

**STRENGTH ANALYSIS OF
HULL STRUCTURES IN TANKERS**

JANUARY 1999

FOREWORD

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In "Rules for Classification of Fixed Offshore Installations", only those Classification Notes which are relevant for this type of structure have been listed.

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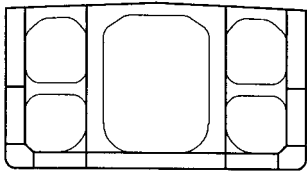
1. General

1.1 Introduction

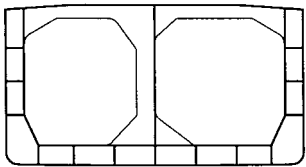
For girders being a part of a complex 2- or 3-dimensional structural system, the Rules require a structural analysis of the relevant structure to be carried out. This Classification Note describes acceptable methods for such analysis with focus on finite element calculations within the midship area. The analysis shall confirm that the stress levels are acceptable when the structures are loaded in accordance with described design conditions.

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

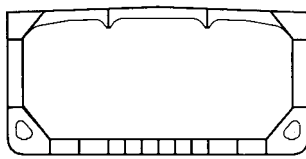
Strength analysis carried out in accordance with this note will be accepted as a basis for class approval in general.



A



B



C

Figure 1.1 Tankers of types A, B and C

1.2 Procedure

Acceptable calculations of 3-dimensional girder systems should normally be carried out by means of finite element analysis. An applicable procedure for such calculations is presented for 3 standard types of tanker in Chapter 2 and 3 of this Classification Note. These three standard types are in the following called tankers of type A, B and C where:

- Type A are tankers with 2 longitudinal bulkheads. Such vessels are typically VLCCs and shuttle tankers with cross ties, and smaller tankers without cross ties.
- Type B are tankers with centreline bulkhead. Such vessels are typically Suezmax tankers, Aframax tankers and shuttle tankers.
- Type C are tankers without longitudinal bulkheads. Such vessels are typically relatively small tankers.

Figure 1.1 shows the different tanker types. Other types of tank arrangements shall be handled in an equivalent way.

For smaller tankers, a 3-dimensional beam analysis or a combination of 2-dimensional beam analyses may be used. A procedure for such calculations is presented in Appendix C.

1.3 Definitions

- D - Moulded depth in m, Ref. Pt.3 Ch.1 Sec.1.
- T - Mean moulded summer draught in m.
- T_A - Minimum relevant seagoing draught. May be taken as 0.35D if not known.
- E - Modulus of elasticity = $2.06 \cdot 10^5$ N/mm² for steel.
- σ - Normal stress
- τ - Shear stress
- η - Usage factor
- Type A - Tanker with two longitudinal bulkheads
- Type B - Tanker with one longitudinal bulkhead
- Type C - Tanker with no longitudinal bulkheads
- Rules - All references to the Rules are to the DNV Rules for Ships, January 1998.

Figure 1.2 and Figure 1.3 shows the nomenclature for a typical double hull midship section.

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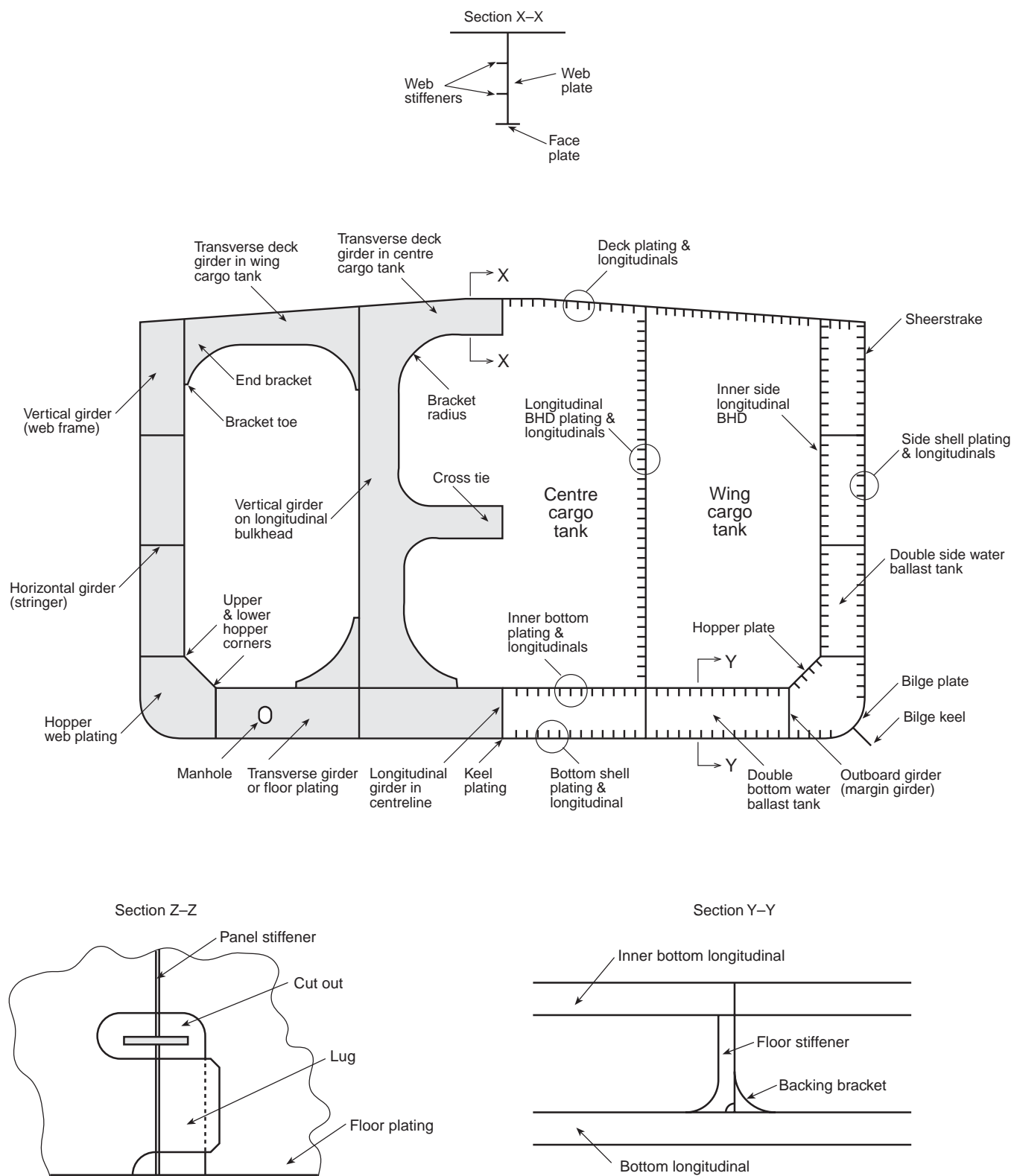


Figure 1.2 Nomenclature for a typical double hull midship section

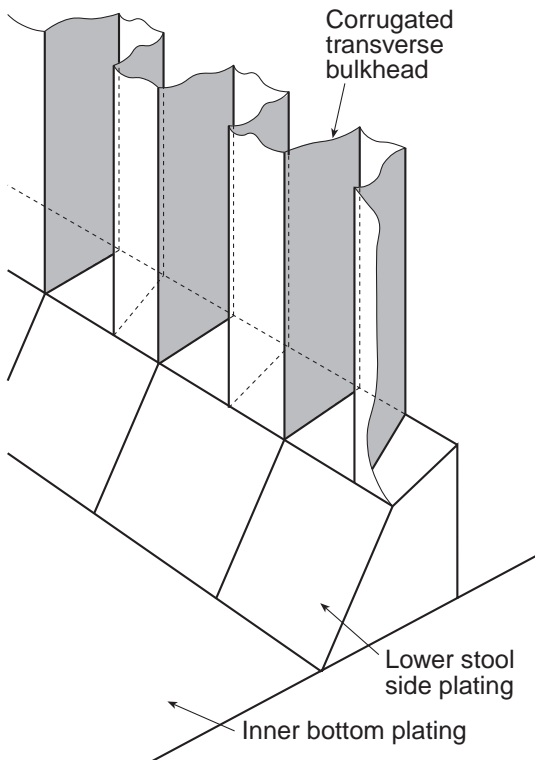


Figure 1.3 Nomenclature for a double hull tanker with corrugated transverse bulkhead

2. Cargo Tank Analysis

2.1 General

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

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

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

In the Rules Pt.3 Ch.1 Sec.13, types of analyses called “cargo tank analysis” and “frame and girder analysis” are described. Two different approaches are shown in Figure 2.1; One with a coarse mesh 3D-model requiring use of submodels, and one with a detailed 3D-model without any submodels. Whichever approach is used, the model or sets of models applied shall include a proper representation of the following structure:

- Typical web frame at middle of tanks
- Web frame adjacent to transverse bulkhead
- Transverse bulkhead horizontal stringers including longitudinal stringers in double side
- Transverse bulkhead vertical girders including longitudinal girders in double bottom
- Typical swash bulkhead

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

In addition, analyses of local structural parts may be made for determining the detailed stress level in stiffeners subject to large relative support deflections. Such analyses are described in Chapter 3 “Local structure analysis”.

It is emphasised that the following description represents *one* acceptable approach for performing such calculations, and that alternative methods may be applicable.

2.2 Model extent

The model extent are in general to comprise two tank lengths ($1/2 + 1 + 1/2$). It should however be noted that for vessels with structural symmetry about transverse bulkheads models comprising one tank length ($1/2 + 1/2$) may be used.

2.2.1 Tanker type A

The analysis model amidships should comprise *two tank lengths* ($1/2 + 1 + 1/2$) and *half breadth* (from centreline to ship’s side) of the vessel. The extent of the model with boundary conditions is visualised in Table 2.1.

If cross ties are arranged in the centre tanks and asymmetric loading of wing tanks may occur, a full breadth model of the vessel has to be considered to examine the increased stresses for such asymmetric loading. For this loadcase, which is represented by LC A10 in chapter 2.6.1, a separate model with one tank length and full breadth may be used.

2.2.2 Tanker type B

The analysis model amidships should comprise *two tank lengths* ($1/2 + 1 + 1/2$) and *full breadth* of the vessel. The extent of the model with boundary conditions is visualised in Table 2.2.

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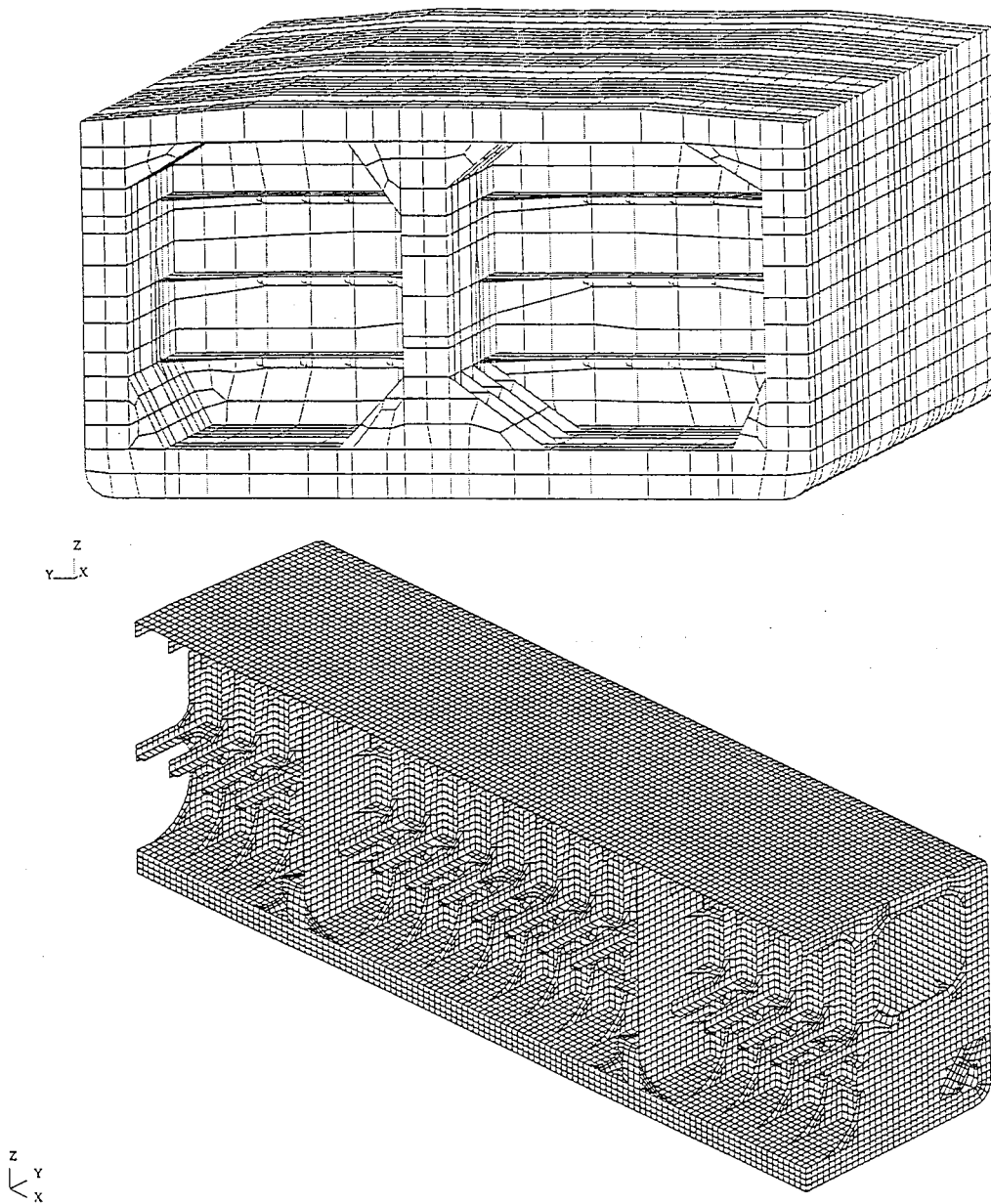


Figure 2.1 Example of a coarse mesh 3D-model of a tanker of type B, and a detailed 3D-model of a tanker of type A. Submodels will be necessary for the coarse mesh model

2.2.3 Tanker type C

The analysis model amidships should comprise *two tank lengths* ($1/2 + 1 + 1/2$) and *full breadth* of the vessel. The extent of the model with boundary conditions is visualised in Table 2.3.

2.3 Modelling of geometry

2.3.1 General model idealisation

All main longitudinal and transverse geometry shall be included in the model. The scantlings shall, according to DNV Rules, be modelled with reduced scantlings; i.e. corrosion addition according to the Rules shall be deducted from the actual scantlings. It should however be noted that other regulations might describe alternative procedures where the gross scantlings shall be applied.

When reduced effectivity of curved flanges are not represented by the model formulation itself, the reduced effectivity shall be defined by assigning reduced thickness of plate elements or cross sectional areas of beam and rod elements. Such reduced effectivity may be calculated as given in Pt.3 Ch.1 Sec.3

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

2.3.2 Girders

Flanges of girders shall be included in the model.

Openings in the girder webs will be present in ship structures for access and pipe penetrations. If such cut-outs affect the overall force distribution or stiffness of the girder, the cut-out shall be accounted for in the model. This may be done by either:

- reducing the thickness according to the formula below or,
- by geometrical modelling of the cut-out.

