# Innovative Ship Design

## - 3rd Exam -

***Friday, June 15th, 2012***

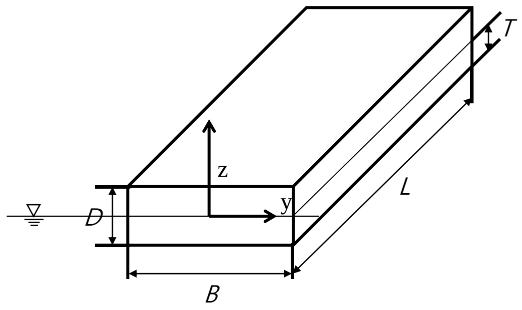
***14:00-17:00 (3 hours)***

| Name | |
|---|---|
| SNU ID # | |

**Note: Budget your time wisely. Some parts of this exam could take you much longer than others. Move on if you are stuck and return to the problem later.**

| Problem Number | | 1 | | | | 2 | | | 3 | | | 4 | 5 | | 6 | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 1 | 2 | 3 | - | 1 | 2 | 1 | 2 | 3 | |
| Grader | Max | 3 | 2 | 10 | 5 | 3 | 10 | 2 | 5 | 10 | 5 | 5 | 5 | 5 | 5 | 10 | 15 | |
| | Score | | | | | | | | | | | | | | | | | /100 |

**[1]** A barge ship is floating on the sea as shown in following figure.




$L$=40m, $B$=10m, $D$=10m, $T$=5m
Density of sea water: $\rho \approx 1\text{Mg/m}^3$
Added mass moment of inertia $I_{added}$ is same as the added mass moment of inertia of the ship.

The equation of roll motion is as follows:

$$I\ddot{\phi} = \sum M = (Body\ Force) + (Surface\ Force)$$

$$= \overbrace{\mathbf{M}_{Gravity}(\phi)} + \overbrace{\mathbf{M}_{Fluid}(\phi)}$$

$$= \overbrace{\mathbf{M}_{Gravity}(\phi)} + \overbrace{\mathbf{M}_{Buoyancy}(\phi) + \mathbf{M}_{F.K} + \mathbf{M}_D + \mathbf{M}_{Radiation}}$$

$$= \mathbf{M}_{Restoring}(\phi) + \mathbf{M}_{Exciting} - I_{added}\ddot{\phi} - B\dot{\phi}$$

$\mathbf{M}_{Gravity}(\phi)$ is the moment due to the gravitational force.

$\mathbf{M}_{Buoyancy}(\phi)$ is the moment due to the buoyant force.

$\mathbf{M}_{F.K}$ is the moment due to the Froude-Krylov force.

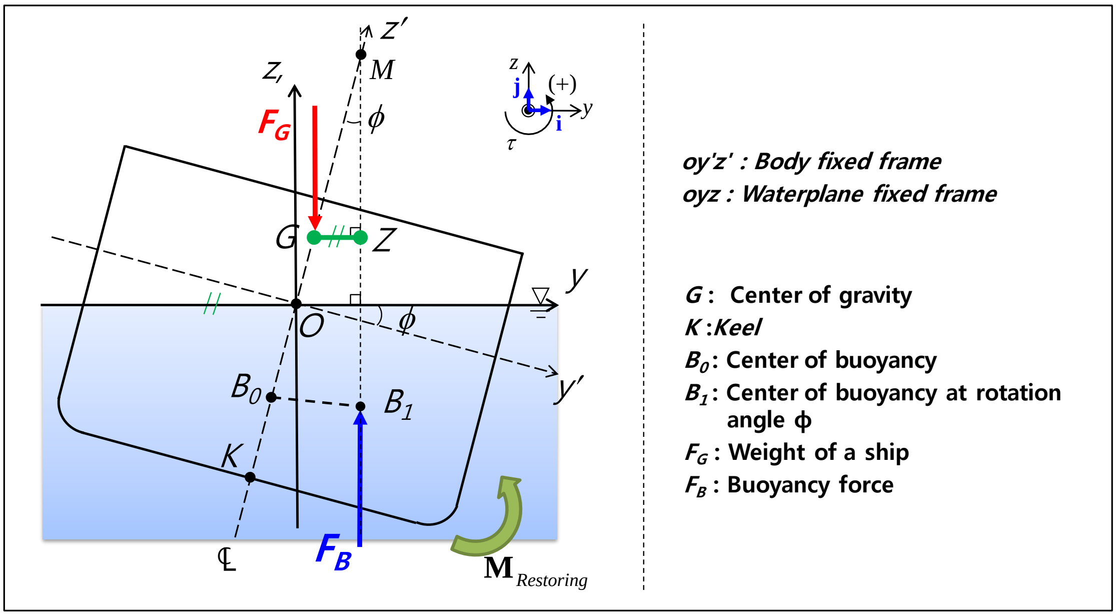
$\mathbf{M}_D$ is the moment due to the diffraction force.

$\mathbf{M}_{Radiation}(\dot{\phi},\ddot{\phi})$ is the moment due to the radiation force.

Two components $\mathbf{M}_{Gravity}(\phi)$ and $\mathbf{M}_{Buoyancy}(\phi)$ produce transverse restoring moment $\mathbf{M}_{Restoring}(\phi)$.

Sum of two components $\mathbf{M}_{F.K}(\phi)$ and $\mathbf{M}_D(\phi)$ is exciting moment $\mathbf{M}_{Exciting}(\phi)$.

$\mathbf{M}_{Radiation}(\dot{\phi},\ddot{\phi})$ is composed of $-I_{added}\ddot{\phi}$ and $-B\dot{\phi}$, where $I_{added}$ is the added mass moment of inertia and $B$ is roll damping coefficient.




*M* : The metacenter is defined as the intersection point of the two lines of action of the buoyant force before and after inclination. Unless there is an change in the shape of the ship in vicinity of the waterline, point M will remain practically stationary as the ship is inclined to small angles.

[1.1] Determine the transverse restoring moment in terms of GM with proper assumption. **[3 points]**

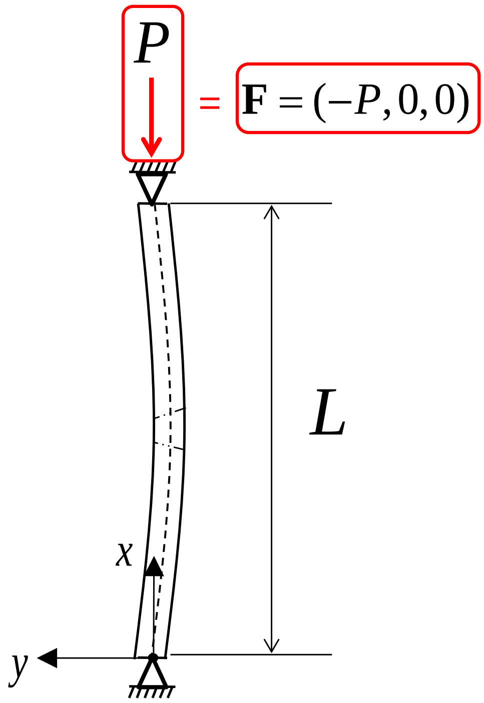
[1.2] Drive the equation of roll motion of the ship. **[2 points]**

[1.3] Find a general solution of roll motion $\phi(t)$ assuming there is no exciting moment and damping moment. **[10 points]**

[1.4] Drive the relation between GM and natural period of roll motion. **[5 points]**

**[2]** Buckling and Euler load

Consider a long slender vertical column of uniform cross-section and length L. The vertical load P is acting on the top of the vertical column.




**[2.1]** Derive the differential equation for column buckling based on the differential equation of the deflection curve of a beam. **[3 points]**

- Differential Equation of the deflection curve of a beam

$$M = EI\frac{d^2y}{dx^2}$$

**[2.2]** Determine Euler load(smallest critical loads). **[10 points]**

**[2.3]** To maximize Euler load, where the physical restraint should be put on? **[2 points]**

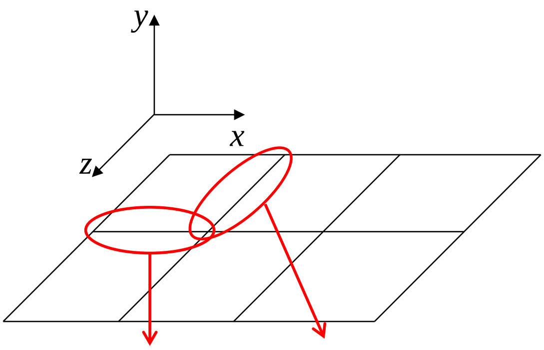
**[3]** Grillage Analysis

Stiffness equations of a beam and shaft, whose length is L, are as follows:

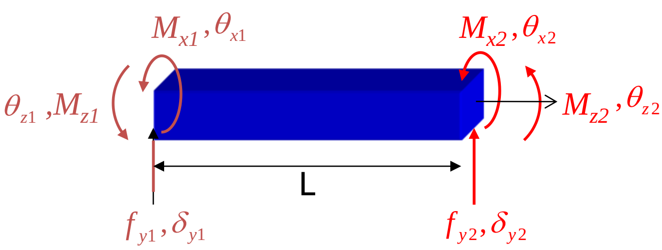
Stiffness equations of a beam:
$$\begin{bmatrix} f_{y1} \\ M_{z1} \\ f_{y2} \\ M_{z2} \end{bmatrix} = \begin{bmatrix} \frac{12EI}{L^3} & \frac{6EI}{L^2} & -\frac{12EI}{L^3} & \frac{6EI}{L^2} \\ \frac{6EI}{L^2} & \frac{4EI}{L} & -\frac{6EI}{L^2} & \frac{2EI}{L} \\ -\frac{12EI}{L^3} & -\frac{6EI}{L^2} & \frac{12EI}{L^3} & -\frac{6EI}{L^2} \\ \frac{6EI}{L^2} & \frac{2EI}{L} & -\frac{6EI}{L^2} & \frac{4EI}{L} \end{bmatrix} \begin{bmatrix} \delta_{y1} \\ \theta_{z1} \\ \delta_{y2} \\ \theta_{z2} \end{bmatrix}$$

Stiffness equations of a shaft:
$$\begin{bmatrix} M_{x1} \\ M_{x2} \end{bmatrix} = \begin{bmatrix} \frac{GJ}{L} & -\frac{GJ}{L} \\ -\frac{GJ}{L} & \frac{GJ}{L} \end{bmatrix} \begin{bmatrix} \theta_{x1} \\ \theta_{x2} \end{bmatrix}$$

**[3.1]** Derive the stiffness equations of a grillage structure in the xz-plane for the element 1 and element 2. **[5 points]**

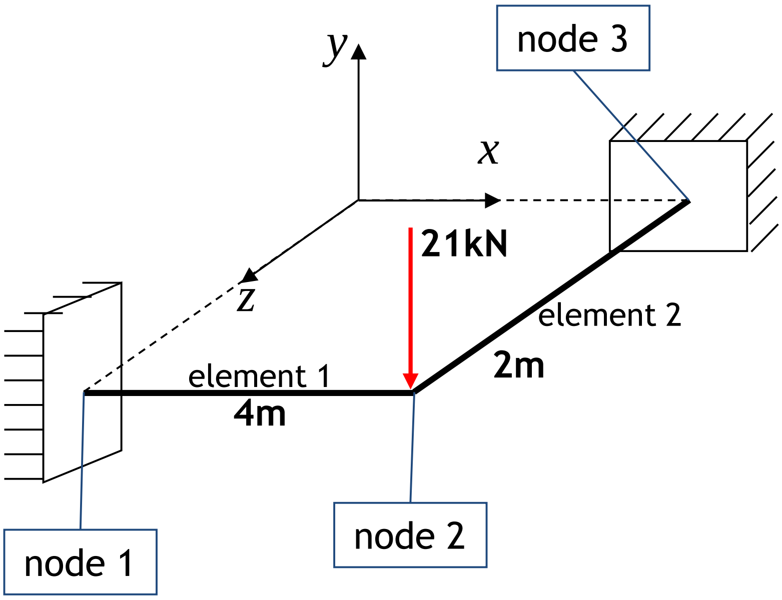



Element 1 Element 2




Element 1

**[3.2]** Find displacement and reaction force at each nodes in the following figure by using the stiffness equations of the grillage structure derived from the problem [3.1] **[10 points]**



