Upper and Lower Connections of Side Frame of Single Side Bulk Carrier

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Yokohama Design Support Office
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Contents

1. Detail FE Structural Analysis

1.1 In order to confirm adequacy of the requirements of Ch. 6, Sec. 2, Para. 3.4 of the CSR for Bulk Carriers for upper and lower connections of side frame of single side bulk carrier, detail FE structural analysis has been carried out using three cargo hold model of a Panamax bulk carrier required in Ch. 7 "Direct Strength Analysis" of the Rules where No. 4 ballast hold is located at the mid hold of the model and relevant side frames, supporting brackets and longitudinal stiffeners are represented by suitable fine meshes. See Fig. 1 "Extent of Cargo Hold Model" and Fig. 2 "Net Scantlings". The net scantlings of the supporting brackets and longitudinal stiffeners comply with the requirements of Ch. 6, Sec. 2, Paras. 3.4.2 and 3.4.1 respectively.

1.2 Loading conditions and load cases have been applied to the model in compliance with the "Standard Loading Condition for Direct Strength Analysis" in Ch. 4, Appendix 2 of the Rules.

1.3 The calculation results are indicated in Figs. 3 to 5, i.e., Figs. 3 (a) to 3 (d) for maximum shear stress in the supporting bracket at each longitudinal stiffener, Figs. 4 (a) to 4 (d) for maximum longitudinal stress in each longitudinal stiffener and Figs. 5 (a) and 5 (b) for maximum bending stress in the side frame together with the corresponding loading condition/load case.

1.3.1 Maximum shear stresses in the supporting brackets have been calculated as follows;

- 45.69 N/mm^2 at the longl stiffener on the topside sloping Bhd
- 45.24 N/mm^2 at the side shell longl in the topside tank
- 48.61 N/mm^2 at the longl stiffener on the hopper side sloping Bhd
- 58.40 N/mm^2 at the side shell longl in the hopper side tank

The shear stress values above are considerably small being compared with those anticipated in the requirement of Ch. 6, Sec. 2, Para. 3.4.2 of the Rules. There may be a possibility of the bracket net thickness required by the Rules to be reduced. The theoretical background to the requirement should be reviewed taking this fact into account.

1.3.2 Maximum or minimum longl stresses in the longitudinal stiffeners have been calculated as follows;

- -245.7 N/mm^2 in the longl stiffener on the topside sloping Bhd
- 267.7 N/mm^2 in the side shell longl in the topside tank
- 152.9 N/mm^2 in the longl stiffener on the hopper sloping Bhd
- 142.6 N/mm^2 in the side shell longl in the hopper side tank

It should be noted that those values result in combination of the hull girder bending stress and the local bending stress by the shear loads at the supporting brackets. It is noted that the order of the stress values of the longl stiffeners in the hopper side tank are about half of that of the longl stiffeners in the topside tank.

1.3.3 The bending stress distribution along the span of the side frame is observed in Figs. 5 (a) and (b). The boundary conditions at both ends of the frame are considered almost as fully fixed.

2. Technical Background to Requirements of Ch. 6, Sec. 2, Para. 3.4 of the Rules

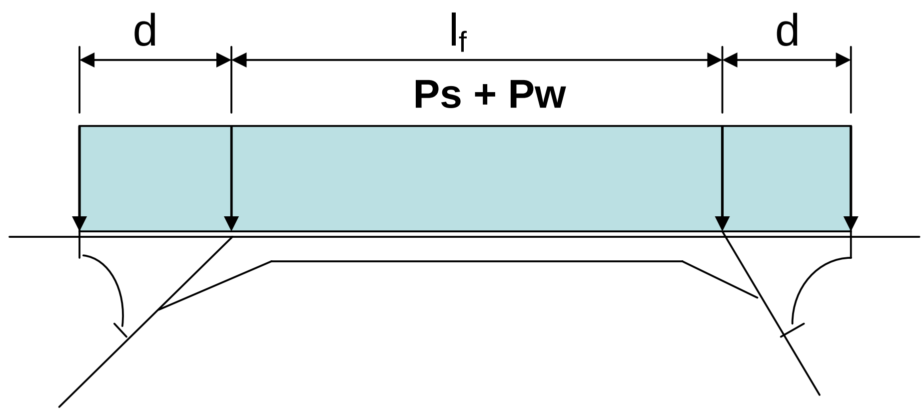
2.1 The technical background (TB) to the requirements of Ch. 6, Sec. 2, Para. 3.4 of the CSR for bulk carriers is available in IACS KC 319. The TB has duly been reviewed in conjunction with the results of the FE structural analysis as stated above and is attached to this document for easy reference.

2.2 Eq.(1) in the TB gives us a turning moment at each end of the side frame which is induced by the pressure working over the span of the frame. The coefficient of α_T in Eq. (1) depends upon the boundary condition of the frame at the end. For fully fixed end, α_T will be 83.3, i.e., 1000/12. This value is compared with 75 at the upper end of the frame and 150 at the lower end of the frame. Ch. 6, Sec. 2, Para. 3.4.1 is referred to for these Rule values. Taking into account the FE analysis result as stated in Para. 1.3.3 above, the value of 150 at the lower end is considered too much severe.

In addition, it is noted that Eq. (1) ignores a counter moment due to the pressure working on the supporting bracket. To take the counter moment into account, Eq. (1) should be multiplied by the following coefficient;

$$\gamma_M = 1 - (500/\alpha_T)\,(d/l_f)^2$$

where l_f is the span of the side frame and d is the lever of the supporting bracket at the side shell.



2.3 From Eq. (3) in the TB, it is noted that the criterion for each longl stiffener is the plastic moment induced by the shear loads at the supporting bracket. Eq. (4) therefore gives us w_i as a required plastic section modulus. However, in Ch. 6, Sec. 2, Para. 3.4.1 of the Rules, w_i is treated as a normal elastic section modulus without any consideration. In general, the plastic section modulus is larger than the elastic section modulus and may be 1.4 times the elastic section modulus. This fact should be suitably reflected in Ch. 6, Sec. 2, Para. 3.4.1 of the Rules.

2.4 Eq. (8) gives us a required shear area of the supporting bracket and the figure of 0.32 in Eq. (8) is rounded up to 0.4 in Ch. 6, Sec. 2, Para. 3.4.2 of the Rules. This “rounded up” figure affects the bracket thickness to a great extent, then, the original figure should be kept in the Rules.

3. Rule Change Proposal

3.1 Taking into account the consideration above, the following Rule change proposal is made for Ch. 6, Sec. 2, Para. 3.4 of the Rules;

3.1.1 For the formula giving us the required section modulus of the longl stiffener,

$$\sum w_{pi} d_i \geq \gamma_M \, \alpha_T \, (p_s + p_w) \, l_f^2 \, l_1^2 / (16 \, Ry)$$

where $w_{pi} = 1.4 \, w_i$

$\gamma_M = 1 - (500/\alpha_T)\,(d/l_f)^2 \approx 0.80$

$\alpha_T = 85$ at the lower end of the side frame

$= 75$ at the upper end of the side frame

3.1.2 For the formula giving us the required shear area of the supporting bracket,

$$A_i = 0.32 \, w_i \, s \, k_{bkt} / (l_1^2 \, k_{lgi})$$

3.1.3 For the minimum net thickness of the supporting bracket, given from the formula in Ch.6, Sec.4, Para. 1.5.

Net thickness is to be not less than $0.6\sqrt{L_2}$

where L_2 = Rule length L, but to be taken not greater than 300m

4. Verification of Rule Change Proposal

4.1 To verify the Rule change proposal, another FE structural analysis has been carried out using the model in which the proposed scantlings have been integrated as shown in Fig. 6.