For the first approach the mean girder web thickness may be taken as follows:

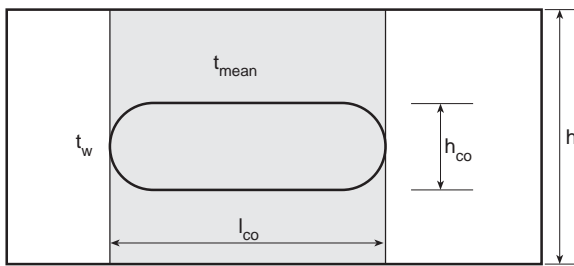


Figure 2.2 Mean girder web thickness

$$t_{\text{mean}} = \frac{h - h_{\text{co}}}{h \cdot r_{\text{co}}} \cdot t_w$$

where:

t_w = web thickness

$$r_{\text{co}} = 1 + \frac{l_{\text{co}}^2}{2.6(h - h_{\text{co}})^2}$$

l_{co} = length of cut-out

h_{co} = height of cut-out

h = height of girder web

When r_{co} is larger than 1.2, ($r_{\text{co}} > 1.2$), it is advised that the cut-out is included in the model in one of the two ways given above. When r_{co} is larger than 2, ($r_{\text{co}} > 2$), it is advised that the cut-out is geometrically included in the model.

Smaller openings for access and piping may be ignored. However, when such openings are ignored this must be considered when evaluating the results, ref. Chapter 2.8.1.

2.3.3 Stiffeners

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

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

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

Stiffeners on girders perpendicular to the flanges may be included in the model when considered important, alternatively by transferring them to the nearest nodes instead of introducing additional nodes. Buckling stiffeners considered less important for the stress distribution, as sniped buckling stiffeners, may be ignored. Buckling stiffeners on brackets and stringers parallel to the girder flanges, like the 2nd, 3rd, 4th etc. stiffeners from the free flanges, as shown in Figure 2.3, may normally be ignored.

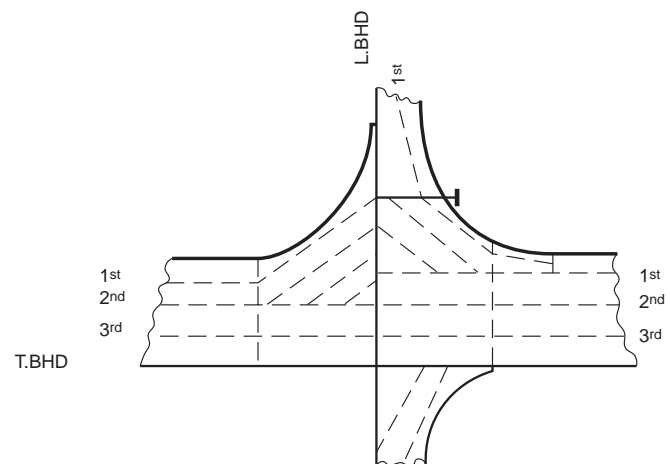


Figure 2.3 Buckling stiffeners, like the 2nd, 3rd, 4th etc. stiffeners from the free flanges on stringers parallel to the girder flanges may normally be ignored

2.3.4 Corrugated bulkheads and stools

Corrugated bulkheads shall be included in the model. Slanted plates (shedder plates) should normally not be included in the model.

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

Diaphragms in the stools are to be included in the model.

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

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

2.4 Elements and mesh size

The performance of the model is closely linked to the type-, shape- and aspect ratio of elements, and the mesh topology that is used. The mesh described here is adequate for representing the cargo tank model and frame and girder model as defined in the Rules Pt.3 Ch.1 Sec.13. The following guidance on mesh size etc. is based on the assumption that 4-noded shell or membrane elements in combination with 2-noded beam or truss elements are used.

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

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

2.4.1 Plating

4-noded shell or membrane elements may be used in connection with mesh size as described below. 3-noded shell or membrane elements with constant strain shall normally not be used. It may however be used to a limited extent for avoiding poor mesh transitions.

The element mesh should preferably represent the actual plate panels between stiffeners so that the stresses for the control of yield and buckling strength can be read and averaged from the results without interpolation or extrapolation.

In practise, the following may be applied:

- There should be minimum three elements over the height of girders. The mesh should in general, and as far as practical, follow the stiffener system on the girders. See Figure 2.4.
- One element between longitudinals. See Figure 2.4. This contributes to a correct load transfer from the longitudinal to the transverse frame.

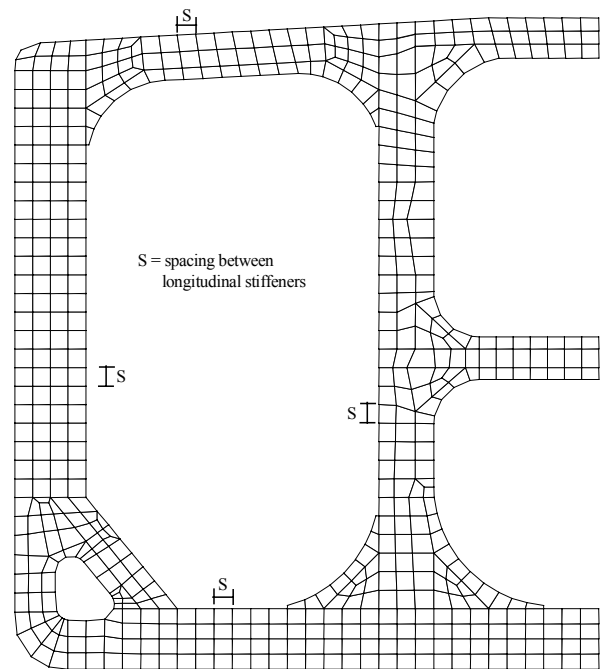


Figure 2.4 Mesh on typical web frame

- Two elements between transverse girders. A more refined mesh may be considered for easier description of brackets on horizontal stringers and brackets on vertical girders at transverse bulkhead. See Figure 2.5. The effect described in Figure 2.9 should then be noted.

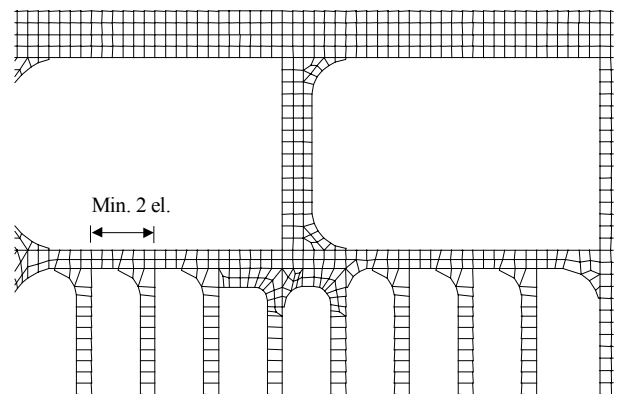


Figure 2.5 Alternative mesh in longitudinal direction

The figure shows horizontal stringer and cross ties.

- For determination of stresses in large brackets mesh sizes equal to stiffener spacing may be accepted, provided that considerable discontinuities (knuckles) along curved free flanges are avoided. An acceptable mesh is shown in Figure 2.6. The mesh at the bracket toes may be terminated at the nearest node as long as this does not influence the force distribution in the bracket. It is emphasised that this relatively coarse mesh is only suited for determination of the stress in the middle of the bracket's free edge as described in 2.8.1.

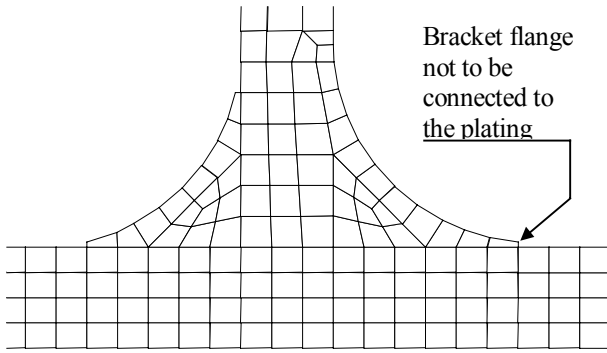


Figure 2.6 Mesh on transverse brackets

- Inside hopper tank areas the mesh should in general follow the stiffener system. The mesh should be fine enough to represent the shape of large openings in the web frame inside the hopper tank. See Figure 2.7.

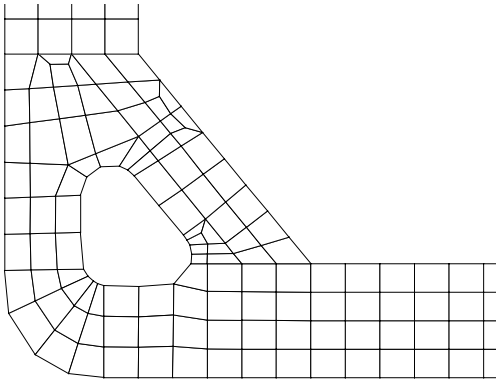


Figure 2.7 Typical mesh in hopper area

- One element or more should be used for each web and flange on the corrugations in corrugated bulkheads. This is normally satisfactory for determining the stress level in the bulkhead.

2.4.2 Longitudinals and stiffeners

Longitudinals and other continuous stiffeners including stiffeners on transverse bulkheads should be included in the model. These structural parts may be represented by 2-noded eccentric beam elements.

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

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

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

Curved flanges are to be represented with their true effectivity in the model, as given in Pt.3 Ch.1 Sec.3.

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

2.5 Boundary conditions

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

The model may be supported in the vertical direction by applying *vertical springs* at the lines formed by the intersections between side and transverse bulkheads, inner side and transverse bulkheads, and longitudinal bulkhead and transverse bulkheads. The spring constant, K_i , should be equally distributed along the line forming the intersection. The spring constant may be calculated as follows, ignoring the effect of bending deflection:

$$K_i = \frac{8 A_{Si} E}{7.8 l_i}$$

Where:

A_{Si} = shear area of i .

l_i = the length of one cargo tank.

i = is the side, inner side or longitudinal bulkhead

Alternatively, unbalanced *vertical forces* for each loading condition may be applied at the intersections between longitudinal and transverse bulkheads and at the intersection between double side and transverse bulkheads. The distribution of unbalanced vertical forces between double side and longitudinal bulkhead may be decided based on a shear flow calculation or according to the Rules Pt.3 Ch.1 Sec.5.

The boundary conditions for the different tanker types are described in the following subchapters.

It should be noted that the boundary conditions for tankers of type A described in Table 2.1 and the boundary conditions for tankers of type B described in Table 2.2 will result in a fictitious compression force caused by loads on the transverse bulkheads. However, for these vessels the longitudinal girder stresses do normally not need to be considered (Ref. Chapter 2.8.1). For tankers of type C these longitudinal girder stresses need to be calculated. The boundary conditions in Table 2.3 introduce a correction for the fictitious compression force.

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2.5.1 Tanker type A

For tankers of type A applicable boundary conditions are given below. Table 2.1 shows boundary conditions with symmetry in the ends of the model and in the centreline.

Line C is the intersection between the vertical part of the shell and the transverse bulkhead. Line D is the intersection between the vertical part of the inner side and the transverse bulkhead. Line E is the intersection between the transverse bulkhead and the longitudinal bulkhead.

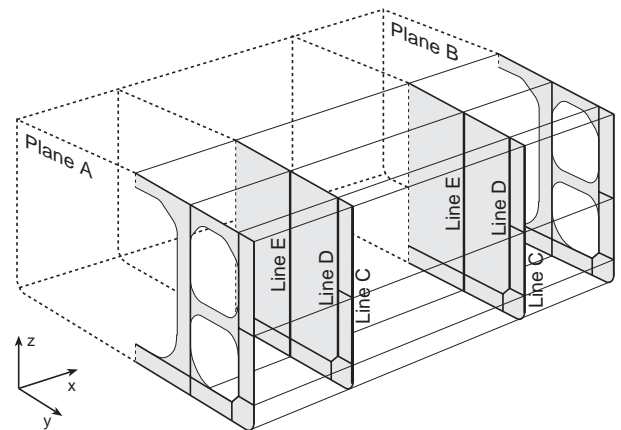
When longitudinal stresses in double bottom or other longitudinal structure are to be considered, boundary conditions following the principles in Table 2.3 with a counteracting force may be applied.

When a full breadth model is made the boundary conditions are to follow the principles for tankers of type B with respect to fixation in the transverse direction.

Table 2.1 Boundary conditions for tankers of type A

Location	Displacement			Rotation		
	δx	δy	δz	θx	θy	θz
Plane A	X	-	-	-	X	X
Plane B	X	-	-	-	X	X
Centreline	-	X	-	X	-	X
Line C, D, E			S/F _v			

X Restricted from displacement or rotation
 - Free
 S Springs (S/F_v means springs or forces)
 F_v Vertical forces. When vertical forces are applied the model must in addition be restricted from translation in the vertical direction by fixing it in one node, taken as the intersection between, outer side, deck and one transverse bulkhead.

**2.5.2 Tanker type B**

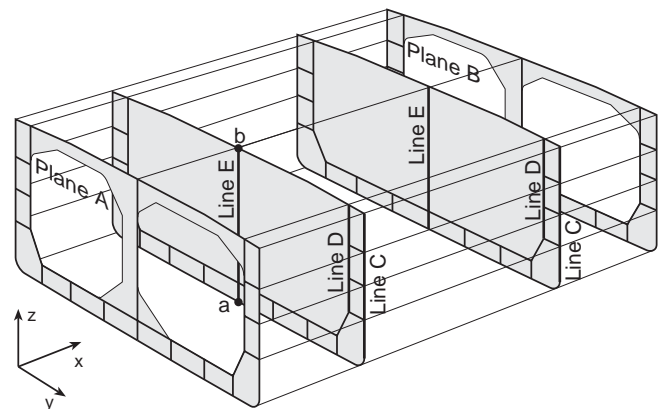
Basically the same boundary conditions apply as for tankers of type A. However, for these vessels unsymmetrical loading conditions about the centreline apply. This leads to boundary conditions as given in Table 2.2, when the longitudinal stresses for double bottom and deck are not considered.

Line C is the intersection between the vertical part of the side shell and the transverse bulkhead. Line D is the intersection between the vertical part of the inner side and the transverse bulkhead. Line E is the intersection between the transverse bulkhead and the longitudinal bulkhead. Line C and D are to be present on both sides of the model.

Table 2.2 Boundary conditions for tankers of type B

Location	Displacement			Rotation		
	δx	δy	δz	θx	θy	θz
Plane A	X	-	-	-	X	X
Plane B	X	-	-	-	X	X
Line C, D, E			S/F _v			
Point a and b		X				

X Restricted from displacement or rotation
 - Free
 S Springs (S/F_v means springs or forces)
 F_v Vertical forces. When vertical forces are applied the model must in addition be restricted from translation in the vertical direction by fixing it in one node



When longitudinal stresses in double bottom or other longitudinal structure are to be considered, boundary conditions following the principles in Table 2.3 with a counteracting force may be applied.

Point a is the point of intersection between the bottom, centreline and transverse bulkhead.

Point b is the point of intersection between the deck, centreline and transverse bulkhead.

2.5.3 Tanker type C

Applicable boundary conditions are shown in Table 2.3.