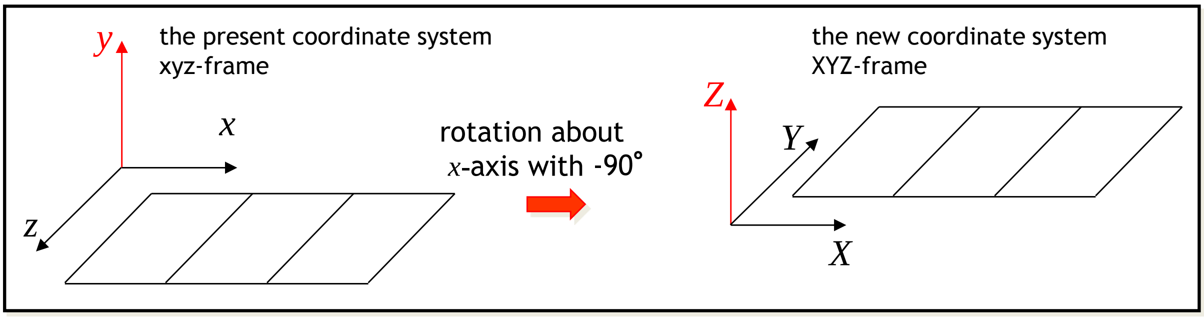

- Moment of inertia $I$ (m$^4$): $16.6\times10^{-5}$

- Young's modulus $E$ (kN/m$^2$): $210\times10^{6}$

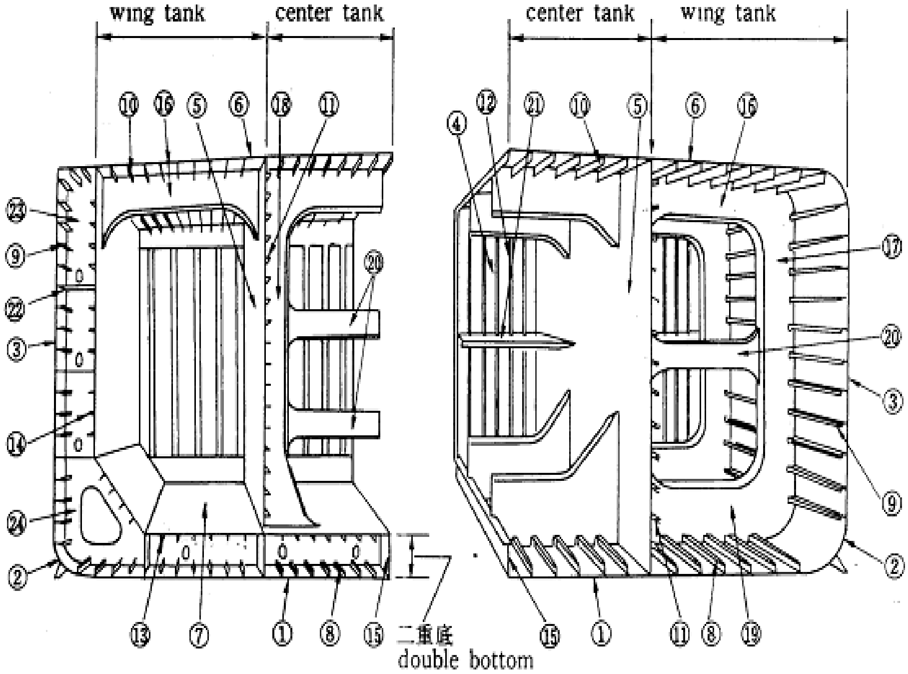
- Shear modulus $G$ (kN/m$^2$): $84\times10^{6}$

- Polar moment of unertia $J$ (m$^2$): $4.6\times10^{-5}$

**[3.3]** The stiffness equation of the grillage structure is derived in the xyz-frame. But the XYZ-frame will be used in general grillage analysis problem. Perform the coordinate transformation of the stiffness equation from the xyz-frame to the XYZ-frame. **[5 points]**



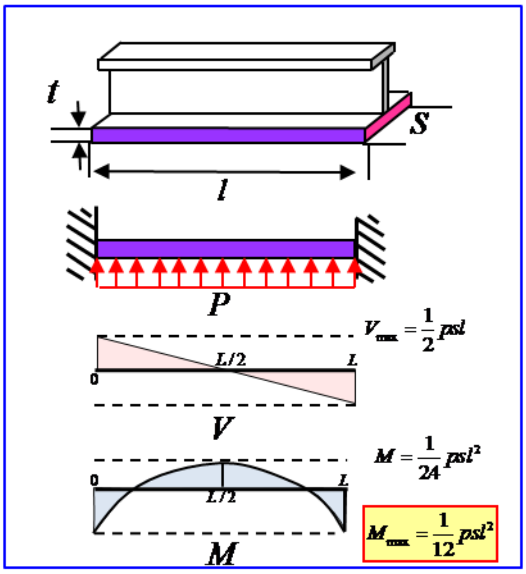
**[4]** Write down the name of cargo hold structure members of a tanker. **[5 points]**



**[5]** Hull girder strength and Midship section rule scantling

**[5.1]** Derive the required section modulus($Z_{req}$) for the scantling of the longitudinal stiffener based on the beam theory. **[5 points]**

$$Z_{req.} = \frac{83 l^2 \cdot s \cdot p \cdot w_k}{\sigma_l} \quad \left(cm^3\right)$$




$p$: "pressure" on the load point for the stiffener

$l$: stiffener span

s: stiffener spacing

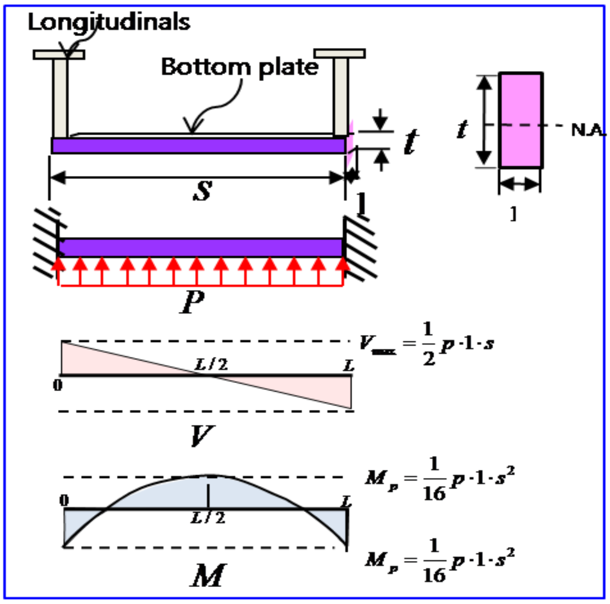
$\sigma_l$ : allowable stress

$w_k$ : section modulus corrosion factor in tanks

Unit: $p\left(kN/m^2\right)$ , $s\left(m\right)$ , $l\left(m\right)$ , $\sigma\left(N/mm^2\right)$

**[5.2]** Derive the required thickness ($t_{req}$) for the scantling of the plates based on the beam theory. **[5 points]**

$$t_{req.} = \frac{15.8 k_a s \sqrt{p}}{\sqrt{\sigma_l}} + t_k \ (mm)$$




p: "pressure" on the load point for the plate

s: span between longitudinals

t: plate thickness

N.A: neutral axis

1: unit length of strip of the plate

$\sigma_l$: allowable stress

$k_a$: correction factor for aspect ratio of plate field

$t_k$: corrosion addition

Unit: $t(mm)$, $s(m)$, $p(kN/m^2)$, $\sigma(N/mm^2)$

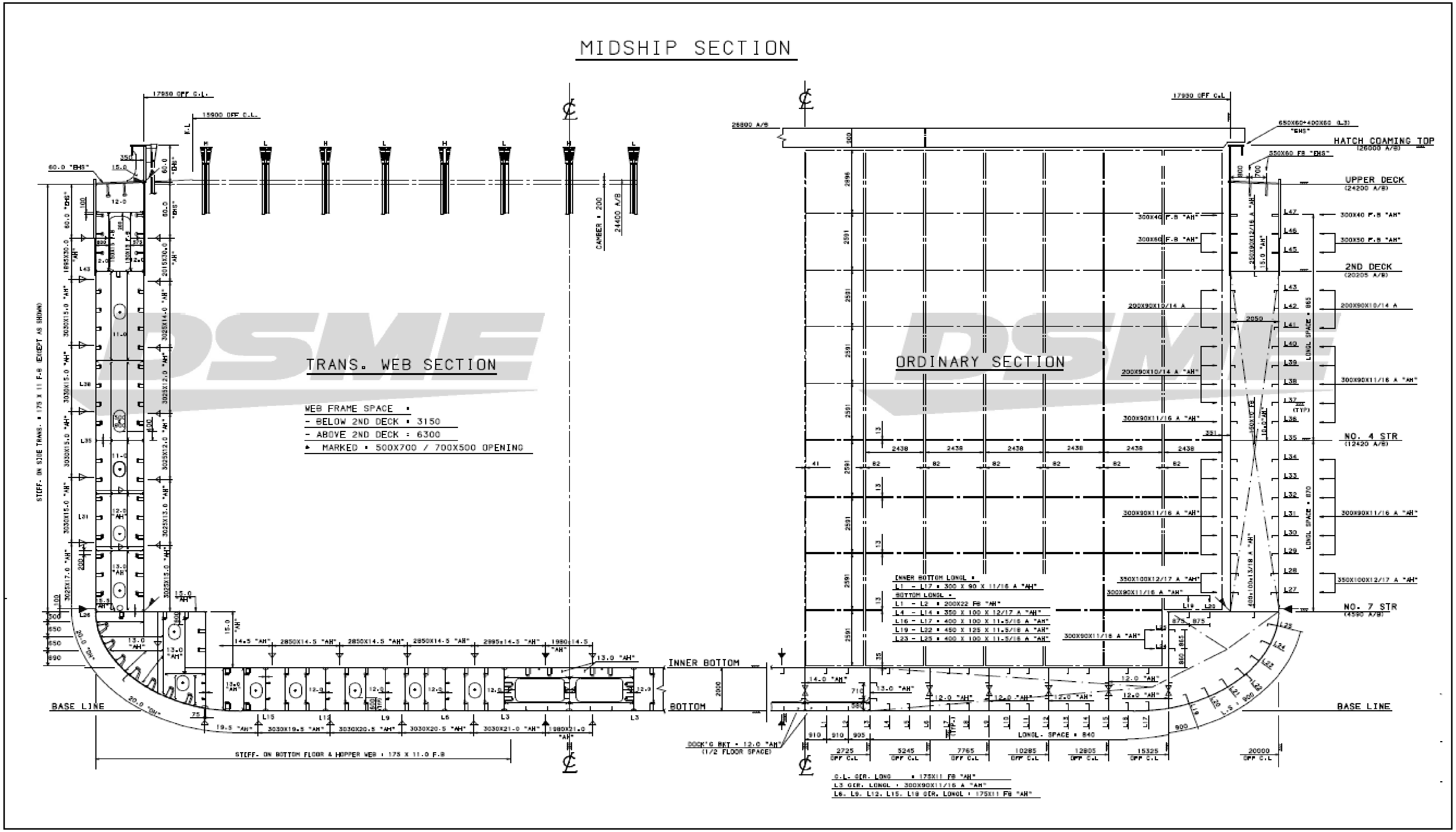
**[6]** Rule Scantling for container ship of LBP 316.45m based on the basis ship of 7,000TEU shown in following table.

| | Basis Ship(7,000 TEU) | Design Ship |
|---|---|---|
| **Main Dimensions** | | |
| LOA(m) | 302.0 | 316.45 |
| LBP(m) | 288.0 | 302.45 |
| Ls(m) | 284.25 | 298.4 |
| B mld(m) | 40.0 | 40.0 |
| D mld(m) | 24.2 | 24.2 |
| d(design) (m) | 12.0 | 12.0 |
| d(scant) (m) | 14.5 | 14.5 |
| $D_{mld,\ to\ second\ deck}$ (m) | 20.144 | 20.144 |
| Cb at Td | 0.691 | 0.725 |
| Cb at Ts | 0.721 | 0.76 |
| **Deadweight(t)** (design/scant.) | 70,367/96,026 | 78,900/107,670 |

**Table 1. Principle Particulars**

| | Sectional area of midship for half part($cm^2$) | First moment of sectional area about baseline for half part [$cm^3$] | moment of inertia of sectional area about neutral axis [$cm^4$] |
|---|---|---|---|
| Total data | 27,160 | $30.714\text{x}10^6$ | $522.542\ \text{x}10^8$ |

**Table 2. Sectional Properties of the Basis Ship**

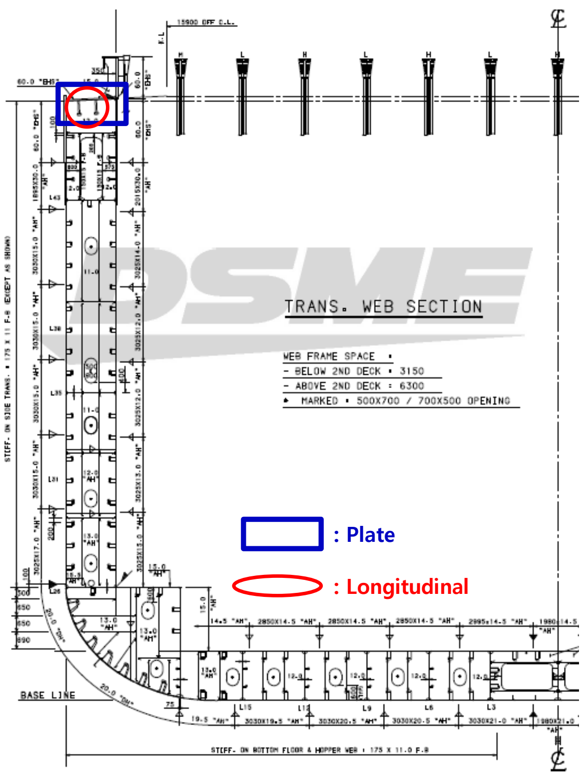



Midship Section of the Basis Ship

**[6.1]** Calculate the rule required minimum design still water bending moment and vertical wave bending moment of the design ship in accordance with the DNV Rule(Part 3, Chapter 1, Section 5. longitudinal strength, B. 100, B. 200). **[5 points]**

**[6.2]** Calculate the actual hull girder bending stress acting on the bottom and the deck. And check that the actual bending stress is satisfied with allowable bending stress at midship by the DNV rule(Part 3, Chapter 1, Section 5. longitudinal strength, C. 300). **[10 points]**

**[6.3]** The plate and the longitudinal stiffeners located at the deck indicated in following figure are most critical members in affecting the actual bending stress. Determine its thickness that satisfy the allowable bending stress at midship by the DNV rule(Part 3, Chapter 1, Section 5. longitudinal strength, C. 300). **[15 points]**



**DNV Rule**



# SECTION 4
# DESIGN LOADS

## A. General

**A 100 Introduction**

**101** In this section formulae for wave induced ship motions and accelerations as well as lateral pressures are given.

The given design wave coefficient is also a basic parameter for the longitudinal strength calculations.

