to compressive stress):

$$m = c\left[1 + \left(\frac{s}{\ell}\right)^2\right]^2 \frac{2.1}{\Psi + 1.1} \quad \text{for} \quad (0 \le \Psi \le 1)$$

where

E	=	2.06×10^5 N/mm² (21,000 kgf/mm², 30×10^6 psi)	
t_b	=	net thickness of plating, in mm (in.), after making standard deductions as given in 3-2-A4/3.3.3 TABLE 1A or 3-2-A4/3.3.3 TABLE 1B, as applicable	
s	=	shorter side of plate panel, in mm (in.)	
ℓ	=	longer side of plate panel, in mm (in.)	
c	=	1.3	when plating stiffened by floors or deep girders
	=	1.21	when stiffeners are angles or T-sections
	=	1.10	when stiffeners are bulb flats
	=	1.05	when stiffeners are flat bars
Ψ	=	ratio of smallest to largest compressive stress, σ_a (see 3-2-A4/7.1), varying linearly across panel.	

3.1.2 Shear

The ideal elastic buckling stress is given by:

$$\tau_E = 0.9 k_t E\left(\frac{t_b}{s}\right)^2 \quad \mathrm{N/mm^2 (kgf/mm^2, psi)}$$

where

$$k_t = 5.34 + 4\left(\frac{s}{\ell}\right)^2$$

E, t_b, s and ℓ are as defined in 3-2-A4/3.1.1

3.3 Elastic Buckling of Longitudinals

3.3.1 Column Buckling without Rotation of the Cross Section

For the column buckling mode (perpendicular to plane of plating), the ideal elastic buckling stress is given by:

$$\sigma_E = \frac{EI_a}{c_1 A \ell^2} \quad \mathrm{N/mm^2 (kgf/mm^2, psi)}$$

where

I_a = moment of inertia, in cm^4 (in^4), of longitudinal, including plate flange and calculated with thickness as specified in 3-2-A4/3.1.1

A = cross-sectional area, in cm^2 (in^2), of longitudinal, including plate flange and calculated with thickness as specified in 3-2-A4/3.1.1

ℓ = span, in m (ft), of longitudinal

c_1 = 1000 (1000, 14.4)

E = as defined in 3-2-A4/3.1.1

3.3.2 Torsional Buckling Mode

The ideal elastic buckling stress for the torsional mode is given by:

$$\sigma_E = \frac{\pi^2 E I_w}{10 c_1 I_p \ell^2}\left(m^2 + \frac{K}{m^2}\right) + 0.385 E \frac{I_t}{I_p} \quad \mathrm{N/mm^2 (kgf/mm^2, psi)}$$

where

K = $c_2 \dfrac{C\ell^4}{\pi^4 E I_w}$

m = number of half waves given by 3-2-A4/3.3.3 TABLE 2

E = as defined in 3-2-A4/3.1.1

c_2 = 10^6 (10^6, 20736)

I_t = St. Venant's moment of inertia, in cm^4 (in^4), of profile (without plate flange)

= $c_3 \dfrac{h_w t_w^3}{3}$ for flat bars (slabs)

= $c_3 \dfrac{1}{3}\left[h_w t_w^3 + b_f t_f^3\left(1 - 0.63\dfrac{t_f}{b_f}\right)\right]$ for flanged profiles

c_3 = 10^{-4} (10^{-4}, 1.0)

I_p = polar moment of inertia, in cm^4 (in^4), of profile about connection of stiffener to plate

= $c_3 \dfrac{h_w^3 t_w}{3}$ for flat bars (slabs)

= $c_3\left(\dfrac{h_w^3 t_w}{3} + h_w^2 b_f t_f\right)$ for flanged profiles

I_w = warping constant, in cm^6 (in^6), of profile about connection of stiffener to plate

= $c_4 \dfrac{h_w^3 t_w^3}{36}$ for flat bars (slabs)

= $c_4\left(\dfrac{t_f b_f^3 h_w^2}{12}\right)$ for "Tee" profiles

= $c_4 \dfrac{b_f^3 h_w^2}{12\left(b_f + h_w\right)^2}\left[t_f\left(b_f^2 + 2b_f h_w + 4h_w^2\right) + 3t_w b_f h_w\right]$ for angles and bulb profiles

c_4 = 10^{-6} (10^{-6}, 1.0)

h_w = web height, in mm (in.)

t_w = web thickness, in mm (in.), after making standard deductions as specified in 3-2-A4/3.1.1

b_f = flange width, in mm (in.)

t_f = flange thickness, in mm (in.), after making standard deductions as specified in 3-2-A4/3.1.1 For bulb profiles the mean thickness of the bulb may be used.

ℓ = span of profile, in m (ft)

s = spacing of profiles, in mm (in.)

C = spring stiffness exerted by supporting plate panel

= $\dfrac{k_p E t_p^3}{3s\left(1 + \dfrac{1.33 k_p h_w t_p^3}{s t_w^3}\right)}$ N (kgf, lbf)

k_p = $1 - \eta_p$, not to be taken less than zero

t_p = plate thickness, in mm (in.), after making standard deductions as specified in 3-2-A4/3.1.1

η_p = $\dfrac{\sigma_a}{\sigma_{Ep}}$

σ_α = calculated compressive stress. For longitudinals, see 3-2-A4/7.1

σ_{Ep} = elastic buckling stress of supporting plate as calculated in 3-2-A4/3.1

For flanged profiles, k_p need not be taken less than 0.1.

3.3.3 Web and Flange Buckling

For web plate of longitudinals the ideal buckling stress is given by:

$$\sigma_E = 3.8E\left(\frac{t_w}{h_w}\right)^2 \quad \mathrm{N/mm^2}\left(\mathrm{kgf/mm^2, psi}\right)$$

For flanges on angles and T-sections of longitudinals, the following requirements will apply:

$$\frac{b_f}{t_f} \le 15$$

b_f = flange width, in mm (in.), for angles, half the flange width for T-sections.

t_f = as built flange thickness, in mm (in.)