Tankers of type C normally have several longitudinal girders in the double bottom. The stresses referred to as longitudinal girder bending stresses in the Rules Pt.3 Ch.1 Sec.13 shall therefore be calculated. The boundary conditions in Table 2.3 introduce a longitudinal counteracting force in the longitudinal direction. The force shall only be applied when

the middle tank is empty and surrounding tanks are full, as for load condition LC-C1. The magnitude of the force will vary for each loadcase but shall in general be equal to the net load on the transverse bulkhead.

Line C is the intersection between the vertical part of the shell and the transverse bulkhead. Line D is the intersection between the vertical part of the inner side and the transverse bulkhead. Line C and D are to be present on both sides of the model.

Point a is the point of intersection between the bottom, centreline and transverse bulkhead.

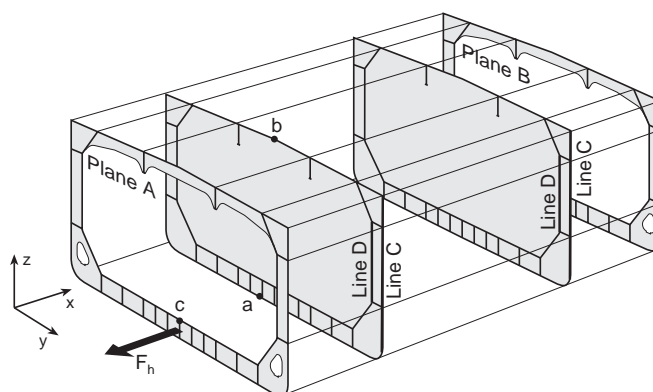
Point b is the point of intersection between the deck, centreline and transverse bulkhead.

Point c is the point where the counteracting longitudinal force is applied.

Table 2.3 Boundary conditions for tankers of type C

Location	Displacement			Rotation		
	δx	δy	δz	θx	θy	θz
Plane A	L ^(*)	-	-	-	X	X
Plane B	X	-	-	-	X	X
Line C, D			S/F _v			
Point a and b		X				
Point c	F _h					

X	Restricted from displacement or rotation
L	Linearly dependant of point c
(*)	Could be given as forced displacement in x direction for all nodes, following Hook's law
-	Free
S	Springs (S/F _v means springs or forces)
F _v	Vertical forces. When vertical forces are applied the model must in addition be restricted from translation in the vertical direction by fixing it in one node
F _h	Counteracting longitudinal force



2.6 Loading conditions

The basic loading conditions as described in Pt.5 Ch.3 of the Rules shall normally be considered. The loading conditions for different types of tankers, described in subchapters below, are based on these conditions. These loading conditions are to be regarded as minimum conditions. Other conditions given in the loading manual are to be considered when relevant.

In addition, dynamic loading conditions relevant for estimating the fatigue life are normally to be considered. A brief description of the fatigue loading conditions is given in Chapter 2.6.4.

For the determination of static and dynamic pressure see the Rules Pt.3 Ch.1 Sec.13

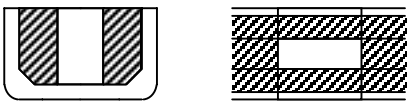

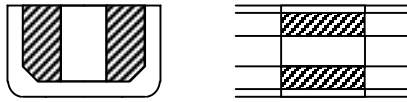
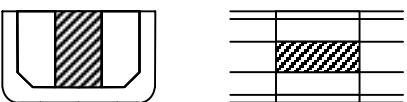
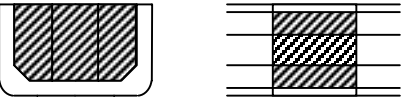
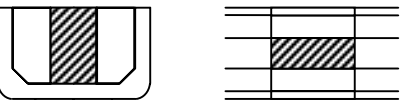
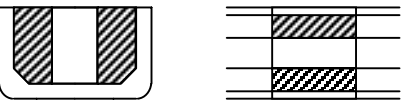
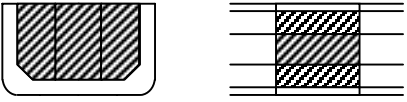
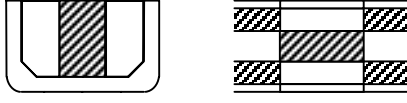
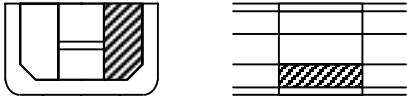
The cargo density used in the calculations shall in general not be less than 1.025 t/m³.

The loading should be applied in the form of lateral pressure on shell elements, (or line loads on membrane elements).

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2.6.1 Tanker type A

Loading conditions as given in Table 2.4 apply. LC-A10 is for vessels with cross ties in centre tanks. This condition is only applicable if no reservation against this condition is given in the loading manual. The "Internal pressure : Static" given in Table 2.4 is normally to be taken as given in Pt.3 Ch.1 Sec.4 C300 (5). It should however be noted that dynamic internal pressure, $p = (g_0 + 0.5a_v)ph$, must be considered in case of heavy liquid.

Table 2.4 Rule loading conditions for tankers of type A					
<i>LC No</i>	<i>Draught</i>	<i>Condition</i>	<i>External pressure</i>	<i>Internal pressure</i>	<i>Figure</i>
A1	T	Sea	Dynamic	Static	
A2	T	Sea	Dynamic	Static	
A3	T _A	Sea	Dynamic	Static	
A4	T _A	Sea	Dynamic	Static	
A5	T _A	Sea	Dynamic	Static	
A6	0.25D	Harbour	Static	Static	
A7	0.25D	Harbour	Static	Static	
A8	0.35D	Harbour	Static	Static	
A9	T _A	Sea	Dynamic	Static	
A10	0.25D	Harbour	Static	Static	

2.6.2 Tanker type B

Loading conditions as given in Table 2.5 apply for tankers of type B. The "Internal pressure : Static" given in Table 2.5 is normally to be taken as given in Pt.3 Ch.1 Sec.4 C300 (5). It should however be noted that dynamic internal pressure, $p = (g_0 + 0.5a_v)\rho h$, must be considered in case of heavy liquid.


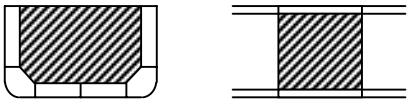
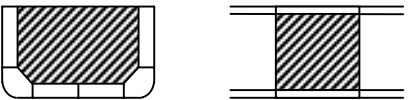
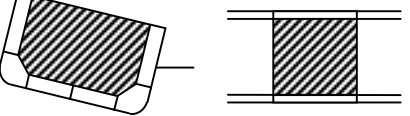
Table 2.5 Rule loading conditions for tankers of type B					
LC No	Draught	Condition	External pressure	Internal pressure	Figure
B1	T	Sea	Dynamic	Static	
B2	T	Sea	Dynamic	Static	
B3	T_A	Sea	Dynamic	Static	
B4	T_A	Sea	Dynamic	Static	
B5	0.25D	Harbour	Static	Static	
B6	0.35D	Harbour	Static	Static	
B7	T_A	Sea	Dynamic	Static	

Note! In case the web frame structure is unsymmetrical, the unsymmetrical loading conditions (LC-B2, LC-B3 and LC-B5) should in addition be run with opposite loading in tanks.

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2.6.3 Tanker type C

Loading conditions as given in Table 2.6 apply for tankers of type C. The "Internal pressure : Static" given in Table 2.4 is normally to be taken as given in Pt.3 Ch.1 Sec.4 C300 (5). It should however be noted that dynamic internal pressure, $p = (g_0 + 0.5a_v) \rho h$, must be considered in case of heavy liquid.

Table 2.6 Rule loading conditions for tankers of type C					
<i>LC No</i>	<i>Draught</i>	<i>Condition</i>	<i>External pressure</i>	<i>Internal pressure</i>	<i>Figure</i>
C1	T	Sea	Dynamic	Static	
C2	T _A	Sea	Dynamic	Static	
C3	0.35D	Harbour	Static	Static	
C4	T _A	Harbour	Static ¹⁾	Static ²⁾	
Comments: 1), 2) Pressure to be taken as given in Pt3. Ch.1 Sec.13					

2.6.4 Fatigue loads

In order to include stresses caused by relative deflection in the fatigue assessment of longitudinals, dynamic load cases as specified in Table 2.7 are to be applied to the cargo hold model. The results from these loadcases may also be used for fatigue assessment of other structural parts, e.g. hopper knuckles.

The fatigue loadcases will be the same for tankers of type A, B and C.

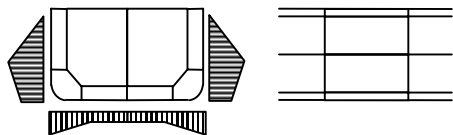
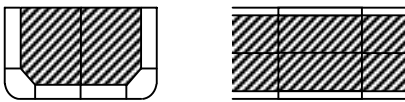
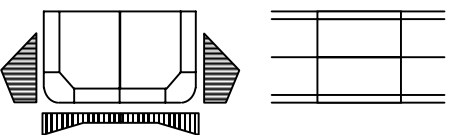
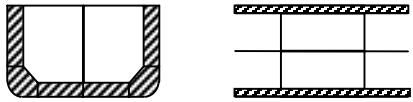
The external and internal dynamic pressures are to be calculated according to Classification Note 30.7 "Fatigue Assessment of Ship Structures". For a midship cargo hold

model the sea pressure is to be taken as the roll dominated pressure p_{dr} . The internal tank pressure is to be taken as the pressure caused by vertical acceleration a_v . In case the model covers a tank in the fore or aft end of the ship, an evaluation should be made if also the pitch dominated sea pressure p_{dp} should be included.

It is emphasized that this is pure dynamic load cases for evaluation of the structures' fatigue life. The static part is therefore not included.

The further procedure for fatigue calculations is given in the mentioned classification note.

Table 2.7 Dynamic loadcases for the evaluation of structures' fatigue life

LC No	Draught	Condition	External pressure	Internal pressure	Figure
D1	T	Full load Sea	Dynamic	-	
D2	T	Full Load Sea	-	Dynamic	
D3	T _A	Ballast Sea	Dynamic	-	
D4	T _A	Ballast Sea	-	Dynamic	

2.7 Presentation of input and results

The requirements given in DNV Rules Pt.3 Ch.1 Sec.13 A300 regarding proper documentation of the model shall be followed. A practical guidance is given in the following. In Appendix B, examples of checklists for internal verification of FEM analyses are given.

2.7.1 Presentation of input data

A reference to the set of drawings (drawing numbers and versions) the model is based on should be given. The modelled geometry is to be documented preferably as an extract directly from the generated model. The following input shall be reflected:

- Plate thickness

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

2.7.2 Presentation of results

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

The following should be presented:

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- Deformed shapes
- Transverse or vertical membrane stress of shell/plate elements in
 - Bottom
 - Inner bottom
 - Deck
 - Side shell
 - Inner side including hopper tank top
 - Longitudinal bulkhead
 - Transverse bulkhead
- Longitudinal membrane stresses when relevant. Ref. 2.8.1
- Shear stress of transverse and longitudinal girders
- Membrane stresses of transverse and longitudinal girders
- Equivalent (Von-Mises) stress of transverse girders
- Axial stress of free flanges. In case the flange is represented by a bar only the axial force may be available.
- The unbalanced forces and moments should be given for all loadcases.

stresses, as they are typical for double bottom structures, and may be taken as results from the cargo tank analysis. For tankers of Type A and Type B with long tanks and without longitudinal girders in double bottom, σ_{DBL} may normally be neglected ($\sigma_{DBL}=0$), ref. comments below.

σ_S = Longitudinal hull girder bending stresses defined as M_S/Z_i , where M_S is the still water bending moment and Z_i is the section modulus at the considered position (i) based on gross scantling. (No corrosion addition deducted). Design limits for sagging or hogging moment to be applied as values for M_S . M_S is defined in DNV Rules Pt.3 Ch.1 Sec.5

σ_W = Longitudinal hull girder bending stresses caused by wave bending moment M_W , which correspond to a probability of exceedance of 10^{-8} . $\sigma_W = M_W/Z_i$. M_W is defined in DNV Rules Pt.3 Ch.1 Sec.5

σ_{WR} = Longitudinal hull girder bending stresses caused by reduced wave bending moment M_{WR} , which corresponds to a probability of exceedance of 10^{-4} . $M_{WR} = 0.59M_W$.

2.8 Result evaluation and applicable acceptance criteria

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

2.8.1 Evaluation of results

2.8.1.1 Longitudinal stress

For buckling control the following longitudinal stresses may normally be considered:

$$\sigma_L = \sigma_{DBL} + \sigma_S + \sigma_W$$

or

$$\sigma_{LR} = \sigma_{DBL} + \sigma_S + \sigma_{WR}$$

where :

- σ_L = Sum of longitudinal stresses based on wave bending moment with a probability of 10^{-8} of exceedance.
- σ_{LR} = Sum of longitudinal stresses based on wave bending moments with a probability of 10^{-4} of exceedance.
- σ_{DBL} = Longitudinal girder bending stresses resulting from bending of large stiffened panels between transverse bulkheads, due to local load on an individual cargo tank. These stresses are often referred to as double bottom

Relevant stress components related to hull girder, girders and stiffeners are defined in Figure 2.8.

Fictitious longitudinal stresses may occur in the model due to assumptions that are made for the boundary conditions. These effects are due to "semi global bending" of the hull girder and a fictitious compression force when the middle tanks are empty as described in 2.5.3. When the longitudinal girder stresses are evaluated, typically for girders in double bottom, the magnitude of these effects should be considered as follows:

- Longitudinal stresses obtained from a cargo hold model as described in this Classification Note may normally be neglected for tankers of Type A and Type B, where the breadth of tanks is small compared with their length and without longitudinal girders in double bottom.
- Tankers of type C normally have longitudinal girders in the double bottom. For these vessels it is advised that the fictitious compression force is eliminated for the mid tank by applying boundary conditions as described in Table 2.3, or by manual corrections after the calculation.