**102** The ship motions and accelerations in B are given as extreme values (i.e. probability level = $10^{-8}$).

**103** Design pressures caused by sea, liquid cargoes, dry cargoes, ballast and bunkers as given in C are based on extreme conditions, but are modified to equivalent values corresponding to the stress levels stipulated in the rules. Normally this involves a reduction of the extreme values given in B to a $10^{-4}$ probability level.

**104** Impact pressures caused by the sea (slamming, bow impact) are not covered by this section. Design values are given in the sections dealing with specific structures.

**A 200 Definitions**

**201** Symbols:

$p$ = design pressure in kN/m$^2$
$r$ = density of liquid or stowage rate of dry cargo in t/m$^3$.

**202** The load point for which the design pressure shall be calculated is defined for various strength members as follows:

a) For plates:
midpoint of horizontally stiffened plate field.
Half of the stiffener spacing above the lower support of vertically stiffened plate field, or at lower edge of plate when the thickness is changed within the plate field.

b) For stiffeners:
midpoint of span.
When the pressure is not varied linearly over the span the design pressure shall be taken as the greater of:

$$p_m \text{ and } \frac{p_a + p_b}{2}$$

$p_m$, $p_a$ and $p_b$ are calculated pressure at the midpoint and at each end respectively.

c) For girders:
midpoint of load area.

## B. Ship Motions and Accelerations

**B 100 General**

**101** Accelerations in the ship's vertical, transverse and longitudinal axes are in general obtained by assuming the corresponding linear acceleration and relevant components of angular accelerations as independent variables. The combined acceleration in each direction may be taken as:

$$a_c = \sqrt{\sum_{m=1}^{n} a_m^2}$$

$n$ = number of independent variables.

Transverse or longitudinal component of angular acceleration considered in the above expression shall include the component of gravity acting simultaneously in the same direction.

**102** The combined effects given in the following may deviate from the above general expression due to practical simplifications applicable to hull structural design or based on experience regarding phasing between certain basic components.

**B 200 Basic parameters**

**201** The acceleration, sea pressures and hull girder loads have been related to a wave coefficient as given in Table B1.

| Table B1 Wave coefficient $C_W$ | |
|---|---|
| $L$ | $C_W$ |
| $L \le 100$ | $0.0792\,L$ |
| $100 < L < 300$ | $10.75 - [(300-L)/100]^{3/2}$ |
| $300 \le L \le 350$ | $10.75$ |
| $L > 350$ | $10.75 - [(L-350)/150]^{3/2}$ |

The above formulae are illustrated in Fig.1.

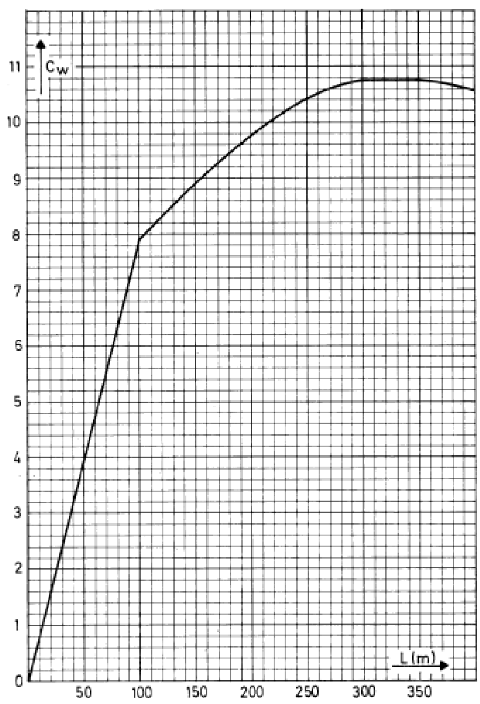



**Fig. 1**
**Wave coefficient**

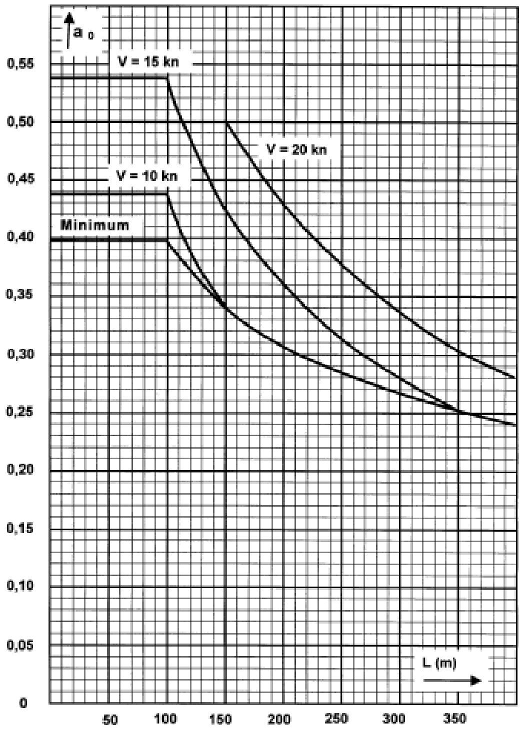



**Fig. 2**
**Acceleration parameter**

**202** For ships with restricted service, $C_W$ may in general be reduced as follows:

— service area notation **R0**: No reduction
— service area notation **R1**: 10%
— service area notation **R2**: 20%
— service area notation **R3**: 30%
— service area notation **R4**: 40%
— service area notation **RE**: 50%.

**203** A common acceleration parameter is given by:

$$a_0 = \frac{3C_W}{L} + C_V C_{V1}$$

$C_V = \frac{\sqrt{L}}{50}$, maximum 0,2

$C_{V1} = \frac{V}{\sqrt{L}}$, minimum 0,8

Values of $a_0$ according to the above formula may also be found from Fig.2.

**B 300 Surge, sway /yaw and heave accelerations**

**301** The surge acceleration is given by:

$$a_x = 0.2\, g_0\, a_0 \sqrt{C_B} \qquad (m/s^2)$$

**302** The combined sway/yaw acceleration is given by:

$$a_y = 0.3\, g_0\, a_0 \quad (m/s^2)$$

**303** The heave acceleration is given by:

$$a_z = 0.7\, g_0 \frac{a_0}{\sqrt{C_B}} \qquad (m/s^2)$$

**B 400 Roll motion and acceleration**

**401** The roll angle (single amplitude) is given by:

$$\phi = \frac{50c}{B + 75} \qquad (rad)$$

c = $(1.25 - 0.025\, T_R)\, k$
k = 1.2 for ships without bilge keel
 = 1.0 for ships with bilge keel
 = 0.8 for ships with active roll damping facilities
$T_R$ = as defined in 402, not to be taken greater than 30.

**402** The period of roll is generally given by:

$$T_R = \frac{2k_r}{\sqrt{GM}} \qquad (s)$$

$k_r$ = roll radius of gyration in m
GM = metacentric height in m.

The values of $k_r$ and GM to be used shall give the minimum realistic value of $T_R$ for the load considered.

In case $k_r$ and GM have not been calculated for such condition, the following approximate design values may be used:

$k_r$ = 0.39 B for ships with even transverse distribution of mass
 = 0.35 B for tankers in ballast
 = 0.25 B for ships loaded with ore between longitudinal bulkheads
GM = 0.07 B in general
 = 0.12 B for tankers and bulk carriers.

**403** The tangential roll acceleration (gravity component not included) is generally given by:

$$a_r = \phi \left(\frac{2\pi}{T_R}\right)^2 R_R \qquad (m/s^2)$$

$R_R$ = distance in m from the centre of mass to the axis of rotation.

The roll axis of rotation may be taken at a height z m above the baseline.

$$z = \text{the smaller of } \left[\frac{D}{4} + \frac{T}{2}\right] \text{ and } \left[\frac{D}{2}\right]$$

**404** The radial roll acceleration may normally be neglected.

**B 500 Pitch motion and acceleration**

**501** The pitch angle is given by:

$$\theta = 0.25 \frac{a_0}{C_B} \qquad (rad)$$

**502** The period of pitch may normally be taken as:

$$T_P = 1.8 \sqrt{\frac{L}{g_0}} \qquad (s)$$

**503** The tangential pitch acceleration (gravity component not included) is generally given by:

$$a_p = \theta \left[\frac{2\pi}{T_P}\right]^2 R_P \quad (m/s^2)$$

$T_P$ = period of pitch
$R_P$ = distance in m from the centre of mass to the axis of rotation.

The pitch axis of rotation may be taken at the cross- section 0.45 L from A.P. z meters above the baseline.

z = as given in 403.

With $T_P$ as indicated in 502 the pitch acceleration is given by:

$$a_p = 120 \, \theta \frac{R_P}{L} \quad (m/s^2)$$

**504** The radial pitch acceleration may normally be neglected.

**B 600 Combined vertical acceleration**

**601** Normally the combined vertical acceleration (acceleration of gravity not included) may be approximated by:

$$a_v = \frac{k_v \, g_0 \, a_0}{C_B} \quad (m/s^2)$$

$k_v$ = 1.3 aft of A.P.
= 0.7 between 0.3 L and 0.6 L from A.P.
= 1.5 forward of F.P.

Between mentioned regions $k_v$ shall be varied linearly, see Fig.3.

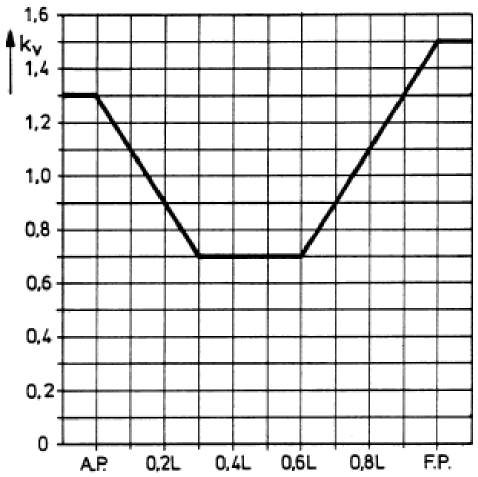



**Fig. 3**
**Acceleration distribution factor**

If for design purposes a constant value of $a_v$ within the cargo area is desirable, a value equal to 85% of the maximum $a_v$ within the same area may be used.

**602** As an alternative the acceleration along the ship's vertical axis (acceleration of gravity not included) is given as the combined effect of heave, pitch and roll calculated as indicated in 100, i.e.:

$$a_v = \max \begin{cases} \sqrt{a_{rz}^2 + a_z^2} \\ \sqrt{a_{pz}^2 + a_z^2} \end{cases} \quad (m/s^2)$$

$a_z$ = as given in 303
$a_{rz}$ = vertical component of the roll acceleration given in 403
$a_{pz}$ = vertical component of the pitch acceleration given in 503.

Note that $a_{rz}$ and $a_{pz}$ are equal to $a_r$ and $a_p$ using the horizontal projection of $R_R$ and $R_P$ respectively.

**B 700 Combined transverse acceleration**

**701** Acceleration along the ship's transverse axis is given as the combined effect of sway/yaw and roll calculated as indicated in 100, i.e.:

$$a_t = \sqrt{a_y^2 + (g_0 \sin\phi + a_{ry})^2} \quad (m/s^2)$$

$a_{ry}$ = transverse component of the roll acceleration given in 403.

Note that $a_{ry}$ is equal to $a_r$ using the vertical projection of $R_R$.

**B 800 Combined longitudinal accelerations**

**801** Acceleration along the ship's longitudinal axis is given as the combined effect of surge and pitch calculated as indicated in 100, i.e.:

$$a_l = \sqrt{a_x^2 + (g_0 \sin\theta + a_{px})^2} \quad (m/s^2)$$

$a_{px}$ = longitudinal component of pitch acceleration given in 503.