4.2 The calculation results are shown in Figs. 7 to 9.

4.2.1 Maximum shear stresses in the supporting brackets have been calculated as follows;

- 60.66 N/mm^2 at the longl stiffener on the topside sloping Bhd
- 51.58 N/mm^2 at the side shell longl in the topside tank
- 52.38 N/mm^2 at the longl stiffener on the hopper side sloping Bhd
- 67.85 N/mm^2 at the side shell longl in the hopper side tank

4.2.2 Maximum or minimum longl stresses in the longitudinal stiffeners have been calculated as follows;

- -291.9 N/mm^2 in the longl stiffener on the topside sloping Bhd
- 296.2 N/mm^2 in the side shell longl in the topside tank
- 170.8 N/mm^2 in the longl stiffener on the hopper sloping Bhd
- 135.3 N/mm^2 in the side shell longl in the hopper side tank

4.3 The shear stresses in the supporting brackets and the longitudinal stresses in the stiffeners are still within the allowable limits even for the scantlings reduced in compliance with the Rule change proposal.

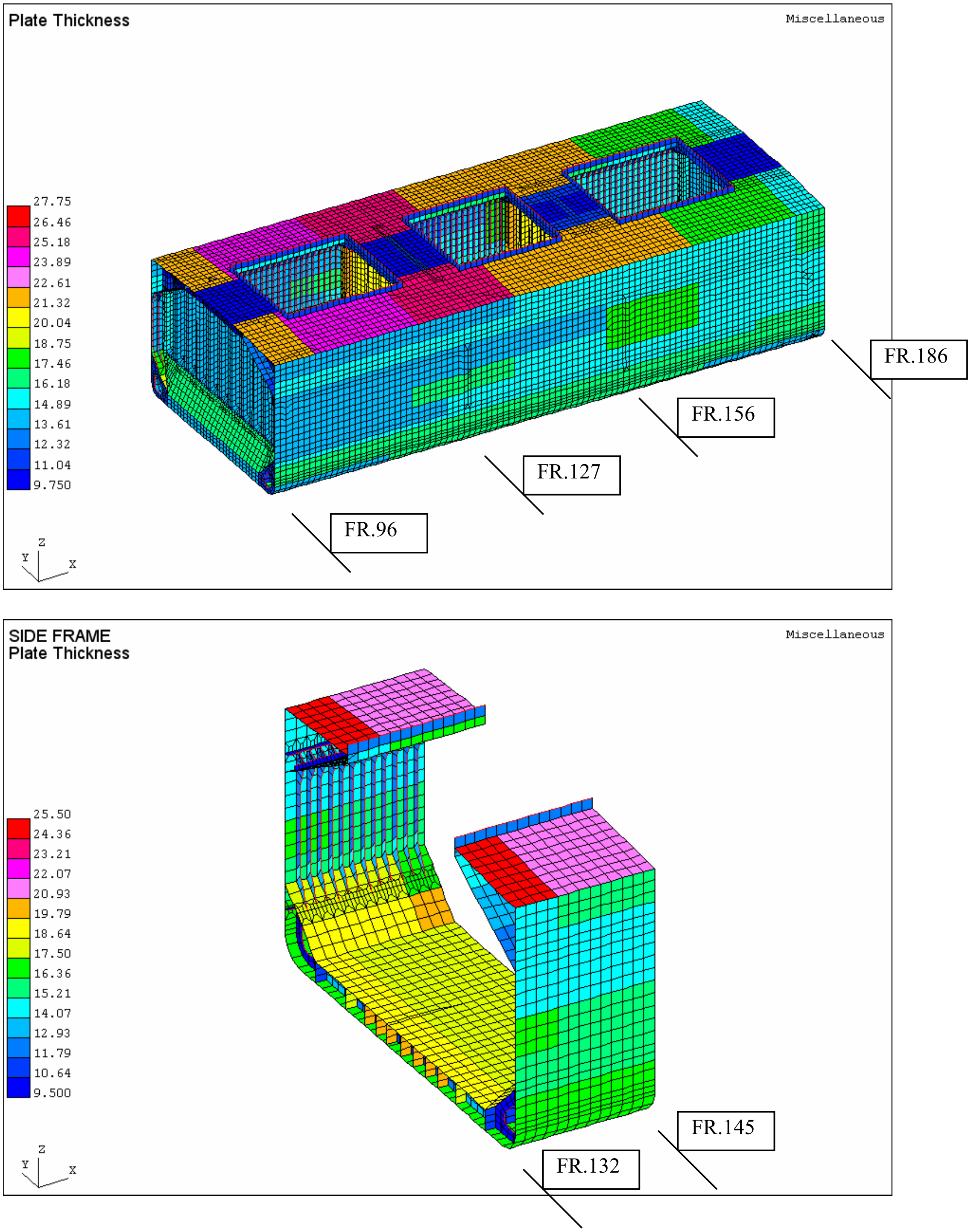
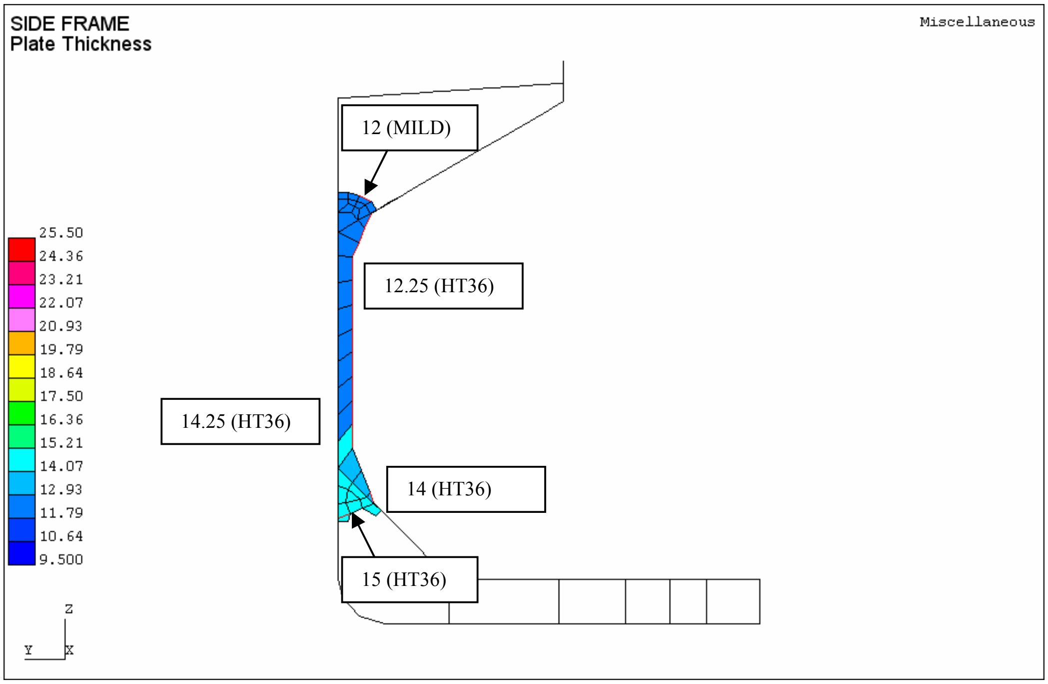