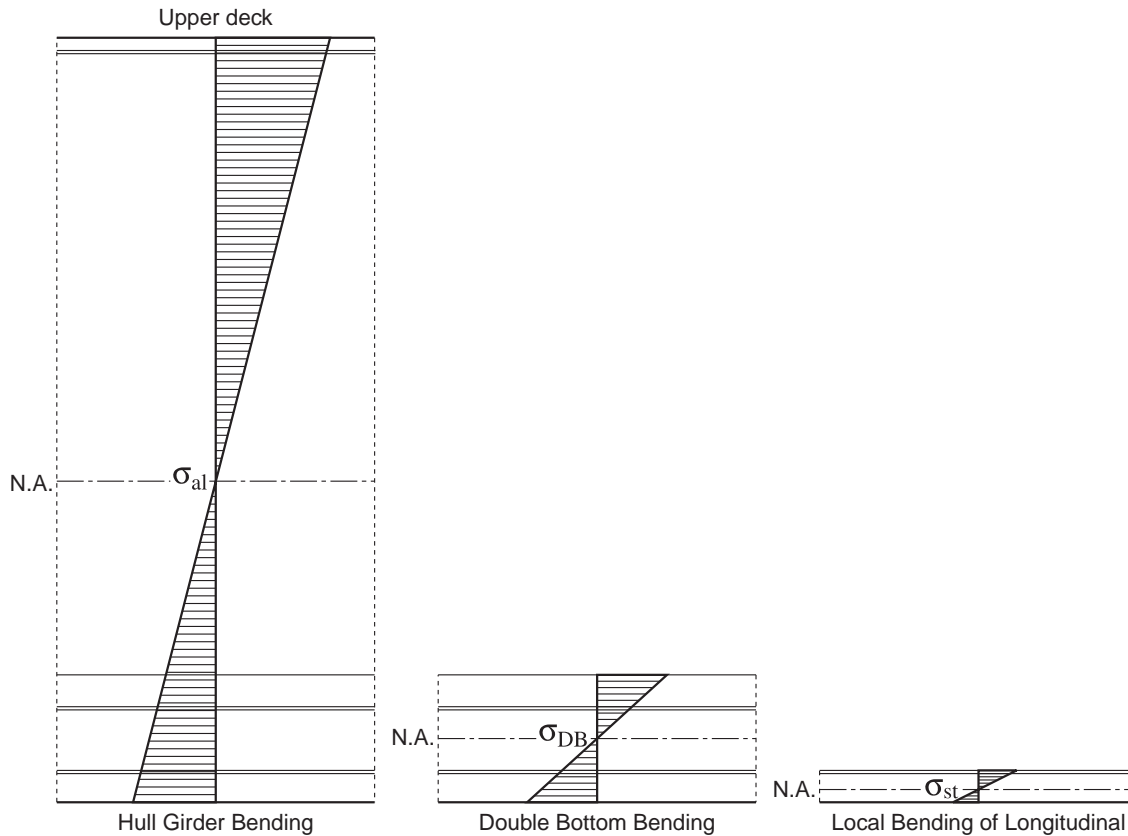


Figure 2.8 Stress components related to hull girder, girders, stiffener and plates

It should also be noted that the stiffener bending stress is not a part of the girder bending stresses. The magnitude of the stiffener bending stress included in the stress results depends on the mesh division and the element type that is used. This is shown in Figure 2.9 where the stiffener bending stress, as calculated by the FE-model, is shown depending on the mesh size (valid for 4-noded shell elements). One element between floors results in zero stiffener bending. Two elements between floors result in a linear distribution with approximately zero bending in the middle of the elements. When a relatively fine mesh is used in the longitudinal direction the effect of stiffener bending stresses should be isolated from the girder bending stresses when buckling and stress level are checked.

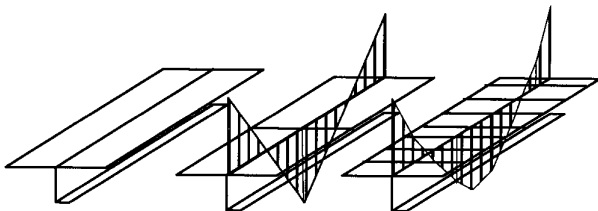


Figure 2.9 Normal stress caused by local load on the stiffener, depending on number of elements along the stiffener

2.8.1.2 Mean shear stress

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

$$\tau_{\text{mean}} = \frac{\sum_{i=1}^{i=n} (\tau_i \cdot A_i)}{A_w}$$

Where

A_i = the effective shear area of element i .

τ_i = the shear stress of element i .

A_w = effective shear area according to the Rules Pt.3 Ch.1 Sec.3.

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2.8.1.3 Stress level in girder brackets

Experience has shown that stresses calculated at the middle of a bracket's free edge (Ref. Figure 2.12) is of the same magnitude for models with mesh size as described in Chapter 2.4.1 as for models with a finer mesh. The stress at the middle of the brackets free edge refers to the stress at the mid 30% of the span. For brackets of well proven designs the evaluation of stress may therefore be limited to a check of the stress at this free edge. Figure 2.10 shows where to take out stresses at the free edge of girder brackets. However, a fine mesh model should be made when the bracket design of the toe areas needs to be verified.

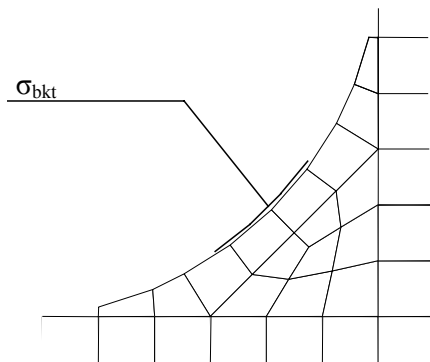


Figure 2.10 Bracket stress may be taken in the middle of the bracket's free edge

2.8.1.4 Shear stress in the hull girder.

It is not necessary to consider hull girder shear stresses in longitudinal bulkheads and ship side unless special boundary conditions as well as loads are applied. The shear strength of the hull girder will normally be evaluated in accordance with the Rules Pt.3 Ch.1 Sec.5.

2.8.2 Buckling control and related acceptance criteria

Table 2.8 gives examples of areas to be checked for buckling and the applicable method and accept criteria. In case of any differences in the acceptance criteria given here compared with those given in the Rules for Ships, the latter shall apply.

Table 2.8 Examples of areas to be checked and procedure to be used for buckling control

<i>Item</i>	<i>Remarks</i>
Buckling of girder plate flanges in: <ul style="list-style-type: none"> • Double bottom (including bottom and inner bottom) • Double side (including side and inner side) • Deck • Long. Bulkhead 	<ol style="list-style-type: none"> 1) Uniaxial buckling in transverse direction to be analysed based on <i>mean transverse compressive stress</i> with $\psi = 1$ and allowable usage factor, $\eta=0.8$ 2) Uniaxial buckling in longitudinal direction to be analysed according to Sec.14 based on hull girder stress $\sigma_{al} = \sigma_s + \sigma_w$. 3) Bi-axial buckling to be analysed based on <i>longitudinal stress</i> and <i>mean transverse stress</i>. When the longitudinal stresses are obtained from hull girder loads on a probability of exceedance of 10^{-4}, usage factors $\eta_x=\eta_y=0.85$ shall be used. For a probability of exceedance of 10^{-8}, usage factors $\eta_x=\eta_y=1.0$ shall be used. <p>Comment: <i>Mean transverse compressive stress</i> is to be calculated from a group of elements representing one plate field between stiffeners. <i>Longitudinal stress</i> are to be taken as described in 2.8.1</p>
Buckling of girder plate flanges in: <ul style="list-style-type: none"> • Transverse bulkheads 	<ol style="list-style-type: none"> 1) Buckling to be analysed based on <i>mean transverse compressive stress</i> with $\psi = 1$ and allowable usage factor, $\eta=0.8$. 2) Bi-axial buckling to be checked when relevant. <p>Comment: <i>Mean transverse compressive stress</i> are normally to be calculated from a group of elements representing one plate field between stiffeners</p>
Buckling of: <ul style="list-style-type: none"> • Cross tie 	<ol style="list-style-type: none"> 1) Buckling to be analysed based on <i>axial stress</i> with usage factor according to Rules. <p>Comment: <i>Axial stress</i> in cross tie may normally be taken as the stress at the mid height and at the mid span. The effective span of the cross tie may be taken as:</p> <ul style="list-style-type: none"> • When the cross tie is located in the centre tank and connected to vertical girders on the longitudinal bulkheads located in the same tank as the cross tie, the effective span of the cross tie may normally be taken as: Breadth of tank – Depth of one vertical girder. • When the cross tie is located in the wing tank and connected to <i>one</i> vertical girder on the longitudinal bulkhead, the effective span of the cross tie may normally be taken as : Breadth of tank – $\frac{1}{2}$ Depth of the vertical girder <ol style="list-style-type: none"> 2) Buckling of local plate panels on cross ties to be checked according to buckling of girder webs with one or two plate flanges as appropriate. 3) Buckling of free flanges on the cross tie to be calculated according to Sec.14
Buckling of girder webs in: <ul style="list-style-type: none"> • Double bottom • Double side • Deck • Longitudinal bulkhead • Transverse bulkhead 	<p><i>Buckling of girder webs with one plate flange:</i></p> <ol style="list-style-type: none"> 1) Buckling to be calculated as for girder plate flanges 2) Buckling to be analysed based on <i>mean shear stress</i> with allowable usage factor, $\eta=0.85$. 3) Bi-axial buckling especially in the bracket areas with shear. <p><i>Buckling of girder webs with two plate flanges:</i></p> <ol style="list-style-type: none"> 1) Buckling to be analysed based on <i>mean shear stress</i> with allowable usage factor, $\eta=0.85$. 2) Buckling caused by compressive loads from sea and cargo, alternatively together with shear, to be checked when relevant. <p>Comment: <i>Mean shear stress</i> to be taken as described in 2.8.1, representing one plate field between stiffeners.</p>

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2.8.3 Stress control and related acceptance criteria

Table 2.9 gives examples of areas where stress level shall be controlled together with the applicable method and accept criteria. In case of any differences in the acceptance criteria given here compared with those given in the Rules, the latter shall apply.

Table 2.9 Examples of areas to be checked and procedure to be used for control of stresses	
Item	Remarks
Stresses in longitudinal girders (when relevant)	<ol style="list-style-type: none"> 1) Allowable longitudinal nominal stress, $\sigma = 190f_1$. Based on a probability of exceedance of 10^{-4}. (longitudinal stress, $\sigma_{LR} = \sigma_{DBL} + \sigma_S + \sigma_{WR} < 190 f_1$, Ref 2.8.1) 2) Allowable mean shear stress $\tau = 90f_1$ (sea) and $\tau = 100f_1$ (harbour) for girders with one plate flange, and $\tau = 100f_1$ (sea) and $\tau = 110f_1$ (harbour) for girders with two plate flanges. Shear stress in way of openings not included in the calculation to be evaluated in terms of mean shear stress Ref. 2.8.1.
Stresses in transverse and vertical girders with two plate flanges like: <ul style="list-style-type: none"> • Double bottom • Double side • Other double skin constructions 	<ol style="list-style-type: none"> 1) Allowable nominal normal stress in flanges of girders $\sigma = 160f_1$ (sea) and $\sigma = 180f_1$ (harbour) in general. 2) Allowable mean shear stress of girder webs, $\tau = 100f_1$ (sea) and $110f_1$ (harbour). Shear stress in way of openings not included in the calculation to be evaluated in terms of mean shear stress Ref. 2.8.1. 3) Allowable equivalent stress, $\sigma_e = 180f_1$ for seagoing conditions and $\sigma_e = 200f_1$ for harbour conditions.
Stresses in transverse and vertical girders with one plate flange like: <ul style="list-style-type: none"> • Deck girders • Long. bhd. girders • Trv. bhd girders • Cross ties • Other single skin constructions 	<ol style="list-style-type: none"> 1) Allowable nominal normal stress, $\sigma = 160f_1$ (sea) and $\sigma = 180f_1$ (harbour) in general. 2) Allowable mean shear stress $\tau = 90f_1$ (sea) and $100f_1$ (harbour). Shear stress in way of openings not included in the calculation to be evaluated in terms of mean shear stress Ref. 2.8.1. 3) Allowable equivalent stress, $\sigma_e = 180f_1$ for seagoing conditions and $\sigma_e = 200f_1$ for harbour conditions
Stresses in brackets	<ol style="list-style-type: none"> 1) Under the assumption that the bracket is of favourable design the allowable axial stress in the middle of the bracket's free edge may be taken as $200f_1$. When there is uncertainty related to the local design of the bracket toe areas a fine mesh model is to be made.

3. Local Structure Analysis

3.1 General

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

- Nominal stresses in stiffeners.
- Stresses in brackets' free edge.

These models may be included in the 3D cargo tank analysis model as described in chapter 2, or run separately as submodels with prescribed boundary deformations from a 3D-analysis.

Local pressure loads must be applied to the local models.

3.2 Stiffeners with brackets subjected to large deformations

3.2.1 General

Relative deformations between stiffener supports may give rise to high stresses in local areas. Typical areas to be considered are:

- Longitudinals in double bottom and adjoining vertical bulkhead members. Ref. Figure 3.1.
- Deck longitudinals and adjoining vertical bulkhead members. Ref. Figure 3.1.
- Double side longitudinals and adjoining horizontal bulkhead members. Ref. Figure 3.2.

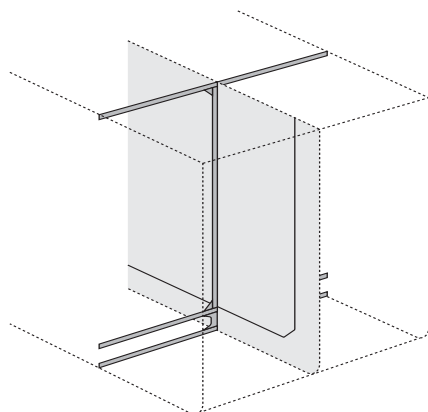


Figure 3.1 Applicable stiffeners for local structure analysis

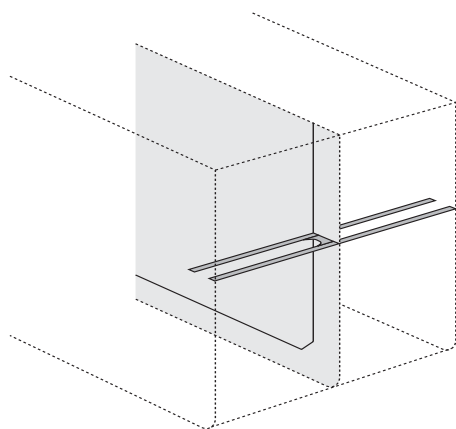


Figure 3.2 Applicable stiffeners for local structure analysis

Model extent

The model is recommended to have the following extent:

- The stiffener model shall extend to a stiffener support at least two frame spacings outside the area subject to the study. See Figure 3.3
- The width of the model shall be at least $\frac{1}{2} + \frac{1}{2}$ stiffener spacing, See Figure 3.5

Figure 3.3 shows a local structure analysis model of a bottom longitudinal, inner bottom longitudinal, transverse bulkhead vertical stiffener and deck longitudinal. Both sides of the transverse bulkhead are subjected to the stress analysis and the model extent is two frame spacings outside this area to either sides of the bulkhead.

3.2.2 Elements and element mesh

Normally three (3) 4-noded elements are to be used over the web height of the stiffeners. Corresponding sizes are to be used for the plate flange. The face plate shall normally be modelled with 2-noded beam elements. Effective flange in curved areas should however be represented properly. An example of a model as described is shown in Figure 3.3.

Generally, the element fineness along the stiffener shall be fine enough for providing a good aspect ratio of the elements.

The last element towards the point of interest shall not be larger than 2% of the stiffener's span length if the results are to be used directly. However, the elements may be up to 8% of the span length if extrapolation of the results towards the point of interest is carried out. A method for extrapolation is given in chapter 3.4.