Note that $a_{px}$ is equal to $a_p$ using the vertical projection of $R_P$.

## C. Pressures and Forces

**C 100 General**

**101** The external and internal pressures considered to influence the scantling of panels are:
— static and dynamic sea pressures
— static and dynamic pressures from liquids in a tank
— static and dynamic pressures from dry cargoes, stores and equipment.

**102** The design sea pressures are assumed to be acting on the ship's outer panels at full draught.

**103** The internal pressures are given for the panel in question irrespectively of possible simultaneous pressure from the opposite side. For outer panels sea pressure at ballast draught may be deducted.

**104** The gravity and acceleration forces from heavy units of cargo and equipment may influence the scantlings of primary strength members.

**C 200 Sea pressures**

**201** The pressure acting on the ship's side, bottom and weather deck shall be taken as the sum of the static and the dynamic pressure as:

— for load point below summer load waterline :

$p_1 = 10 h_0 + p_{dp}$ [1)] (kN/m$^2$)

— for load point above summer load waterline :

$p_2$ = a ( $p_{dp} - (4 + 0.2\, k_s)\, h_0$ ) [1] (kN/m²)
= minimum $6.25 + 0.025\, L_1$ for sides
= minimum 5 for weather decks.

The pressure $p_{dp}$ is taken as:

$$p_{dp} = p_l + 135\frac{y}{B+75} - 1.2\,(T - z) \quad (kN/m^2)$$

$$p_l = k_s C_W + k_f$$

$$= (k_s C_W + k_f)\left(0.8 + 0.15\frac{V}{\sqrt{L}}\right) \text{ if } \frac{V}{\sqrt{L}} > 1.5$$

$$k_s = 3C_B + \frac{2.5}{\sqrt{C_B}} \text{ at AP and aft}$$

= 2 between 0.2 L and 0.7 L from AP

$$= 3C_B + \frac{4.0}{C_B} \text{ at FP and forward.}$$

Between specified areas $k_s$ shall be varied linearly.

a = 1.0 for ship's sides and for weather decks forward of 0.15 L from FP, or forward of deckhouse front, whichever is the foremost position
= 0.8 for weather decks elsewhere
$h_0$ = vertical distance from the waterline at draught T to the load point (m)
z = vertical distance from the baseline to the load point, maximum T (m)
y = horizontal distance from the centre line to the load point, minimum B/4 (m)
$C_W$ = as given in B200
$k_f$ = the smallest of T and f
f = vertical distance from the waterline to the top of the ship's side at transverse section considered, maximum $0.8\, C_W$ (m)
$L_1$ = ship length, need not be taken greater than 300 (m).

1) For ships with service restrictions, $p_2$ and the last term in $p_1$ may be reduced by the percentages given in B202. $C_W$ should not be reduced.

**202** The sea pressure at minimum design draught which may be deducted from internal design pressures shall be taken as:

p = $10\,(T_M - z)$ (kN/m²)
= minimum 0

$T_M$ = minimum design draught in m normally taken as 0.35 T for dry cargo vessels and 2 + 0.02 L for tankers
z = vertical distance in m from the baseline to the load point.

**203** The design pressure on watertight bulkheads (compartment flooded) shall be taken as:

$$p = 10\, h_b \quad (kN/m^2)$$

$h_b$ = vertical distance in metres from the load point to the deepest equilibrium waterline in damaged condition obtained from applicable damage stability calculations.

**204** The design pressure on inner bottom (double bottom flooded) shall not be less than:

$$p = 10\, T \quad (kN/m^2).$$

## C 300 Liquids in tanks

**301** Tanks for crude oil or bunkers are normally to be designed for liquids of density equal to that of sea water, taken as $\rho = 1.025$ t/m³ (i.e. $\rho\, g_0 \approx 10$). Tanks for heavier liquids may be approved after special consideration. Vessels designed for 100% filling of specified tanks with a heavier liquid will be given the notation **HL(ρ)**, indicating the highest cargo density applied as basis for approval. The density upon which the scantling of individual tanks are based, will be given in the appendix to the classification certificate.

**302** The pressure in full tanks shall be taken as the greater of:

$$p = \rho\,(g_0 + 0.5\, a_v)\, h_s \quad (kN/m^2) \qquad [1]$$

$$p = \rho\, g_0\, [0.67(h_s + \phi b) - 0.12\sqrt{H b_t \phi}] \quad (kN/m^2) \qquad [2]$$

$$p = \rho\, g_0\, [0.67(h_s + \theta l) - 0.12\sqrt{H l_t \theta}] \quad (kN/m^2) \qquad [3]$$

$$p = 0.67\,(\rho\, g_0\, h_p + \Delta p_{dyn}) \quad (kN/m^2) \qquad [4]$$

$$p = \rho\, g_0\, h_s + p_0 \quad (kN/m^2) \qquad [5]$$

$a_v$ = vertical acceleration as given in B600, taken in centre of gravity of tank.
$\phi$ = as given in B400
$\theta$ = as given in B500
H = height in m of the tank
$\rho$ = density of ballast, bunkers or liquid cargo in t/m³, normally not to be taken less than 1.025 t/m³ (i.e. $\rho\, g_0 \approx 10$)
b = the largest athwartship distance in m from the load point to the tank corner at top of the tank which is situated most distant from the load point. For tank tops with stepped contour, the uppermost tank corner will normally be decisive
$b_t$ = breadth in m of top of tank
$l$ = the largest longitudinal distance in m from the load point to the tank corner at top of tank which is situated most distant from the load point. For tank tops with stepped contour, the uppermost tank corner will normally be decisive
$l_t$ = length in m of top of tank
$h_s$ = vertical distance in m from the load point to the top of tank, excluding smaller hatchways.
$h_p$ = vertical distance in m from the load point to the top of air pipe
$p_0$ = 25 kN/m² in general
= 15 kN/m² in ballast holds in dry cargo vessels
= tank pressure valve opening pressure when exceeding the general value.
$\Delta p_{dyn}$ = calculated pressure drop according to Pt.4 Ch.6 Sec.4 K201.

For calculation of girder structures the pressure [4] shall be increased by a factor 1.15.

The formulae normally giving the greatest pressure are indicated in Figs. 4 to 6 for various types.

For sea pressure at minimum design draught which may be deduced from formulae above, see 202.

Formulae [ 2 ] and [ 3 ] are based on a 2% ullage in large tanks.

**Guidance note:**

With respect to the definition of $h_s$, hatchways may be considered small to the extent that the volume of the hatchway is negligible compared to the minimum ullage of the tank. Hatchways for access only may generally be defined as small with respect to the definition of $h_s$.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

**Guidance note:**

If the pressure drop according to Pt.4 Ch.6 Sec.4 K201 is not available, $\Delta p_{dyn}$ may normally be taken as 25 kN/m². for ballast tanks and zero for other tanks. If arrangements for the prevention of overpumping of ballast tanks in accordance with Pt.4 Ch.6 Sec.4 K200 are fitted, $p_{dyn}$ may be taken as zero.

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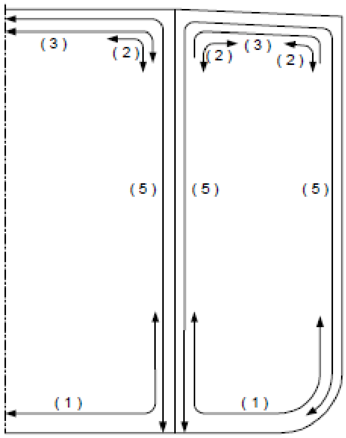



**Fig. 4**
**Section in cargo tanks**

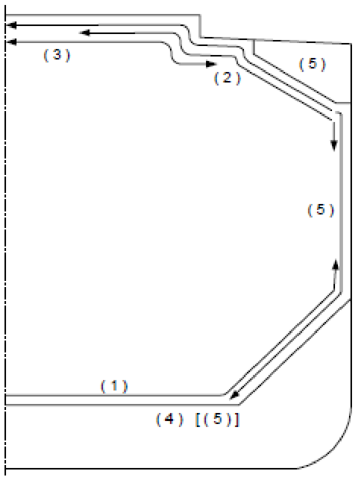



**Fig. 5**
**Section in bulk cargo hold**

**303** Tanks with $l_b < 0.13$ L and $b_b < 0.56$ B shall have scantlings for unrestricted filling height.

For strength members located less than 0.25 $l_b$ away from wash and end bulkheads the pressure shall not be taken less than:

$$p = \rho\left[4 - \frac{L}{200}\right] l_b \quad (kN/m^2)$$

$l_b$ = distance in m between transverse tank bulkheads or fully effective transverse wash bulkheads at the height at which the strength member is located ($\alpha_t < 0.2$).

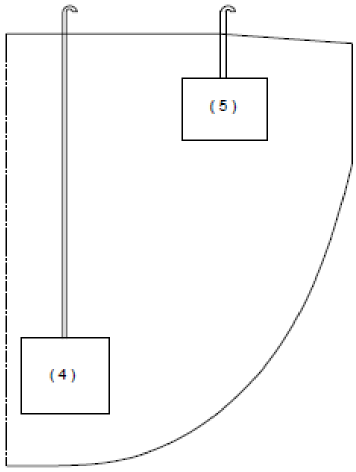



**Fig. 6**
**Section in engine room**

For strength members located less than 0.25 $b_b$ away from longitudinal wash bulkheads and tank sides the pressure shall not be taken less than:

$$p = \rho\left[3 - \frac{B}{100}\right] b_b \quad (kN/m^2)$$

$b_b$ = distance in m between tank sides or fully effective longitudinal wash bulkheads at the height at which the strength member is located ($\alpha_l < 0.2$)

If the wash bulkheads are not fully effective ($\alpha_t > 0.2$ $\alpha_l > 0.2$). $l_b$ and $b_b$ may be substituted by $l_s$ and $b_s$ given in 306. $\alpha_t$ and $\alpha_l$ are defined in 306.

**304** The minimum sloshing pressure on webframes and girder panels in cargo and ballast tanks shall not be taken less than 20 kN/m².

In long or wide tanks with many webframes or girders the sloshing pressure on the frames or girders near to the wash or end bulkheads shall be taken as:

$$p = p_{bhd}\left(1 - \frac{s}{l_s}\right)^2 \quad (kN/m^2) \text{ for webframes}$$

$$p = p_{bhd}\left(1 - \frac{s}{b_s}\right)^2 \quad (kN/m^2) \text{ for longitudinal griders.}$$

$p_{bhd}$ = sloshing pressure on wash or end bulkheads as given in 306

s = distance in m from bulkhead to webframe or girder considered.

$l_s$ and $b_s$ as given in 306.

**305** Tanks with free sloshing breadth $b_s > 0.56$ B will be subject to specified restrictions on maximum GM. In addition such tanks and or tanks with a sloshing length such that 0.13 L $< l_s < 0.16$ L may be designed for specified restrictions in filling height.

Maximum allowable GM, cargo density and possible restrictions on filling heights will be stated in the appendix to the classification certificate.

The sloshing pressures (p) given in 306 and 309 shall be considered together with the normal strength formulae given in

Sec.7, Sec.8 and Sec.9.

The impact pressures ($p_i$) given in 307, 308, 309, and 310 shall be used together with impact strength formulae given in Sec.9 E400.

$b_s$ and $l_s$ as given in 306.

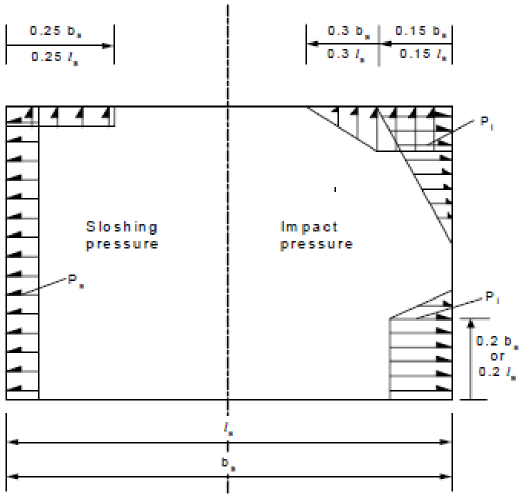



**Fig. 7**
**Pressure distribution**

**306** *Sloshing pressure*

For strength members located less than 0.25 $l_s$ away from transverse wash and end bulkheads the pressure shall not be taken less than (see Fig.7):

$$p = \rho g_0 l_s k_f \left[0.4 - \left(0.39 - \frac{1.7 l_s}{L}\right)\frac{L}{350}\right] \quad (\text{kN/m}^2)$$

For strength members located less than 0.25 $b_s$ from longitudinal wash bulkheads and tank sides the pressure shall not be taken less than:

$$p = 7 \rho g_0 k_f \left(\frac{b_s}{B} - 0.3\right) GM^{0.75} \quad (\text{kN/m}^2)$$

$k_f$ = $1 - 2\left(0.7 - \frac{h}{H}\right)^2$ , maximum = 1

$$\left(\frac{h}{H}\right)_{max} = 1$$

h = filling height (m)
H = tank height (m) within 0.15 $l_s$ or 0.15 $b_s$
GM = maximum GM including correction for free surface effect. $GM_{minimum}$ = 0.12 B (m)

$l_s$ = effective sloshing length in m given as:

$$= \frac{(1 + n_t \alpha_t)(1 + \beta_t n_2)\, l}{(1 + n_t)(1 + n_2)} \quad \text{for end bulkheads}$$

$$= \frac{[1 + \alpha_t(n_t - 1)](1 + \beta_t n_2)\, l}{(1 + n_t)(1 + n_2)} \quad \text{for wash bulkheads}$$

$b_s$ = effective sloshing breadth in m given as:

$$= \frac{(1 + n_l \alpha_l)(1 + \beta_l n_4)\, b}{(1 + n_l)(1 + n_4)} \quad \text{for tank sides}$$

$$= \frac{[1 + \alpha_l(n_l - 1)](1 + \beta_l n_4)\, b}{(1 + n_l)(1 + n_4)} \quad \text{for wash bulkhead}$$

$l$ = tank length in m
b = tank breadth in m
$n_t$ = number of transverse wash bulkheads in the tank with $\alpha_t < 0.5$
$\alpha_t$ = ratio between openings in transverse wash bulkhead and total transverse area in the tank below considered filling height, see Fig.8.