TABLE 1A
Standard Deduction t_k for Vessels Under 90 m (295 ft) in Length *(2019)*

	Structure	*Standard Deduction*	*Limit Values min.-max. in mm (in.)*
—	Compartments carrying dry bulk cargoes	0.05*t*	0.5-1.0
—	One side exposure to ballast and/or liquid cargo		(0.02-0.04)
	Vertical surfaces and surfaces sloped at an angle greater than 25° to the horizontal line		
—	One side exposure to ballast and/or liquid cargo	0.10*t*	1.0-3.0
	Horizontal surfaces and surfaces sloped at an angle less than 25° to the horizontal line		(0.04-0.12)
—	Two side exposure to ballast and/or liquid cargo		
	Vertical surfaces and surfaces sloped at an angle greater than 25° to the horizontal line		
—	Two side exposure to ballast and/or liquid cargo	0.15*t*	1.5-4.0
	Horizontal surfaces and surfaces sloped at an angle less than 25° to the horizontal line		(0.06-0.16)

Notes:

1 Provided the structural members are protected against corrosion by coating or equivalent, zero corrosion deduction for structural members may be considered for bulkheads separating passenger spaces at both sides.

2 For the side shell below the waterline, the side structure below loading line with void spaces inside is to consider 0.05t (0.5 mm (0.02 in.) – 1.0 mm (0.04 in.)) corrosion deduction.

3 For the side shell below the waterline, the side structure below loading line with ballast or liquid cargo inside the tanks is to consider 0.10t (1.0 mm (0.04 in.) – 3.0 mm (0.12 in.)) corrosion deduction.

TABLE 1B
Standard Deduction t_k for Vessels 90 m (295 ft) in Length and Above *(2019)*

	Structure	*Standard Deduction*	*Limit Values min.-max. in mm (in.)*
—	Compartments carrying dry bulk cargoes	0.05*t*	0.5-1.0
—	One side exposure to ballast and/or liquid cargo		(0.02-0.04)
	Vertical surfaces and surfaces sloped at an angle greater than 25° to the horizontal line		
—	One side exposure to ballast and/or liquid cargo	0.10*t*	2.0-3.0
	Horizontal surfaces and surfaces sloped at an angle less than 25° to the horizontal line		(0.08-0.12)
—	Two side exposure to ballast and/or liquid cargo		

	Structure	*Standard Deduction*	*Limit Values min.-max. in mm (in.)*
	Vertical surfaces and surfaces sloped at an angle greater than 25° to the horizontal line		
—	Two side exposure to ballast and/or liquid cargo	$0.15t$	2.0-4.0
	Horizontal surfaces and surfaces sloped at an angle less than 25° to the horizontal line		(0.08-0.16)

Notes:

1 Provided the structural members are protected against corrosion by coating or equivalent, zero corrosion deduction for structural members may be considered for bulkheads separating passenger spaces at both sides.

2 For the side shell below the waterline, the side structure below loading line with void spaces inside is to consider $0.05t$ (0.5 mm (0.02 in.) – 1.0 mm (0.04 in.)) corrosion deduction.

3 For the side shell below the waterline, the side structure below loading line with ballast or liquid cargo inside the tanks is to consider $0.10t$ (2.0 mm (0.08 in.) – 3.0 mm (0.12 in.)) corrosion deduction.

TABLE 2
Number of Half Waves

	$0 < K \leq 4$	$4 < K \leq 36$	$36 < K \leq 144$	$144 < K \leq 400$	$(m-1)^2 \quad m^2 < K \leq m^2(m+1)^2$
m	1	2	3	4	m

5 Critical Buckling Stresses

5.1 Compression

The critical buckling stress in compression, σ_c, is determined as follows:

$$\sigma_c = \sigma_E \qquad \text{when} \quad \sigma_E \leq \frac{\sigma_F}{2}$$

$$= \sigma_F\left(1 - \frac{\sigma_F}{4\sigma_E}\right) \qquad \text{when} \quad \sigma_E > \frac{\sigma_F}{2}$$

where

σ_F = yield stress of material, in N/mm^2 (kgf/mm^2, lbf/in^2). σ_F may be taken as 235 N/mm^2 (24 kgf/mm^2, 34,000 psi) for mild steel.

σ_E = ideal elastic buckling stress calculated according to 3-2-A4/3

5.3 Shear

The critical buckling stress in shear, τ_c, is determined as follows:

$$\tau_c = \tau_E \qquad \text{when} \quad \tau_E \leq \frac{\tau_F}{2}$$

$$= \tau_F\left(1 - \frac{\tau_F}{4\tau_E}\right) \qquad \text{when} \quad \tau_E > \frac{\tau_F}{2}$$

where

τ_F = $\dfrac{\sigma_F}{\sqrt{3}}$

σ_F = as given in 3-2-A4/5.1

τ_E = ideal elastic buckling stress in shear calculated according to 3-2-A4/3.1.2

7 Working Stress

7.1 Longitudinal Compressive Stress

The compressive stresses are given in the following formula:

σ_a = $c_5 \dfrac{M_w + M_{sw}}{I_n} y$ N/mm^2 (kgf/mm^2, lbf/in^2)

= minimum $30/Q$ N/mm^2 ($3.1/Q$ kgf/mm^2, $4400/Q$ lbf/in^2)

where

M_{sw} = still water bending moment, as given in 3-2-1/3.7.1(a), in kN-m (tf-m, Ltf-ft)

M_w = wave bending moment, as given in 3-2-1/3.7.1(a), in kN-m (tf-m, Ltf-ft)

I_n = moment of inertia, in cm^4 (in^4), of the hull girder

y = vertical distance, in m (ft), from the neutral axis to the considered point

Q = as defined in 3-2-1/5.3 (1.0 for ordinary strength steel)

c_5 = 10^5 (10^5, 322,560)

M_w and M_{sw} are to be taken as sagging or hogging bending moments, respectively, for members above or below the neutral axis.