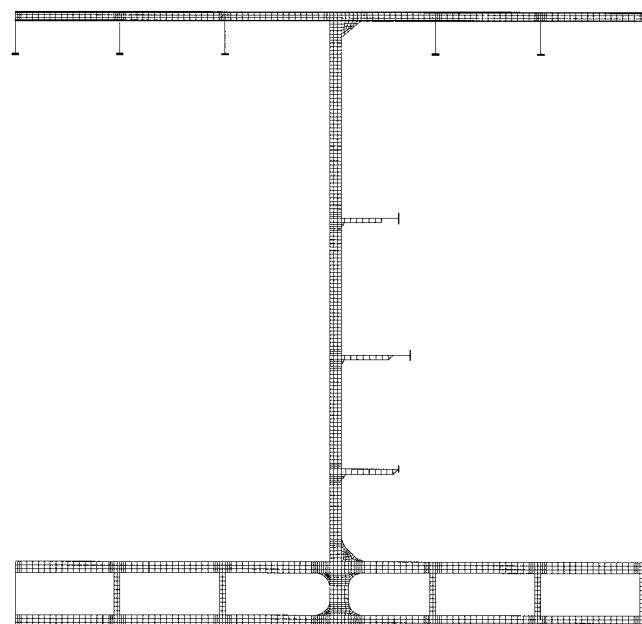


Figure 3.3 Local structure model of double bottom longitudinals, deck longitudinal and transverse bulkhead stiffener

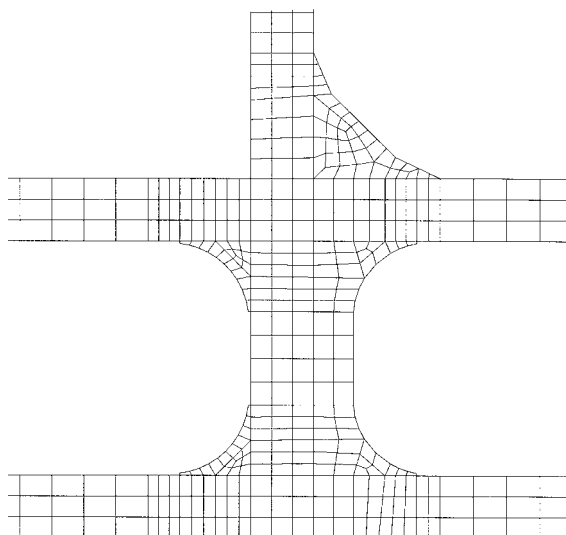


Figure 3.4 Typical mesh on double bottom longitudinals and transverse bulkhead stiffener, with associated brackets

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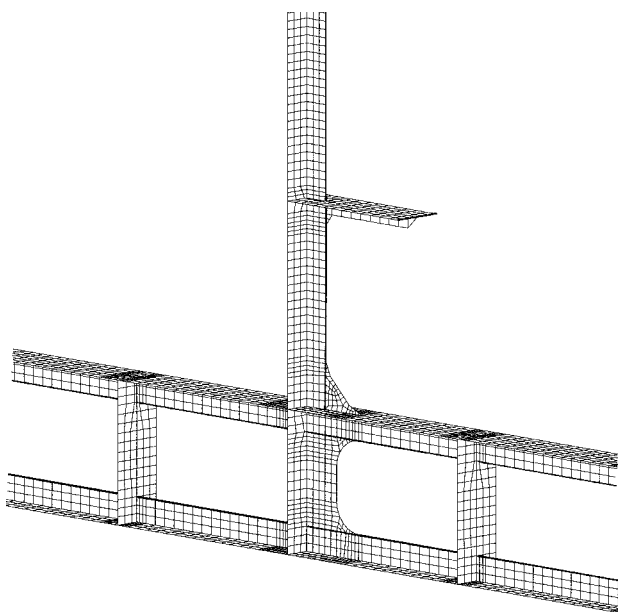


Figure 3.5 Detailed view of local structure model

3.2.3 Boundary conditions

If the model is run separately, prescribed displacements or forces are to be taken from the cargo tank analysis (or frame and girder analysis when relevant). These displacements or forces are to be applied to the boundaries of the local structure model in points where the results from the global model are representative. Table 3.1 shows a set of boundary conditions for a local structure model as shown in Figure 3.6. For other models the same principles apply.

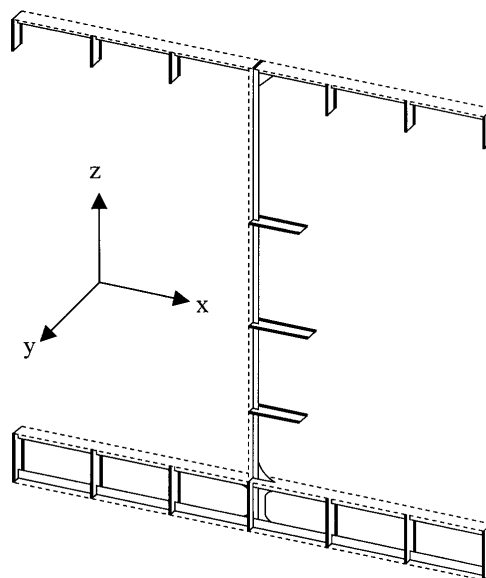


Figure 3.6 Lines where boundary conditions are applied as described in Table 3.1

3.3 Other fine mesh models.

Other fine mesh models may be made for the study of critical details. If the accept criteria are based on maximum allowable nominal stresses the modelling principles described above should be followed.

Table 3.1 Boundary conditions for model as shown in Figure 3.6

Location	Displacement			Rotation		
	δx	δy	δz	θx	θy	θz
Free edge of plate flanges forming the bottom, inner bottom, transverse bulkhead and deck (non-continuous lines in Figure 3.6)	-	-	-	X	-	X
Intersection line between deck and transverse bulkhead, and free edges of: transverse web frames stringers on bulkhead transverse bulkhead in double bottom (thick solid lines in Figure 3.6)	D	D	D	D	D	D
X	Restricted from displacement or rotation					
-	Free					
D	Displacements transferred from cargo tank model or frame and girder model					

3.4 Documentation and result presentation

When extrapolation of results is required, ref Ch. 3.2.2, this shall normally be based on the results in the two last elements towards the point of interest. The results in the Gauss point in the middle of the element representing the flange of the longitudinal shall be used for the extrapolation. The extrapolation method is indicated in Figure 3.7.

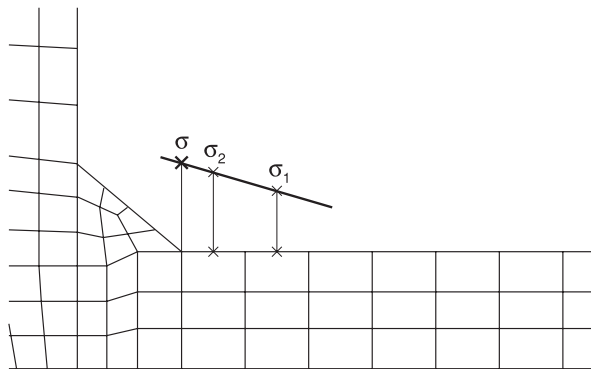


Figure 3.7 Extrapolation towards point of interest based on results in elements representing the flange

Documentation and result presentation is to follow the principles given in chapter 2.7.

The following stresses shall be given.

- Normal stresses and shear stresses of plate/membrane elements.
- Axial stress of truss/beam elements.

3.5 Acceptance criteria

Acceptance criteria for stress results from local structure analysis are given in the Rule Pt.3 Ch.1 Sec.13 Table B1.

4. Shear Force Correction

4.1 Introduction

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

However, actual shear force distributions from various loading conditions will be different from those calculated by "Shear Flow Calculation", where 3-D effect of the load distribution on bottom structure is not considered. Therefore, for the correct shear strength evaluation of each element, the corrected shear force has to be calculated taking into account the local load distribution.. The Rule Pt.3 Ch.1 Sec.5 D300

and D400 describe the principle of this shear force corrections for 3 different type of tankers.

In addition, the horizontal shear force from the transverse bulkhead girders (stringers) which should be combined with vertical shear force, should also be considered, Rules Pt.3 Ch.1 Sec.5 D500.

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

4.1.1 Definitions

Symbols:

I_N	=	moment of inertia in cm^4 about the transverse neutral axis
S_N	=	first moment of area in cm^3 of the longitudinal material above or below the horizontal neutral axis, taken about this axis.
I_N/S_N	=	value valid for the neutral axis, is calculated in the program "Section Scantlings", or may be taken as 90D
Q_s	=	conventional (not corrected distribution of local load in centre tank(s)) still water shear force in kN
ΔQ	=	shear force correction due distribution of local loads in centre tank(s)
Q_w	=	rule wave shear force in kN as given in Pt.3 Ch.1 Sec.5 B200
Φ	=	Shear force distribution factor for the effective longitudinal shear carrying elements in the hull girder, see Pt.3 Ch.1 Sec. 5 D103
t	=	thickness of effective longitudinal shear carrying element
τ	=	allowable shear stress, the lesser of $(110f_1$ or $0.9\tau_{cr}(\text{buckling stress})$)
P_c	=	Resulting force in kN due to difference between tank contents and boyancy along the centre tank length.

4.2 Rule requirement

The rule requirements to thickness of ship side or longitudinal bulkhead as given in Pt.3 Ch.1 Sec.5 D103 of the Rules may be formulated as follows:

$$Q_s \pm \frac{0.5}{\Phi} \Delta Q_s = \frac{t\tau}{\Phi 100 S_N} I_N - Q_w$$

The left hand side of the equation should be considered as "Corrected Shear Force" which could further be simplified as $Q_s \pm K P_c$. The calculation method for K and P_c is described in chapter 4.4.

The right hand side of the of equation should be considered as allowable still water shear force. The calculation method for establishing allowable shear force curves is described in chapter 4.3.

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4.3 Allowable shear force

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

$$Q_{\text{allowable}} = \frac{t\tau}{\Phi 100 S_N} - Q_w$$

With reference to Figure 4.1, the thickness, t , in the above formula may be decided as:

$$t = \min(t_1, t_2, t_{3c}, t_{4c}, t_{5,eq}, t_{6,eq}, t_{7,eq})$$

where

t_1, t_2 are the thickness of the longitudinal bulkhead at position as indicated in Figure 4.1

t_{3c}, t_{4c} are the corrected thickness of t_3 and t_4 as indicated with positioned as indicated in Figure 4.1. Due to the reduction in shear stress value when moving above $D/2$, the plate thicknesses above $D/2$ may be corrected as shown below.

$$t_{ic} = \frac{t_i}{0.9 + \frac{0.1}{0.5D}(0.5D - y)}$$

where y is the vertical distance from $D/2$, see Figure 4.1.

$t_{5,eq}, t_{6,eq}, t_{7,eq}$ are the equivalent thicknesses in way of the stringer reinforced areas, the equivalent thickness can be calculated as follows.

$$t_{i,eq} = \frac{t_i - \frac{P_{str}}{240f_1 b_{str}}}{0.75}$$

where:

P_{str} is the sum of the shear forces from the stringers on both side of the bulkhead, based on the loading conditions with one side of TBHD abreast full and the other side abreast empty.

b_{str} largest depth of stringer in m at support, brackets included, see Figure 4.2.

The thickness of double ship side will normally not need to be corrected for the stringer effect.

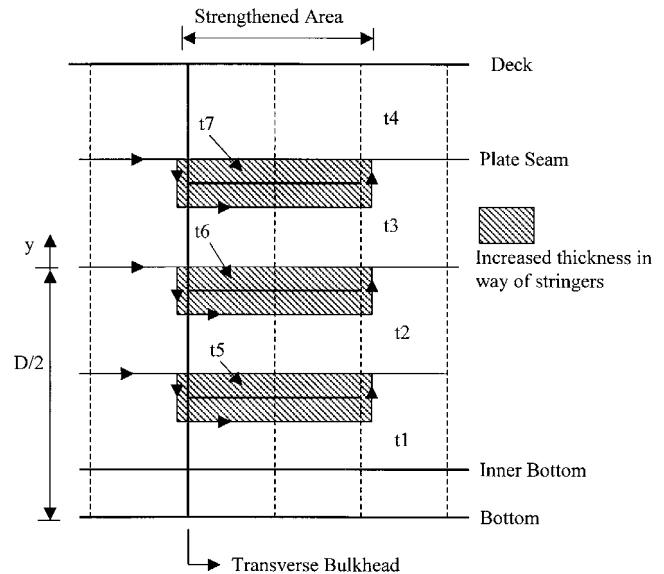


Figure 4.1 Longitudinal bulkhead at the intersection with transverse bulkhead

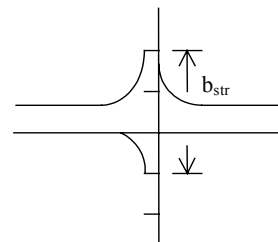


Figure 4.2 Single longitudinal bulkhead

4.4 Corrected shear force

With reference to the formula in chapter 4.2 the corrected shear force $Q_{S,C}$ can be expressed as follows

$$Q_{S,C} = Q_S \pm KP_C$$

where

Q_S is the uncorrected shear force or the shear force normally found in the loading manual. The sign convention for Q_S and $Q_{S,C}$ is as described in our rules Pt.3 Ch.1 Sec.5 B100 (surplus in weight → positive), “+” applies to the corrected shear force at fore end of the tank and “-” applies to the corrected shear force at aft end of the tank,

K is the shear force correction factor. K are further described in chapter 4.4.1 to 4.4.3 for tanker types A, B and C.

P_C is the resulting force.
 P_C may be calculated as follows:

$$P_C = W_{CT} + W_{CWBT} - 1.025(bL_t T_{mean})$$

where:

- W_{CT} = cargo weight in centre tank(s)
 W_{CWBt} = weight of ballast water between longitudinal bulkheads (shaded area in Figure 4.3)
 L_t = length of centre cargo tank(s)
 T_{mean} = mean draught at the middle of tank
 b = breadth of centre tank for tankers of type A
 = breadth between inner sides, across both port and starboard tanks for tankers of type B
 = breadth between inner sides for tankers of type C

The calculated KP_C -value should be considered in connection with the peak values of the conventional shear force curve at the transverse bulkheads.

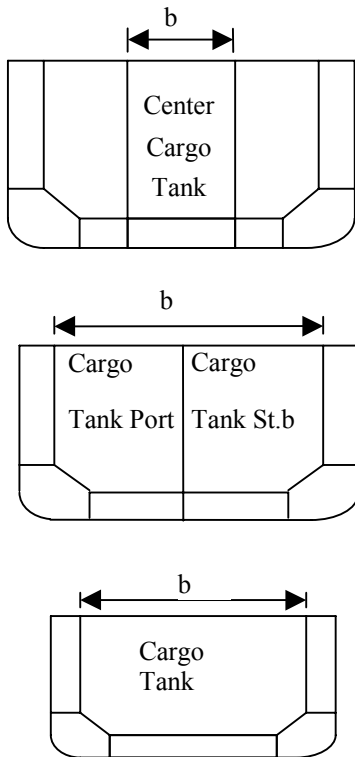


Figure 4.3 Breadth to be included for different tanker types

4.4.1 Correction factor K for tankers of type A

Generally, the load in wing tanks will be distributed by longitudinal bulkhead and double sides in proportion to the Φ factor, while loads in centre tanks would not be distributed in the same manner. In case there is an unbalanced force in way of the centre tank(s) and also an unbalanced force for the whole cross section and these forces have the same sign (i.e. weight excess or buoyancy excess), the longitudinal bulkhead will carry more force than that calculated by the Φ factor. Accordingly the double side will carry less force.

On the other hand, if the unbalanced forces in way of the centre tank and the whole cross section have different signs, the longitudinal bulkhead will carry less force than that calculated by the Φ factor, meaning that double side should carry more force.

This means that shear force should be re-distributed, considering load unbalance in way of centre tank(s). This is elaborated in Table D2 in the Rules Pt.3 Ch.1 Sec.5.