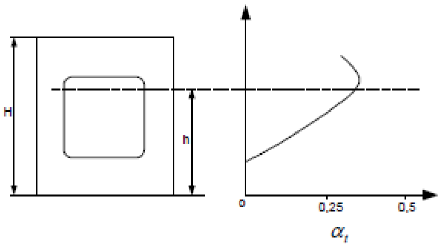



**Fig. 8**
**Wash bulkhead coefficient**

If no restriction to filling height, h is taken as 0.7 H.

$n_2$ = number of transverse web-ring frames in the tank over the length:

$$\frac{l}{(1 + n_t)}$$

$\beta_t$ = ratio between openings in web-ring frames and total transverse area in the tank below considered filling height, see Fig.9.

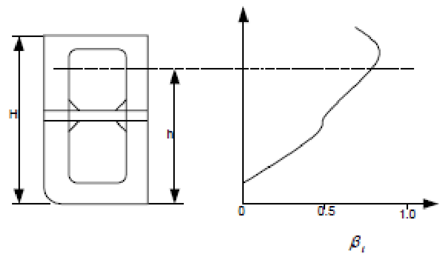



**Fig. 9**
**Webframe coefficient**

If no restriction to filling height, h is taken as 0.7 H.

$n_l$ = number of longitudinal wash bulkheads in the tank with $\alpha_l < 0.5$
$\alpha_l$ = similar to $\alpha_t$ but taken for longitudinal wash bulkhead
$n_4$ = number of longitudinal ring-girders in the tank between the breadth

$$\frac{b}{(1 + n_l)}$$

$\beta_l$ = similar to $\beta_t$ taken for longitudinal ring-girders.

**307** *Impact pressure in upper part of tanks.*

Tanks with free sloshing length 0.13 L < $l_s$ < 0.16 L or with free sloshing breadth $b_s$ > 0.56 B will generate an impact pressure on horizontal and inclined surfaces adjacent to vertical surfaces in upper part of the tank due to high liquid velocities meeting these surfaces. For horizontal or inclined panels (deck, horizontal stringers etc.) the impact pressure on upper parts of the tank may be taken as:

Within 0.15 $l_s$ from transverse wash or end bulkheads:

$$p_i = \rho g_0 k_f \left(\frac{220\, l_s}{L} - 7.5\right) \sin^2\gamma \quad (\text{kN/m}^2)$$

for $\frac{l_s}{L} < \frac{350 + L}{3550}$

$$= \rho\, g_0\, k_f \left(25 + \frac{L}{13}\right)\left(0.5 + \frac{l_s}{L}\right) \sin^2\gamma \quad (\text{kN/m}^2)$$

for $\frac{l_s}{L} > \frac{350 + L}{3550}$

Within 0.15 $b_s$ from longitudinal wash bulkheads and tank sides:

$$p_i = \frac{240\, \rho\, g_0\, k_f}{B}\left(\frac{b_s}{B} - 0.3\right) GM^{1.5} \sin^2\gamma$$

Outside 0.15 $l_s$ and 0.15 $b_s$ the pressure may be reduced to zero at 0.3 $l_s$ and 0.3$b_s$, respectively, see Fig.7.
In tank corners within 0.15 $l_s$ and 0.15 $b_s$ the impact pressure shall not be taken smaller than $p_i$ (transversely) or $p_i$ (longitudinally) + 0.4 $p_i$ (transversely).
The reflected impact pressure on vertical surfaces adjacent to horizontal or inclined surfaces above will have an impact pressure linearly reduced to 50% of the pressure above, 0.1 $l_s$ or 0.1 $b_s$ m below.

$l_s$, $b_s$ and GM are as given in 306.

$$k_f = 1 - 4\left(0.6 - \frac{h}{H}\right)^2, \text{ maximum} = 1,$$

$$\left(\frac{h}{H}\right)_{max} = 1$$

h = maximum allowable filling height (m)
H = tank height (m) within 0.15 $l_s$ or 0.15 $b_s$
$\gamma$ = angle between considered panel and the vertical.

**308** *Impact pressure in lower part of smooth tanks*

In larger tanks ( $l_s$ > 0.13 L or $b_s$ > 0.56 B) with double bottom and which have no internal transverse or longitudinal girders restraining the liquid movement at low minimum filling heights (2 < h < 0.2 $l_s$ or 2 < h < 0.2 $b_s$) the impact pressure on vertical and inclined tank surfaces shall not be taken less than:

$$p_i = 1.42\, \rho\, g_0\, k\, l_s \sin^2\delta \quad (\text{kN/m}^2)$$

on transverse bulkheads up to a height of 0.2 $l_s$

$$p_i = 1.5\, \rho\, g_0\, b_s \sin^2\delta \quad (\text{kN/m}^2)$$

on longitudinal bulkheads up to a height of 0.2 $b_s$

The impact pressure may be reduced to zero 1 metre above the heights given, see Fig.7.

In tank corners at outermost side of transverse bulkheads the impact pressure within 0.15 $b_s$ shall not be taken smaller than:

$p_i$ (longitudinally) + 0.4 $p_i$ (transversely)

If the tank is arranged with a horizontal stringer within the height h < 0.2 $l_s$ or h < 0.2 $b_s$ a reflected impact pressure of the same magnitude as on adjacent transverse or longitudinal bulkhead shall be used on the under side of the stringer panel.

$l_s$ and $b_s$ are free sloshing length and breadth in m at height considered, as given in 306.

k = 1 for L < 200
= 1.4 – 0.002L for L > 200
$\delta$ = angle between the lower boundary panel and the horizontal.

**309** For tanks with upper panels higher than L/20 m above lowest seagoing waterline the sloshing and impact pressures given in 306 and 307 shall be multiplied by the following magnification factors:

1 + 6 $z_e$/L for longitudinal sloshing

1 + 7.5 $z_e$ GM/$B^2$ for transverse sloshing

1 + 18 $z_e$/L for longitudinal impact

1 + 17.5 $z_e$ GM/$B^2$ for transverse impact

$z_e$ = $z_t - T_s$ – L/20 (m)
$z_t$ = distance from baseline to panel consider (m)
$T_S$ = lowest seagoing draught (m)
= 0.50 T may normally be used.

**310** For tanks with smooth boundaries (no internal structural members) with tank bottom higher than the D/2, the low filling impact pressure as given in 308 shall be multiplied by the following magnification factor:

$$\left(1 + \frac{2 z_i \theta}{l_s}\right)^2 \text{ in longitudinal direction}$$

$$\left(1 + \frac{2 z_i \phi}{b_s}\right)^2 \text{ in transverse direction}$$

$\theta$ and $\phi$ = pitch and rolling angle given in B400 and B500
$z_i$ = distance from panel considered to D/2 in m.

## C 400 Dry cargoes, stores, equipment and accommodation

**401** The pressure on inner bottom, decks or hatch covers shall be taken as:

$$p = \rho\,(g_0 + 0.5\, a_v)\, H \quad (\text{kN/m}^2)$$

$a_v$ = as given in B600
H = stowage height in m.

Standard values of $\rho$ and H are given in Table C1.

If decks (excluding inner bottom) or hatch covers are designed for cargo loads heavier than the standard loads given in Table C1 the notation **DK(+)** or **HA(+)** respectively, will be assigned. The design cargo load in t/m$^2$ will be given for each individual cargo space in the appendix to the classification certificate.

**402** When the weather deck or weather deck hatch covers are designed to carry deck cargo the pressure is in general to be taken as the greater of p according to 201 and 401.

In case the design stowage height of weather deck cargo is smaller than 2.3 m, combination of loads may be required after special consideration.

**Table C1 Standard load parameters.**

| *Decks* | *Parameters* | |
|---|---|---|
| | $\rho$ | *H* |
| Sheltered deck, sheltered hatch covers and inner bottom for cargo or stores | 0.7 t/m³ [1)] | vertical distance in m from the load point to the deck above. For load points below hatchways H shall be measured to the top of coaming. |
| | $\rho$ H | |
| Weather deck and weather deck hatch covers intended for cargo | 1.0 t/m² for L=100 m<br>1.3 t/m² for L > 150 m at superstructure deck.<br>1.75 t/m² for L > 150 m at freeboard deck.<br>For vessels corresponding to 100 m < L < 150 m, the standard value of $\rho$ H is obtained by linear interpolation. | |
| Platform deck in machinery space | 1.6 t/m² | |
| Accommodation decks | 0.35 t/m², when not directly calculated, including deck's own mass.<br>Minimum 0.25 t/m². | |

1) If $\Sigma\rho$H for cargo spaces exceeds the total cargo capacity of the vessel, $\rho$ may be reduced after special consideration in accordance with specified maximum allowable load for individual decks. When the deck's own mass exceeds 10% of the specified maximum allowable loads, the $\rho$H shall not be taken less than the combined load of deck mass and maximum allowable deck load.

**403** The pressure from bulk cargoes on sloping and vertical sides and bulkheads shall be taken as:

$$p = \rho\,(g_0 + 0.5\,a_v)\,K\,h_c \quad (kN/m^2)$$

K = $\sin^2\alpha\,\tan^2(45 - 0.5\,\delta) + \cos^2\alpha$
$\alpha$ = angle between panel in question and the horizontal plane in degrees
$a_v$ = as given in B600
$\delta$ = angle of repose of cargo in degrees, not to be taken greater than 20 degrees for light bulk cargo (grain etc.), and not greater than 35 degrees for heavy bulk cargo (ore)
$h_c$ = vertical distance in m from the load point to the highest point of the hold including hatchway in general. For sloping and vertical sides and bulkheads, $h_c$ may be measured to deck level only, unless the hatch coaming is in line with or close to the panel considered.

## C 500 Deck cargo units. Deck equipment

**501** The forces acting on supporting structures and securing systems for heavy units of cargo, equipment or structural components (including cargo loads on hatch covers) are normally to be taken as:

— vertical force alone: $P_V = (g_o + 0.5\,a_v)\,M$ (kN)

— vertical force in combination with transverse force: $P_{VC} = g_o\,M$ (kN)

— transverse force in combination with vertical force: $P_{TC} = 0.67\,a_t\,M$ (kN)

— vertical force in combination with longitudinal force: $P_{VC} = (g_o + 0.5\,a_v)\,M$ (kN),

acting downwards at vessels ends together with downward pitch, acting in 60° - 90° phasing with $P_{LC}$ amidships, where heave part of $P_{VC}$ is prevailing

— longitudinal force in combination with vertical force: $P_{LC} = 0.67\,a_l\,M$ (kN)

M = mass of unit in t
$a_v$ = as given in B600
$a_t$ = as given in B700
$a_l$ = as given in B800

— $P_{TC}$ and $P_{LC}$ may be regarded as not acting simultaneously, except when the stress $\sigma_L$ C > 0.6 $\sigma_{TC}$, in which case $\sigma_{LC}$ + 0.4 $\sigma_{TC}$ shall be substituted for $\sigma_{LC}$.

**502** Regarding forces acting on cargo containers, their supports and lashing systems, reference is made to Pt.5 Ch.2 Sec.6.

# SECTION 5 LONGITUDINAL STRENGTH

## A. General

### A 100 Introduction

**101** In this section the requirements regarding the longitudinal hull girder scantlings with respect to bending and shear are given.

**102** The wave bending moments and shear forces are given as the design values with a probability of exceedance of $10^{-8}$.

These values are applied when determining the section modulus and the shear area of the hull girder and in connection with control of buckling and ultimate strength. Reduced values will have to be used when considering combined local and longitudinal stresses in local elements, see B204.

**103** The buckling strength of longitudinal members is not covered by this section. Requirements for such control are given in Sec.13.

**104** For ships with small block coefficient, high speed and large flare the hull girder buckling strength in the forebody may have to be specially considered based on the distribution of still water and vertical wave bending moments indicated in B100 and B200 respectively. In particular this applies to ships with length L > 120 m and speed V > 17 knots.