Fig.1 Extent of Cargo Hold Model



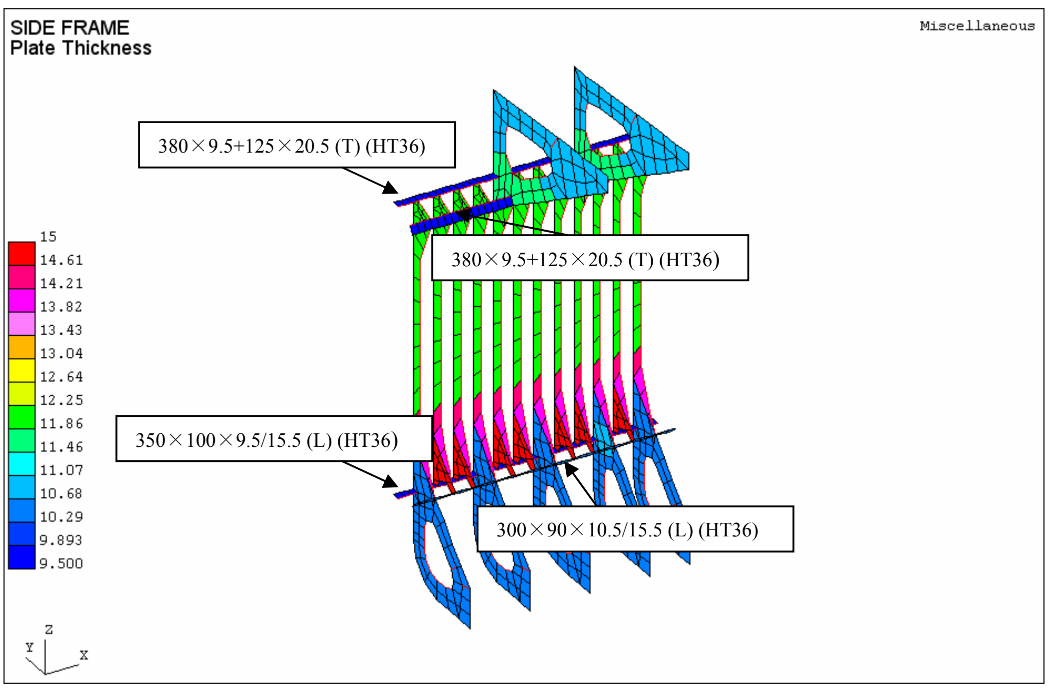
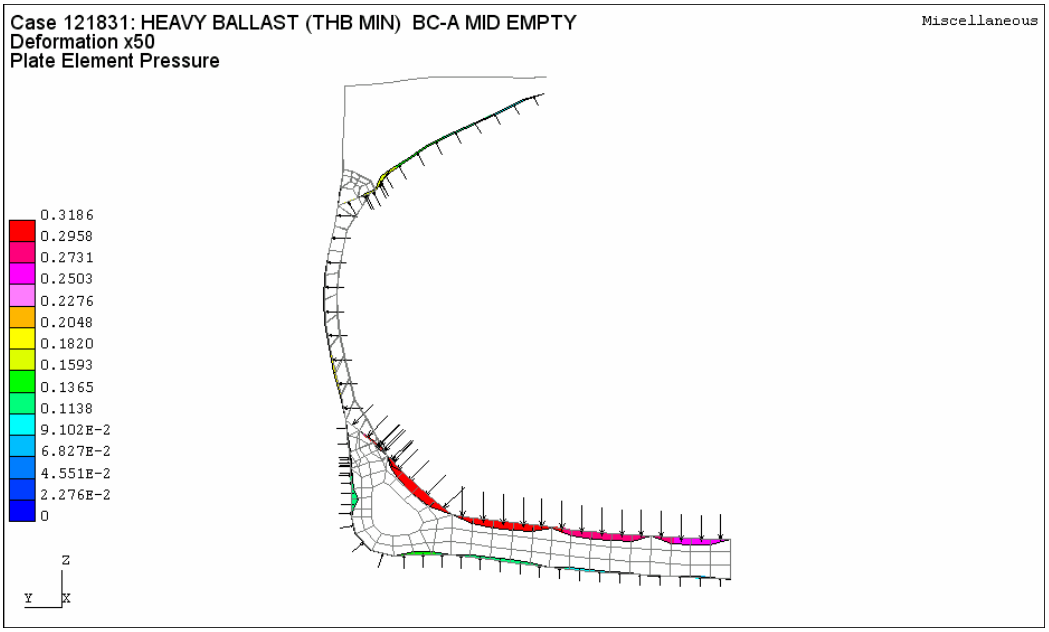


Fig.2 Net Scantlings

14	Heavy Ballast	$T_{HB}(min)$		R1	R1			11), 12), 13)
				0	$M_{SW,S}$			



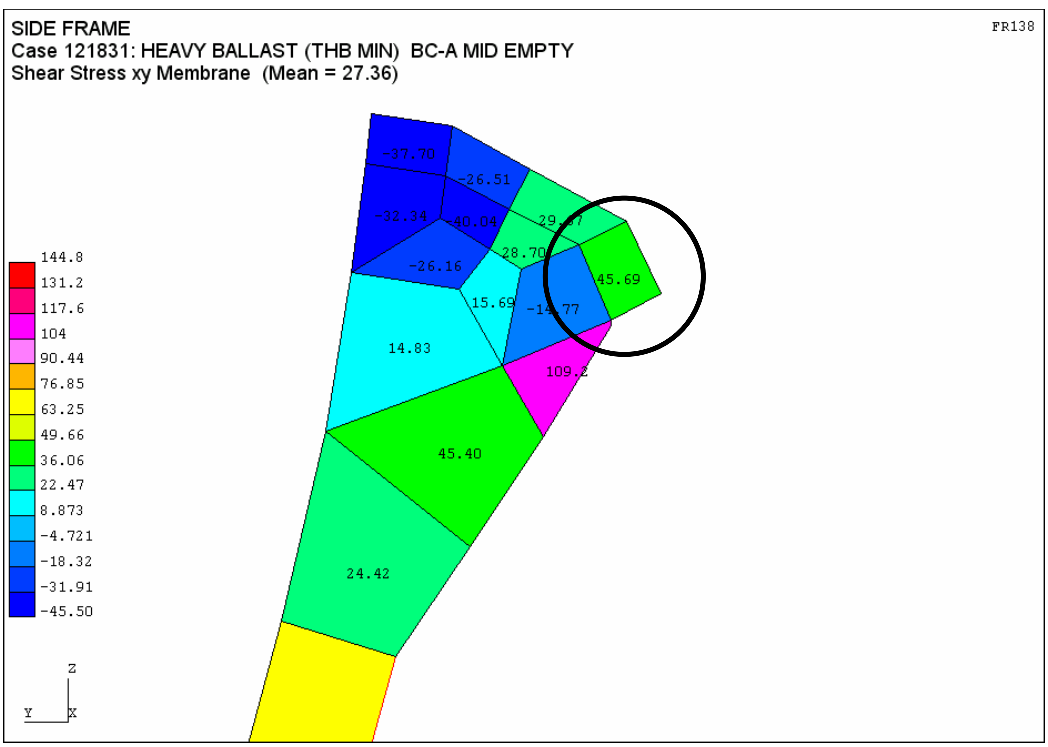
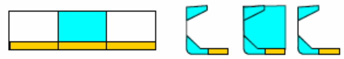
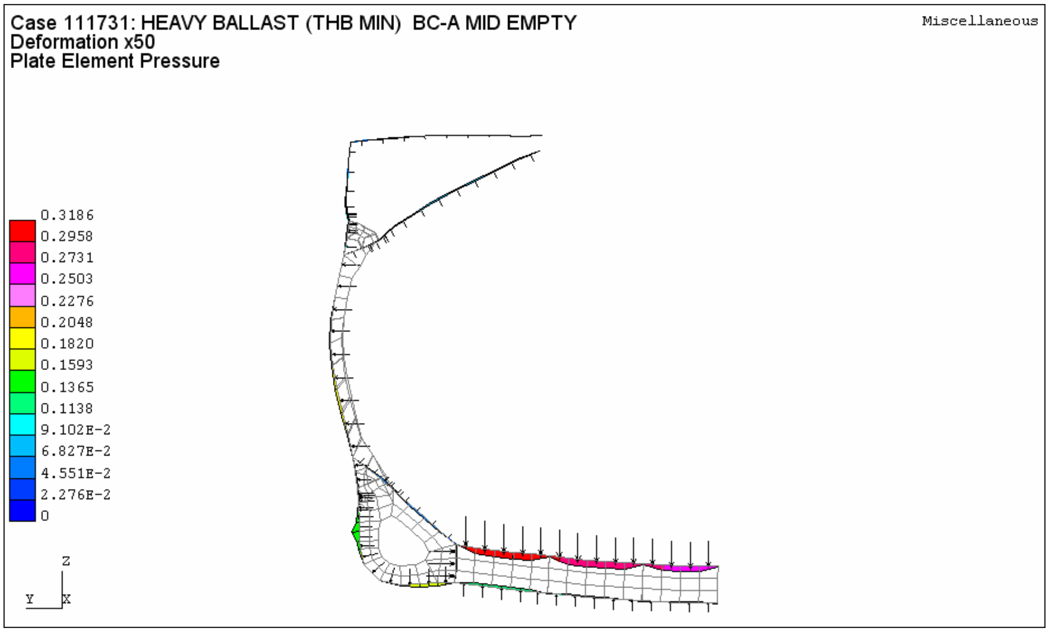