The correction factor, K, may be calculated as shown below:

$$K_s = \left[0.5 \left(1 - \frac{s}{l_c} \right) (1 - C_T) \left(\frac{r}{r+1} \right) - \Phi_s \right] \frac{0.5}{\Phi_s}$$

or

$$K_L = \left[0.5 \left(1 - \frac{s}{l_c} \right) (1 - C_T) \left(\frac{1}{r+1} \right) - \Phi_L \right] \frac{0.5}{\Phi_L}$$

where

K_s = correction factor for ship side

K_L = correction factor for longitudinal bulkhead

$(1 - C_T)$ = fraction of P_c to be transferred to LBHD and double side without going through the transverse bulkhead. (C_T is P_c going through longitudinal girders and into transverse bulkhead).

$(1 - s/l_c)$ = fraction of P_c going through the main girder system. s/l_c is the fraction of P_c that is "transferred" directly to the transverse bulkhead. (I.e. carried by bottom and inner bottom stiffeners and not going through the main girder system.)

$r / (r + 1)$ = fraction of P_c to be transferred to double side. (r is the fraction of the load transferred from LBHD to double side and depends on the stiffness of wing tank structures.)

$1 / (r + 1)$ = fraction of P_c to remain in LBHD

The first term within the main brackets above represent the corrected fraction of P_c , based on load distribution by local girders, carried by ship side/longitudinal bulkhead, while the last term within the main brackets represent the fraction of P_c carried by ship side/longitudinal bulkhead based of shear flow distribution. Thus the terms within the main brackets represent the correction to be made to the shear force based shear flow, Φ .

For other definitions reference is made to the rules Pt.3 Ch.1 Sec.5 D302

$$\Delta Q_s = 0.5 P_c \left(1 - \frac{s}{l_c} \right) \left[1 - C_T \right] \frac{r}{r+1} - P_c \Phi_s$$

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$$= P_c \left[0.5 \left(1 - \frac{s}{l_c} \right) [1 - C_T] \frac{r}{r+1} - \Phi_S \right]$$

or

$$\Delta Q_L = 0.5 P_c \left(1 - \frac{s}{l_c} \right) [1 - C_T] \frac{1}{r+1} - P_c \Phi_L$$

$$= P_c \left[0.5 \left(1 - \frac{s}{l_c} \right) [1 - C_T] \frac{1}{r+1} - \Phi_L \right]$$

4.4.2 Correction factor K for tankers of type B

The correction factor, K, may be calculated as follows

$$K_S = \left[0.3 \left(1 - \frac{s}{l_c} \right) [1 - C_T] - \Phi_S \right] \frac{0.5}{\Phi_S}$$

or

$$K_L = \left[0.4 \left(1 - \frac{s}{l_c} \right) [1 - C_T] - \Phi_C \right] \frac{0.5}{\Phi_C}$$

where:

K_S = Correction factor for ship side

K_L = Correction factor for longitudinal bulkhead

$(1 - C_T)$ = fraction of P_c to be transferred to LBHD and double side without going through the transverse bulkhead. (C_T fraction of P_c going through longitudinal girders and into transverse bulkhead).

$(1 - s/l_c)$ = Fraction of P_c going through the main girder system.

For other definitions reference is made to the rules Pt.3 Ch.1 Sec.5 D302

The following aspect should be considered when calculating ΔQ_s

The total amount of load to be transferred to centreline bulkhead *and* double side is $P_c(1 - s/l_c)(1 - C_T)$. The Rules assume that 40 % of this force should be supported by CL BHD, and 30 % by each double side.

$$\Delta Q_{SL} = P_c \left[0.3 \left(1 - \frac{s}{l_c} \right) [1 - C_T] - \Phi_S \right]$$

or

$$\Delta Q_{SL} = P_c \left[0.4 \left(1 - \frac{s}{l_c} \right) [1 - C_T] - \Phi_C \right]$$

4.4.3 Correction factor K for tankers of type C

For this type of vessel without LBHD, but with several longitudinal girders, some of the load should go directly to TBHD through longitudinal girders. In this case corrected shear force will always result in reduction of shear force inclination from the peak value, compared with conventional (uncorrected) shear force.

The fraction of force should preferably be found from direct calculation. If not the following simplified formula for the correction factor, k, may be used:

$$K = 0.5 \frac{b}{b + l_c}$$

where

b = breadth in m of the inner bottom between the inner sides

l_c = distance in m between oil tight transverse bulkheads in the centre tank

Appendix A. Boundary Conditions for the Application of Hull Girder Loads.

When hull girder loads are applied to the model the following loads and boundary conditions may be used. The described boundary conditions and load application are summarised in Table A.1 and Table A.2.

Bending moment

Boundary conditions

One end should be restricted as shown in Table A.1. The other end should be kept plane and the displacements of the plane should be as a rigid body. The latter is necessary to apply the hull girder bending moment. In order to keep the nodes in one plane they are to be linearly dependent of each other as a rigid body.

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

Application of hull girder loads

In general a bending moment shall be applied to the end of the model. The bending moment at the end may be applied as a force pair acting in the opposite direction applied at two points. The points should be positioned vertically above each other with one point in the deck and one point in bottom. The size of the bending moment shall be such that the vertical

hull girder bending moment, as described in the rules, is achieved in the middle of the model. Some modifications to the size of this bending moment are however necessary. The background for this is that the allowable hull girder bending moment ($M_S + M_W$) is based on gross scantlings. The FEM model is based on net scantlings (gross scantling reduced by t_k). It is therefore necessary to reduce the Hull girder bending moment by a factor of Z_{mod} / Z_{gross} . Where Z_{mod} is the hull girder section modulus as modelled (i.e gross scantling reduced by the corrosion addition, t_k) and Z_{gross} , the hull girder section modulus based on actual scantlings. In addition to this bending moment the local loads will also set up a “semi-global hull girder bending moment” that may be compensated for when applying the bending moment. (It is advised that the loads are adjusted to match the acceptance criteria and not the opposite.)

The magnitude of the force pair will be as follows:

$$F = \frac{M}{h}$$

Where

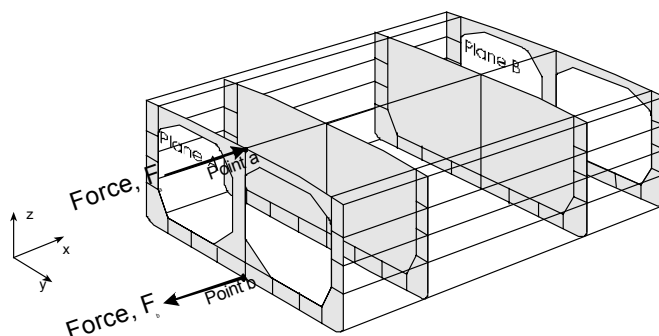
F = Magnitude of force at points in deck and bottom

M = Modified bending moment as described above

h = Height from base line to point in deck

Table A.1 Boundary conditions for cargo tank analysis of tankers when hull girder bending moments are applied

Location	Displacement			Rotation		
	δx	δy	δz	θx	θy	θz
Plane A	L	L	L	L	L	L
Plane B	X	X	X	X	X	X
Centreline (when applicable)		X		X		X
Point a,b	$F_{a,b}$					
X	Fixed.					
L	Rigid body linearly dependent.					
$F_{a,b}$	Force according to the above. Forces acting in opposite direction at point a and b.					



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Shear force**Boundary conditions**

The boundary conditions are given in Table A.2.
Symmetrical boundary conditions are to be applied at ends.

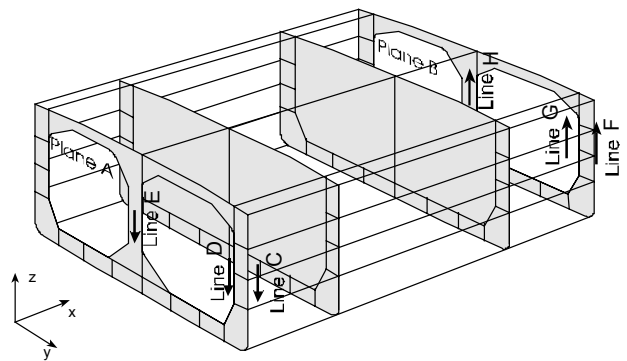
Symmetry conditions along the centreline of the model are to be applied for models covering a half breadth of the ship. For models covering the full breadth of the ship the model must be fixed in the transverse direction at the intersections between the transverse bulkhead and the longitudinal bulkhead/gider at inner bottom.

Application of shear forces

The shear forces are to be applied at the longitudinal bulkheads, vertical parts of the inner side and the outer shell at the ends of the model (Line C,D,E and F,G,H). The shear forces are to be applied as vertical line loads. The forces are to be distributed according to a shear flow calculation with the forces acting in opposite directions at the two ends as shown in Table A.2. The magnitude of the shear force shall be such that the maximum allowable shear force is achieved within the model. Springs shall be applied at one end.

Table A.2 Boundary conditions for cargo tank analysis of tankers when shear forces are applied

Location	Displacement			Rotation		
	δx	δy	δz	θx	θy	θz
Plane A	X				X	X
Plane B	X				X	X
Centreline (when applicable)		X		X		X
Line C,D,E			S&F _v			
Line F,G,H			F _v			
X Fixed. S Springs F _v Vertical forces acting in opposite directions at the ends						



Appendix B. Checklist for Finite Element Analysis

The checklist is developed in order to ensure a satisfactory level of technical quality of work for analysis performed by the finite element method. The checklist may also function as guidance for the process of completing the finite element analysis.

It is recommended that the checklist is used for self-checking while carrying out the analysis, and in addition used during independent verification.

The control may be further adapted to the computer program used in the analysis. In general the following main items should be checked:

- Geometry and element mesh
- Stiffness properties
- Boundary conditions
- Loads and pressures
- Stresses and reaction forces

CHECKLIST FOR GEOMETRY, MESH AND ELEMENT PROPERTIES		
STRUCTURAL PART:		
Reference drawings:		
Directory:		
Input and model file names:		
FEM file name:		
Units (have been checked):		Controlled by / date:
Length: [mm]	Mass: [t]	
Time: [s]	Force: [N]	
Pressure: [N/mm ²]		
Constants (have been checked):		
Gravity:	0.0981 [mm/s ²]	
Density (steel):	7.85E10 ⁻⁹ [t/mm ³]	
Young's mod.:	2.1E10 ⁵ [N/mm ²]	
Thermal exp. coeff.:	0.0	
Poisson's ratio:	0.3	
Scantlings:		
Net scantlings applied/ not applied		
Check of nodes:		
Spot checks of co-ordinates for key-nodes and nodes at border lines have been performed.		
Check of elements:		
Elements have been checked for having correct material.		
Elements have been checked for having correct thickness (membrane/shell) or cross section properties (truss/beam).		
Truss/beam elements have been checked for having correct eccentricity.		
Free flange sectional area has been checked for efficiency of curved flanges.		
Secondary elements (buckling stiffeners) been checked for having correct efficiency according to end connection (sniped/welded).		
Boundary conditions:		
The boundary conditions given (fixations) have been checked.		
Spring constants calculated according to prevailing Class Note <u>used</u> / <u>not used</u>		
Loads:		
Load directions are found to be correct		
Plots:		
Plots of element mesh with thickness (colour plots or by numerical value on elements) and boundary conditions are submitted with the checklists.		
There is conformance between drawings and plots.		

Structural part accepted: date: _____ sign. _____

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CHECKLIST FOR LOADS	
Structural part:	Controlled by / date:
Loads: Hand calculations or other program calculation for each basic load case are compared with the results from datacheck performed by the solver. Load directions are found to be correct The sum of loads from datacheck are checked Superelements <u>are/are not</u> mirrored or rotated. Loads are checked for mirrored and rotated superelements. Prints with datacheck of all loadcases is submitted with the checklists	

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

CHECKLIST FOR LOAD COMBINATIONS AND RESULTS PRESENTATION	
Structural part:	Controlled by / date:
Plots: Plots of structural part with <i>deformed shape</i> in proper scale are submitted with the checklists. Plots of <i>transverse membrane stresses</i> of shell elements for relevant structural parts are submitted with the checklists (contour plots and/or plots with numerical values). Plots of <i>shear stresses</i> for relevant structural parts are submitted with the checklists (contour plots and/or plots with numerical values). Plots of <i>in plane stresses</i> for relevant structural parts are submitted with the checklists (contour plots and/or plots with numerical values). Plots of <i>equivalent (von-Mises) stresses</i> for relevant structural parts are submitted with the checklists (contour plots and/or plots with numerical values). Plots of <i>axial stress</i> of free flange for relevant structural parts are submitted with the checklists (contour plots and/or plots with numerical values).	
Stresses / forces: Spot checks of the calculated stresses have been compared to values calculated by simplified methods. Plots have been used to identify peak stresses. Cross sectional forces and moments have been checked with simplified methods.	
Code checks / acceptance criteria: Yield check of main structure performed based on relevant load cases and stresses. Hull girder stresses <u>added/not added</u> manually. Yield check of secondary structure performed based on relevant load cases and stresses. Local bending has been taken into account. Buckling check of transverse elements performed based on relevant load cases and stresses. Buckling check of longitudinal elements performed based on relevant load cases and stresses. Hull girder stresses <u>added/not added</u> manually. Fatigue check performed based on relevant load cases, stresses and available stress concentration factors.	

Analysis accepted: date: _____ sign. _____

Appendix C. Beam Models

C.1 Beam modelling general

C.1.1 General

C.1.1.1

The structure of the cargo region of tankers may be analysed by means of 3-dimensional beam models within a given length of the cargo region. The 3-dimensional model may be replaced by smaller 2- or 3- dimensional beam models as described in the following.

C.1.1.2

The reduced beam models which may be applied are as follows:

- Transverse frame structure which is calculated by a framework structure subjected to in plane loading.
- Transverse bulkhead structure which is calculated by a framework structure.
- Bottom structure which is calculated by a grillage model with lateral loading. Note that this calculation may utilize stiffness data and loads calculated by the transverse frame calculation and the transverse bulkhead calculation under a) and b) above.

Alternatively, load and stiffness data may be based on approximate formulae.

C.1.1.3

The symbols used in the model figures are described in Figure C.1.

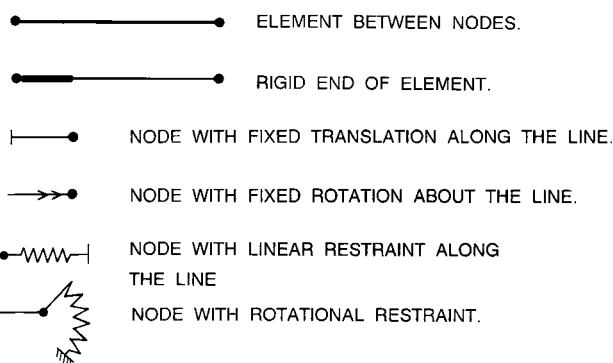


Figure C.1 Symbols

C.1.1.4

The reference location of element with well defined cross-section (e.g. cross-ties in side tanks of tankers) is taken as the neutral axis for the element.

The reference location of member where the shell or bulkhead comprises one flange is taken as the line of intersection between the web plate and the plate flange.

In the case of double bottom floors and girders, cofferdam stringers etc. where both flanges are formed by plating, the reference location of each member is normally at half distance between plate flanges.

The reference location of bulkheads will have to be considered in each case and should be chosen in such a way that the overall behaviour of the model is satisfactory.

C.1.1.5

Variable cross-section or curved beams will normally have to be represented by a string of straight uniform beam elements.

For variable cross-section the number of subdivisions depends on the rate of change of the cross-section and the expected influence on the overall behaviour of the model.

For curved beam the lengths of the straight elements must be chosen in such a way that the curvature of the actual beam is represented in a satisfactory manner.