**105** For narrow beam ships the combined effects of vertical and horizontal bending of the hull girder may have to be specially considered as indicated in C300.

**106** For ships with large deck openings (total width of hatch openings in one transverse section exceeding 65% of the ship's breadth or length of hatch opening exceeding 75% of hold length) the longitudinal strength including torsion may be required to be considered as given in Pt.5 Ch.2 Sec.6 B200. For ships with block coefficient $C_B$ < 0.7 the longitudinal/local strength outside of the midship region may, subject to special consideration in each case, be taken according to Pt.5 Ch.2 Sec.6 B.

**107** In addition to the limitations given in 104 to 106, special considerations will be given to vessels with the following proportions:

$L/B \leq 5$
$B/D \geq 2.5$.

### A 200 Definitions

**201** Symbols:

$I_N$ = moment of inertia in $cm^4$ about the transverse neutral axis
$I_C$ = moment of inertia in $cm^4$ about the vertical neutral axis
$C_W$ = wave coefficient as given in Sec.4 B
$S_N$ = first moment of area in $cm^3$ of the longitudinal material above or below the horizontal neutral axis, taken about this axis
$z_n$ = vertical distance in m from the baseline or deckline to the neutral axis of the hull girder, whichever is relevant
$z_a$ = vertical distance in m from the baseline or deckline to the point in question below or above the neutral axis, respectively
$M_S$ = design stillwater bending moment in kNm as given in B100
$Q_S$ = design stillwater shear force in kN as given in B100
$M_W$ = rule wave bending moment in kNm as given in B200
$Q_W$ = rule wave shear force in kN as given in B200
$M_{WH}$ = rule wave bending moment about the vertical axis as given in B205
$M_{WT}$ = rule wave torsional moment as given in B206.

**202** Terms:

*Effective longitudinal bulkhead* is a bulkhead extending from bottom to deck and which is connected to the ship's side by transverse bulkheads both forward and aft.

*Loading manual* is a document which describes:

- the loading conditions on which the design of the ship has been based, including permissible limits of still water bending moment and shear force and shear force correction values and, where applicable, permissible limits related to still water torsional moment [1] and lateral loads
- the results of calculations of still water bending moments, shear forces and still water torsional moments if unsymmetrical loading conditions with respect to the ships centreline
- the allowable local loadings for the structure (hatch covers, decks, double bottom, etc.).

1) Permissible torsional still water moment limits are generally applicable for ships with large deck openings as given in 106 and class notation CONTAINER or Container Carrier.

For bulk carriers of 150 m in length and above, additional requirements as given in Pt.5 Ch.2 Sec.5 A also apply.

A *Loading computer system* is a system, which unless stated otherwise is digital, by means of which it can be easily and quickly ascertained that, at specified read-out points, the still water bending moments, shear forces, and the still water torsional moments and lateral loads, where applicable, in any load or ballast condition will not exceed the specified permissible values.

**Guidance note:**
The term "Loading computer system" covers the term "Loading instrument" as commonly used in IACS UR S1.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

An operation manual is always to be provided for the loading instrument. Single point loading instruments are not acceptable.

*Category I ships*. Ships with large deck openings where combined stresses due to vertical and horizontal hull girder bending and torsional and lateral loads have to be considered.

Ships liable to carry non-homogeneous loadings, where the cargo and or ballast may be unevenly distributed. Ships less than 120 m in length, when their design takes into account uneven distribution of cargo or ballast, belong to Category II.

Chemical tankers and gas carriers.

*Category II Ships*. Ships with arrangement giving small possibilities for variation in the distribution of cargo and ballast, and ships on regular and fixed trading pattern where the Loading Manual gives sufficient guidance, and in addition the exception given under Category I.

## B. Still Water and Wave Induced Hull Girder Bending Moments and Shear Forces

### B 100 Stillwater conditions

**101** The design stillwater bending moments, $M_S$, and stillwater shear forces, $Q_S$, shall be calculated along the ship length for design cargo and ballast loading conditions as specified in 102.

For these calculations, downward loads are assumed to be taken as positive values, and shall be integrated in the forward direction from the aft end of L. The sign conventions of $Q_S$ and $M_S$ are as shown in Fig.1.

(IACS UR S11.2.1.1 Rev.3)

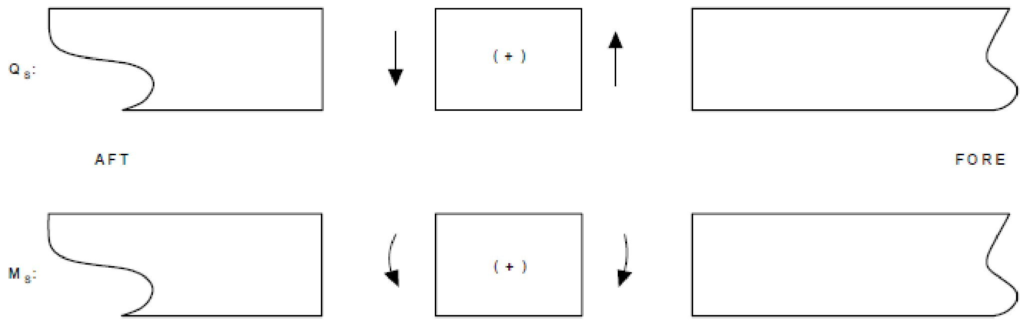



**Fig. 1**
**Sign Conventions of $Q_S$ and $M_S$**

**102** In general, the following design cargo and ballast loading conditions, based on amount of bunker, fresh water and stores at departure and arrival, shall be considered for the $M_S$ and $Q_S$ calculations. Where the amount and disposition of consumables at any intermediate stage of the voyage are considered more severe, calculations for such intermediate conditions shall be submitted in addition to those for departure and arrival conditions. Also, where any ballasting and or deballasting is intended during voyage, calculations of the intermediate condition just before and just after ballasting and or deballasting any ballast tank shall be submitted and where approved included in the loading manual for guidance.

*Cargo ships, container carriers, roll-on/roll-off and refrigerated carriers, ore carriers and bulk carriers:*

— homogenous loading conditions at maximum draught
— ballast conditions
— special loading conditions, e.g. container or light load conditions at less than the maximum draught, heavy cargo, empty holds or non-homogenous cargo conditions, deck cargo conditions, etc. where applicable
— docking condition afloat
— for vessels with **BC-A**, **BC-B**, **BC-C** or **BC-B*** notation, loading conditions as specified in Pt.5 Ch.2 Sec.5 A107 to A110 and A112 to A114.

*Oil tankers:*

— homogenous loading conditions (excluding dry and clean ballast tanks) and ballast or part-loaded conditions
— any specified non-uniform distribution of loading
— mid-voyage conditions relating to tank cleaning or other operations where these differ significantly from the ballast conditions
— docking condition afloat
— for oil carriers complying with the requirements for the segregated ballast tanks as stipulated in Pt.5 Ch.3 Sec.3 B, the ballast conditions shall in addition to the segregated ballast condition include one or more relevant conditions with additional ballast in cargo tanks.

*Chemical and product tankers:*

— conditions as specified for oil tankers
— conditions for high density or segregated cargo where these are included in the approved cargo list.

*Liquefied gas carriers:*

— homogenous loading conditions for all approved cargoes
— ballast conditions
— cargo condition where one or more tanks are empty or partially filled or where more than one type of cargo having significantly different densities is carried
— harbour condition for which an increased vapour pressure has been approved
— docking condition afloat.

*Combination carriers:*

— conditions as specified for oil tankers and cargo ships.

For smaller ships the stillwater bending moments and shear forces may have to be calculated for ballast and particular non-homogeneous load conditions after special considerations.

Also short voyage or harbour conditions including loading and unloading transitory conditions shall be checked where applicable.

**Guidance note:**
It is advised that the ballast conditions determining the scantlings are based on the filling of ballast in as few cargo tanks as practicable, and it is important that the conditions will allow cleaning of all cargo tanks with the least possible shifting.

---e-n-d---of---G-u-i-d-a-n-c-e---n-o-t-e---

(IACS UR S11.2.1.2 Rev.3).

**103** Ballast loading conditions involving partially filled peak and or other ballast tanks at departure, arrival or during intermediate conditions are not permitted to be used as design conditions unless:

— design stress limits are satisfied for all filling levels between empty and full and
— for bulk carriers, Pt.5 Ch.2 Sec.8 C, as applicable, is complied with for all filling levels between empty and full.

However, for the purpose of design, it will be acceptable if, in each condition at departure, arrival and, where required by 102, any intermediate condition, the tanks intended to be partially filled are assumed to be empty and full. In addition, the specified partly filled level in the intended condition shall be considered.

(IACS UR S11.2.1.3 Rev.3)

**104** In cargo loading conditions, the requirements given in 103 applies to peak tanks only.

(IACS UR S11.2.1.4 Rev.3)

**105** The design stillwater bending moments amidships (sagging and hogging) are normally not to be taken less than:

$$M_S = M_{SO} \quad \text{(kNm)}$$

$M_{SO}$ = $-0.065\, C_{WU}\, L^2\, B\, (C_B + 0.7)$ (kNm) in sagging
= $C_{WU}\, L^2\, B\, (0.1225 - 0.015\, C_B)$ (kNm) in hogging
$C_{WU}$ = $C_W$ for unrestricted service.

Larger values of $M_{SO}$ based on cargo and ballast conditions shall be applied when relevant, see 102.

For ships with arrangement giving small possibilities for variation of the distribution of cargo and ballast, $M_{SO}$ may be dispensed with as design basis.

**106** When required in connection with stress analysis or buckling control, the stillwater bending moments at arbitrary positions along the length of the ship are normally not to be taken less than:

$$M_S = k_{sm}\, M_{SO} \quad \text{(kNm)}$$

$M_{SO}$ = as given in 103
$k_{sm}$ = 1.0 within 0.4 L amidships
= 0.15 at 0.1 L from A.P. or F.P.
= 0.0 at A.P. and F.P.

Between specified positions $k_{sm}$ shall be varied linearly.

Values of $k_{sm}$ may also be obtained from Fig.2.

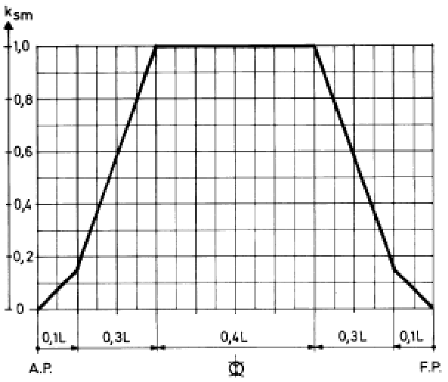



**Fig. 2**
**Stillwater bending moment**

The extent of the constant design bending moments amidships may be adjusted after special consideration.

**107** The design values of stillwater shear forces along the length of the ship are normally not to be taken less than:

$$Q_S = k_{sq}\, Q_{SO} \quad \text{(kN)}$$

$$Q_{SO} = 5\frac{M_{SO}}{L} \quad \text{(kN)}$$

$M_{SO}$ = design stillwater bending moments (sagging or hogging) given in 103.

Larger values of $Q_S$ based on load conditions ($Q_S$ = $Q_{SL}$) shall be applied when relevant, see 102. For ships with arrangement giving small possibilities for variation in the distribution of cargo and ballast, $Q_{SO}$ may be dispensed with as design basis

$k_{sq}$ = 0 at A.P. and F.P.
= 1.0 between 0.15 L and 0.3 L from A.P.
= 0.8 between 0.4 L and 0.6 L from A.P.
= 1.0 between 0.7 L and 0.85 L from A.P.

Between specified positions $k_{sq}$ shall be varied linearly.

Sign convention to be applied:

- when sagging condition positive in forebody, negative in afterbody
- when hogging condition negative in forebody, positive in afterbody.

### B 200 Wave load conditions

**201** The rule vertical wave bending moments amidships are given by:

$$M_W = M_{WO} \quad \text{(kNm)}$$

$M_{WO}$ = $-0.11\, \alpha\, C_W\, L^2\, B\, (C_B + 0.7)$ (kNm) in sagging
= $0.19\, \alpha\, C_W\, L^2\, B\, C_B$ (kNm) in hogging
$\alpha$ = 1.0 for seagoing conditions
= 0.5 for harbour and sheltered water conditions (enclosed fjords, lakes, rivers).

$C_B$ is not be taken less than 0.6.

**202** When required in connection with stress analysis or buckling control, the wave bending moments at arbitrary positions along the length of the ship are normally not to be taken less than:

$$M_W = k_{wm}\, M_{WO} \quad \text{(kNm)}$$

$M_{WO}$ = as given in 201
$k_{wm}$ = 1.0 between 0.40 L and 0.65 L from A.P.
= 0.0 at A.P. and F.P.

For ships with high speed and or large flare in the forebody the adjustments to $k_{wm}$ as given in Table B1, limited to the control for buckling as given in Sec.13, apply.