Fig.3 (a) Shear Stress in Supporting Bracket at Longl Stiffener on Topside Sloping Bhd

13	Heavy Ballast ([3.5.1])	$T_{HB}(min)$		H1	R1	R1		11),12)
				$M_{sw,s}$	0	$M_{sw,s}$		



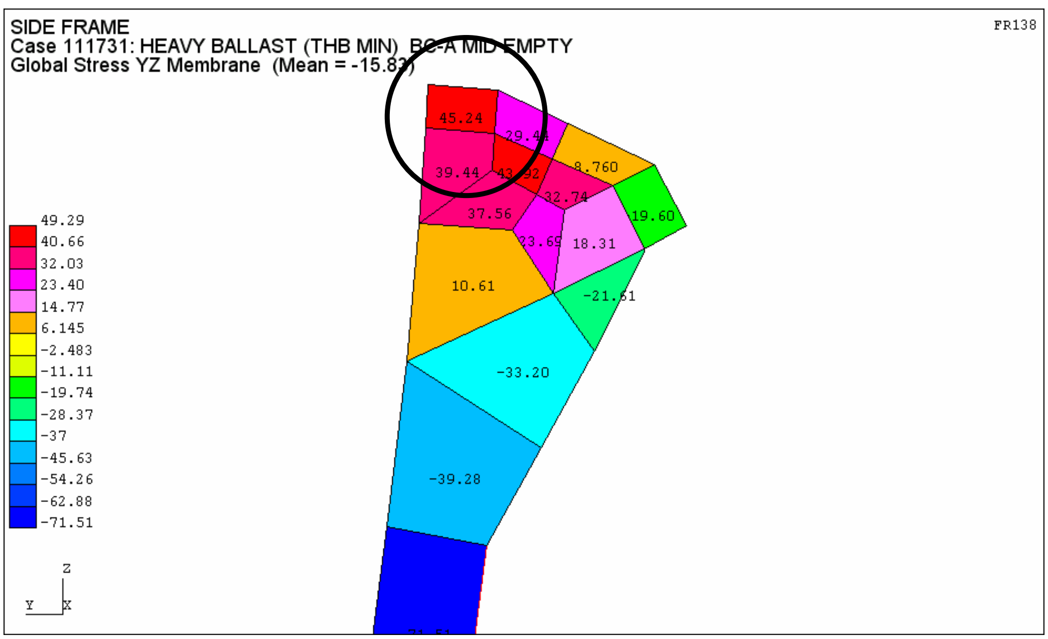
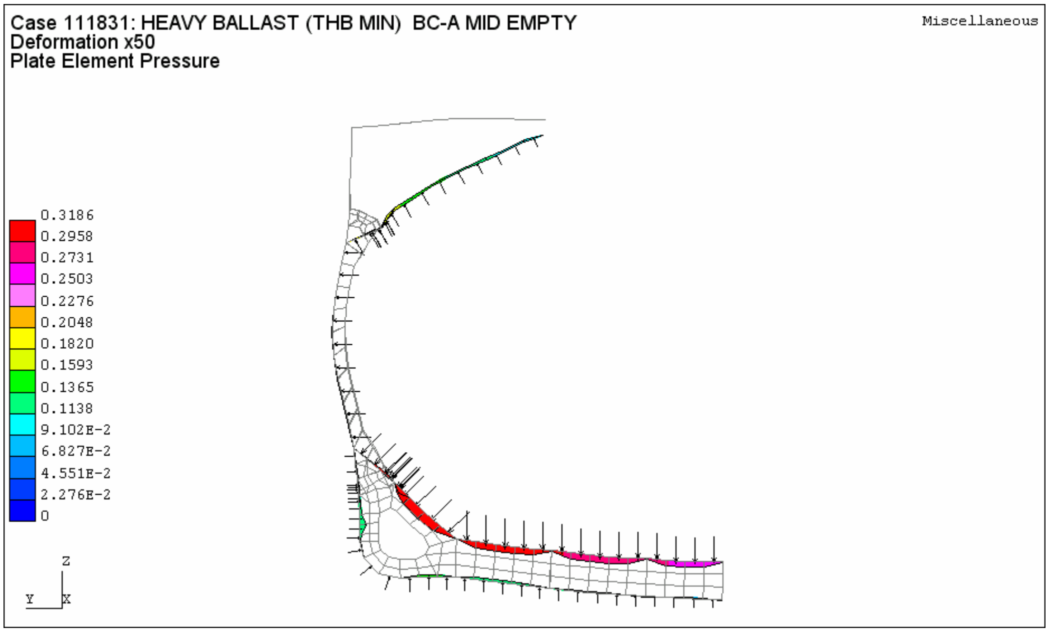


Fig.3 (b) Shear Stress in Supporting Bracket at Side Shell Longl in Topside Tank

14	Heavy Ballast	$T_{HB}(min)$			R1 0	R1 $M_{SW,S}$			11), 12), 13)



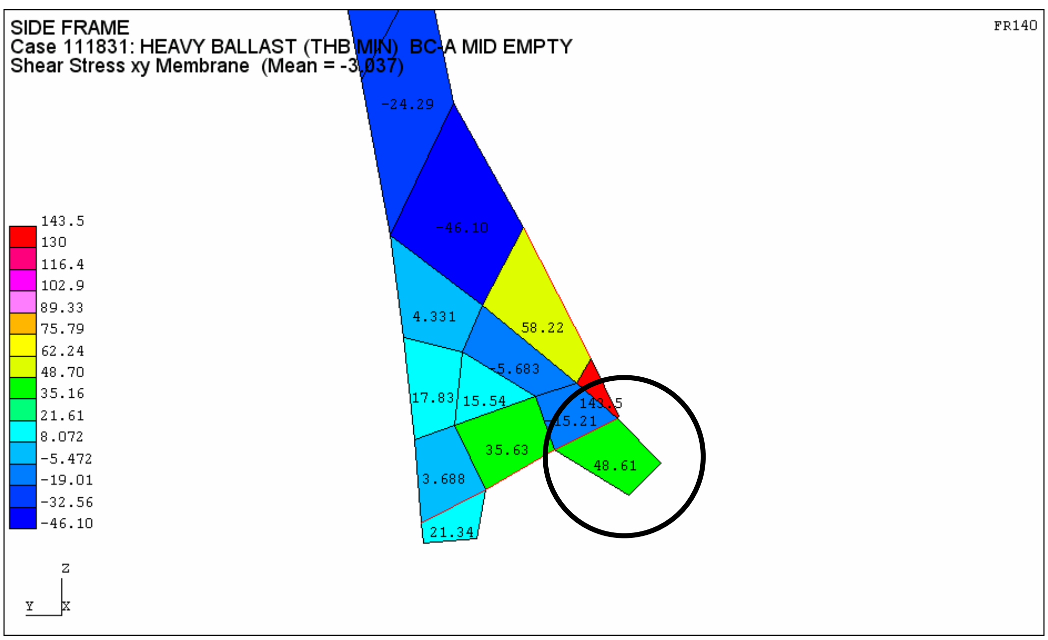
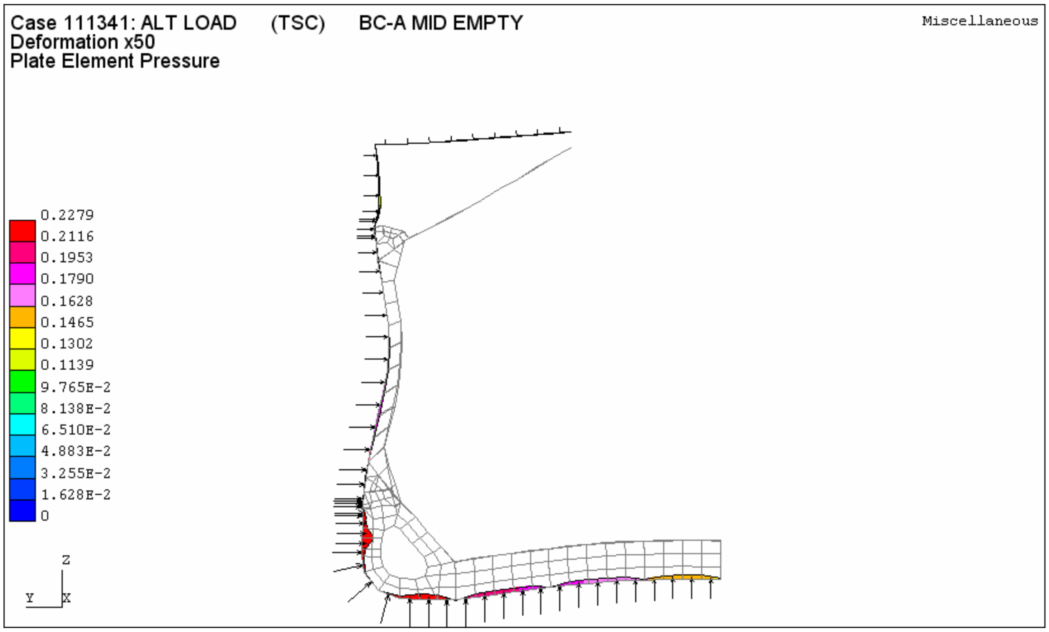


