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RULES

PUBLICATION NO. 18/P

**ZONE STRENGTH ANALYSIS OF BULK CARRIER
HULL STRUCTURE**

1995

GDAÑSK

Publication No. 18/P "Zone Strength Analysis of Bulk Carrier Hull Structure – 1995" is an extension of the requirements contained in Part II "Hull" of the Rules for the Classification and Construction of Sea-going Ships – 1995.

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The present Publication replaces its 1986 edition.

CONTENTS

1 GENERAL

1.1 Introduction

1.1.1 For design of ships, the technical documentation of which is subject to approval of PRS, the "Rules for the Classification and Construction of Sea-going Ships" (henceforth referred to as the "Rules") require a zone strength analysis of the structure to be carried out.

1.1.2 Strength analysis of the ship's hull is related, for the most part, to fragments of particular hull structures (bottom, sides, decks, bulkheads) or their systems. It is generally related to the system of primary girders considered as 2- or 3-dimensional bar systems. In special cases the structure idealization by means of other finite elements than bars may be required.

The present Publication refers to bar idealization.

1.1.3 The structural analysis is to show that in all, described below, design load condition (LC), the stresses in specified sections will not exceed the values prescribed by the Rules.

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

1.1.5 Acceptable results of strength analysis carried out in accordance with the procedure given in the present Publication will be the basis for the PRS approval of hull documentation.

1.1.6 The present Publication contains guidelines on carrying out analysis of stresses in cross-sections of primary strength members of bulk carrier hull with the double bottom, without longitudinal bulkheads.

1.1.7 The strength analysis of 3-dimensional structural systems within the cargo area of the bulk carrier hull may generally be carried out by means of computer programs of 2-dimensional systems (2-dimensional framework or grillage).

Fig. 1.1.7 presents stress analysis procedure of a bulk carrier with hopper tanks and topside tanks at the ship's sides and vertically corrugated transverse bulkheads with stooltanks at the inner bottom.

1.1.8 For bulkheads without stools, the boundary conditions at the double bottom and stress analysis may be based on simple hand calculations.

1.2 Definitions

1.2.1 For the purpose of the present Publication, symbols corresponding, in general, with those of the Rules have been adopted.

| Transverse bulkhead structures | Ship's side and wing tank structures | Double bottom structures |

Load conditions "Unit deflection"

| Design loads | Design loads | Design loads |

Computer programs

| Structural modelling | Structural modelling | Structural modelling |

| Boundary conditions | Boundary conditions | Boundary conditions |

| Response calculations | Response calculations | Response calculations |

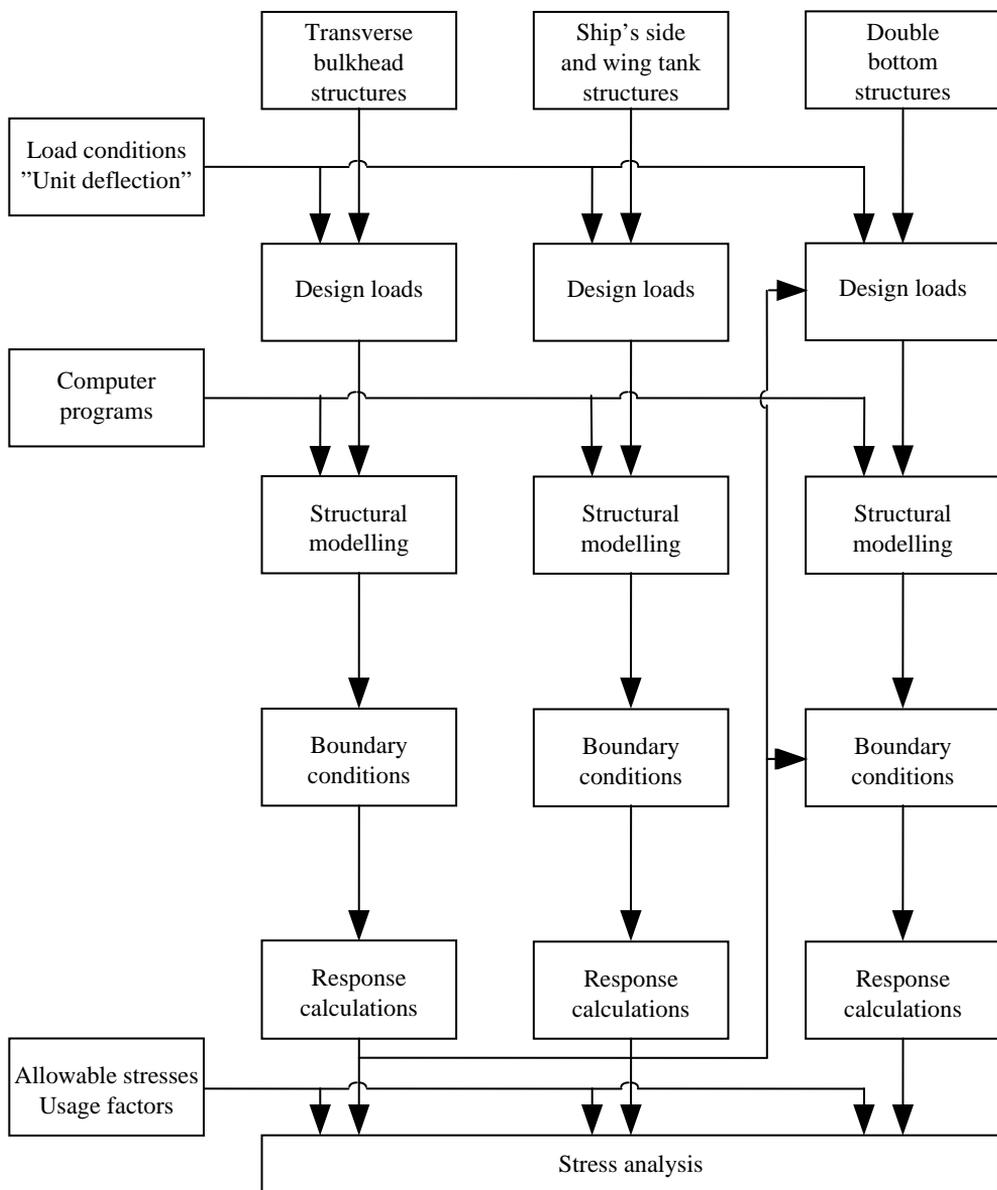Allowable stresses Usage factors

Stress analysis

Fig. 1.1.7   Strength analysis procedure

1.2.2   Symbols

The below-given list contains symbols that are most commonly used; symbols not mentioned in the following list are given in connection with relevant formulae and figures.

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L_0 – design length of the ship, in m;
B – breadth of the ship, in m;
H – depth of the ship, in m;
T – draught, in m;
δ – block coefficient;

For details, see Part II "Hull" of the Rules

E – modulus of elasticity; $E = 2.06 \cdot 10^5$, MPa, may be taken for steel;
g – standard acceleration of gravity, $g = 9.807$ m/s^2;
v – maximum service speed, in knots, at draught T;
C_w – wave coefficient;
a_v – combined vertical acceleration, m/s^2;
a_T – combined transverse acceleration, m/s^2;
Φ_A – roll angle (amplitude of roll), in radians;
Θ_A – pitch angle (amplitude of pitch), in radians;
Q – cargo density, in t/m^3,

For details, see Part II "Hull" of the Rules

$$Q = \frac{\text{cargo capacity, in } t, \text{ of hold (tank)}}{\text{volume, in m}^3, \text{ of hold (tank)}},$$

($Q \geq 0.875$ t/m^3 for class notation ZM and $Q = 1.025$ for oil cargo and ballast water, are to be taken);

γ – angle of repose for bulk cargo, degrees:
   $\gamma = 35°$ for ore cargo,
   $\gamma = 25°$ for cement of density $Q = 1.35$ t/m^3,
   $\gamma = 20°$ for light bulk cargo (coal, grain);

h_0 – cargo/ballast head, in m – vertical distance from the load point to the top of hold (including hatchway coaming) or to the tank top or to the upper end of air pipe – according to the information given under each formula or figure.

1.2.3 Units

SI – units (the units of the International System of Units), as well as other units not covered by the system and permitted temporarily for use are adopted in the present Publication.

The following SI – units are used in the Publication:
– Mass unit   – tonne (t);
– Length unit   – centimetre (cm) or metre (m);
– Angle unit   – radian (rad);
– Time unit   – second (s);
– Force unit   – newton (N) or kilonewton (kN);
– Pressure unit   – kilopascal (kPa);
– Stress unit   – megapascal (MPa).

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2 LOAD CONDITIONS

2.1 General

2.1.1 Introduction

The design loads to be applied to particular structures may be derived from the load conditions given in the present Chapter.

For parts of the structure where certain load conditions are obviously decisive for the scantlings, standard or additional load conditions need not, in general, be calculated. Depending on the calculation method applied, however, such calculations may be necessary to obtain the boundary conditions for other structures where the condition may be decisive for the scantlings.

2.1.2 Selection of load condition

The load conditions LC1, LC2 and LC3 are ballast conditions. The load conditions LC4, LC5 LC6 are ore cargo conditions to be examined for bulk carriers with an additional mark ZM/ZP affixed to the symbol of class. The load conditions LC7 and LC8 are heavy cargo conditions (or the conditions with a non-uniform distribution of cargo) and are, in general, applicable to ships with an additional mark ZM affixed to the symbol of class. For ships with the mark ZM/ZP arranged to carry heavy cargo, load condition LC8 will have to be examined. For oil-bulk-ore carriers (OBO – carriers), the load condition LC9 is to be examined in addition to relevant conditions mentioned above.

2.1.3 Additional load conditions

For ships with special hull geometry and for special cargoes or special loading arrangement, additional load conditions may be required.

2.2 LC1 – water ballast/liquid cargo in hold, adjacent hold empty

2.2.1 This condition is shown in Fig. 2.2.1 and may be decisive for the double bottom and transverse bulkhead scantlings. In ships with additional mark ZM, this condition may be decisive for the inner bottom plating (buckling) when applied to holds which may be empty at full draught.

2.2.2 Liquid cargo or ballast loads

The design pressure due to water ballast or liquid cargo is to be determined from the formula:

$$p_w = 10h_0, \quad \text{kPa} \tag{2.2.2}$$

h_0 – height of liquid pressure measured downwards from a level of 2.5 metres above the top of tank (hold).
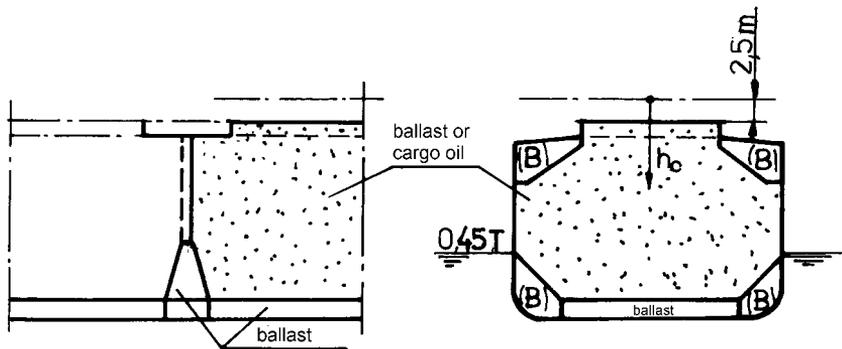
Fig. 2.2.1   Load condition LC1

2.2.3   Sea pressures

The design sea pressures are to be taken as corresponding to a draught of 0.45T, excluding dynamic loads.

At baseline

$$p_z = 4.5T, \quad \text{kPa} \tag{2.2.3}$$

The design ballast draught may be modified based on the real ballast condition.

2.2.4   The double bottom tanks

Tanks situated below the ballast holds are assumed to be filled.