C.1.1.6

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

C.1.1.7

The increased stiffness of elements with bracketed ends is to be properly taken into account by the modelling. The rigid length to be used in the model, l_r , may normally be taken as:

$$l_r = 0.5h_o + k h, \text{ (see Figure C.2)}$$

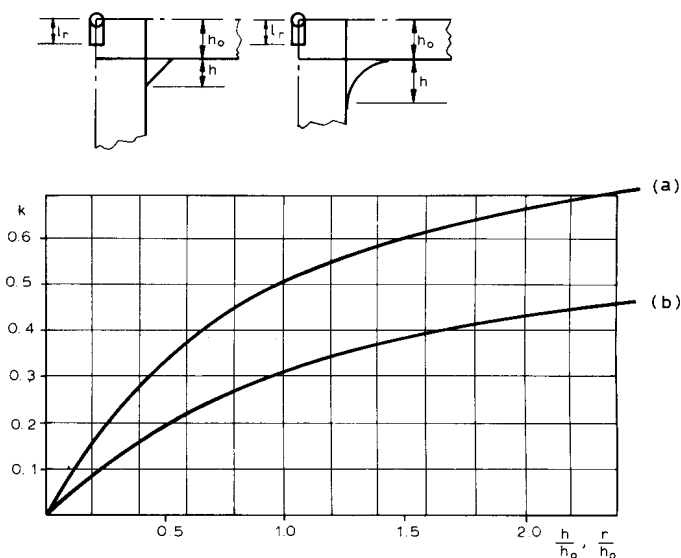


Figure C.2 Rigid ends of beam elements

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C.1.1.8

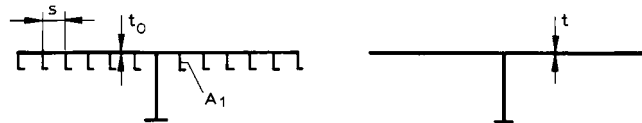
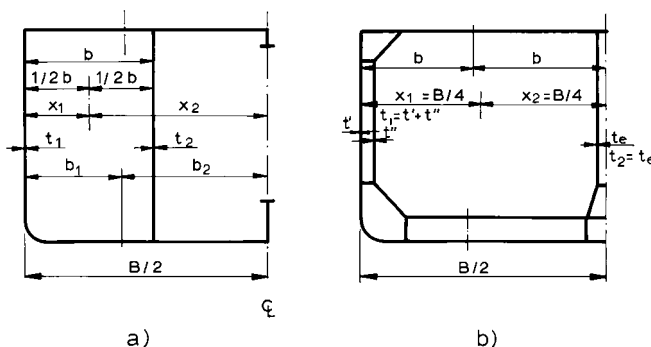
The effective area of plating forming one flange of a member varies in general along the member.

The variation depends primarily upon the characteristic length a of the member, the flange width b , and the type of loading. However, for practical purposes one specific flange area must be chosen. The average effective area, A_{ef} , as required in the model is given by:

$$A_{ef} = C b t$$

- C = as given in Table C.1 for I-profiles with various numbers of evenly spaced point loads (r) on the span.
- = 1 for double skin section (double bottom, double side etc.)
- b = equivalent flange width, normally taken to half the distance from nearest girder or bulkhead.
- t = equivalent flange thickness, $t_0 + 0.5 A_1/s$, see Figure C.3. For double skin sections with stiffeners parallel to the web, see also 1.1.11.

For transverse bulkheads the effective flange width may be taken as 20% of the breadth B .

**Figure C.3 Equivalent flange thickness****Figure C.4 Hull girder sections****Table C.1 Equivalent flange coefficient**

a/b	0	1	2	3	4	5	6	7
$C (r \geq 6)$	0.00	0.38	0.67	0.84	0.93	0.97	0.99	1.00
$C (r=5)$	0.00	0.33	0.58	0.73	0.84	0.89	0.92	0.93
$C (r=4)$	0.00	0.27	0.49	0.63	0.74	0.81	0.85	0.87
$C (r \leq 3)$	0.00	0.22	0.40	0.52	0.65	0.73	0.78	0.80

The characteristic length " a " is defined as the distance between the points of zero bending moments. This length varies with the loading conditions. However, for practical purposes one specific value of characteristic length may be chosen for each member as representative for all the different loading conditions.

- a = equal to the span for simply supported members
- = 60% of the span for members fixed at both ends.

Longitudinal bulkheads and shipsides should obviously be treated as a shell problem. However, for the analysis of internal structures, they may with reasonably good accuracy be considered as separate profiles.

With reference to Figure C.4 (a) and (b) the equivalent flange widths may be taken as:

$$b_i = \frac{B}{2} \cdot \frac{x_i t_i^2}{\sum x_i t_i^2} \quad i = 1, 2, \dots$$

C.1.1.9

The shear stiffness is in general to be reduced for girders having openings. For normal arrangement of access and lightening holes a factor of 0.8 may be suitable.

C.1.1.10

If the member is a corrugated bulkhead with forces in the direction of corrugations the effective shearing area is to be reduced with the factor.

$$k = \frac{b_s}{b_k}$$

b_s = breadth of corrugation.

b_k = breadth of corrugation measured along the corrugation profile.

See also 1.1.13 and Figure C.6.

C.1.1.11

If the flanges in double skin sections have local stiffening parallel to the girders, see Figure C.5, the bending stiffness contribution of stiffeners may be included by increasing the web thickness (t_w) and the thickness (t_1) of flange 1 as follows.

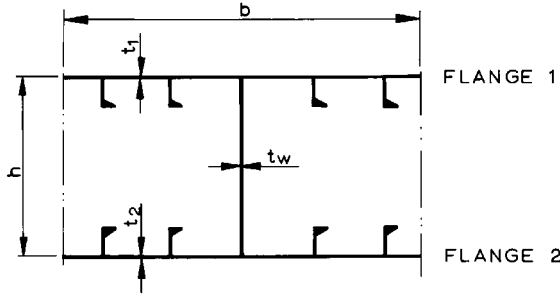


Figure C.5 Double skin sections

$$\Delta t_w = \frac{6 A_2 \left(1 - \frac{2 h_1}{h}\right)^2}{h}$$

$$\Delta t_1 = \frac{A_1 \left(1 - \frac{2 h_2}{h}\right)^2 - A_2 \left(1 - \frac{2 h_1}{h}\right)^2}{6}$$

where

A_1 = Sum of cross sectional area of stiffeners within breadth b of flange 1.

A_2 = Sum of cross sectional area of stiffeners within breadth b of flange 2.

h_1 = distance from flange 1 to neutral axis of stiffeners thereon.

h_2 = distance from flange 2 to neutral axis of stiffeners thereon.

Note that the formula for Δt_1 is based on the assumption that the cross sectional area of profiles on flange 1 is larger than for flange 2.

The correct shear area for the girder is obtained by multiplying the shear factor by

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

C.1.1.12

Elements representing members where the flanges are formed by double skin as double bottom, double side, double deck and cofferdam bulkheads etc. should have a torsional moment inertia equal to

$$I_t = \frac{b h^2}{\frac{1}{t_1} + \frac{1}{t_2}}$$

where

b = flange breadth.

h = web height.

t_1 , and t_2 = thickness of flange 1 and 2 respectively.

C.1.1.13

When considering the overall stiffness of vertically corrugated bulkheads with stool tanks (transverse or longitudinal) subjected to in plane loading the elements should represent the shear and bending stiffnesses of the bulkhead and the torsional stiffness of the stool.

For corrugated bulkheads, due to the large shear flexibility of the upper corrugated part compared to the lower stool part, the bulkhead should be considered as split into two parts, here denoted the bulkhead part and the stool part, see also Figure C.6.

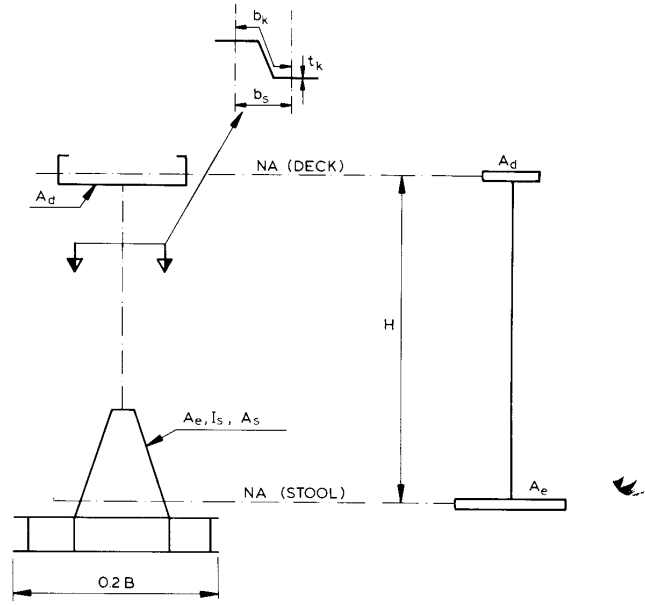


Figure C.6 Cross-sectional data for bulkhead

For the corrugated bulkhead part, the cross-sectional moment of inertia, I_b , and the effective shear area A_b may be calculated as follows:

$$I_b = H^2 \frac{A_d A_e}{A_d + A_e}$$

$$A_b = t_k H \frac{b_s}{b_k}$$

where

A_d = cross-sectional area of deck part.

A_e = cross-sectional area of stool and bottom part.

H = distance between neutral axis of deck part and stool and bottom part.

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t_k = thickness of bulkhead corrugation.

b_s = breadth of corrugation.

b_k = breadth of corrugation along the corrugation profile.

For the stool and bottom part, the cross-sectional properties, moment of inertia I_s and shear area A_s , should be calculated as normal. Based on the above a factor, K , may be determined by the formula:

$$K = 1 + \frac{I_s \left(1 + \frac{100 I_b}{A_b B^2} \right)}{I_b \left(1 + \frac{100 I_s}{A_s B^2} \right)}$$

Applying this factor, the cross-sectional properties of the transverse bulkhead members moment of inertia I and effective shear area A as a whole may be calculated to:

$$I = K I_b$$

$$A = K A_b$$

which should be applied in the double bottom calculation.

The torsional moment of inertia for the bulkhead members may be calculated according to the following formula, see also Figure C.9.

$$I_t = \frac{\left(\sum_{i=1}^{i=n} r_i s_i \right)^2}{\left(\sum_{i=1}^{i=n} \frac{s_i}{t_i} \right)}$$

C.1.1.14

In order to simulate the elastic supports a system of springs may be introduced in order to obtain correct deflections of the model at intersection points of crossing members. See C.1.2.

C.1.2 Springs

C.1.2.1

Linear springs: $k = P/\delta$

In the examples shown in Table C.2, the calculation of the springs in different cases of support and loads is shown.

C.1.2.2

Rotational springs $k_r = M/\theta$

a) Springs representing the stiffness of adjoining girders.

With reference to Figure C.7 and Figure C.8 the rotational spring may be calculated using the following formula:

$$k_r = \frac{E}{\frac{l \psi}{s I} + \frac{2.6 \beta}{l A_s} + \frac{E}{k l^2}}$$

s = 3 for pinned end connection.

= 4 for fixed end connection, see Figure C.7.

l' and l_l , see Figure C.8.

b) Springs representing the torsional stiffness of box structures.

Such springs may be calculated using the formula

$$k_r = \frac{8 c G I_t}{l}$$

c = $\frac{n+1}{n(n+2)}$ when n = even number.

= $\frac{1}{n+1}$ when n = odd number.

l = length between fixed box ends.

n = number of loads along the box.

I_t = torsional moment of inertia of the box which may be calculated according to the formulae

$$I_t = \frac{\left(\sum_{i=1}^{i=n} r_i s_i \right)^2}{\left(\sum_{i=1}^{i=n} \frac{s_i}{t_i} \right)}$$

See also Figure C.9 and Figure C.10.

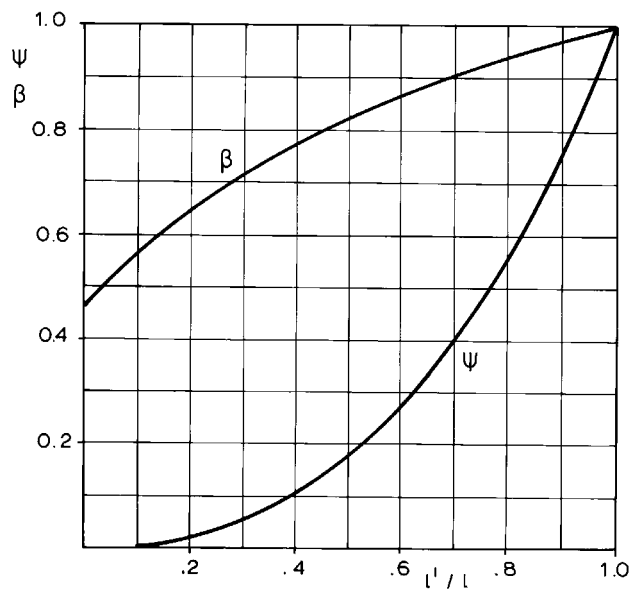


Figure C.7 Determination of spring stiffness

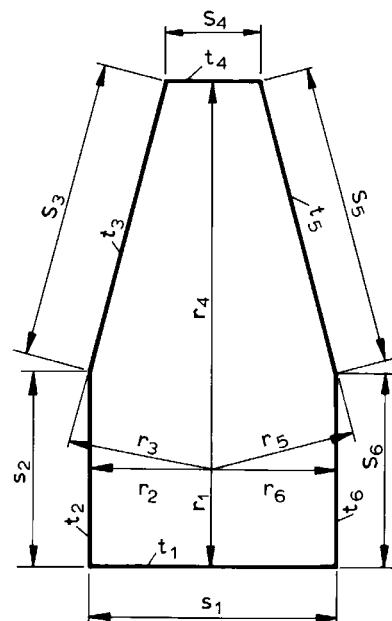


Figure C.9 Definition of thickness and lengths for stool tank structure

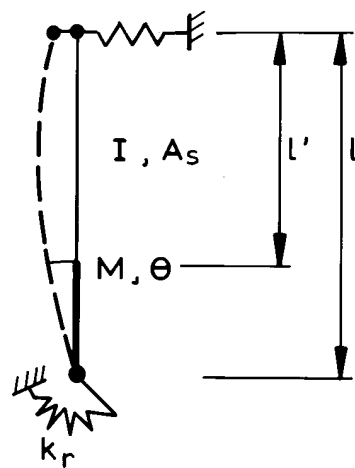
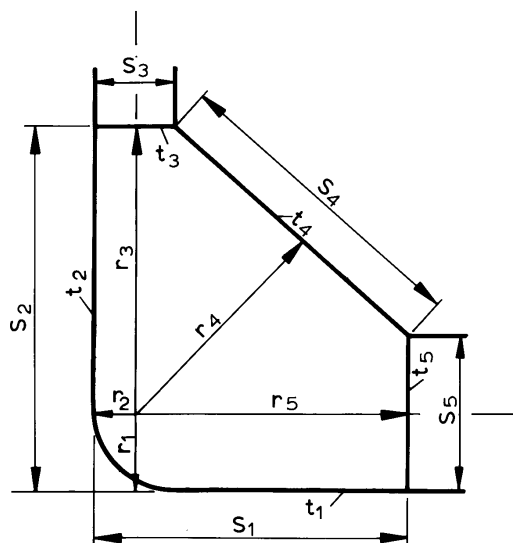
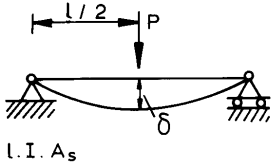
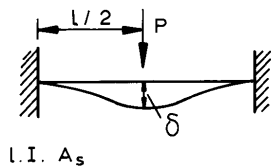
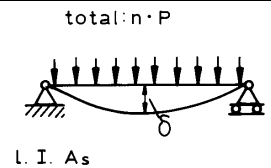
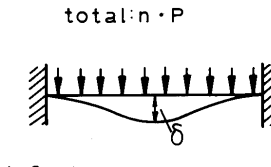
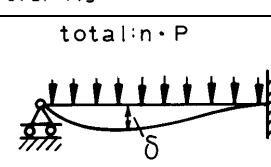
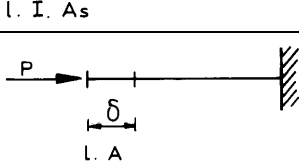
Figure C.8 Effective length, l' 