Fig.3 (c) Shear Stress in Supporting Bracket at Longl Stiffener on Hopper Sloping Bhd

10	Alternate Load ([3.4.1])	T_S		F2	P1			2)
				$M_{SW,H}$	0			



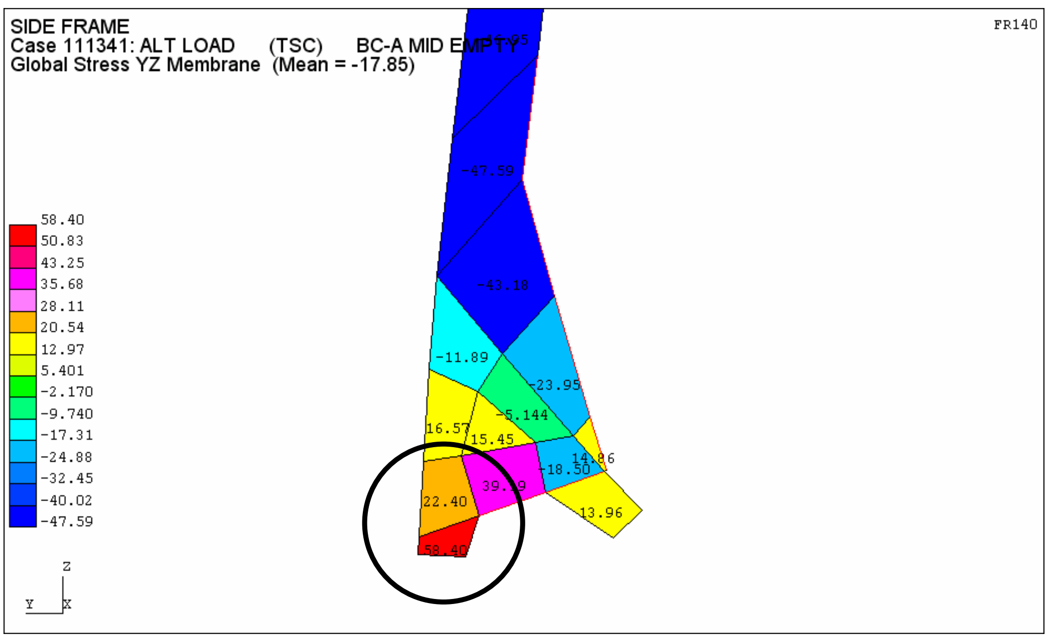
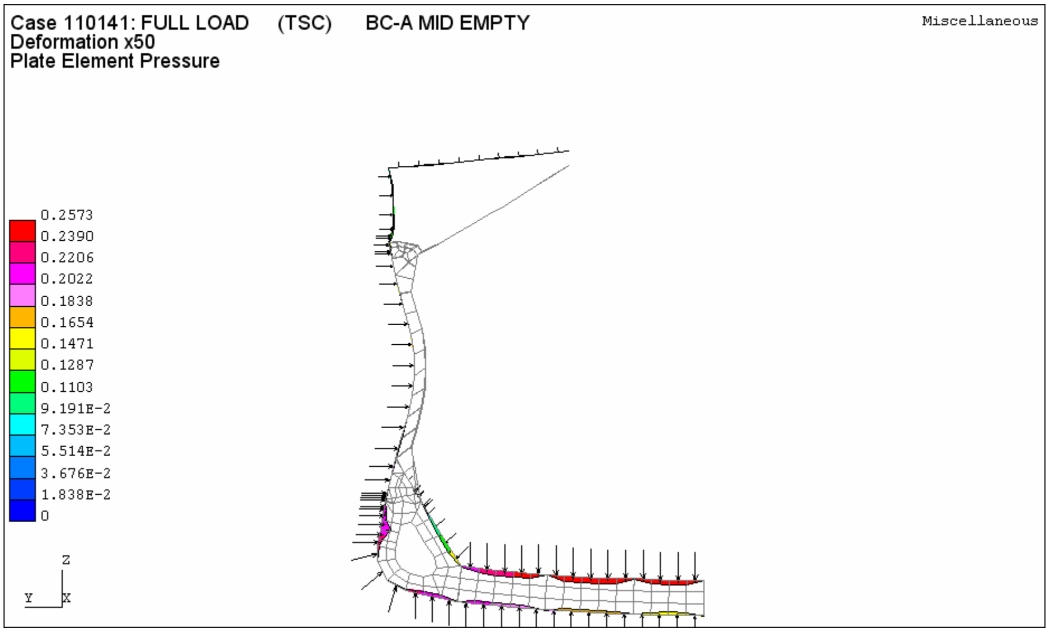


Fig.3 (d) Shear Stress in Supporting Bracket at Side Shell Longl
in Hopper Side Tank