**Table B1 Adjustments to $k_{wm}$**

| *Load condition* | *Sagging and hogging* | | *Sagging only* | |
|---|---|---|---|---|
| $C_{AV}$ | $\leq 0.28$ | $\geq 0.32$ [1]) | | |
| $C_{AF}$ | | | $\leq 0.40$ | $\geq 0.50$ |
| $k_{wm}$ | No adjustment | 1.2 between 0.48 L and 0.65 L from A.P. 0.0 at F.P. and A.P. | No adjustment | 1.2 between 0.48 L and 0.65 L from A.P. 0.0 at F.P. and A.P. |

1) Adjustment for $C_{AV}$ not to be applied when $C_{AF} \geq 0.50$.

$$C_{AV} = \frac{c_v V}{\sqrt{L}}$$

$$C_{AF} = \frac{c_v V}{\sqrt{L}} + \frac{A_{DK} - A_{WP}}{L z_f}$$

$$c_v = \frac{\sqrt{L}}{50}, \quad \text{maximum } 0.2$$

$A_{DK}$ = projected area in the horizontal plane of upper deck (including any forecastle deck) forward of 0.2 L from F.P.
$A_{WP}$ = area of waterplane forward of 0.2 L from F.P. at draught T
$z_f$ = vertical distance from summer load waterline to deckline measured at F.P.

Between specified $C_A$-values and positions $k_{wm}$ shall be varied linearly. Values of $k_{wm}$ may also be obtained from Fig.3.

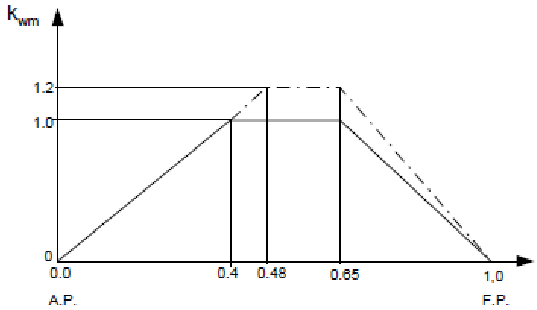



**Fig. 3**
**Wave bending moment distribution**

**203** The rule values of vertical wave shear forces along the length of the ship are given by:

Positive shear force, to be used when positive still water shear force:

$$Q_{WP} = 0.3\,\beta\,k_{wqp}\,C_W\,L\,B\,(C_B + 0.7) \quad (kN)$$

Negative shear force, to be used when negative still water shear force:

$$Q_{WN} = -\,0.3\,\beta\,k_{wqn}\,C_W\,L\,B\,(C_B + 0.7) \quad (kN)$$

Positive shear force when there is a surplus of buoyancy forward of section considered, see also Fig.1.

Negative shear force when there is a surplus of weight forward of section considered.

$\beta$ = 1.0 for seagoing conditions
= 0.5 for harbour and sheltered water conditions (enclosed fjords, lakes, rivers)
$k_{wqp}$ = 0 at A.P. and F.P.
= $1.59\,C_B/(C_B + 0.7)$ between 0.2 L and 0.3 L from A.P.
= 0.7 between 0.4 L and 0.6 L from A.P.
= 1.0 between 0.7 L and 0.85 L from A.P.
$k_{wqn}$ = 0 at A.P. and F.P.
= 0.92 between 0.2 L and 0.3 L from A.P.
= 0.7 between 0.4 L and 0.6 L from A.P.
= $1.73\,C_B/(C_B + 0.7)$ between 0.7 L and 0.85 L from A.P.
$C_W$ = as given in 201.

For ships with high speed and or large flare in the forebody, the adjustments given in Table B2 apply.

**Table B2 Adjustments to $k_{wq}$**

| *Load condition* | *Sagging and hogging* | | *Sagging only* | |
|---|---|---|---|---|
| $C_{AV}$ | $\leq 0.28$ | $\geq 0.32$ [1]) | | |
| $C_{AF}$ | | | $\leq 0.40$ | $\geq 0.50$ |
| Multiply $k_{wq}$ by | 1.0 | 1.0 aft of 0.6 L from A.P. 1.2 between 0.7 L and 0.85 L from A.P. | 1.0 | 1.0 aft of 0.6 L from A.P. 1.2 between 0.7 L and 0.85 L from A.P. |

1) Adjustment for $C_{AV}$ not to be applied when $C_{AF} \geq 0.50$.

$C_{AV}$ = as defined in 202
$C_{AF}$ = as defined in 202.

Between specified positions $k_{wq}$ shall be varied linearly. Values of $k_{wq}$ may also be obtained from Fig.4.

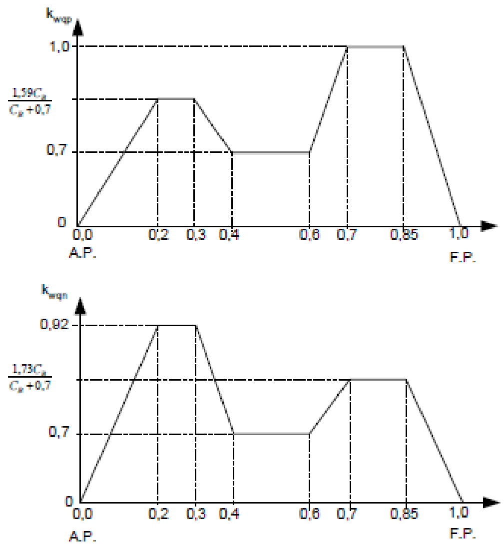



**Fig. 4**
**Wave shear force distribution**

**204** When hull girder stresses due to wave loads are combined with local stresses in girder systems, stiffeners and plating in accordance with Sec.12, the wave bending moments and shear forces may be reduced as follows:

$$M_{WR} = 0.59\,M_W$$

$$Q_{WR} = 0.59\,Q_W$$

**205** The rule horizontal wave bending moments along the length of the ship are given by:

$$M_{WH} = 0.22\,L^{9/4}\,(T + 0.3\,B)\,C_B\,(1 - \cos(360\,x/L))\ (kNm)$$

x = distance in m from A.P. to section considered.

**206** The rule wave torsional moments along the length of the ship due to the horizontal wave- and inertia forces and the rotational wave- and inertia moment loads are given by:

$$M_{WT} = K_{T1}\,L^{5/4}\,(T + 0.3\,B)\,C_B\,z_e \pm K_{T2}\,L^{4/3}\,B^2\,C_{SWP} \quad (kNm)$$

$K_{T1}$ = $1.40 \sin(360\,x/L)$
$K_{T2}$ = $0.13\,(1 - \cos(360\,x/L))$
$C_{SWP}$ = $A_{WP}/(LB)$
$A_{WP}$ = water plane area of vessel in $m^2$ at draught T
$z_e$ = distance in m from the shear centre of the midship section to a level 0.7 T above the base line
x = distance in m from A.P. to section considered.

## C. Bending Strength and Stiffness

### C 100 Midship section particulars

**101** When calculating the moment of inertia and section modulus, the effective sectional area of continuous longitudinal strength members is in general the net area after deduction for openings as given in E.

The effective sectional area of strength members between hatch openings in ships with twin or triple hatchways shall be taken as the net area multiplied by a factor 0.6 unless a higher factor is justified by direct calculations.

Superstructures which do not form a strength deck shall not be included in the net section. This applies also to deckhouses, bulwarks and non-continuous hatch side coamings.

For definition of strength deck, see Sec.1 B205.

**102** The rule section modulus generally refers to the baseline and the deckline.

**103** Continuous trunks, longitudinal hatch coamings and above deck longitudinal girders shall be included in the longitudinal sectional area provided they are effectively supported by longitudinal bulkheads or deep girders. The deck modulus is then to be calculated by dividing the moment of inertia by the following distance, provided this is greater than the distance to the deck line at side:

$$z = (z_n + z_a)\left[0.9 + 0.2\,\frac{y_a}{B}\right],\quad \text{minimum } z_n$$

$y_a$ = distance in m from the centre line of the ship to the side of the strength member.

$y_a$ and $z_a$ shall be measured to the point giving the largest value of z.

**104** The main strength members included in the hull section modulus calculation shall extend continuously through the cargo region and sufficiently far towards the ends of the ship.

**105** Longitudinal bulkheads shall terminate at an effective transverse bulkhead, and large transition brackets shall be fitted in line with the longitudinal bulkheads.

**C 200 Extent of high strength steel (HS-steel)**

**201** The vertical extent of HS-steel used in deck or bottom shall not be less than:

$$z_{hs} = z_n\,\frac{f_2 - f_3}{f_2}$$

$f_2$ = stress factor, for the bottom given in Sec.6 and for the deck in Sec.8

$f_3$ = material factor (general symbol $f_1$) for the members located more than $z_{hs}$ from deck or bottom, see Fig.5.

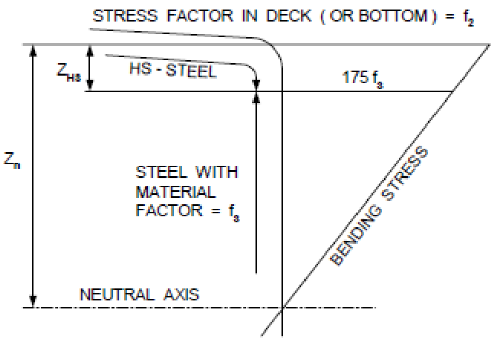



**Fig. 5**
**Vertical extent of HS-steel**

For narrow beam ships the vertical extent of HS-steel may have to be increased after special consideration.

**202** The longitudinal extent of HS-steel used in deck or bottom shall not be less than $x_{hs}$ as indicated in Fig.6.

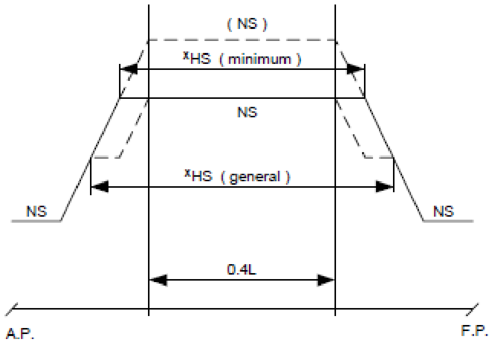



**Fig. 6**
**Longitudinal extent of HS-steel**

$x_{hs}$ (minimum) implies that the midship scantlings shall be maintained outside 0.4 L amidships to a point where the scantlings equal those of an identical ship built of normal strength steel over the full length. $x_{hs}$ (general) implies that the scantlings outside 0.4 L may be gradually reduced as if HS-steel was used over the full length. Where material strength group changes, however, continuity in scantlings shall be maintained.

**C 300 Section modulus**

**301** The requirements given in 302 and 303 will normally be satisfied when calculated for the midship section only, provided the following rules for tapering are complied with:

a) Scantlings of all continuous longitudinal strength members shall be maintained within 0.4 L amidships.

   In special cases, based on consideration of type of ship, hull form and loading conditions, the scantlings may be gradually reduced towards the ends of the 0.4 L amidship part, bearing in mind the desire not to inhibit the vessel's loading flexibility.

b) Scantlings outside 0.4 L amidships are gradually reduced to the local requirements at the ends, and the same material strength group is applied over the full length of the ship.

The section modulus at other positions along the length of the ship may have to be specially considered for ships with small block coefficient, high speed and large flare in the forebody or when considered necessary due to structural arrangement, see A106.

In particular this applies to ships of length L > 120 m and speed V > 17 knots.

**302** The midship section modulus about the transverse neutral axis shall not be less than:

$$Z_O = \frac{C_{WO}}{f_1}\,L^2\,B\,(C_B + 0.7)\quad (\text{cm}^3)$$

$C_{WO}$ = $10.75 - [\,(300 - L)/100\,]^{3/2}$ for $L < 300$
= $10.75$ for $300 \le L \le 350$
= $10.75 - [\,(L - 350)/150\,]^{3/2}$ for $L > 350$

Values of $C_{WO}$ are also given in Table C1.

$C_B$ is in this case not to be taken less than 0.60.

**Table C1 Values for $C_{WO}$**

| L | $C_{WO}$ | L | $C_{WO}$ | L | $C_{WO}$ |
|---|---|---|---|---|---|
| | | 160 | 9.09 | 260 | 10.50 |
| | | 170 | 9.27 | 280 | 10.66 |
| | | 180 | 9.44 | 300 | 10.75 |
| | | 190 | 9.60 | 350 | 10.75 |
| 100 | 7.92 | 200 | 9.75 | 370 | 10.70 |
| 110 | 8.14 | 210 | 9.90 | 390 | 10.61 |
| 120 | 8.34 | 220 | 10.03 | 410 | 10.50 |
| 130 | 8.53 | 230 | 10.16 | 440 | 10.29 |
| 140 | 8.73 | 240 | 10.29 | 470 | 10.03 |
| 150 | 8.91 | 250 | 10.40 | 500 | 9.75 |

For ships with restricted service, $C_{WO}$ may be reduced as follows:

— service area notation **R0**: No reduction
— service area notation **R1**: 5%
— service area notation **R2**: 10%
— service area notation **R3**: 15%
— service area notation **R4**: 20%
— service area notation **RE**: 25%.