7.3 Shear Stresses

7.3.1 Ships without Effective Longitudinal Bulkheads

The working shear stress, τ_a, in the side shell of ships without effective longitudinal bulkheads is given by the following formula:

$$\tau_a = c_6 \frac{(F_{sw} + F_w) m_s}{2 t_s I} \quad \mathrm{N/mm^2 (kgf/mm^2, lbf/in^2)}$$

where

I = moment of inertia of the hull girder section, in cm^4 (in^4), at the section under consideration.

m_s = first moment, in cm^3 (in^3), about the neutral axis of the area of the effective longitudinal material between the horizontal level at which the shear stress is being determined and the vertical extremity of effective longitudinal material, taken at the position under consideration.

t_s = thickness of the side shell plating, in cm (in.), at the position under consideration.

F_{sw} = hull girder shearing force in still water, in kN (tf, Ltf). See 3-2-1/3.3.

F_w = F_{wp} or F_{wn}, in kN (tf, Ltf), as specified by 3-2-1/3.5.3, depending upon loading

c_6 = 10 (10, 2240)

7.3.2 Ships with Two or More Effective Longitudinal Bulkheads

The working shear stress, τ_a, in the side shell or longitudinal bulkhead plating is to be calculated by an acceptable method and in accordance with 3-2-1/3.9.4.

9 Scantling Criteria

9.1 Buckling Stress

The design buckling stress, σ_c, of plate panels and longitudinals (as calculated in 3-2-A4/5.1) is to be such that:

$$\sigma_c \geq \beta\sigma_a$$

where

β = 1 for plating and for web plating of stiffeners (local buckling)

β = 1.1 for stiffeners

The critical buckling stress, τ_c, of plate panels (as calculated in 3-2-A4/5.3) is to be such that:

$$\tau_c \geq \tau_a$$

where

τ_a = the working shear stress in the plate panel under consideration, in N/mm^2 (kgf/mm^2, lbf/in^2), as determined by 3-2-A4/7.3.

Alternatively for transverse framing vessels between 61 meters (200 feet) and 90 meters (295 feet) in length, the deck and bottom plate may be taken not less than:

$$t = \frac{s}{45}\sqrt{\frac{SM_R}{SM_A}} \cdot \frac{1}{\sqrt{Q}} + t_k \quad \text{mm(in.)}$$

where

t = thickness of bottom shell or deck plating, in mm (in.)

t_k = Standard deduction as given in 3-2-A4/Table 1A or 1B as the case may be, in mm(in.)

s = frame spacing, in mm (in.)

SM_R = hull girder section modulus required by 3-2-1/3, in cm^2-m (in^2-ft)

SM_A = bottom or deck hull girder section modulus, in cm^2-m (in^2-ft)

Q = as defined in 3-2-1/5.3

PART
3

CHAPTER 2 Hull Structures and Arrangements

APPENDIX 5 Guidelines for Calculating Bending Moment and Shear Force in Rudders and Rudder Stocks

1 Application

Bending moments, shear forces and reaction forces of rudders, stocks and bearings may be calculated according to this Appendix for the types of rudders indicated. Moments and forces on rudders of different types or shapes than those shown are to be calculated using alternative methods and will be considered based on submitted documents and calculations supporting the review.

3 Spade Rudders

3.1 Rudder Blade

3.1.1 Shear Force *(2020)*

For regular spade rudders as shown in 3-2-A5/3 FIGURE 1(a), the shear force, $V(z)$, at a horizontal section of the rudder above baseline is given by the following equation:

$$V(z) = \frac{zC_R}{A}\left[c_\ell + \frac{z}{2\ell_R}(c_u - c_\ell)\right] \quad \text{kN(tf, Ltf)}$$

where

z = distance from the rudder baseline to the horizontal section under consideration, in m (ft)

C_R = rudder force, as defined in 3-2-14/3, in kN (tf, Ltf)

A = total projected area of rudder blade in m^2 (ft^2), as defined in 3-2-14/3

c_ℓ, c_u and ℓ_R are dimensions as indicated in 3-2-A5/3 FIGURE 1(a), in m (ft).

For spade rudders with embedded rudder trunks let deep in the rudder blade, as shown in 3-2-A5/3 FIGURE 1(b), the shear forces at rudder horizontal sections above rudder baseline in areas A_1, and A_2, are given by the following equations:

$$V(z')_1 = \frac{z'C_{R1}}{A_1}\left[c_u - \frac{z'}{2\ell_\ell}(c_u - c_b)\right] \quad \text{kN(tf, Ltf), over area } A_1$$

$$V(z)_2 = \frac{zC_{R2}}{A_2}\left[c_\ell + \frac{z}{2\ell_b}(c_b - c_\ell)\right] \quad \text{kN(tf, Ltf), over area } A_2$$

where

z' = $\ell_R - z$

C_{R1} = rudder force over rudder area A_1, in kN (tf, Ltf)

= $\frac{A_1}{A}C_R$

C_{R2} = rudder force over rudder area A_2, in kN (tf, Ltf)

$= \frac{A_2}{A} C_R$

A_1 = partial rudder blade area above neck bearing and below rudder top, in mm² (ft²)

A_2 = partial rudder blade area above rudder baseline and below neck bearing, in mm² (ft²)

z, A, and C_R are as indicated in 3-2-A5/3.1.1.

c_ℓ, c_b, c_u, ℓ_u and ℓ_b are dimensions as illustrated in 3-2-A5/3 FIGURE 1(b).