2.3   LC2 – water ballast/liquid cargo in hold, heeled condition

2.3.1   This condition is shown in Fig. 2.3.1; it may be decisive for the topside tanks if these are empty. If topside tanks are filled with ballast water, the condition is normally irrelevant.
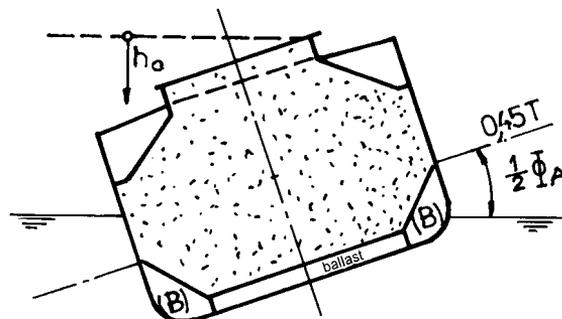

Fig. 2.3.1   Load condition LC2

2.3.2   Liquid cargo or ballast loads

The design pressure due to water ballast or liquid cargo is to be determined from formula 2.2.2; the height h_0 is to be measured from the tank top at the roll angle, equal to $0.5\Phi_A$ (see Part II "Hull" of the Rules).

2.3.3   Sea pressures

The design sea pressures are to be determined from formula 2.2.3 at a draught of $0.45T$, measured at the ship's centreplane at the roll angle $0.5\Phi_A$, excluding dynamic loads. The design ballast draught may be taken in accordance with the real ballast condition.

2.4   LC3 – water ballast in topside and hopper tanks

2.4.1   This condition is shown in Fig. 2.4.1; may be decisive for the topside tanks and hopper tanks.
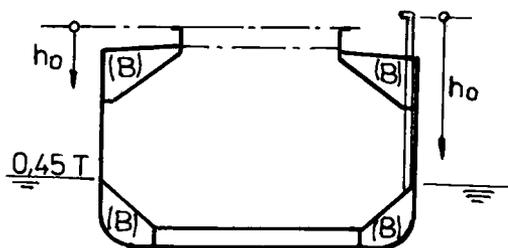

Fig. 2.4.1   Load condition LC3

2.4.2   Water ballast pressures

2.4.2.1   The design pressure due to water ballast in topside tanks is to be determined from formula 2.2.2, taking h_0 measured from the level of 2.5 m above the top of tank.

2.4.2.2   The design pressure due to water ballast in hopper tanks is to be determined from the formula:

$$p_w = 6.7h_0, \quad \text{kPa} \tag{2.4.2.2}$$

(h_0 is to be measured from the top of air pipes).

2.4.3   Sea pressures

The design sea pressures are of minor importance for this condition. The pressures determined in accordance with 2.2.3 may be taken.

2.5   LC4 – heavy ore cargo, adjacent hold empty

2.5.1   This condition is shown in Fig. 2.5.1; it may be decisive for the double bottom in heavy ore cargo holds and empty holds.

Note: "Heavy ore cargo" means ore (ore concentrate) or other heavy bulk cargo which will not occupy the complete volume of the hold when this is loaded to the maximum of its capacity. It means that the stowage rate is less than the cargo density. In consequence, only the lower parts of the holds will be exposed to the pressure from such cargo.
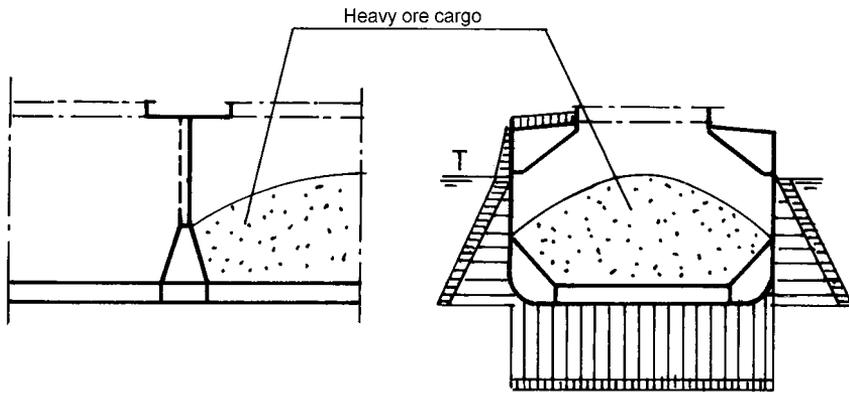

Fig. 2.5.1   Load condition LC4

2.5.2   Heavy ore cargo pressures

The design pressures due to heavy ore cargo are to be taken from the formula:

$$p = Qh_0 K(g + 0.5a_v), \quad \text{kPa} \tag{2.5.2-1}$$

$$K = \sin^2(\alpha - \beta)\, \text{tg}^2\left(45 - \frac{\gamma}{2}\right) + \cos^2(\alpha - \beta) \tag{2.5.2-2}$$

α – angle between panel in question and the horizontal plane, in degrees;

$\beta = \dfrac{90}{\pi}\Phi_A$, degrees – for longitudinal panels,

$\beta = \dfrac{90}{\pi}\Phi_A$, degrees – for transverse panels;

$(\alpha - \beta)$ is not to be taken less than zero;

$K = 1$ for horizontal panels (inner bottom);

h_0 – pressure head, m, measured from the top of hold (including hatchway) within 60% of the width/length of the hold, linearly reduced to a level $0.3(H - h_{dp})$ (see Fig. 2.5.2) above the plane part of the inner bottom at ship's sides and transverse bulkheads.
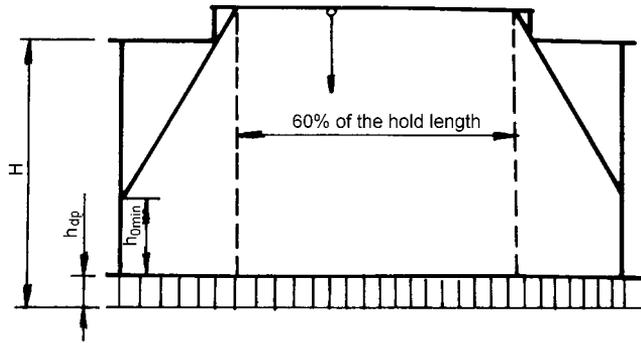
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Fig. 2.5.2 Pressure head h_0 for load condition LC4

2.5.3 Sea pressures

The design sea pressures are to be calculated for full draught, including dynamic loads in accordance with the formulae given in Part II "Hull" of the Rules.

The assumed values of pressures are to be not less than those given below:
– for the ship's sides: 10 kPa,
– for the weather deck within the bow region $(x > 0.4L_0)$: 15 kPa,
– for the weather deck outside the bow region: 5 kPa.

2.6 LC5 – light ore cargo, adjacent hold empty

2.6.1 This condition is shown in Fig. 2.6.1; it may be decisive for the double bottom in light ore cargo holds and in empty holds.

Note: "Light ore cargo" means ore or other bulk cargo which will occupy the complete volume when the hold is loaded to the maximum of its capacity (stowage rate equal to cargo density). Consequently, lateral cargo pressures are assumed to act over the full height of the ore hold.
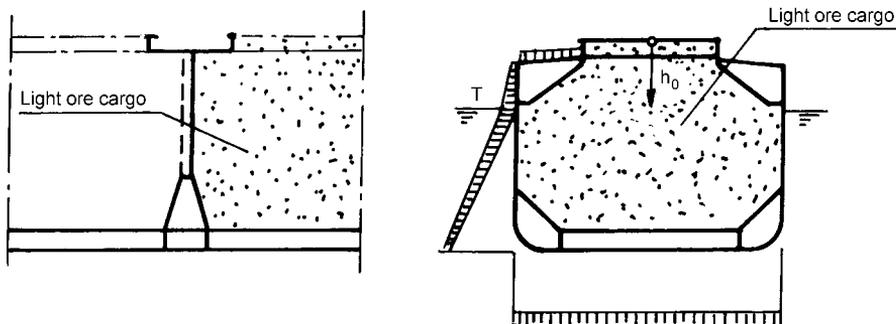

Fig. 2.6.1 Load condition LC5. Light ore cargo

2.6.2 Pressures due to light ore cargo

The design pressures due to light ore cargo are to be calculated from formula 2.5.2-1, taking h_0 as measured from the top of hold (including hatchway).

2.6.3 Sea pressures

The design sea pressures are to be calculated in accordance with the requirements given in 2.5.3.

2.7   LC6 – heavy ore cargo, adjacent hold empty, harbour condition

2.7.1   This condition is shown in Fig. 2.7.1; it may be decisive for the double bottom in heavy ore cargo holds.
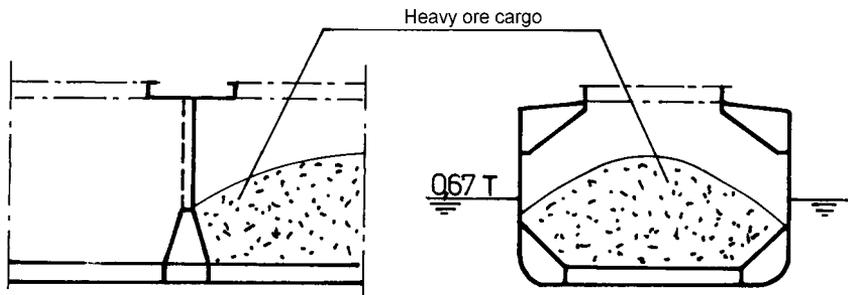

Fig. 2.7.1   Load condition LC6. Heavy ore cargo

2.7.2   Pressures due to heavy ore cargo

The design pressures due to heavy ore cargo are to be calculated from the formula:

$$p_w = QgK_1 h_0, \quad \text{kPa} \tag{2.7.2-1}$$

$$K_1 = \sin^2 \alpha \, \text{tg}^2 \left(45 - \frac{\gamma}{2} \right) + \cos^2 \alpha$$

α, h_0 – measured as for LC4 – see 2.5.2.

2.7.3   Sea pressures

The design sea pressures are to be calculated for a draught of $0.67T$, excluding dynamic loads, in accordance with the formula:

$$p_z = 6.7T, \quad \text{kPa} – \text{at baseline} \tag{2.7.3-1}$$

2.8   LC7 – heavy cargo, adjacent hold empty, minimum condition

2.8.1   This condition is shown in Fig. 2.8.1; it may be decisive for the double bottom structure when an additional mark ZM (without empty holds at full draught), is affixed to the symbol of class.
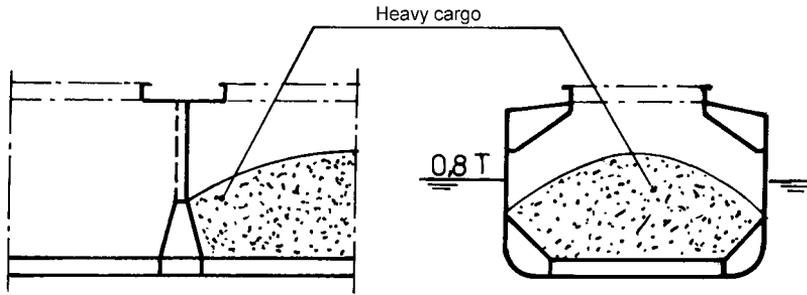
Fig. 2.8.1   Load condition LC7. Heavy cargo

2.8.2   Pressures due to heavy cargo

The design pressures due to heavy cargo are to be taken as given for LC6 in accordance with the requirements of 2.7.2.