1	Full Load ([2.1.3])	T_S		P1 $0.5M_{SW,S}$				1), 2)



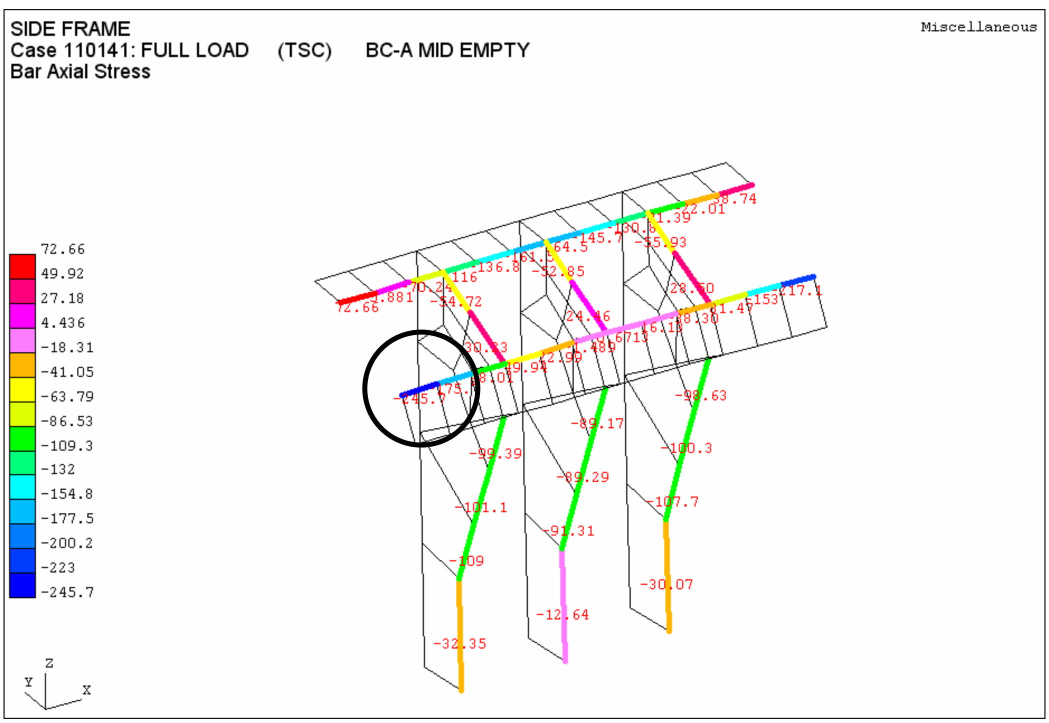
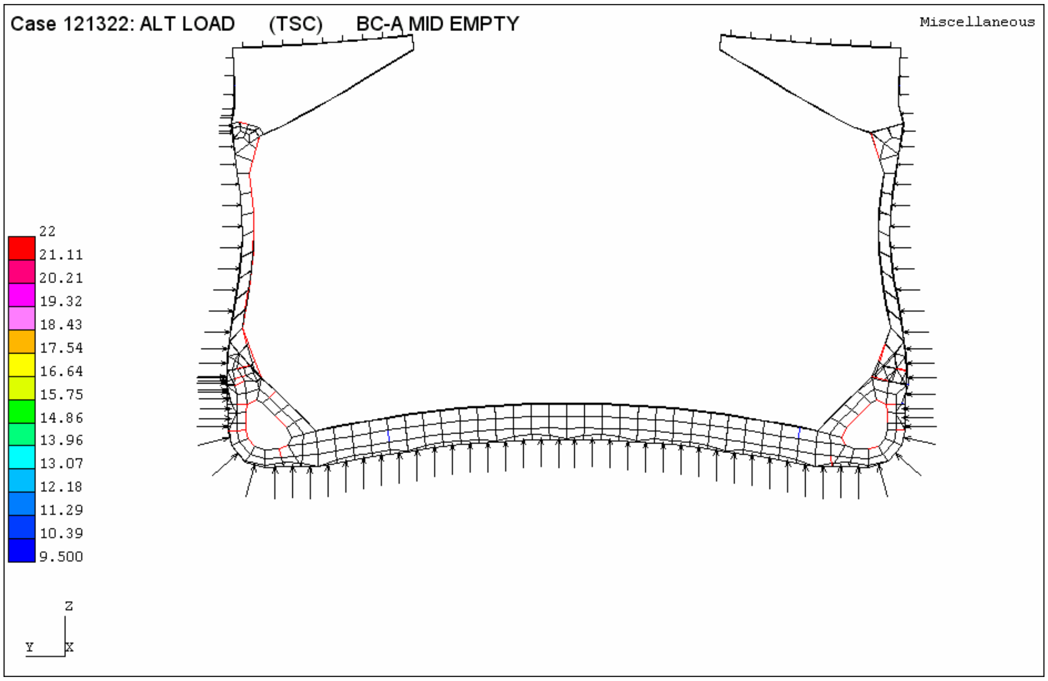


Fig.4 (a) Longl Stress in Longl Stiffener on Topside Sloping Bhd

10	Alternate Load ([3.4.1])	T_S		F2 $M_{SW,H}$	P1 0			2)



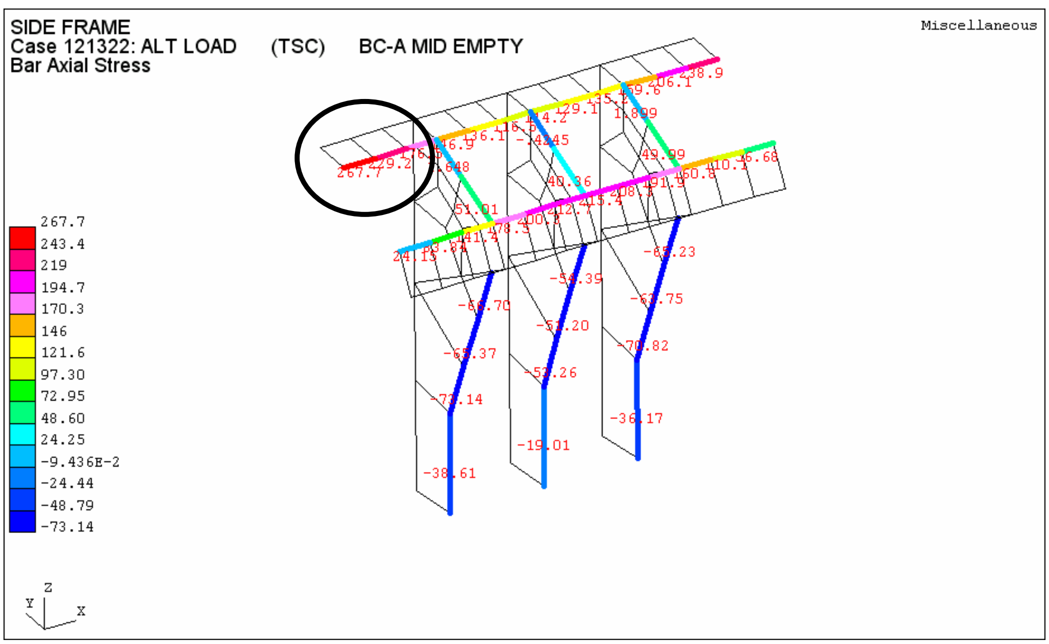
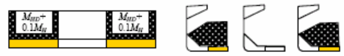
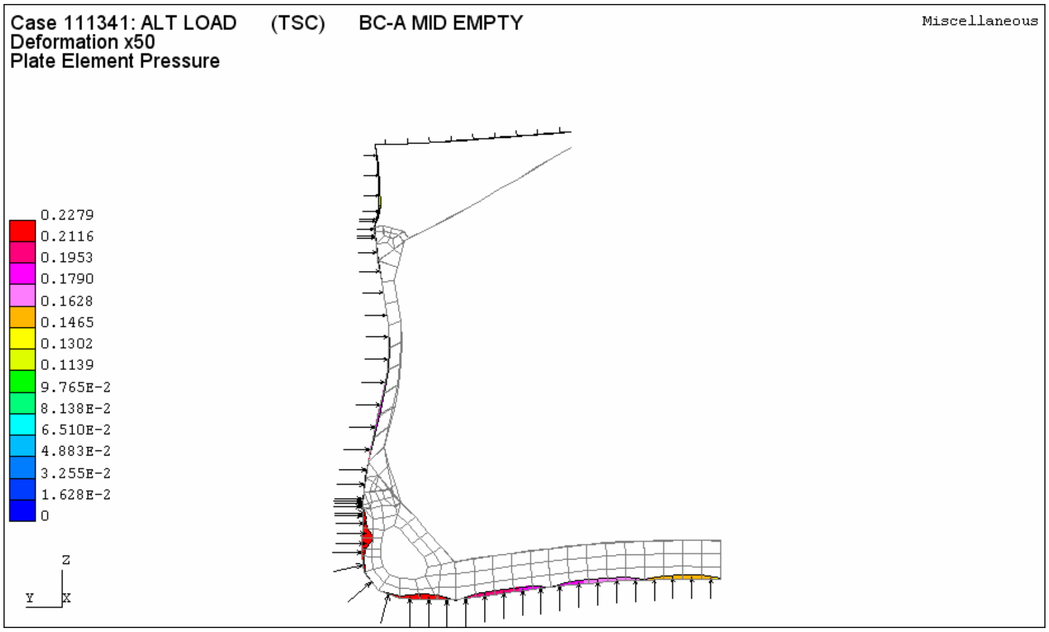