3.1.2 Bending Moment *(2020)*

For regular spade rudders, bending moment, $M(z)$, at a horizontal section z meters (feet) above the baseline of the rudder is given by the following equation:

$$M(z) = \frac{z^2 C_R}{2A}\left[c_\ell + \frac{z}{3\ell_R}(c_u - c_\ell)\right] \quad \text{kN} - \text{m}, (\text{tf} - \text{m}, \text{Ltf} - \text{ft})$$

For spade rudders with embedded rudder trunk, the bending moment at a horizontal section within area A_1 is obtained from the following:

$$M(z')_1 = \frac{(z')^2 C_{R1}}{2A_1}\left[c_u - \frac{z'}{3\ell_\ell}(c_u - c_b)\right] \quad \text{kN} - \text{m}, (\text{tf} - \text{m}, \text{Ltf} - \text{ft})$$

With the maximum bending moment M_1 over area A_1 equals to:

$$M_1 = C_{R1}\ell_\ell\left[1 - \frac{2c_b + c_u}{3(c_b + c_u)}\right] \quad \text{kN} - \text{m}, (\text{tf} - \text{m}, \text{Ltf} - \text{ft})$$

For spade rudders with embedded rudder trunk, the bending moment at a horizontal section within area A_2 is obtained from the following:

$$M(z)_2 = \frac{z^2 C_{R2}}{2A_2}\left[c_\ell + \frac{z}{3\ell_b}(c_b - c_\ell)\right] \quad \text{kN} - \text{m}, (\text{tf} - \text{m}, \text{Ltf} - \text{ft})$$

With the maximum bending moment M_2 over area A_2 equals to:

$$M_2 = C_{R2}\ell_b\frac{2c_\ell + c_b}{3(c_\ell + c_b)} \quad \text{kN} - \text{m}, (\text{tf} - \text{m}, \text{Ltf} - \text{ft})$$

where $z, z', C_{R1}, C_{R2}, A_1, A_2, c_\ell, c_u$ and ℓ_R are as defined in 3-2-A5/3.1.1.

3.3 Lower Stock

3.3.1 Shear Force

For regular spade rudder, the shear force, V_ℓ , at any section of the lower stock between the top of the rudder and the neck bearing is given by the following equation:

$$V_\ell = C_R \quad \text{kN}(\text{tf}, \text{Ltf})$$

For spade rudder with embedded rudder trunk, the shear force at any section of the stock between the top of the rudder and the neck bearing is given by the following equation:

$$V_\ell = \frac{M_2 - M_1}{\ell_u + \ell_\ell} \quad \text{kN}(\text{tf}, \text{Ltf})$$

where C_R, ℓ_ℓ, and ℓ_u are as defined in 3-2-A5/3.1.1.

3.3.2 Bending Moment at Neck Bearing

For regular spade rudder, the bending moment in the rudder stock at the neck bearing, M_n, is given by the following equation:

$$M_n = C_R\left[\ell_\ell + \frac{\ell_R(2c_\ell + c_u)}{3(c_\ell + c_u)}\right] \quad \mathrm{kN-m(tf-m, Ltf-ft)}$$

where

C_R = rudder force as defined in 3-2-14/3

c_ℓ, c_u, ℓ_ℓ and ℓ_R are dimensions as indicated in 3-2-A5/3 FIGURE 1, in m (ft.).

For spade rudder with embedded rudder trunk, the bending moment in the rudder stock at the neck bearing is given by the following equation:

$$M_n = M_2 - M_1 \quad \mathrm{kN-m(tf-m, Ltf-ft)}$$

where M_1 and M_2 as defined in 3-2-A5/3.1.2.

Where partial submergence of the rudder leads to a higher bending moment in the rudder stock at the neck bearing (compared with the fully submerged condition), M_n is to be calculated based on the most severe partially submerged condition.

3.5 Moment at Top of Upper Stock Taper

For regular spade rudder, the bending moment in the upper rudder stock at the top of the taper, M_t, is given by the following equation:

$$M_t = C_R\left[\ell_\ell + \frac{\ell_R(2c_\ell + c_u)}{3(c_\ell + c_u)}\right] \times \left[\frac{(\ell_u + \ell_R + \ell_\ell - z_t)}{\ell_u}\right] \quad \mathrm{kN-m, (tf-m, Ltf-ft)}$$

For spade rudder with embedded rudder trunk, the bending moment in the upper rudder stock at the top of the taper is given by the following equation:

$$M_t = M_R \left[\frac{(\ell_R + \ell_u - z_t)}{\ell_u}\right] \quad \mathrm{kN-m(tf-m, Ltf-ft)}$$

where

z_t = distance from the rudder baseline to the top of the upper rudder stock taper in m (ft.)

C_R = rudder force, as defined in 3-2-A5/3.1.1

M_R = is the greater of M_1 and M_2, as defined in 3-2-A5/3.1.2

$c_\ell, c_u, \ell_\ell, \ell_u$ and ℓ_R are dimensions as indicated in 3-2-A5/3 FIGURE 1, in m (ft).