2.8.3   Sea pressures

The design sea pressures are to be calculated for a draught of 0.8T, excluding dynamic loads, in accordance with the formula:

$$p_z = 8T, \quad \text{kPa} \ - \ \text{at baseline} \tag{2.8.3-1}$$

2.9   LC8 – heavy cargo in adjacent holds, minimum condition

2.9.1   This condition is shown in Fig. 2.9.1; it may be decisive for the buckling strength of the deck between hatchways.
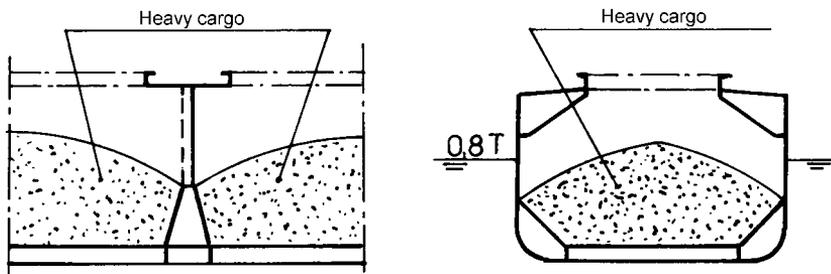

Fig. 2.9.1   Load condition LC8. Heavy cargo

2.9.2   Pressures due to heavy cargo

The design pressures due to heavy cargo are to be determined as for condition LC6, in accordance with the requirements of 2.7.2.

2.9.3   Sea pressures

The design sea pressures are to be calculated as for LC7, in accordance with the requirements of 2.8.3.

2.10 LC9 – liquid cargo, adjacent hold empty, maximum part load

2.10.1 This condition is shown in Fig. 2.10.1; it may be decisive for the bottom plating (due to buckling) in way of empty holds not designed to be empty at full draught.
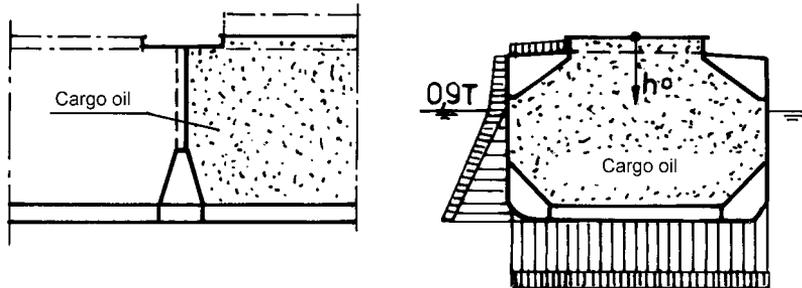

Fig. 2.10.1 Load condition LC9

2.10.2 Liquid cargo loads

The design pressures due to liquid cargo are to be determined from the formula:

$$p_w = Q h_0 \left(g + 0.5 a_v \right), \quad \text{kPa} \tag{2.10.2-1}$$

(h_0 is to be measured from the top of the tank)

2.10.3 Sea pressures

The design sea pressures are to be determined for a draught of $0.9T$, including dynamic loads, in accordance with the formulae given in Part II "Hull" of the Rules.

The assumed values of pressures are to be not less than those given below:
– for ship's sides: 10 kPa;
– for the weather deck within the bow region ($x > 0.4L_0$): 15 kPa;
– for the weather deck outside the bow region: 5 kPa.

3 MODELLING

3.1 General

3.1.1 Modelling

The structure in the cargo region of ordinary bulk carriers may be calculated by means of three separate 2-dimensional beam models:

.1 Transverse bulkhead structure – framework model (model A). Inplane loading.

.2 Ship's side structure – framework model, including bilge and topside tanks (model B). Inplane loading.

.3 Double bottom structure – double bottom grillage (model C). Loading perpendicular to the grillage plane.

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Assumption and modelling techniques are so selected that the number of degrees of freedom of boundary nodes influenced by adjacent structures is limited to a minimum for each of the models.

3.1.2   Basic assumptions of modelling

The following modelling simplifications are assumed:
– The vertical deflection of ship's sides is regarded as negligible with respect to structural strength. For long holds (more than 1.5 times the hold breadth), the influence of ship's sides deflection is to be considered in calculations.
– The shear deflections of hopper tank internal structures are neglected.
– The torsional stiffness of hopper tank and stool tank are included in the double bottom grillage model.
– Loads on the hopper tank are included in model B.
– Loads on the stool tank are included in model A.
– The load responses of model A and B are applied to model C (see Fig. 3.1.2-2).

3.1.3   Calculation guidelines

Calculations of the stresses and displacements may be carried out in the following three stages:

Stage 1   –   Calculations for models A and B.
For model A, reactions in nodes 1 and 3 (see Fig. 3.2.1) and spring stiffness K_r of the stool tank are to be calculated (acc. to 3.2.5).
For model B, reactions in node 4 and the vertical spring stiffness K_1 are to be determined (acc. to 3.3.5).

Stage 2   –   Calculations for model C.
In boundary conditions, spring stiffness K_r and K_1 are to be considered; as to the loads, account is to be taken of reactions in nodes determined for models A and B in Stage 1.
Complete strength analysis of model C is to be carried out.

Stage 3   –   Repeated calculations for models A and B.
In models A and B, initial displacement of nodes 1, 3 and 4 due to the grillage deformation – model C, are to be considered.
Complete strength analysis of models A and B is to be carried out.

Calculation for Stage 3 may be carried out in the following alternative way:
– Node forces for all loading conditions (including the load condition with initial displacement of nodes 1, 3 and 4) are to be determined according to Stage 1.

Displacements of nodes are obtained from Stage 2. Node forces in models A and B are to be corrected; unit displacements are to be corrected proportionally to the displacements of the respective nodes in model C.

The corrected node forces are superposed to the results of Stage 1 calculations.

Complete strength analysis of models A and B is to be carried out.

	– Elements between nodes
	– Rigid element
	– Dummy element of very high shear stiffness
	– Rigid end of element (two variants)
	– Element hinged at node
	– Fixed node
	– Node with fixed in-plane rotation and x-movement, free y-movement
	– Node with fixed x and y-movement, free in-plane rotation
	– Node with fixed y-movement, free in-plane rotation and x-movement
	– Node with linear in-plane restraint (linear spring)
	– Rotational spring

Fig. 3.1.2-1   Symbols

Transverse sections

Fixed end reaction from hopper
tank in way of empty hold

CL

q_z - sea load in way
of empty hold

CL

q_w - net load in way
of full hold

Fixed end reaction from hopper
tank in way of hull hold

Longitudinal section

q_w

q_z - fixed end reaction from stool
side in way of empty hold

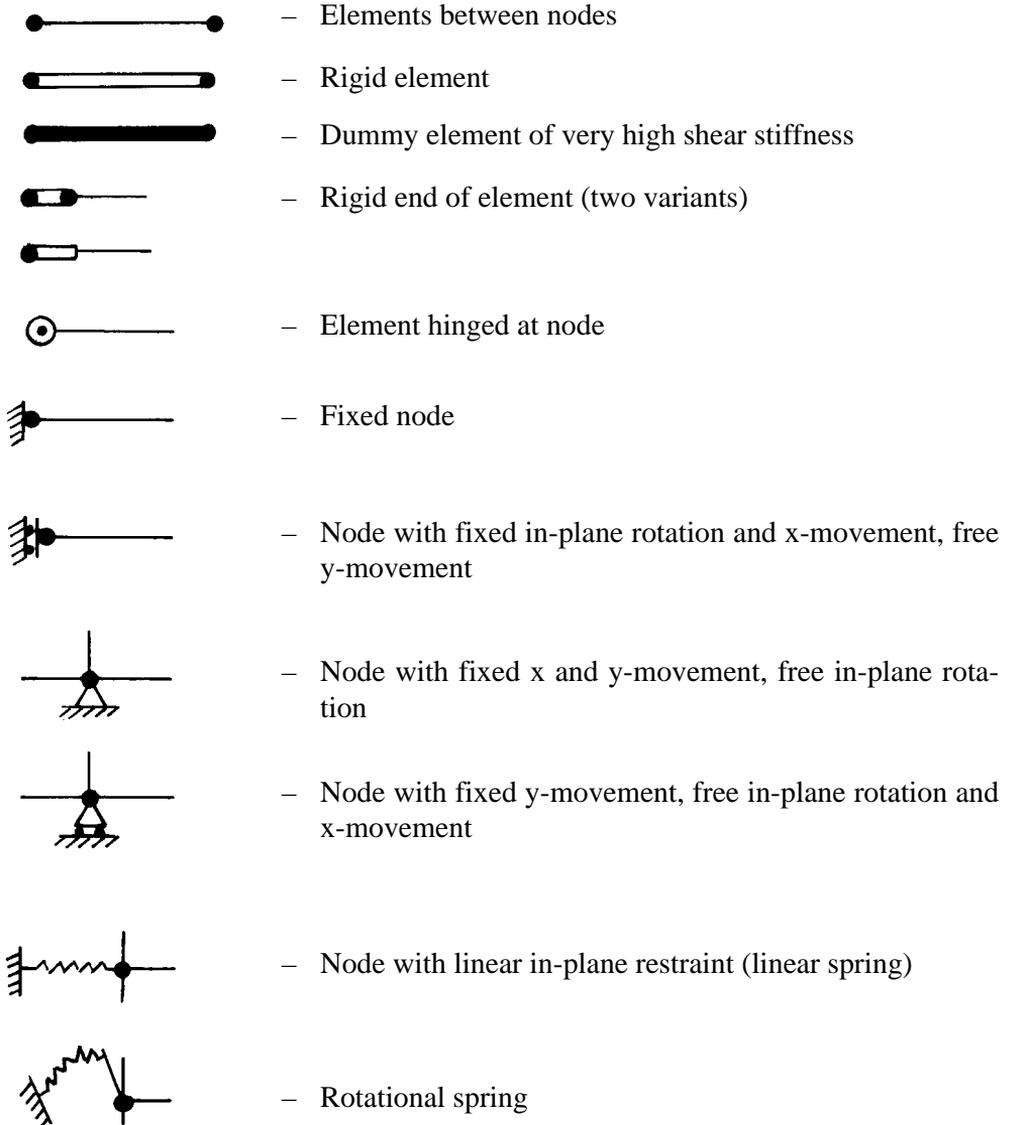q_w - fixed end reaction from stool
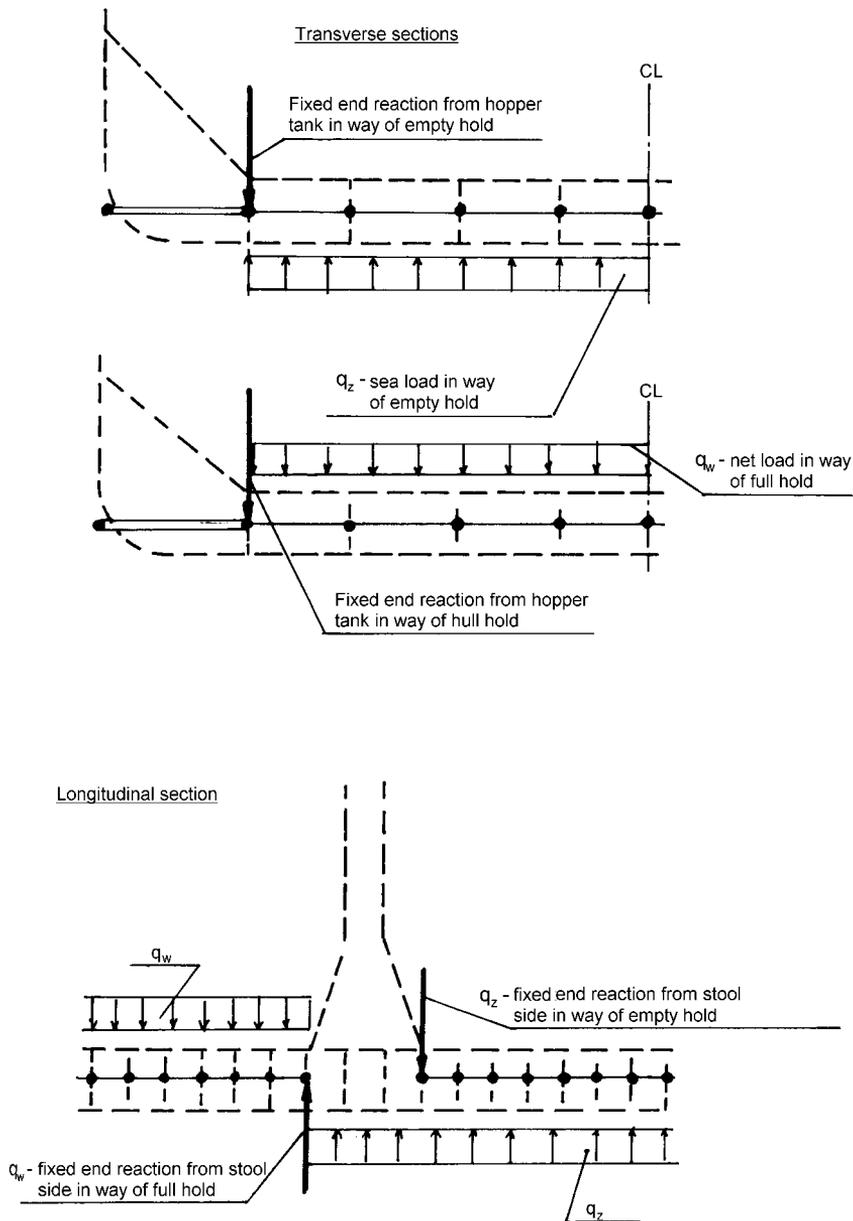side in way of full hold

q_z

Fig. 3.1.2-2   Load distribution on double bottom

3.1.4   Rigid ends of beam elements

Bracketed end connections of beam elements within brackets are to be represented as perfectly rigid beam ends. Due to limitations of computer programs, the rigid beam ends may have to be considered as separate beams.