**303** The section modulus requirements about the transverse neutral axis based on cargo and ballast conditions are given by:

$$Z_O = \frac{|M_S + M_W|}{\sigma_l} 10^3 \quad (cm^3)$$

$\sigma_l$ = 175 $f_1$ N/mm$^2$ within 0.4 L amidship
= 125 $f_1$ N/mm$^2$ within 0.1 L from A.P. or F.P.

Between specified positions $\sigma_l$ shall be varied linearly.

**304** The midship section modulus about the vertical neutral axis (centre line) is normally not to be less than:

$$Z_{OH} = \frac{5}{f_1} L^{9/4} (T + 0.3B) C_B \quad (cm^3)$$

The above requirement may be disregarded provided the combined effects of vertical and horizontal bending stresses at bilge and deck corners are proved to be within 195 $f_1$ N/mm$^2$.

The combined effect may be taken as:

$$\sigma_s + \sqrt{\sigma_w^2 + \sigma_{wh}^2}$$

$\sigma_s$ = stress due to $M_S$
$\sigma_w$ = stress due to $M_W$
$\sigma_{wh}$ = stress due to $M_{WH}$, the horizontal wave bending moment as given in B205.

**305** The stress concentration factor due to fatigue control of scallops e.g. in way of block joints shall not be greater than:

- for scallops in deck

$$K_{ga} = \frac{\sigma_d Z_{deck}}{240 (M_{W,hog} - M_{W,sag})}$$

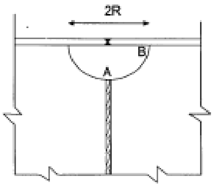
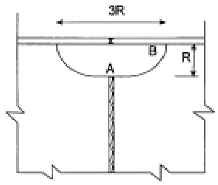
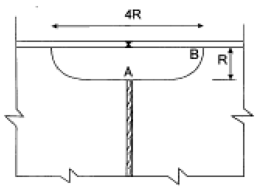
- for scallops in bottom

$$K_{ga} = \frac{\sigma_d Z_{bottom}}{240 (M_{W,hog} - M_{W,sag})}$$

$\sigma_d$ = permissible single amplitude dynamic stress in (N/mm$^2$)
= 110 c, in general
c = 1.0 for uncoated cargo and ballast tanks
= 1.15 for fully coated tanks and fuel tanks
= 1.28 for dry cargo holds and void spaces
$Z_{deck}$ = midship section modulus in cm$^3$ at deck as built
$Z_{bottom}$ = midship section modulus in cm$^3$ at bottom as built
$M_{W, hog}$ = the rule vertical wave hogging bending moment amidship, as defined in B201
$M_{W, sag}$ = the rule vertical wave sagging bending moment amidship, as defined in B201.

Stress concentration factors for scallops are given in Table C2.

**Table C2 Stress concentration factors $K_{ga}$ for scallops**

| *Structure* | *Point A* | *Point B* |
|---|---|---|
|  | 1.67 | 1.2 |
|  | 1.13 | 1.2 |
|  | 1.07 | 1.2 |
| For scallops without transverse welds, the K-factor at B will be governing for the design | | |

**C 400 Moment of inertia**

**401** The midship section moment of inertia about the transverse neutral axis shall not be less than:

$$I = 3\, C_W L^3 B (C_B + 0.7) \quad (cm^4)$$

## D. Shear Strength

**D 100 General**

**101** The shear stress in ship's sides and longitudinal bulkheads shall not exceed 110 $f_1$ N/mm$^2$. In addition the plate panels shall be checked for adequate shear and combined buckling strength as outlined in Sec.13 B300 and B500.

**102** The thickness requirements given below apply unless smaller values are proved satisfactory by an accepted method of direct stress calculation, including a shear flow calculation and a calculation of bottom load distribution.

Acceptable calculation methods are outlined in Classification Notes on «Strength Analysis of Hull Structures» for various ship types.

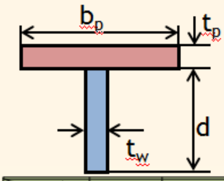
**103** The thickness requirements for side shell (or combined thickness of inner and outer shell when double skin) and pos-

# Sectional Properties of Steel Sections for Ship Building [1]

<Sectional properties including attached plate >

[1] "조선설계편람", 제 4판 (일본어), 일본관서조선협회, 1996

(Base plate dimension : $b_p x t_p$ = 420 x 8 )




$b_p$ = breadth of plate (mm)
$t_p$ = thickness of plate (mm)

*A* = Area including plate($cm^2$)
*Z* = Section modulus including plate ($cm^3$)
*I* = Moment of inertia of area including plate($cm^4$)

| d \ $t_w$ | | 6 | 9 | 11 | 12.7 | 14 |
|---|---|---|---|---|---|---|
| 50 | A | 3.00 | 4.5 | 5.50 | 6.35 | 7.00 |
| | Z | 6.05 | 8.81 | 10.6 | 12.1 | 13.3 |
| | I | 31.2 | 44.5 | 53.0 | 59.7 | 75.2 |
| 65 | A | 3.90 | 5.85 | 7.15 | 8.26 | 9.10 |
| | Z | 9.55 | 14.0 | 16.8 | 19.3 | 21.1 |
| | I | 62.3 | 88.8 | 105 | 119 | 129 |
| 75 | A | 4.50 | 6.75 | 8.25 | 9.53 | 10.5 |
| | Z | 12.3 | 18.1 | 21.8 | 25.0 | 27.3 |
| | I | 91.4 | 130 | 154 | 174 | 189 |
| 90 | A | 5.40 | 8.10 | 9.90 | 11.4 | 12.6 |
| | Z | 17.2 | 25.3 | 30.5 | 34.8 | 38.0 |
| | I | 150 | 214 | 252 | 284 | 307 |
| 100 | A | 6.00 | 9.00 | 11.0 | 12.7 | 14.0 |
| | Z | 20.9 | 30.6 | 37.0 | 42.2 | 46.1 |
| | I | 200 | 284 | 335 | 376 | 407 |
| 125 | A | 7.50 | 11.3 | 13.8 | 15.9 | 17.5 |
| | Z | 31.7 | 46.4 | 55.8 | 63.6 | 69.5 |
| | I | 370 | 521 | 612 | 685 | 738 |
| 150 | A | 9.00 | 13.5 | 16.5 | 19.1 | 21.0 |
| | Z | 44.7 | 65.2 | 78.3 | 89.1 | 97.2 |
| | I | 614 | 856 | 1000 | 1120 | 1200 |

| d \ $t_w$ | | 16 | 19 | 22 | 25.4 | 28 | 32 | 35 | 38 |
|---|---|---|---|---|---|---|---|---|---|
| 200 | A | 32.0 | 38.0 | 44.03 | 50.8 | 56.0 | 64.0 | 70.0 | 76.0 |
| | Z | 215 | 259 | 05 | 359 | 401 | 469 | 521 | 576 |
| | I | 3900 | 4730 | 5600 | 6640 | 7460 | 8790 | 9830 | 10900 |
| 250 | A | 40.0 | 47.5 | 55.0 | 63.5 | 70.0 | 80.0 | 87.5 | 95.0 |
| | Z | 325 | 390 | 458 | 536 | 597 | 694 | 769 | 845 |
| | I | 7120 | 8600 | 10100 | 11900 | 13400 | 15600 | 17400 | 19200 |
| 300 | A | 48.0 | 57.0 | 66.0 | 76.2 | 84.0 | 96.0 | 105.0 | 114.0 |
| | Z | 455 | 546 | 639 | 746 | 829 | 961 | 1060 | 1160 |
| | I | 11700 | 14000 | 16500 | 19300 | 21600 | 25100 | 27800 | 30700 |
| 350 | A | 56.0 | 66.5 | 77.0 | 88.9 | 98.0 | 112.0 | 122.5 | 133.0 |
| | Z | 606 | 726 | 847 | 988 | 1100 | 1270 | 1400 | 1530 |
| | I | 17700 | 21200 | 24800 | 29100 | 32400 | 37600 | 41600 | 45700 |
| 400 | A | 64.0 | 76.0 | 88.0 | 101.6 | 112.0 | 128.0 | 140.0 | 152.0 |
| | Z | 776 | 928 | 1080 | 1260 | 1400 | 1610 | 1780 | 1940 |
| | I | 25300 | 30300 | 35400 | 41400 | 46000 | 53300 | 58900 | 64600 |
| 450 | A | 72.0 | 85.5 | 99.0 | 114.3 | 126.0 | 144.0 | 157.5 | 171.0 |
| | Z | 965 | 1150 | 1340 | 1560 | 1730 | 2000 | 2200 | 2400 |
| | I | 34700 | 41500 | 48500 | 56500 | 62800 | 72600 | 80100 | 87700 |
| 500 | A | 80.0 | 95.0 | 110.0 | 127.0 | 140.0 | 160.0 | 175.0 | 190.0 |
| | Z | 1170 | 1400 | 1630 | 18907 | 2100 | 2420 | 2660 | 2900 |
| | I | 46000 | 55000 | 64200 | 4700 | 82900 | 95700 | 10500 | 11500 |

A = 42*0.8 + 15*1.4 = 21 [$cm^2$]
$Z_{Top}$ = 349.6 [$cm^3$]
$Z_{Bottom}$ = **97.2** [$cm^3$]

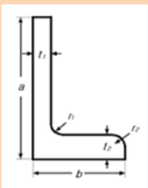
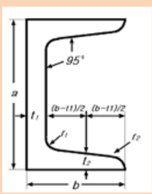
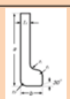


# Sectional Properties of Steel Sections for Ship Building [1]

< Sectional Properties of Steel Sections including attached plate>

[1] "조선설계편람", 제 4판 (일본어), 일본관서조선협회, 1996

- Use the standard dimension of plate depending on "a" ($b_p \times t_p$) => (a≤75 : 420×8, 75<a<150 : 610×10, 150≤a : 610×15)

| | Dimension | | | | | | Area | Including plate | |
|---|---|---|---|---|---|---|---|---|---|
| Symbol | a | b | $t_1$ | $t_2$ | $r_1$ | $r_2$ | A | I | Z |
| Unit | mm | | | | | | $cm^2$ | $cm^4$ | $cm^3$ |
| Unequal Angle | L | | | | | | | ⊤ (with plate) | |
|  | 200 | 90 | 9 | 14 | 14 | 7.0 | 29.66 | 5870 | 340 |
| | 250 | 90 | 10 | 15 | 17 | 8.5 | 37.47 | 10300 | 494 |
| | 250 | 90 | 12 | 16 | 17 | 8.5 | 42.95 | 11000 | 540 |
| | 300 | 90 | 11 | 16 | 19 | 9.5 | 46.22 | 16400 | 681 |
| | 300 | 90 | 13 | 17 | 19 | 9.5 | 52.67 | 17600 | 743 |
| | 400 | 100 | 11.5 | 16 | 24 | 12 | 61.09 | 34200 | 1120 |
| | 400 | 100 | 13 | 18 | 24 | 12 | 68.59 | 36700 | 1230 |
| | 450 | 125 | 11.5 | 18 | 24 | 12 | 73.11 | 51200 | 1570 |
| | 450 | 150 | 11.5 | 15 | 24 | 12 | 73.45 | 51700 | 1590 |
| | 500 | 150 | 11.5 | 18 | 24 | 12 | 83.6 | 70400 | 2020 |
| | 550 | 150 | 12 | 21 | 24 | 12 | 95.91 | 93300 | 2520 |
| | 600 | 150 | 12.5 | 23 | 24 | 12 | 107.6 | 118000 | 3000 |
| Channels | [ | | | | | | | [ (with plate) | |
|  | 150 | 75 | 6.5 | 10 | 10 | 5 | 23.71 | 2160 | 154 |
| | 200 | 90 | 8 | 13.5 | 14 | 7 | 38.65 | 5650 | 322 |
| | 250 | 90 | 9 | 13 | 14 | 7 | 44.07 | 9420 | 439 |
| | 250 | 90 | 11 | 14.5 | 17 | 8.5 | 51.17 | 10500 | 499 |
| | 300 | 90 | 9 | 13 | 14 | 7 | 48.57 | 14300 | 567 |
| | 300 | 90 | 10 | 15.5 | 19 | 9.5 | 55.74 | 16000 | 646 |
| | 300 | 90 | 12 | 16 | 19 | 9.5 | 61.90 | 16900 | 693 |
| | 380 | 100 | 10.5 | 16 | 18 | 9 | 69.39 | 29900 | 989 |
| | 380 | 100 | 13 | 20 | 24 | 12 | 85.71 | 34900 | 1190 |
| Bulb flats | \| | | | | | | | ⊤ | |
|  | 180 | 32.5 | 9.5 | – | 7 | 2 | 21.06 | 2860 | 172 |
| | 200 | 36.5 | 10 | – | 8 | 2 | 25.23 | 4160 | 231 |
| | 230 | 41 | 11 | – | 9 | 2 | 31.98 | 6610 | 330 |
| | 250 | 45 | 12 | – | 10 | 2 | 38.13 | 8960 | 424 |