3.7 Bearing Reaction Forces

For regular spade rudder, the reaction forces at the bearings are given by the following equations:

P_u = reaction force at the upper bearing

= $-\frac{M_n}{\ell_u}$ kN(tf, Ltf)

P_n = reaction force at the neck bearing

= $C_R + \frac{M_n}{\ell_u}$ kN(tf, Ltf)

For spade rudder with embedded rudder trunk, the reaction forces at the bearings are given by the following equations:

P_u = $-\frac{M_n}{\ell_u + \ell_\ell}$ kN(tf, Ltf)

P_n = $C_R + P_u$ kN(tf, Ltf)

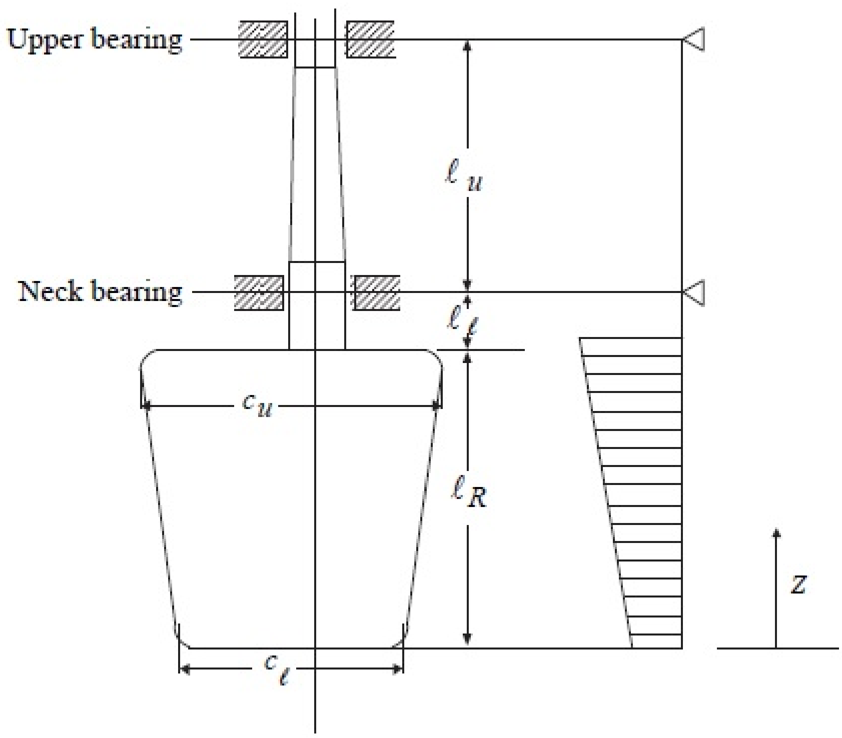
where

M_n = bending moment at the neck bearing, as defined in 3-2-A5/3.3.2

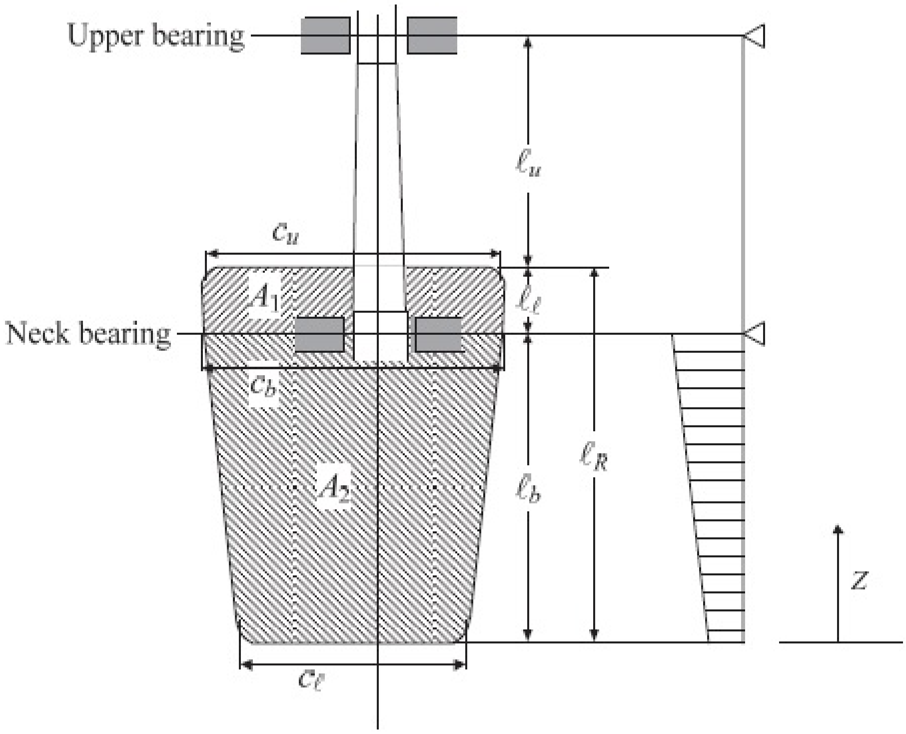
C_R = rudder force, as defined in 3-2-14/3.

ℓ_u is as indicated in 3-2-A5/3 FIGURE 1, in m (ft).

FIGURE 1
Spade Rudder



(a) Regular Spade Rudder



(b) Spade Rudder With Embedded Rudder Trunk

5 Rudders Supported by Shoe Piece

5.1 Shear Force, Bending Moment and Reaction Forces

Shear force, bending moment and reaction forces are to be assessed by the simplified beam model given in 3-2-A5/5.1 FIGURE 2.

w_R = rudder load per unit length

= $\frac{C_R}{\ell_R}$ kN/m (tf/m, Ltf/ft)