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The length of perfectly rigid ends depends on the bracket form. In Fig. 3.1.4 a guidance on the extent of rigid parts is given.
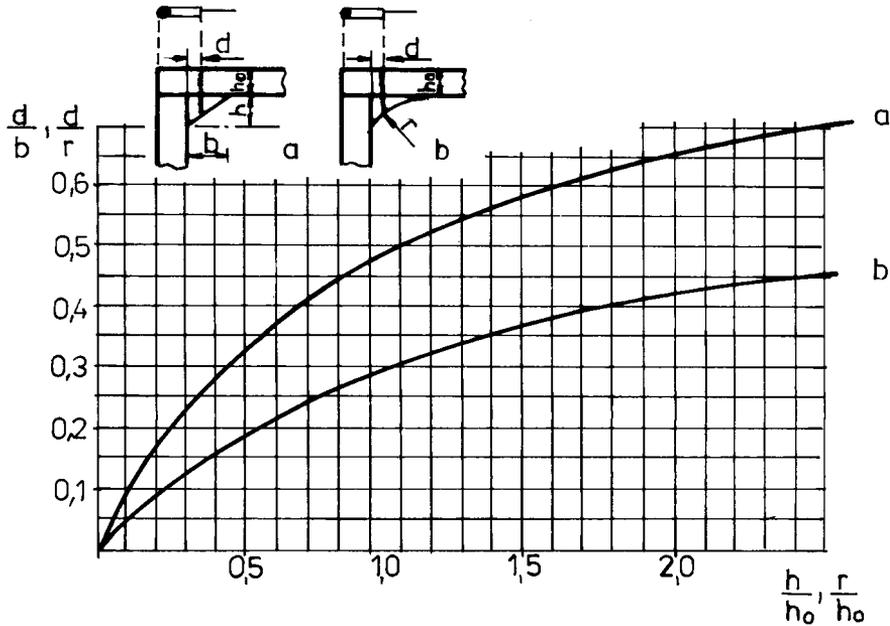

Fig. 3.1.4   Rigid ends of beam elements

3.1.5   Rigid elements

3.1.5.1   If, due to programme limitations, it is not required otherwise, characteristics of perfectly rigid elements are to be, in general, assumed as follows:
- the moment of inertia should exceed approximately 100 times the mean moment of inertia of the non-rigid elements,
- cross-sectional area and shear area – 10 times the mean area of the non-rigid elements.

3.1.5.2   Characteristics of alternative elements (dummy elements) of perfect shear stiffness are to be taken as follows:
- cross-sectional area and shear area – as given in 3.1.5.1;
- the cross-section moment of inertia close to zero (however, due to numerical difficulties in computing it should have a definite stiffness).

3.1.5.3   Characteristics of alternative spring elements representing springs acting in other direction than along the x- and y-axes to be taken in accordance with the requirements of 3.3.3.

3.1.6 Corrosion additions

The models are to represent the "net" structure, i.e. the corrosion additions, as specified in Part II "Hull" of the Rules are to be deduced from the given scantlings, unless an additional mark WZR is affixed to the symbol of class.

3.1.7 Face flanges of the modelled girders

Further on in the present Chapter, girders are modelled as webs with face flanges determined according to Part II of the Rules.

For the bottom grillage, the width of face flanges is taken as 100% of the girders spacing.

3.1.8 Location of the model elements

The model elements are, in general, located in the neutral axis of the relevant elements (e.g. for an element consisting of the double bottom girder web and the bottom and inner bottom plating).

Where only one face plate of an element exists (i.e. transverse frames in bilge tank), the element may be located at the intersection of the element web with plating.

3.2 Modelling of transverse bulkhead (model A)

3.2.1 Basic model

Fig. 3.2.1 shows a typical transverse bulkhead design and corresponding structural model. The horizontal system lines in the stool tank connects the stool side plating forming an integrated structural system.

The number of horizontal rigid elements will depend on the height and the arrangement of stool. It is recommended that the stiffener spacing of stool may be used as spacing between these elements.

Other models of stool are shown in Fig. 3.2.2.

3.2.2 Models of stool tanks

Figs. 3.2.1 and 3.2.2 show various design of stool tanks and corresponding structural models. In the regions where the stool sides are supported by separate webs (not the bulkhead between these sides), the sloping system lines represent the complete stiffness of webs, including the plate flanges.
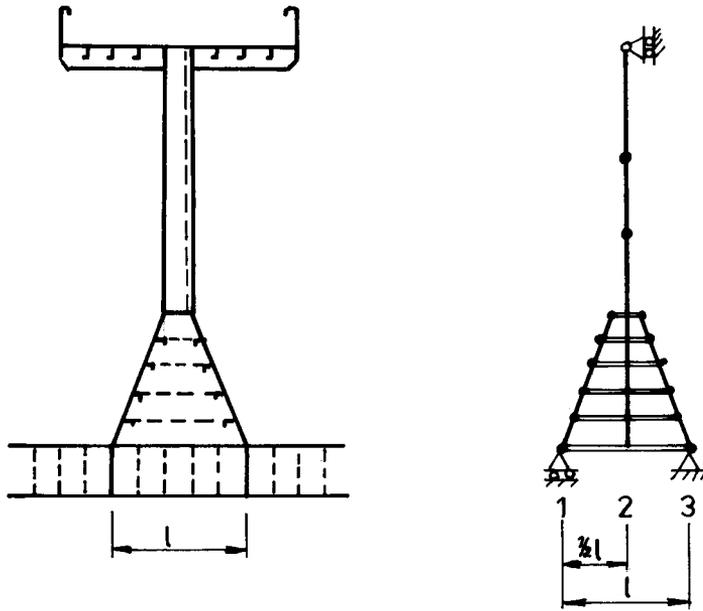
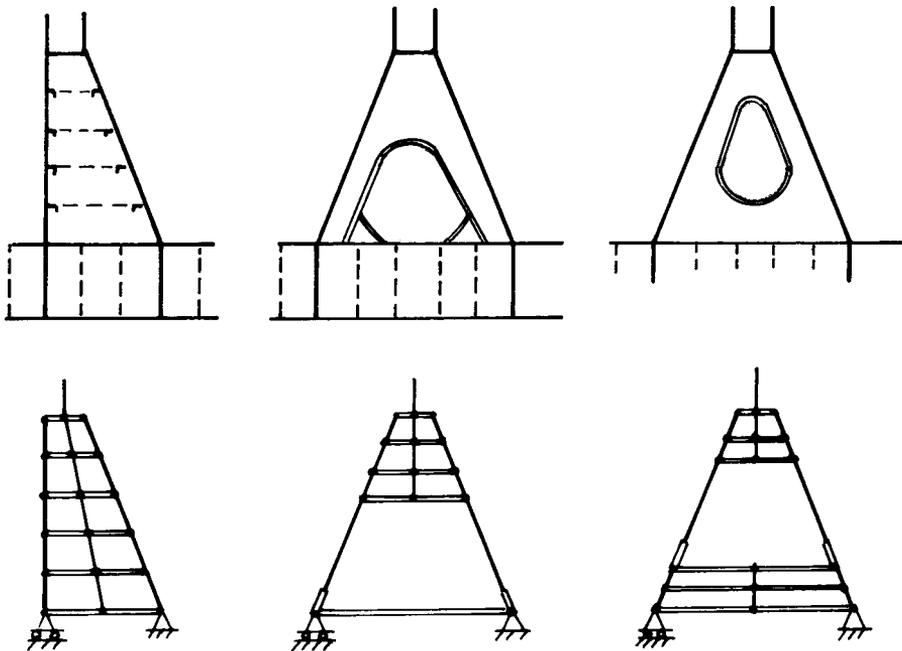Fig. 3.2.1   Transverse bulkhead modelling

Fig. 3.2.2   Stools modelling

3.2.3 Models of the upper part of the bulkhead

As it is shown in Fig. 3.2.1, it is normally sufficient to represent the upper part of the bulkhead as a simply supported node. In some cases a more detailed modelling may be necessary. In Fig. 3.2.3 some examples of extended models at the deck are indicated.
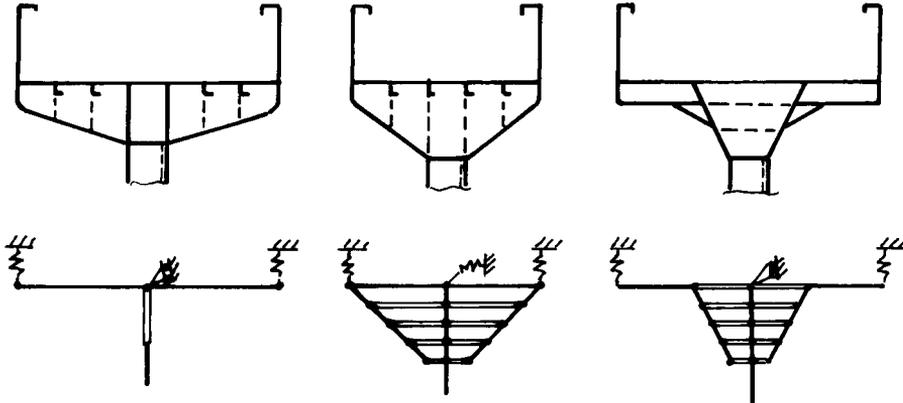
Fig. 3.2.3   Modelling of the upper part of the bulkhead

3.2.4 Location of model and choice of the model breadth

The model of the bulkhead section is normally taken at the centre line of the ship. The model breadth will depend on the actual design. Fig. 3.2.4 shows a natural choice of the model breadth. It is recommended to choose the breadth of the model corresponding to the longitudinal bottom girder spacings. The characteristics of stiffness of corrugated bulkhead above the stool are to be taken as a multiple of the stiffness of one corrugation. For elements of different breadth, the results may be obtained by linear interpolation.
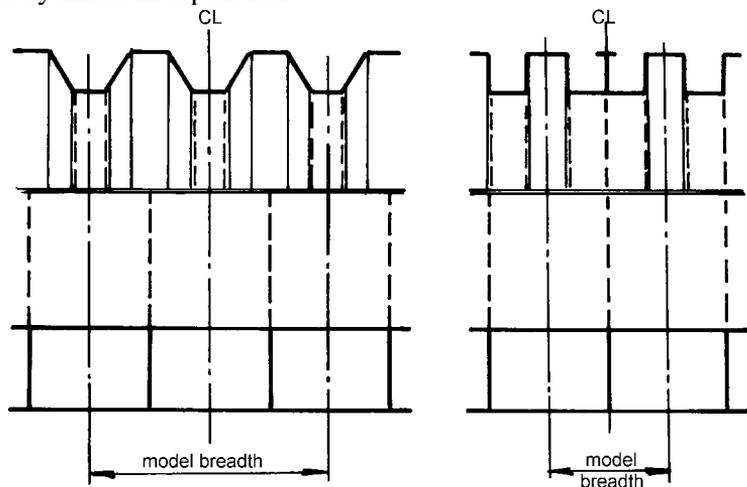
Fig. 3.2.4   Location and breadth of the transverse bulkhead model

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3.2.5 Response of the transverse bulkhead on the double bottom

To determine the values of stiffness response of the transverse bulkhead on the double bottom structure, a "unit" rotation of the lower part of the stool is to be calculated when the structure is unloaded.