Fig.4 (b) Longl Stress in Side Shell Longl in Topside Tank

10	Alternate Load ([3.4.1])	T_S		F2	P1			2)
				$M_{SW,H}$	0			



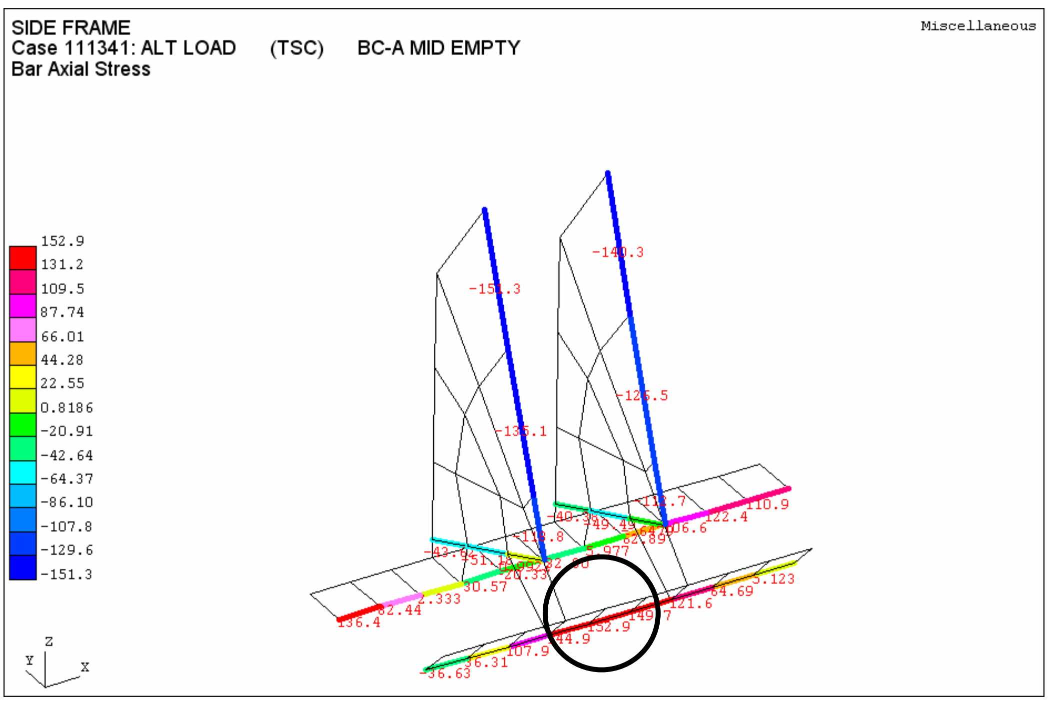
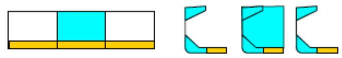
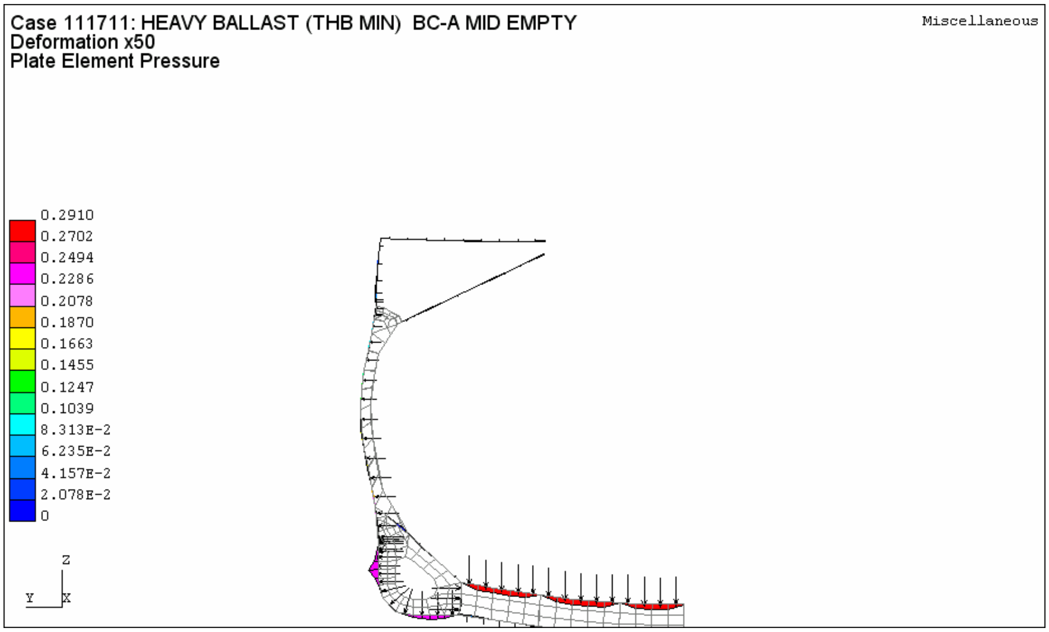