where

C_R = rudder force, as defined in 3-2-14/3

k_s = spring constant reflecting support of the shoe piece

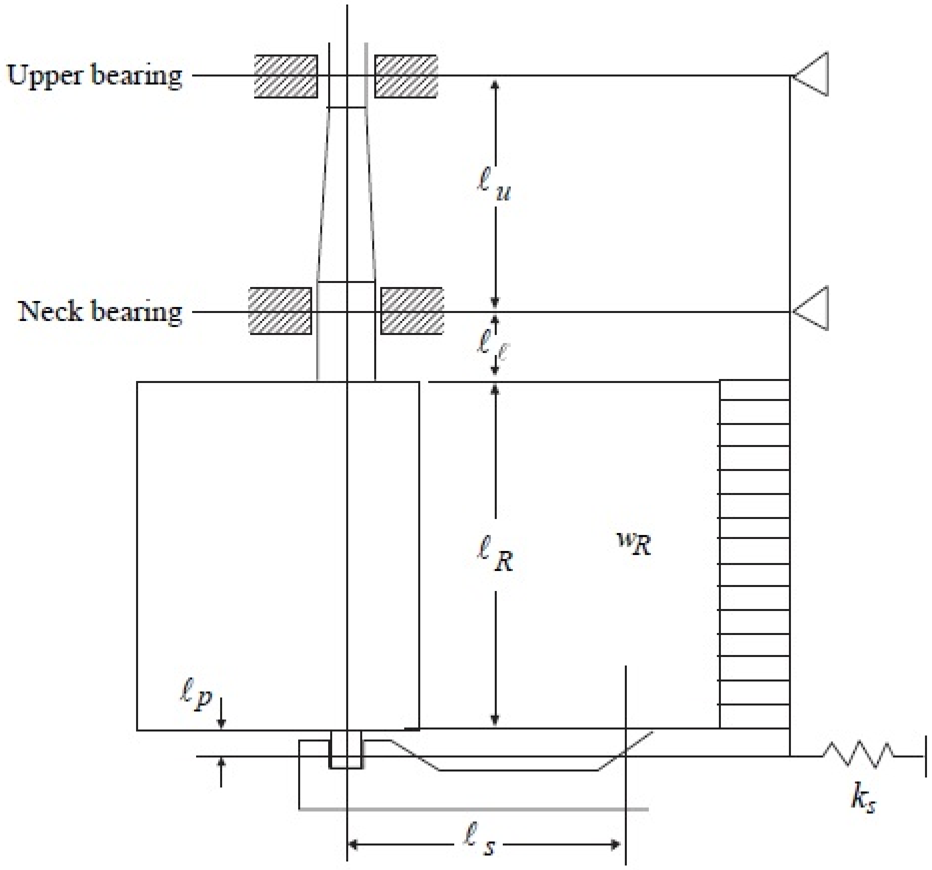
= $\frac{n_S I_S}{\ell_S^3}$ kN/m (tf/m, Ltf/ft)

n_s = 6.18 (0.630, 279)

I_s = moment of inertia of shoe piece about the vertical axis, in cm^4 (in^4)

ℓ_S, ℓ_R and ℓ_p are dimensions as indicated in 3-2-A5/5.1 FIGURE 2, in m (ft).

FIGURE 2
Rudder Supported by Shoe Piece



7 Rudders Supported by a Horn with One Pintle

7.1 Shear Force, Bending Moment and Reaction Forces

Shear force, bending moment and reaction forces are to be assessed by the simplified beam model shown in 3-2-A5/7.1 FIGURE 3.

w_{R1} = rudder load per unit length above pintle

= $-\frac{C_{R1}}{\ell_{R1}}$ kN/m (tf/m, Ltf/ft)

w_{R2} = rudder load per unit length below pintle

= $\frac{C_{R2}}{\ell_{R2}}$ kN/m (tf/m, Ltf/ft)

where

C_{R1} = rudder force, as defined in 3-2-14/3.3

C_{R2} = rudder force, as defined in 3-2-14/3.3

k_h = spring constant reflecting support of the horn

$$= \frac{1}{\dfrac{\ell_h^3}{n_b I_h} + \dfrac{\sum\left(\frac{s_i}{t_i}\right)e^2 \quad \ell_h}{n_t \quad a^2}} \quad \text{kN/m(tf/m, Ltf/ft)}$$

n_b = 4.75 (0.485, 215)

n_t = 3.17 (0.323, 143)

a = mean area enclosed by the outside lines of the rudder horn, in cm^2 (in^2)

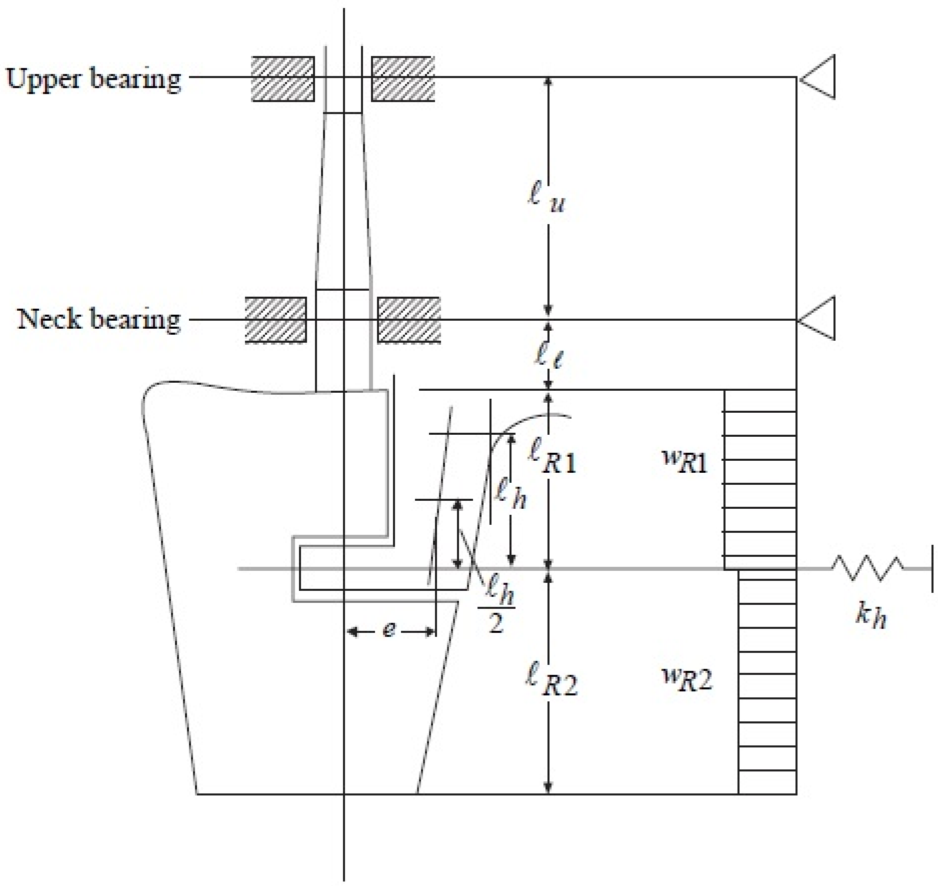
s_i = the girth length of each segment of the horn of thickness t_i, in cm (in.)

t_i = the thickness of each segment of horn outer shell of length s_i , in cm (in.)