Figure C.10 Definition of thickness and lengths for hopper tank structure

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Table C.2 Spring stiffness for different boundary conditions and loads

Type	Deflection δ	Spring stiffness $k = P/\delta$
 l, I, A_s	$\delta = \frac{P l^3}{48 E I} + \frac{P l}{4 A_s G}$	$k = \frac{E}{\frac{l^3}{48 I} + \frac{2.6 l}{4 A_s}}$
 l, I, A_s	$\delta = \frac{P l^3}{192 E I} + \frac{P l}{4 A_s G}$	$k = \frac{E}{\frac{l^3}{192 I} + \frac{2.6 l}{4 A_s}}$
 l, I, A_s	$\delta = \frac{5 P n (n+2) l^3}{384 E I (n+1)} + \frac{P (n+1) l}{8 A_s G}$	$k = \frac{E}{\frac{5 n (n+2) l^3}{384 I (n+1)} + \frac{2.6 (n+1) l}{8 A_s}}$
 l, I, A_s	$\delta = \frac{P (n+1) l^3}{384 E I} + \frac{P (n+1) l}{8 A_s G}$	$k = \frac{E}{\frac{(n+1) l^3}{384 I} + \frac{2.6 (n+1) l}{8 A_s}}$
 l, I, A_s	$\delta = \frac{P (n+1) l^3}{185 E I} + \frac{P (n+1) l}{8 A_s G}$	$k = \frac{E}{\frac{(n+1) l^3}{185 I} + \frac{2.6 (n+1) l}{8 A_s}}$
 l, A	$\delta = \frac{P l}{A E}$	$k = \frac{E}{\left(\frac{l}{A}\right)}$

C.2 Beam modelling for tankers of type A

Introductions

Instead of making a full 3-dimensional frame work model, it is possible to make separate models of transverse web frame, transverse bulkhead girders and bottom grillage as described in section C.2.2, C.2.3 and C.2.4.

C.2.1 Load conditions

C.2.1.1

The load conditions to be considered are described in chapter 2.6.1.

C.2.2 Transverse web frame

C.2.2.1

The web frame analysis may be carried out independently of any other preceding structural analysis. In Figure C.11 is shown a typical model for a tanker of type A.

C.2.2.2

Elastic supports at the ship side k_s , longitudinal bulkhead k_c and possible longitudinal bottom girders k_g may be calculated as described in C.1.2.1. Elements in centre line (symetry line) must be included with half-properties.

C.2.2.3

The rotational spring k_{rs} , giving the torsional stiffness of the bilge tanks may be calculated as described in C.1.2.2b.

At the deck at side and at the top of the centre line bulkhead rotational springs to be calculated in a similar way if box shaped constructions are arranged.

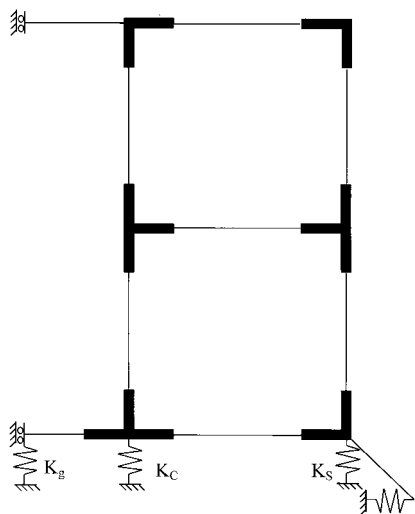


Figure C.11 Transverse frame

C.2.3 Transverse bulkhead girders

C.2.3.1

The girders on transverse oiltight bulkheads may be analysed using a 3-dimensional framework model. A typical model is shown in Figure C.12.

The only practically significant boundary conditions that remain unknown are the rotational response at the lower end of the vertical centre girder and possible side girders. Information regarding the rotation at these locations is to be found from the bottom grillage investigation.

With reference to Figure C.12 the following procedure is recommended:

- The relevant loading conditions are applied assuming fixed end at "x".
- Unit rotation at "x" should be applied as an additional loading condition. Thus the stiffness of the system as felt by the bottom grillage may be calculated and used in the bottom grillage analysis.
- The stresses in the system is obtained by using the actual rotation in "x" found from the bottom grillage calculation together with relevant loading conditions.

Note that half-values of cross-sectional properties must be applied for the vertical centre girder due to symmetry whereas full-values must be used for the longitudinal deck girder. This is because the longitudinal deck girder of the model represents the actual longitudinal deck girders in the tanks forward and aft of the transverse bulkhead. The length of the equivalent deck girder is half the tank length.

In the case of vertical side girders these may be arranged and connected in a similar way as the vertical centre girder. It is, however, recommended that a full 3-dimensional frame work analysis is carried out.

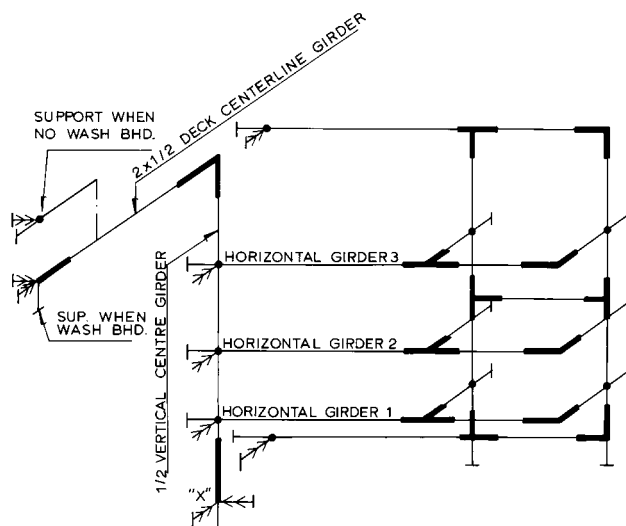


Figure C.12 Transverse bulkhead girders

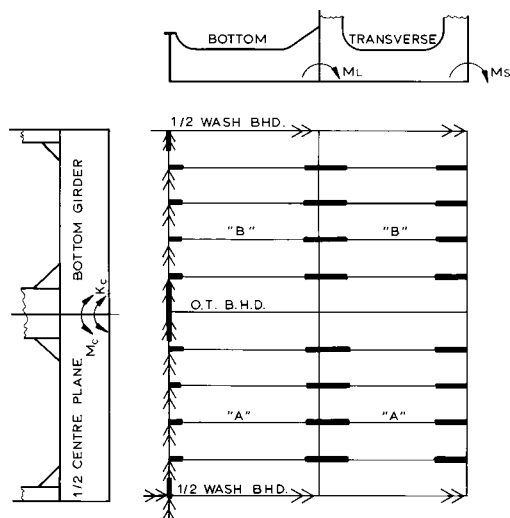
C.2.4 Bottom grillage

C.2.4.1

The bottom centre girder and possible side girders are analysed using a grillage model. A typical model is shown in Figure C.13. The centre tank "A" is of particular interest. As indicated in the figure this analysis depends on information regarding the reactions from the structures above at each transverse web frame and in the centre line at transverse oiltight bulkheads. This information is most conveniently obtained from analysis based on the models described in C.2.2 and C.2.3.

The bottom grillage model may also be used to double check the analysis of the bottom transverses based on the transverse web frame model. The stresses in the bottom transverse near the transverse oiltight bulkheads generally differ to some extent from the bottom transverse in the middle of the tank. This variation may be investigated using the bottom grillage model

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**Figure C.13 Bottom grillage****C.2.4.2**

When the structural arrangement is symmetrical in the longitudinal direction about the centre of the tank to be analysed, the model shown in Figure C.13 is assumed to be sufficiently large. The model is here carried half-way into the neighbouring tanks "B" where symmetry is assumed.

If the structural arrangement or loadings have asymmetries the model should be extended.

With reference to Figure C.13 the reactions from the vertical webs on the longitudinal bulkhead and the ship side may be represented by the bending moments M_l and M_s . Suffices l and s refer to longitudinal bulkhead and shipside, respectively. These moments may be obtained from the transverse web frame model subjected to the relevant loading conditions.

The reactions from the vertical girders on transverse oiltight bulkheads may be represented by the fixed end moment M_c and the spring constant k_c . M_c and k_c may be calculated using the transverse bulkhead girder model

C.3 Beam modelling for tankers type B**Introductions**

Instead of making a full 3-dimensional frame work model, it is possible to make separate models of transverse web frame, transverse bulkhead girders and bottom grillage as described in section C.3.2, C.3.3 and C.3.4.

C.3.1 Load conditions**C.3.1.1**

The load conditions to be considered are described in Ch. 2.6.2.

C.3.2 Transverse web frame**C.3.2.1**

The web frame analysis may be carried out independently of any other preceeding structural analysis. In Figure C.14 is shown a typical model for a ship type as indicated in Figure 1.1. The model includes the full breadth of the ship in order to include unsymmetrical filling of cargo tanks in transverse direction.

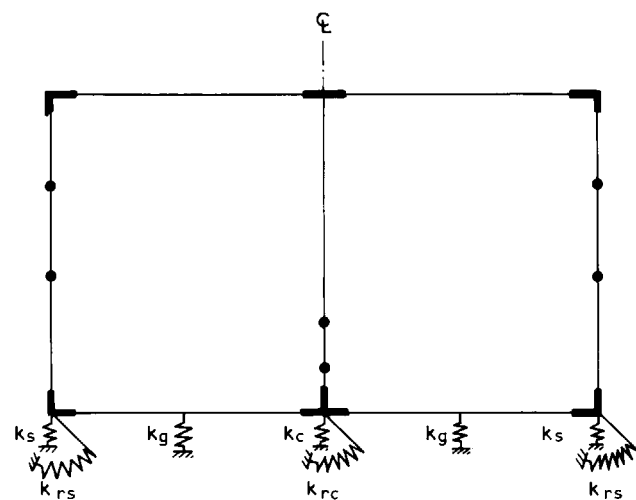
C.3.2.2

Elastic supports at the ship side k_s , longitudinal bulkhead k_c and possible longitudinal bottom girders k_g may be calculated as described in C.1.2.1.

C.3.2.3

The rotational spring k_{rc} and k_{rs} giving the torsional stiffness of the stool tanks at the lower end of the centreline bulkhead and of the bilge tanks may be calculated as described in C.1.2.2b.

At the deck at side and at the top of the centre line bulkhead rotational springs to be calculated in a similar way if box shaped constructions are arranged

**Figure C.14 Transverse frame****C.3.3 Transverse bulkhead****C.3.3.1**

For vertically corrugated bulkheads with stooltank(s) models as described in Classification Note No. 31.1 "Strength analysis of hull structures in bulkcarriers" may be used.

The following procedure is recommended:

- The relevant loading conditions are applied assuming fixed boundary conditions at lower end.
- Unit rotation at supporting node should be applied as an additional condition. Thus the stiffness of the bottom grillage may be calculated and used in the bottom grillage analysis.

- The stresses in the system is obtained by using the actual rotation at the lower end found from the bottom grillage calculation together with relevant loading conditions.

C.3.3.2

If the upper end of the bulkhead is supported by a grillage system in the deck it is recommended to extend the model to a 3-dimensional one where the deck girder system is included.

C.3.4 Double bottom structure

C.3.4.1

A typical double bottom structure and corresponding model is shown in Figure C.15.

The model is extended athwartships from one ship side to the other. In the longitudinal direction the model should extend at least from the middle length of one tank to the middle length of the adjacent tank. Symmetry is assumed at both ends of the model. If the girder structure on transverse bulkheads is not symmetrik the model should include $\frac{1}{2} + 1 + \frac{1}{2}$ tank length.

Floors in line with the stool sides for the transverse bulkhead stool and side girders in line with the stool sides for the centre line bulkhead and the side girders in line with the sloped bilge tank sides are omitted in the model. This may normally be done without significant reduction of the modelling accuracy

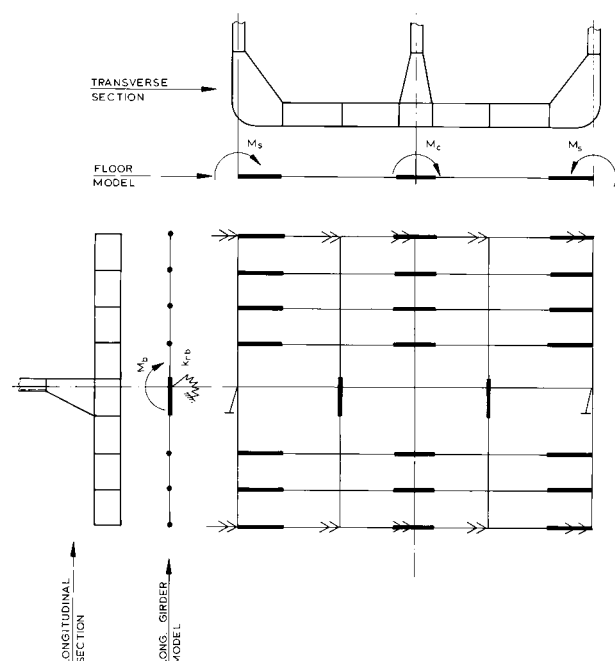


Figure C.15 Grillage model

C.3.4.2

At the nodes at ship sides and centreline moment-values M_s and M_c Figure C.15, taken from relevant loading conditions for the transverse frame calculation may be applied.

C.3.4.3

The constraining stiffness per longitudinal girder of the transverse bulkhead structure should be included in the double bottom grillage model as rotational springs, k_{rb} . These rotational springs may be determined from the transverse bulkhead calculation, see C.3.3.1.

C.3.4.4

The moment M_b to be applied per longitudinal girder at the transverse bulkhead nodes due to the lateral pressure from cargo on the transverse bulkhead may be determined from the transverse bulkhead calculation using fixed boundary conditions at lower end, see C.3.3.1

C.4 Beam modelling for tankers type C

Introductions

Instead of making a full 3-dimensional frame work model, it is possible to make separate models of transverse web frame, transverse bulkhead girders and bottom grillage as described in section C.4.2.

C.4.1 Load conditions

C.4.1.1

The load conditions to be considered are described in Ch. 2.6.3.

C.4.2 Girder system

C.4.2.1

For the strength analysis of the girder system the models as described in C.3.2, C.3.3 and C.3.4 for the transverse frame, transverse bulkhead and bottom grillage respectively may be applied deleting the centre line bulkhead.