With reference to Fig. 3.2.1, this may be done by simultaneously given nodes 1 and 3 vertical displacements:

$\pm \Delta$ (e.g. ± 0.5 cm).

The unit rotation, φ, is given by:

$$\varphi = \frac{2\Delta}{l}, \quad \text{rad} \tag{3.2.5-1}$$

l – breadth of the model base (distance between nodes 1 and 3), cm.

The corresponding bending moment may be calculated from the formula:

$$m = 0.5l(R_1 + R_3), \quad \text{Ncm} \tag{3.2.5-2}$$

R_1, R_3 – vertical reaction forces at nodes 1 and 3, N.

The spring stiffness used in the double bottom grillage calculation is to be determined from the formula:

$$K_r = \frac{m}{\varphi}, \quad \frac{\text{Ncm}}{\text{rad}} \tag{3.2.5-3}$$

Note: K_r may have to be adjusted to correspond with different spacings of longitudinal bottom girders.

3.3 Ship's side modelling (model B)

3.3.1 Basic model

Fig. 3.3.1 shows a typical ship's side section of bulk carrier, including wing tank and the corresponding structural model.

The purpose of the element connecting the bilge and the intersection between inner bottom and hopper tank top is to ensure that the hopper tank section remains undeformed during loading (see Fig. 3.3.1).

The springs A, B and C represent the stiffness of deck, top side tank bottom and hatch side coaming (hatch side girder), respectively.

Fig. 3.3.2 shows an alternative top side tank design and its model.

3.3.2 Stiffness of springs A and B

The stiffness coefficient for springs A and B (see Figs. 3.3.1 and 3.3.2) may be determined from the formula:

$$K_{A,B} = \frac{50E}{\dfrac{l_1^3}{192I_e} + \dfrac{2.6l_1}{4A_e}}, \quad \frac{\text{N}}{\text{cm}} \tag{3.3.2-1}$$

l_1 –   hatchway length (for spring A), hold length (for spring B), cm;

I_e –   equivalent moment of inertia of a given element, cm^4;

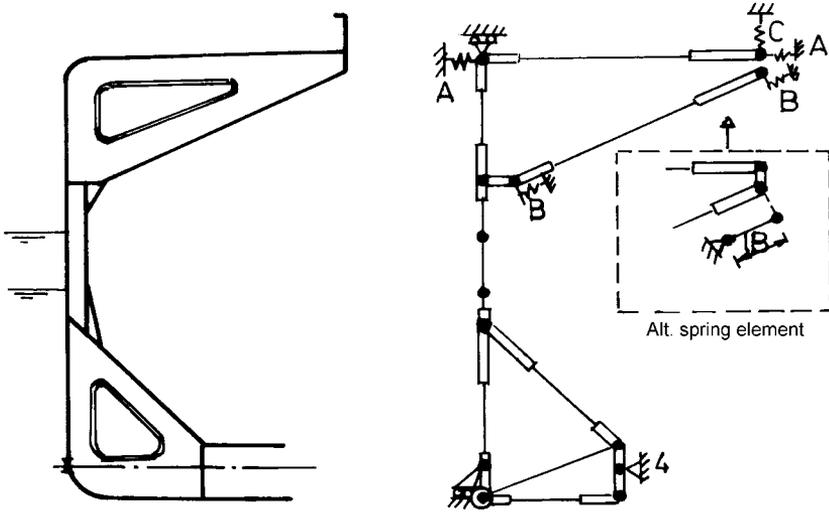A_e –   equivalent shear area, cm^2.

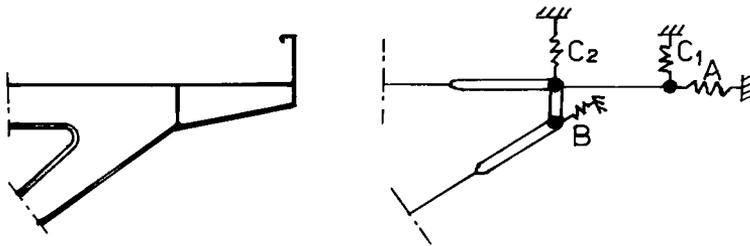Fig. 3.3.1   Ship's side modelling

Fig. 3.3.2   Top side tank model

The equivalent moment of inertia of a given element is to be calculated from the formula:

$$I_e = \frac{ctb^3}{6nk}, \quad \text{cm}^4 \tag{3.3.2-2}$$

The equivalent shear area is to be calculated from the formula:

$$A_e = \frac{2tb}{nk}, \quad \text{cm}^2 \tag{3.3.2-3}$$

c – effect of the ship's side and hatch coaming; it may normally be taken equal 2;

t – relevant thickness of plating, cm;

b – breadth of deck between the ship's side and hatch opening (for spring A) or breadth of top side tank measured along the tank bottom (for spring B), cm;

n – number of transverse web frames on the length l;

k – correction factor according to Table 3.3.2.

Table 3.3.2

Correction factor k

Number of transverse web frames	1	2	3	4	5	6	7	8	9	10
k	2.00	1.50	1.33	1.25	1.20	1.18	1.14	1.12	1.11	1.00

3.3.3 "Spring element" B

If spring, acting in other direction than along the x- and y-axes is not acceptable by the computer program, spring B may be replaced by a "spring element" (see Fig. 3.3.1) with cross-sectional area determined from the formula:

$$A_B = K_B \frac{L_B}{E}, \quad \text{cm}^2 \tag{3.3.3-1}$$

K_B – stiffness calculated in accordance with 3.3.2-1, N/cm;

L_B – length of "spring element", cm.

Notes:
1) Length L_B is to be so selected that the value A_B exceeds not more than 10 times the cross-sectional area of typical elements adopted in the given model.
2) Shear area and the moment of inertia of "spring element" are to be taken close to zero.

3.3.4 Determination of stiffness of spring C

$$K_C = \frac{100E}{\dfrac{l_1^3}{48I_e} + \dfrac{2.6l_1}{4A_e}}, \quad \text{N/cm} \tag{3.3.4}$$

l_1 – hatchway length, cm;

$$I_e = \frac{8}{5nk} I \text{ , cm}^4;$$

$$A_e = \frac{2}{nk} A \text{ , cm}^2;$$

for n, k – see 3.3.2;

I – relevant moment of inertia of hatch side coaming, including possible girder below deck, cm^4;

A – relevant shear area of hatch side coaming, including possible girder below deck, cm^2.

3.3.5   Ship's side stiffness response on the double bottom

To obtain the value of the stiffness response of the ship's side on the double bottom structure, a "unit rotation" of the hopper tank is to be calculated when the structure is unloaded.

With reference to Fig. 3.3.1, this may be done by giving node 4 a vertical displacement Δ (e.g. 1 cm).

The vertical spring stiffness to be applied on the corresponding nodes in the double bottom calculations is to be determined from the formula:

$$K_1 = \frac{R_4}{\Delta}, \quad \text{N/cm} \qquad (3.3.5\text{-}1)$$

R_4 – vertical reaction force at node 4, N.

Note: K_1 may have to be adjusted to correspond with the spacing of floors.

3.3.6   Location of the model and choice of its breadth

The model is to be made for cross-section in the middle of the hold. The breadth of the model is equal to the spacing of floors in this part of hold.

3.4   Modelling of double bottom (model C)

3.4.1   The basic model and its location

Fig. 3.4.1 shows a typical double bottom structure of bulk carrier and a corresponding structural model. The model is to extend athwartships from one side to the centreline, where symmetry is assumed for relevant load conditions. In the longitudinal direction, the model is to extend from the middle of one hold to the middle of the adjacent hold. Symmetry is assumed at each end of the model.

The spring stiffnesses K_r and K_1 correspond to the values calculated from models A and B in accordance with formulae 3.2.5-3 and 3.3.5-1.

In accordance with the basic assumption of 3.1.2 the vertical deflection of the ship's side may normally be neglected. If the ship's side is modelled as a flexible beam element, the vertical spring K_1 will have to be replaced by rotational springs K_b, calculated from the formula:

$$K_b = K_1 b^2, \quad \text{Ncm/rad} \tag{3.4.1-1}$$

b – athwartship distance from the intersection of the margin plate with the inner bottom plating to the ship's side, cm (see Fig. 3.4.1).
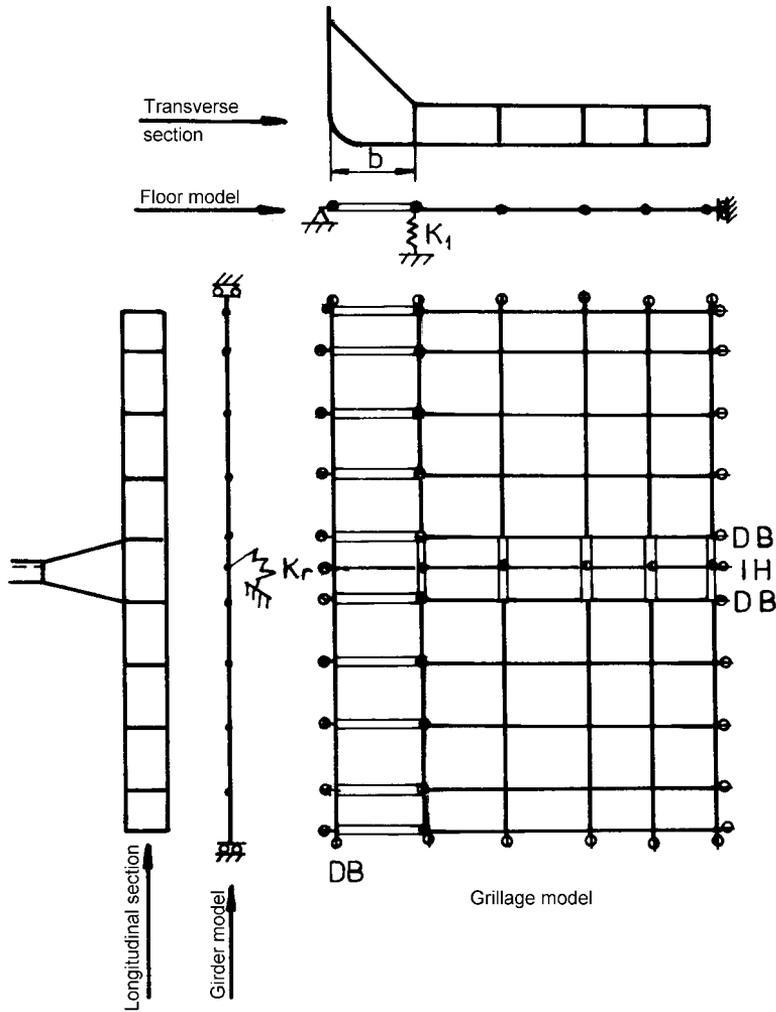