I_h = moment of inertia of horn section at ℓ_h about the longitudinal axis, in cm^4 (in^4)

e, ℓ_h, ℓ_{R2} and ℓ_{R2} are dimensions as indicated in 3-2-A5/7.1 FIGURE 3, in m (ft)

FIGURE 3
Rudder Supported by a Horn with One Pintle



9 Rudders Supported by a Horn Arranged with Two Pintles (Supports)

9.1 Shear Force, Bending Moment and Reaction Forces

Shear force, bending moment and reaction forces are to be assessed by the simplified beam model shown in 3-2-A5/9 FIGURE 4.

w_{R1} = rudder load per unit length above lower rudder support/pintle

= $-\frac{C_{R1}}{\ell_{R1}}$ kN/m (tf/m, Ltf/ft)

w_{R2} = rudder load per unit length below lower rudder support/pintle

= $\frac{C_{R2}}{\ell_{R2}}$ kN/m (tf/m, Ltf/ft)

where

C_{R1} = rudder force, as defined in 3-2-14/3.3

C_{R2} = rudder force, as defined in 3-2-14/3.3

ℓ_{R1} and ℓ_{R2} are dimensions as indicated in 3-2-A5/9 FIGURE 4, in m (ft).

In 3-2-A5/9 FIGURE 4 the variables K_{11}, K_{22}, K_{12} are rudder horn compliance constants calculated for rudder horn with 2-conjugate elastic supports. The 2-conjugate elastic supports are defined in terms of horizontal displacements, y_i, by the following equations:

- At the lower rudder horn bearing:

$$y_1 = -K_{12} \quad B_2 - K_{22} \quad B_1 \text{ m (ft)}$$

- At the upper rudder horn bearing:

$$y_2 = -K_{11} \quad B_2 - K_{12} \quad B_1 \text{ m (ft)}$$

where

y_1, y_2 = horizontal displacement at lower and upper rudder horn bearings, respectively

B_1, B_2 = horizontal support force, in kN (tf, Ltf), at lower and upper rudder horn bearings, respectively

K_{11}, K_{22}, K_{12} = spring constant of the rudder support obtained from the following:

K_{11} = $m\left[1.3\frac{\lambda^3}{3EJ_{1h}} + \frac{e^2\lambda}{GJ_{th}}\right]$ m/kN (m/tf, ft/Ltf)

K_{22} = $m\left[1.3\left[\frac{\lambda^3}{3EJ_{1h}} + \frac{\lambda^2(d-\lambda)}{2EJ_{1h}}\right] + \frac{e^2\lambda}{GJ_{th}}\right]$ m/kN (m/tf, ft/Ltf)

K_{12} = $m\left[1.3\left[\frac{\lambda^3}{3EJ_{1h}} + \frac{\lambda^2(d-\lambda)}{EJ_{1h}} + \frac{\lambda(d-\lambda)^2}{EJ_{1h}} + \frac{(d-\lambda)^3}{3EJ_{2h}}\right] + \frac{e^2d}{GJ_{th}}\right]$ m/kN (m/tf, ft/Ltf)

m = 1.00 (9.8067, 32.691)

d = height of the rudder horn, in m (ft), defined in 3-2-A5/9 FIGURE 4. This value is measured downwards from the upper rudder horn end, at the point of curvature transition, to the mid-line of the lower rudder horn pintle.

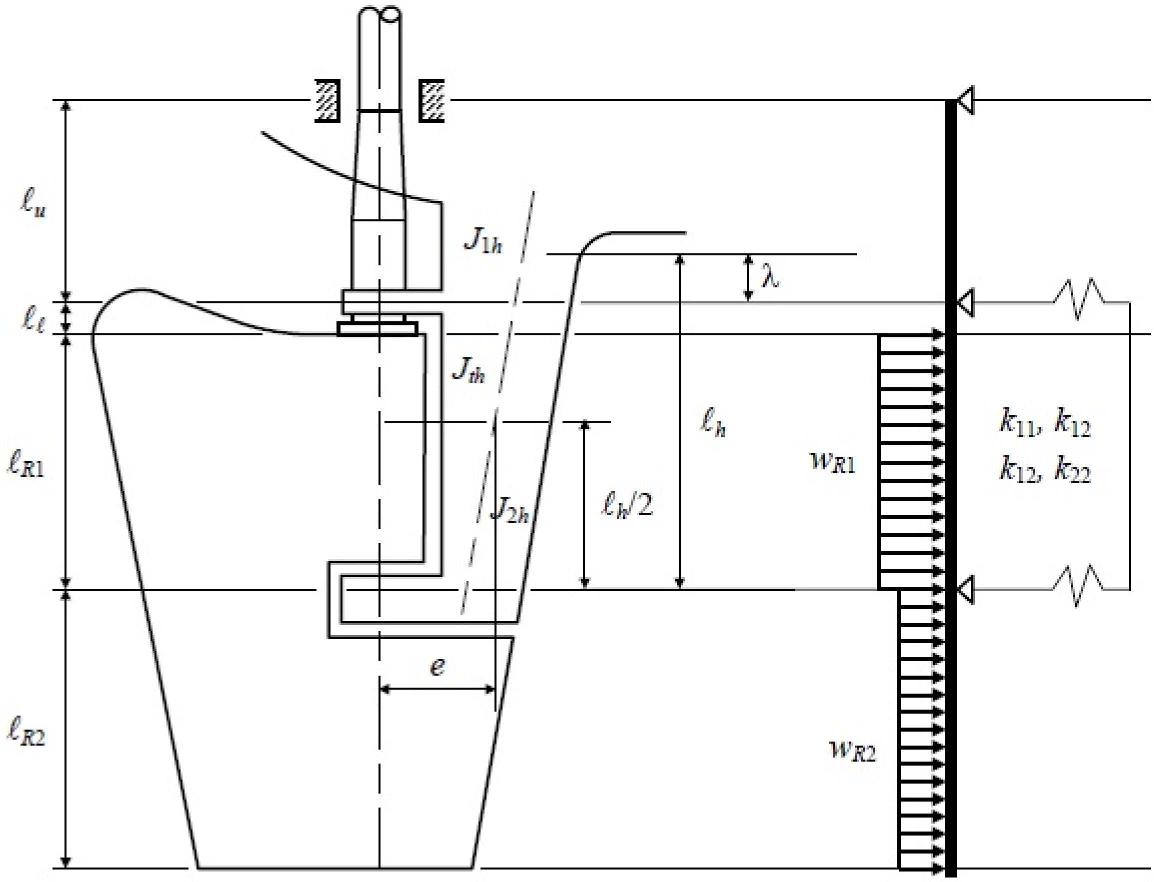
λ = length, in m (ft), as defined in 3-2-A5/9 FIGURE 4. This length is measured downwards from the upper rudder horn end, at the point of curvature transition, to the mid-line of the upper rudder horn bearing. For $\lambda = 0$, the above formulae converge to those of spring constant k_h for a rudder horn with 1-pintle (elastic support), and assuming a hollow cross section for this part.

e	=	rudder-horn torsion lever, in m (ft), as defined in 3-2-A5/9 FIGURE 4 (value taken at vertical location $\ell_h/2$).
E	=	Young's modulus of the material of the rudder horn in kN/m^2 (tf/m^2, Ltf/in^2)
G	=	modulus of rigidity of the material of the rudder horn in kN/m^2 (tf/m^2, Ltf/in^2)
J_{1h}	=	moment of inertia of rudder horn about the x axis, in m^4 (ft^4), for the region above the upper rudder horn bearing. Note that J_{1h} is an average value over the length λ (see 3-2-A5/9 FIGURE 4).
J_{2h}	=	moment of inertia of rudder horn about the x axis, in m^4 (ft^4), for the region between the upper and lower rudder horn bearings. Note that J_{2h} is an average value over the length $d - \lambda$ (see 3-2-A5/9 FIGURE 4).
J_{th}	=	torsional stiffness factor of the rudder horn, in m^4 (ft^4)
	=	$\dfrac{4F_T^2}{\sum_i \frac{u_i}{t_i}}$ for any thin wall closed section, in m^4 (ft^4)

Note that the J_{th} value is taken as an average value, valid over the rudder horn height.

F_T	=	mean of areas enclosed by outer and inner boundaries of the thin walled section of rudder horn, in m^2 (ft^2)
u_i	=	length, in mm (in.), of the individual plates forming the mean horn sectional area
t_i	=	thickness, in mm (in.), of the individual plates mentioned above

FIGURE 4
Rudder Supported by a Horn Arranged with Two Pintles (Supports)



PART 3

CHAPTER 2 Hull Structures and Arrangements

APPENDIX 6 Portable Beams and Hatch Cover Stiffeners of Variable Cross Section

1 Application

For portable beams and hatch cover stiffeners with free ends and varying cross section along their spans, the section modulus *SM* and inertia *I* at the midspan required by 3-2-15/8.1.1, 3-2-15/8.3.2, 3-2-15/8.5.1 and 3-2-15/9.1 may be obtained from the following equations.

$$SM = \frac{C_1 K_1 p s l^2}{\sigma_a} \quad \text{cm}^3(\text{in}^3)$$

$$I = C_2 K_2 p s \ell^3 \quad \text{cm}^4(\text{in}^4)$$

where

C_1	=	125 (125, 1.5)
C_2	=	2.87 (28.2, 2.85×10^{-5}) for 3-2-15/8.1.1 and 3-2-15/8.3.2
	=	2.26 (22.1, 2.24×10^{-5}) for 3-2-15/8.5.1 and 3-2-15/9.1
K_1	=	$1 + \frac{3.2\alpha - \gamma - 0.8}{7\gamma + 0.4}$, but not less than 1.0
α	=	length ratio
	=	ℓ_1/ℓ
γ	=	*SM* ratio
	=	SM_1/SM

$\ell_1/\ell, SM_1$ and SM are as indicated in 3-2-A6/1 FIGURE 1

σ_a	=	allowable stress given in 3-2-15/8.1.1, 3-2-15/8.3.2, 3-2-15/8.5.1 and 3-2-15/9.1, in kN/mm^2 (kgf/mm^2, psi)
K_2	=	$1 + 8\alpha^3 \frac{(1-\beta)}{(0.2 + 3\sqrt{\beta})}$, but not less than 1.0
β	=	ratio of the moments of inertia, I_1 and I, at the locations indicated in 3-2-A6/1 FIGURE 1
	=	I_1/I
p	=	design load given in 3-2-15/3.3, in kN/m^2 (tf/m^2, psi)
s	=	spacing of beams or stiffeners, in m (ft).
ℓ	=	span of free ended constructional elements, in m (ft).

FIGURE 1
SM and I of Construction Elements