Fig. 3.4.1 Double bottom modelling

3.4.2 Types of beam elements

Two types of beam elements are assumed to be applied for the double bottom analysis:
– open section (IH-element) – element having cross-sectional properties corresponding to an open section with respect to torsion,
– closed section (DB-element) – element having torsional stiffness corresponding to box torsion. The section consists of two webs and two face

plates. The thickness of webs is equal to 0.5 their actual thickness. The total thickness of two webs is equal to the thickness of an individual web.
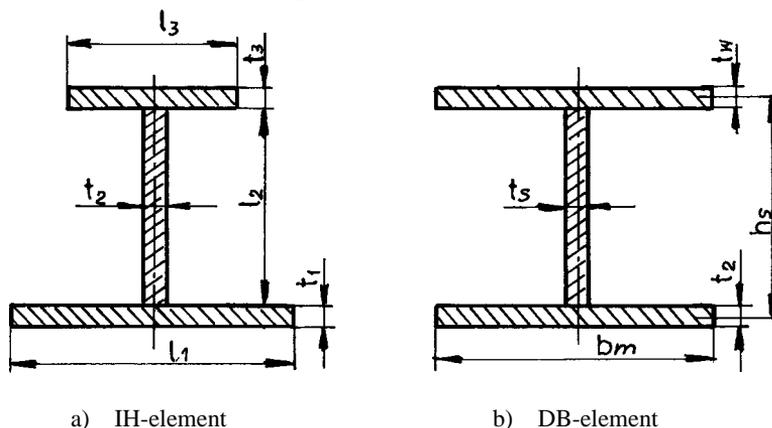

a) IH-element   b) DB-element

Fig. 3.4.2

For element IH, the torsional moment of inertia is to be calculated from the formula:

$$I_0 = \frac{1}{3}\sum_{i=1}^{3} l_i t_i^3, \quad cm^4 \qquad (3.4.2\text{-}1)$$

For element DB, the torsional moment of inertia is to be calculated from the formula:

$$I_0 = \frac{b_m h_s^2}{\dfrac{1}{t_z} + \dfrac{1}{t_w}}, \quad cm^4 \qquad (3.4.2\text{-}2)$$

b_m –   breadth of face flange of the bottom girder equal to the spacing of bottom girders, cm.

Other symbols are given in relevant figures. All dimensions are given in cm.

3.4.3   Effects of large openings

The shear area of floor and girder webs having large openings is, in general, to be adequately reduced. For normal arrangement of access and lightening holes, a factor of 0.8 may be taken.

The exact value of the factor will be determined when analysing the results of calculations (for each element separately).

3.4.4   The modelling of transverse elements

Fig. 3.4.4 shows modelling of transverse elements. Floors are modelled as DB-elements. Adjacent elements are assumed to be separated half-way between the floors.

Fig. 3.4.4   Modelling of transverse elements

3.4.5 Modelling of pipe tunnels

Transverse elements in way of pipe tunnels (with separate bottom and inner bottom stiffening) are to be modelled in the same way as the in-plane floor element.

In this case, the effective shear area is to be determined from the formula:

$$A_e = \frac{2.6}{\dfrac{l_u^2}{12\sum I} + \dfrac{2.6}{\sum A}}, \quad cm^2 \tag{3.4.5–1}$$

l_u – span of transverse stiffeners in pipe tunnel, cm;

$\sum I$ – sum of moments of inertia of bottom and inner bottom transverse stiffeners within the flange breadth, cm^4;

$\sum A$ – sum of shear areas of bottom and inner bottom transverse stiffeners within the flange breadth, cm^2.

3.4.6 The effect of transverse bulkhead and the stool tank

3.4.6.1 The stiffness of transverse bulkhead and the stool is represented by one IH-element and two DB-elements (see Fig. 3.4.4) and the spring K_r (see Fig. 3.2.5).

3.4.6.2 The transverse bending stiffness of bulkhead corrugations may be neglected.

The effective shear area (in the vertical direction) of corrugated bulkhead may be calculated from the formula:

$$A_s = t_g h_g \frac{b_s}{b_k}, \quad cm^2 \tag{3.4.6-1}$$

t_g – bulkhead plates thickness, cm;
h_g – height of the corrugated bulkhead, cm;
b_s, b_k – dimensions of corrugations, cm (see Fig. 3.4.4).

To calculate the moment of inertia of IH-element, the corrected web thickness is to be taken:

$$t_{ge} = 0.1 \frac{A_s}{h_s}, \quad cm \tag{3.4.6-2}$$

The top and bottom flange area may be taken as equal and corresponding to the cross-sectional area of deck between hatches A_p, cm^2.

3.4.6.3 The torsional stiffness of the stool may be modelled (approximated) by applying fictitious flange areas of the two DB-elements. The flange areas may be calculated from the formula:

$$A_m = 2 \sum_{n=1}^{5} \frac{b_n t_n e_n^2}{h_c^2}, \quad cm^2 \tag{3.4.6-3}$$

b_n, t_n – dimensions of plates, cm (see Fig. 3.4.4);

e_n – distance to the centre of the rotation indicated in Fig. 3.4.4, perpendicular to the plating, cm;

h_c – height of the DB-element web, cm (see Fig. 3.4.4).

The shear stiffness of the stool sides may be approximated by applying the thickness of the DB-element web, calculated from the formula:

$$T_{ce} = \sum_{n=1}^{2} \frac{b_n t_n}{h_c}, \quad \text{cm} \qquad (3.4.6\text{-}4)$$

For b_n, t_n, h_c – see above.

For unsymmetric stools, two DB-elements are to be modelled individually according to the above procedure.

3.4.7   The modelling of longitudinal elements

3.4.7.1   Fig. 3.4.7 shows the modelling of longitudinal elements in the double bottom. Centre and side girders are represented by in-line DB-elements.

3.4.7.2   Cross-sectional areas of the bottom and inner bottom longitudinals are not to be included in the flange areas of DB-elements since this would influence the torsional stiffness of the element.

The bending stiffness contribution of the bottom and inner bottom longitudinals may be included by increasing the web thickness by the value calculated from the formula:

$$\Delta t_w = 3\sum A_1 \frac{h_{sc}^2}{h_{dp}^3}, \quad \text{cm} \qquad (3.4.7\text{-}1)$$

$\sum A_1$ – sum of cross-sectional areas of bottom and inner bottom longitudinals within the flange breadth of DB-element, cm^2;

h_{sc} – vertical distance between the centre of gravity of cross-sectional areas of bottom and inner bottom longitudinals, cm (see Fig. 3.4.7);

h_{dp} – double bottom height, cm.

The corrected web thickness may be used for calculations of the moment of inertia of the element cross-sectional area.

The shear area of DB-element is to be calculated from the formula:

$$A_w = k h_{dp} t_w, \quad \text{cm}^2 \qquad (3.4.7\text{-}2)$$

k – coefficient considering openings in the web;

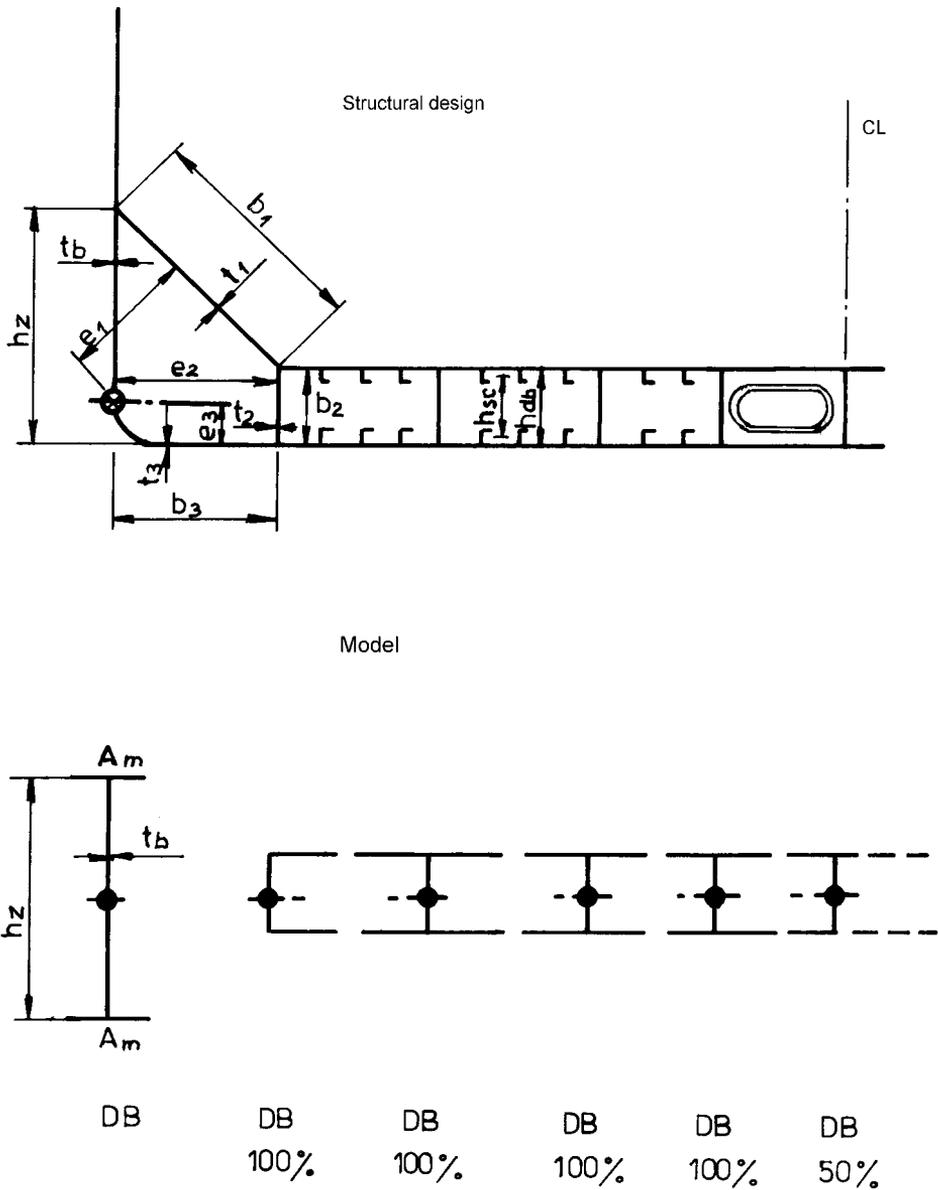t_w – thickness of the girder web, cm.

Fig. 3.4.7   Modelling of longitudinal double bottom elements

3.4.8   Effect of the ship's side and hopper tank

3.4.8.1   The stiffness of the ship's side and hopper tank is represented by one DB-element and springs having the stiffness K_1 (see 3.3.5) and simple supports placed at the ship's side.

3.4.8.2   The torsional stiffness of hopper tanks may be approximated in model C by applying fictitious flange areas A_m to the DB-element calculated as given in 3.4.6-3.

4   STRESS ANALYSIS[*)]

4.1   General

4.1.1   Permissible stresses

The girder stresses are not to exceed the permissible values specified in Part II "Hull" of the Rules.

The longitudinal double bottom bending stresses may be accepted by PRS, if:
–   the sum of stresses due to hull girder bending, double bottom bending and local bending of the longitudinals is not exceeding 225 k, MPa (the summation is to be carried out as shown in Fig. 4.1.1);
–   the sum of stresses due to hull girder bending and double bottom bending is not exceeding 190 k, MPa.
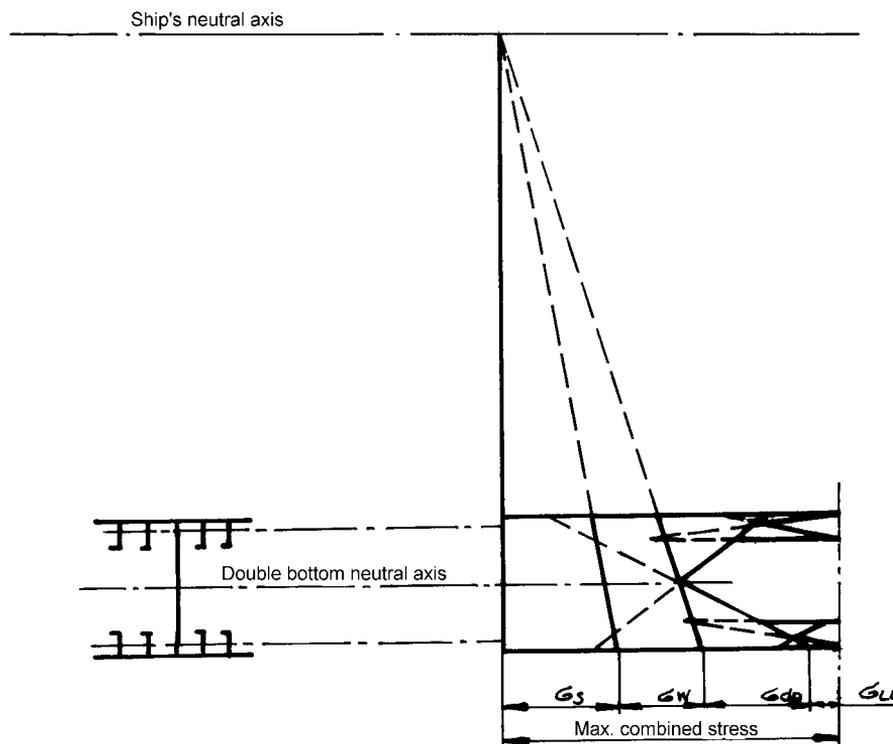

Fig. 4.1.1   Longitudinal double bottom bending stresses

[*)] If, in the formulae of Chapter 4 used for determining the stresses, the unit of 1 kN is applied instead of the unit force 1 N, then the value of recalculation coefficient 0.01 is to be changed to 10.

Explanations to Fig. 4.1.1

σ_s – hull girder stillwater bending stress at baseline, MPa (see Part II "Hull" of the Rules,);

σ_w – hull girder wave bending stress at baseline, MPa (see Part II "Hull" of the Rules), exceeded with probability 10^{-4};

σ_{dp} – double bottom bending stress according to direct stress calculations, MPa;

σ_u – bending stress in longitudinals due to local lateral loads, MPa.

4.1.2 Usage factors for critical stresses

4.1.2.1 The usage factors for critical stresses of bottom and inner bottom platings are to comply with the following requirements:

– for longitudinal stresses

$$\eta_{1l} = \frac{\sigma_l}{\sigma_{cl}} \le 0.87, \qquad (4.1.2\text{-}1)$$

– for transverse stresses

$$\eta_{1t} = \frac{\sigma_t}{\sigma_{ct}} \le 0.87, \qquad (4.1.2\text{-}2)$$

σ_l – calculated combined longitudinal stresses, MPa,

$\sigma_{l=}\sigma_w + \sigma_{s+}\sigma_{dp}$, MPa;

σ_t – calculated transverse girder bending stress, MPa;

σ_{cl} – critical buckling stress in longitudinal direction, MPa;

σ_{ct} – critical buckling stress in transverse direction, MPa;

σ_w, σ_s, σ_{dp}, – as given in 4.1.1.

For platings with aspect ratio 1÷1.5, the combined biaxial stability factor is to comply with the requirement:

$$\eta_1 = \sqrt{\left(\frac{\sigma_c}{\sigma_{cl}}\right)^2 + \left(\frac{\sigma_t}{\sigma_{ct}}\right)^2} \le 0.87 \qquad (4.1.2\text{-}3)$$

4.1.2.2 The shear stability factor is to comply with:

$$\eta_1 = \frac{\tau_a}{\tau_c} \le 0.87 \qquad (4.1.2\text{-}4)$$

τ_a – calculated shear stress, MPa;

τ_c – critical shear buckling stress, MPa.

4.2 Pipe tunnel strength

4.2.1 The modelling of the double bottom structure, discussed in 3.4, reflects the transverse stiffness of the bottom and inner bottom structure in the pipe tunnel. The local stress distribution within this region is to be checked according to the instructions given below.

4.2.2 The stresses analysis related to the transverse bottom and inner bottom stiffness in the pipe tunnel (see Fig. 4.2.2) is to include the following:

- shear stresses τ_{pz}, τ_{pw} due to average shear force carried across the pipe tunnel, determined in the bottom grillage analysis,
- shear stresses τ_{qz}, τ_{qw} due to local pressure on the bottom and inner bottom,
- normal stresses σ_{mz}, σ_{mw} due to double bottom bending (bottom grillage),
- normal stresses σ_{pz}, σ_{pw} due to tunnel side racking,
- normal stresses σ_{qz}, σ_{qw} due to local lateral pressure on bottom and inner bottom.
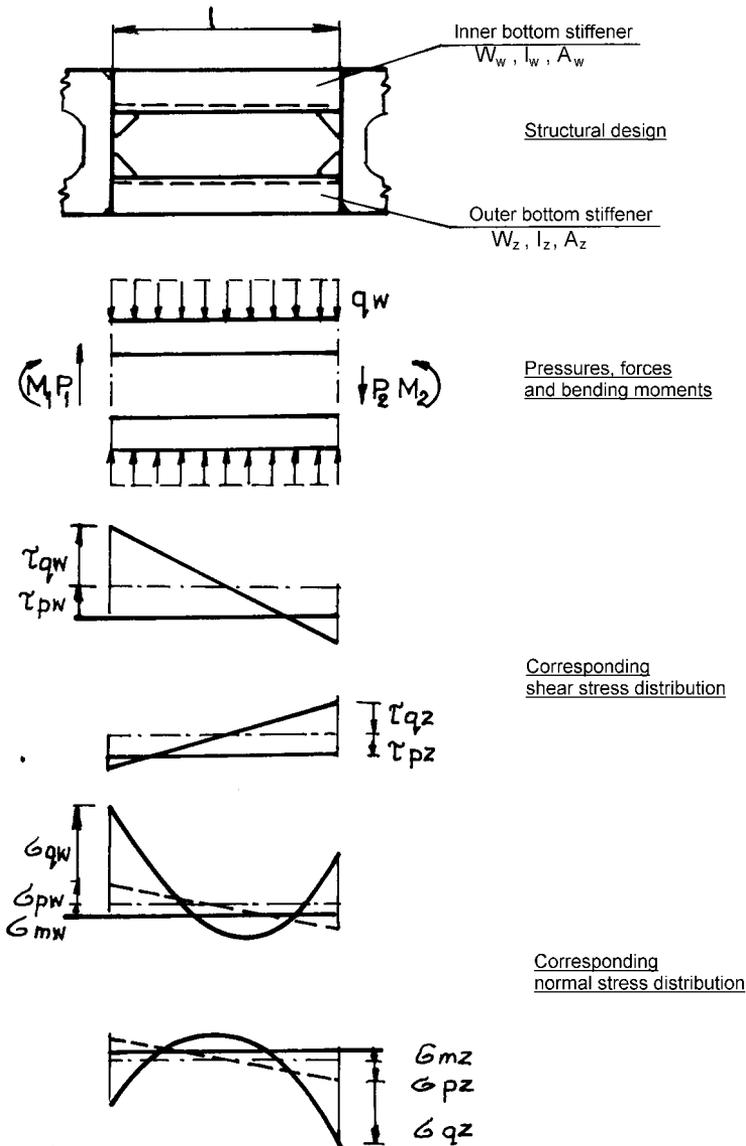

Fig. 4.2.2   Analysis of pipe tunnel stresses

4.2.3   Summing up the stresses

The maximum sum of the components mentioned in 4.2.2 may be calculated by the following formulae:

$$\tau_z = \tau_{pz} + \tau_{qz} = 0.01\left(\frac{PI_z}{A_z I} + \frac{q_z l}{2A_z}\right), \quad \text{MPa} \tag{4.2.3-1}$$

$$\tau_w = \tau_{pw} + \tau_{qw} = 0.01\left(\frac{PI_w}{A_w I} + \frac{q_w l}{2A_w}\right), \quad \text{MPa} \tag{4.2.3-2}$$

$$\sigma_z = \sigma_{mz} + \sigma_{pz} + \sigma_{qz} = 0.01\left(\frac{M}{W_{tz}} + \frac{PI_z l}{W_z I} + \frac{q_z l^2}{12W_z}\right), \quad \text{MPa} \tag{4.2.3-3}$$

$$\sigma_w = \sigma_{mw} + \sigma_{pw} + \sigma_{qw} = 0.01\left(\frac{M}{W_{tw}} + \frac{PI_w l}{W_w I} + \frac{q_w l^2}{12W_w}\right), \quad \text{MPa} \tag{4.2.3-4}$$

$$\left.\begin{array}{l} P = 0.5(P_1 + P_2), \quad \text{N} \\ M = 0.5(M_1 + M_2), \quad \text{N cm} \\ I = I_w + I_z, \quad \text{cm}^4 \end{array}\right\} \quad \text{see Fig. 4.2.2;}$$

l – breadth of pipe tunnel, cm;
W_{tw}, W_{tz} – section modul of the pipe tunnel at bottom and inner bottom, cm³;
W_w, W_z – section modul of stiffeners of bottom and inner bottom, cm³;
I_w, I_z – moments of inertia of stiffeners of bottom and inner bottom, cm⁴;
A_w, A_z – shear areas of stiffeners, cm²;
q_w, q_z – lateral line pressures acting on the stiffeners, N/cm.

4.3   Strength of double bottom below transverse bulkhead stool

4.3.1   Forces and stresses

When vertically stiffened transverse bulkheads are subjected to lateral load from one side only (adjacent hold empty), largebending forces P_f are transmitted from the stool to the double bottom (see Fig. 4.3.1). These forces are balanced by the shear forces P_s in the adjoining longitudinal bottom girders. For narrow stools, the vertical component of the stool side forces may become very large with high shear stresses in web area below the stool as a consequence.

The design shear stresses may normally be calculated as the average of:

$$\tau = 0.01\frac{P_{f1} - P_{s1}}{A_s} \quad \text{and} \quad \tau = 0.01\frac{P_{f2} - P_{s2}}{A_s}, \quad \text{MPa} \tag{4.3.1-1}$$

A_s – effective shear area of longitudinal bottom girder, cm².

Note: The values (P_f - P_s) may be obtained directly from the computer calculations when modelling is carried out as described previously (see Chapter 3).
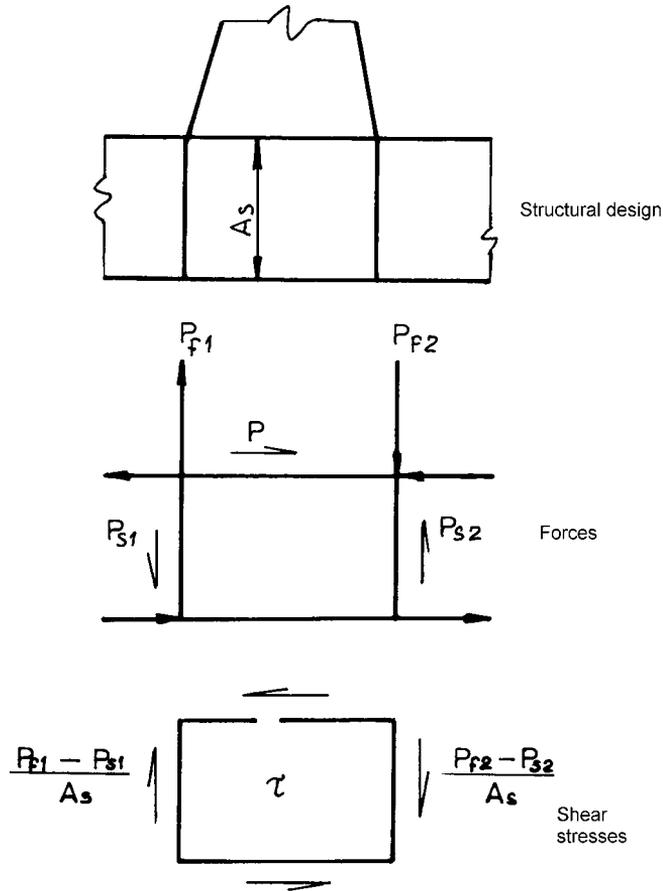
Fig. 4.3.1 Analysis of longitudinal girder below bulkhead stool

4.3.2 Stress concentration

Where the floors below the stool side are discontinuous (e.g. pipe tunnels), large stress concentration may occur when the bending force P_f is transmitted from the stool to the double bottom.

With reference to Fig. 4.3.2, the design normal stress through the inner bottom plating may be calculated from the formula:

$$\sigma = 0.01 \frac{3b - b_e}{2b_e} \frac{P_f}{A_f}, \quad \text{MPa} \tag{4.3.2-1}$$

b – breadth of the stool side corresponding to longitudinal bottom girder, cm;
b_e – effective breadth of the stool side considering discontinuity, cm;
P_f – force transmitted from the stool to bottom, N;
A_f – cross-sectional area of stool side at inner bottom, corresponding to b, cm^2.

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The design shear stresses at intersection between floor and longitudinal girder may be calculated from the formula:

$$\tau = \frac{0.01 P_f}{A_{s1} + A_{s2}}, \quad \text{MPa} \tag{4.3.2-2}$$

A_{s1}, A_{s2} – shear areas, cm^2 (see Fig. 4.3.2).
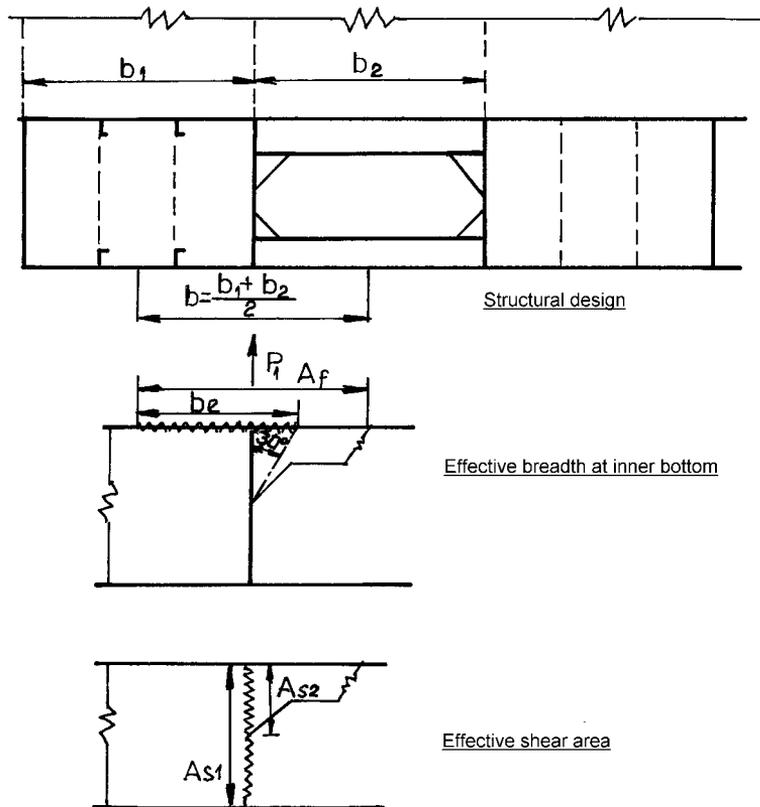

Fig. 4.3.2   Analysis of floor below bulkhead stool side

4.4   Shear strength of webs with cutouts

4.4.1   Shear stress for vertical section

The design value of shear stress in web with scallops and holes may be calculated from the formula:

$$\tau = 0.01 \frac{P_s}{A_s}, \quad \text{MPa} \tag{4.4.1-1}$$

P_s – calculated shear force on section in question, N;
A_s – effective shear areas, cm^2.

Note: The procedure of calculating the effective shear area is given in Part II "Hull" of the Rules.

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4.4.2 Shear stress for horizontal section

For floor panels, a section parallel to the element neutral axis may be decisive for the design shear stress. The shear stress for horizontal section may be calculated from formula 4.4.1.-1, substituting the following (see also Fig. 4.4.2):

P_{s1} – shear force between stiffeners a neutral axis, N,

$$P_{s1} = \frac{s}{h_{dp}} P_s, \quad N, \tag{4.4.2-1}$$

P_{s2} – shear force between stiffeners at bottom or inner bottom, N,

$$P_{s2} = 0.9 P_{s1}, \quad N; \tag{4.4.2-2}$$

A_{s1}, A_{s2} – effective shear area between stiffeners, cm^2;
s – spacing between stiffeners, cm;
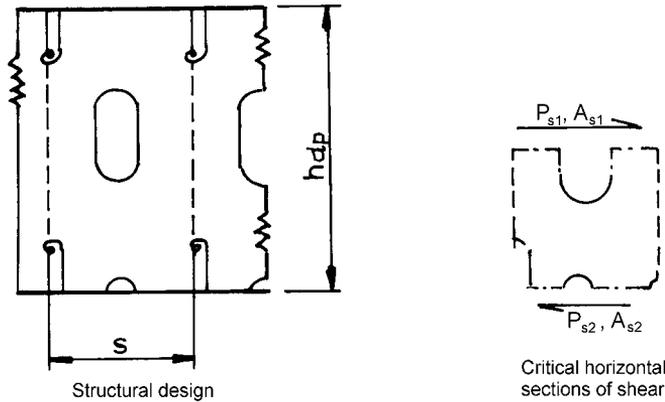h_{dp} – height of the double bottom, cm.

Fig. 4.4.2 Strength analysis of webs with cutouts

4.5 Strength of transverse bulkhead

4.5.1 Introduction

The conventional structural arrangement of transverse bulkhead is illustrated in Fig. 4.5.1. The shear forces P_c transmitted by the stool structure into the hopper tank may be calculated directly on the basis of the double bottom calculations. The design shear stresses, however, may require to be recalculated considering the shear area inside the hopper tank at side.
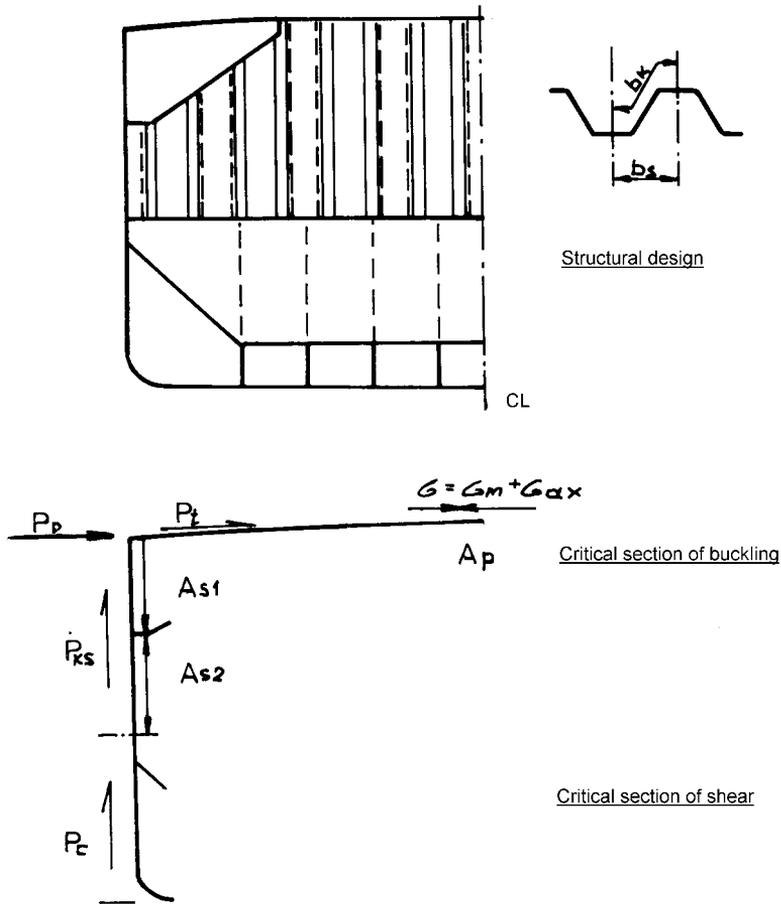
Fig. 4.5.1   Transverse bulkhead strength

4.5.2   Stresses in the upper part of bulkhead

4.5.2.1   The connection between of plane bulkhead in the top wing tank and corrugated bulkhead below is not reflected in the structural model. It is assumed that the plane bulkhead part inside the top wing tank will absorb a major part of the shear force P_{ks} calculated for corrugated bulkhead. The design shear stress may normally be taken as:

$$\tau = \frac{0.01 P_{ks}}{A_{s1} + \dfrac{b_s}{b_k} A_{s2}}, \quad \text{MPa} \tag{4.5.2.1}$$

A_{s1}, A_{s2} –   net shear area, cm^2 (see Fig. 4.5.1);
b_s, b_k –   dimensions of corrugations, cm (see Fig. 4.5.1).

4.5.2.2   The deck area between hatches is to be examined with respect to stability when exposed to load conditions giving compressive bending stresses in the deck flange of the transverse bulkhead.

The minimum load standard is given by load condition LC8.

4.5.3   The compressive bending stress in the bulkhead

The compressive bending stress which may be derived from the double bottom and side calculations is to be combined with axial stresses taken as:

$$\sigma_{ax} = 0.01 \frac{P_p - P_t}{A_p}, \quad \text{MPa} \qquad (4.5.3\text{-}1)$$

P_p – horizontal reaction force at deck strip between hatches due to sea pressure, N;

P_t – horizontal shear force in deck outside hatchways, N;

A_p – effective deck area between hatches, cm^2.

The value of P_p may be derived from the ships side calculations, taking into account the hold length compared with model length.

The value of P may be derived from shear flow analysis of the hull cross-section.

The approximate value of P_t may be calculated from the formula:

$$P_t = \frac{P_Q (B - b_1)}{4H}, \quad \text{N} \qquad (4.5.3\text{-}2)$$

P_Q – total vertical unbalance according to double bottom calculations (half breadth and half length of adjacent holds), N;

b_1 – breadth of hatchways, m.

4.6   Additional strength analysis of open type bulk carriers

4.6.1   General

For ships with large deck opening (total width of hatch openings in one transverse section exceeding 60 % of the ship's breadth B and length of hatch opening exceeding 70 % of hold length), the Rules require the combined effect of hull girder bending, hull girder torsion and local bending to be specially considered.

In addition to the stresses derived from the structural models described in Chapter 3 of the present Publication, the normal warping stress and local bending and shear stresses in the longitudinal and transverse deck strips will have to be evaluated.

4.6.2   Stresses

The method of determining torsional moments and the principles of summing the stresses components are given in the PRS Publication No. 24/P "Analysis of Hull Structure of Container Ship".[*]

4.6.3   Hatch corners

At the hatch corners of open type ships, large local stresses occur due to the combined effect of longitudinal and transverse bending and shear in the deck strips.[**]

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[*]   In the above Publication, permissible values of stresses particularly in longitudinal deck strips and girders, are also given.
[**]   The method of determining the required radius of hatch corners curvature and parameters of required thickenings of deck in way of hatch corners are given in the Publication mentioned in 4.6.2.