Fig.4 (c) Longl Stress in Longl Stiffener on Hopper Sloping Bhd

13	Heavy Ballast ([3.5.1])	$T_{HB}(min)$		H1 $M_{SW,S}$	R1 0	R1 $M_{SW,S}$		11),12)



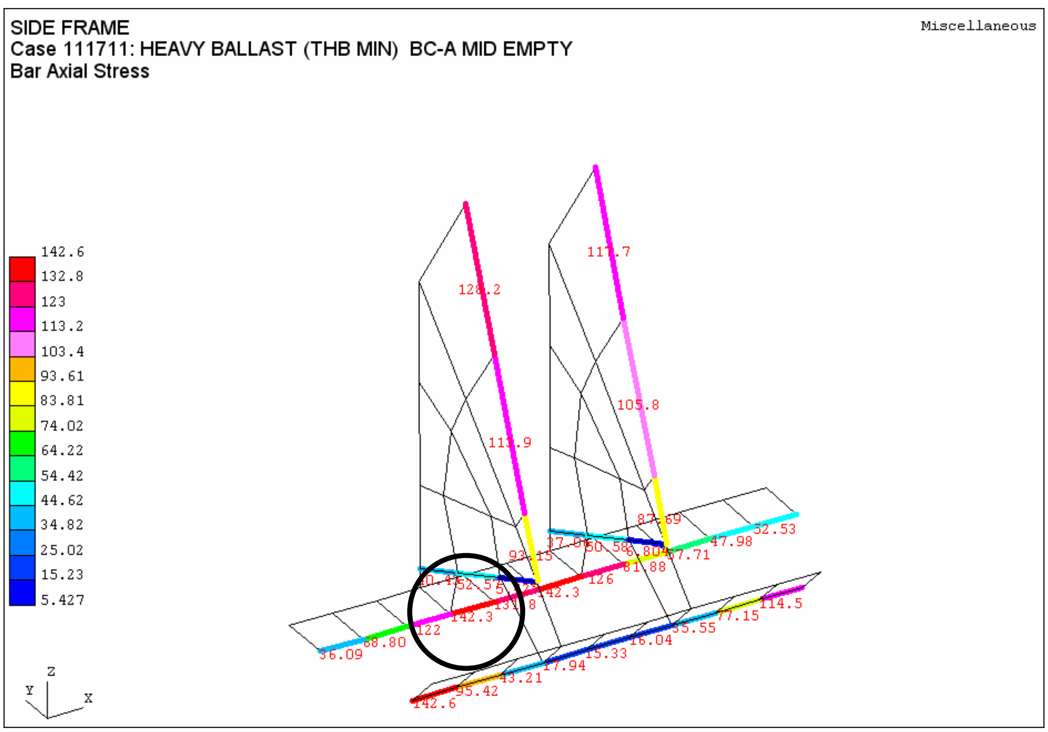
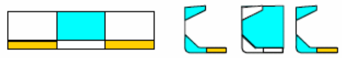
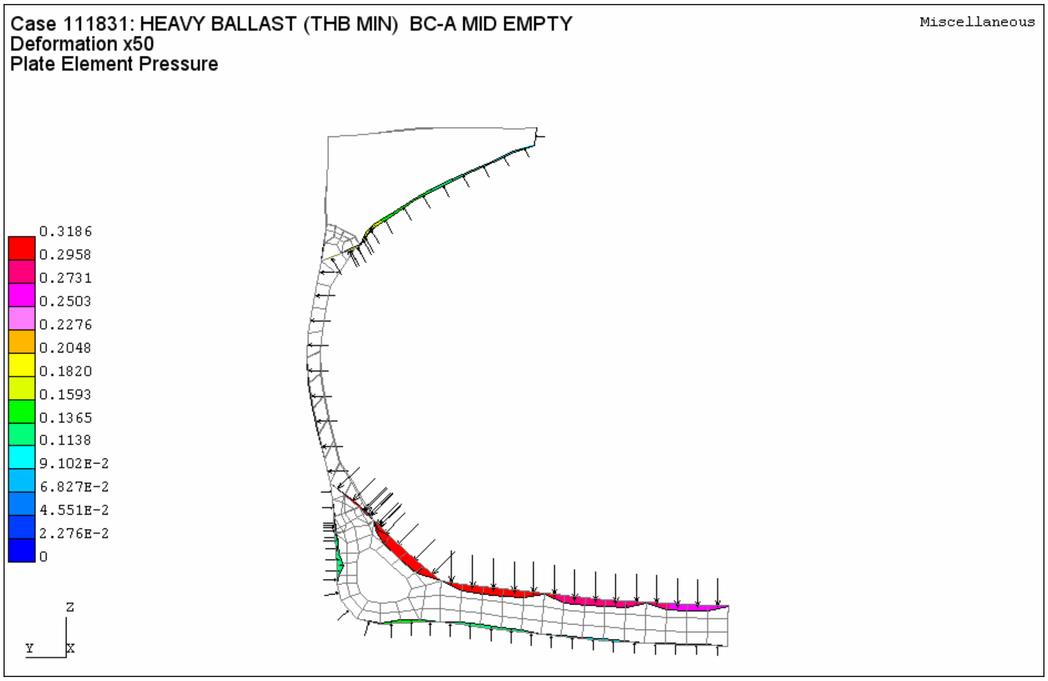


Fig.4 (d) Longl Stress in Side Shell Longl in Hopper Side Tank

14	Heavy Ballast	$T_{HB}(min)$		R1	R1			11), 12), 13)
				0	$M_{SW,S}$			



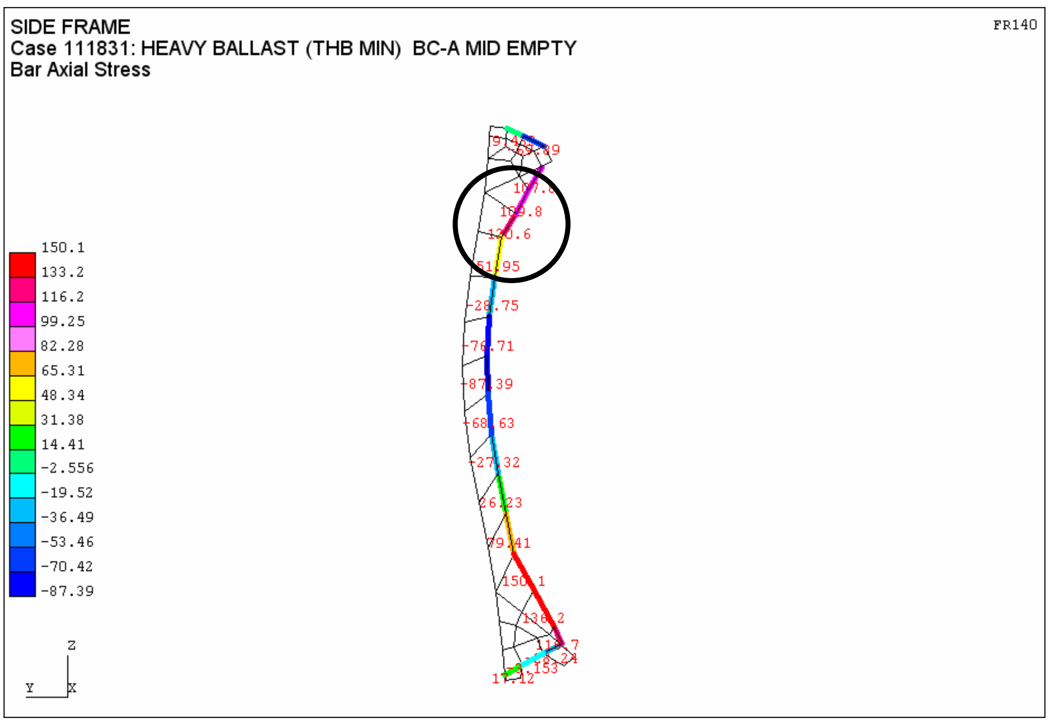
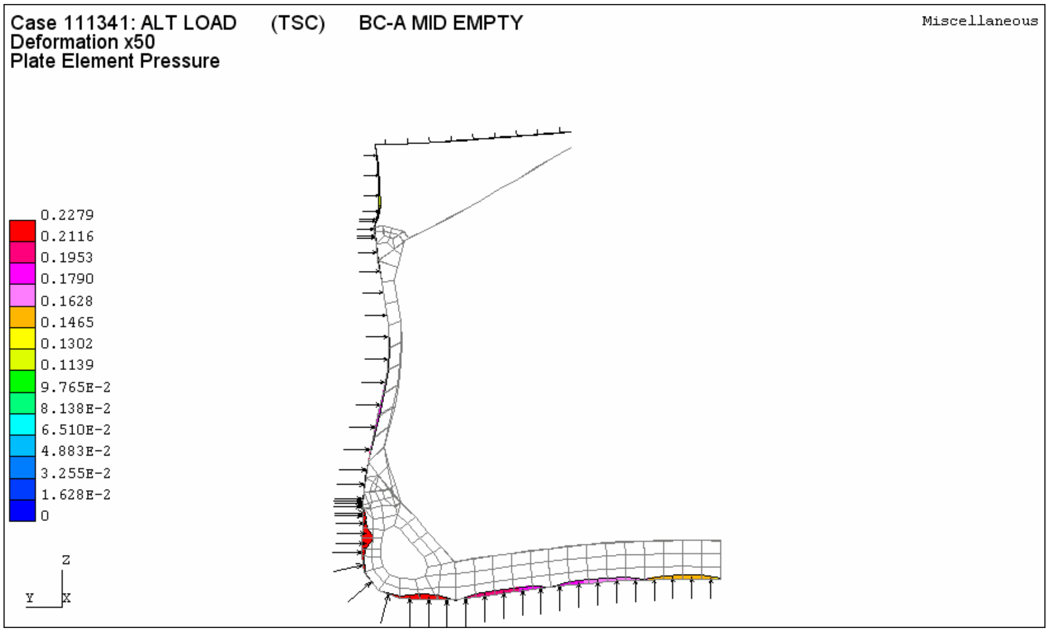


Fig.5 (a) Bending Stress in Side Frame in way of Upper Bracket

10	Alternate Load ([3.4.1])	T_S		F2	P1			2)
				$M_{SW,H}$	0			



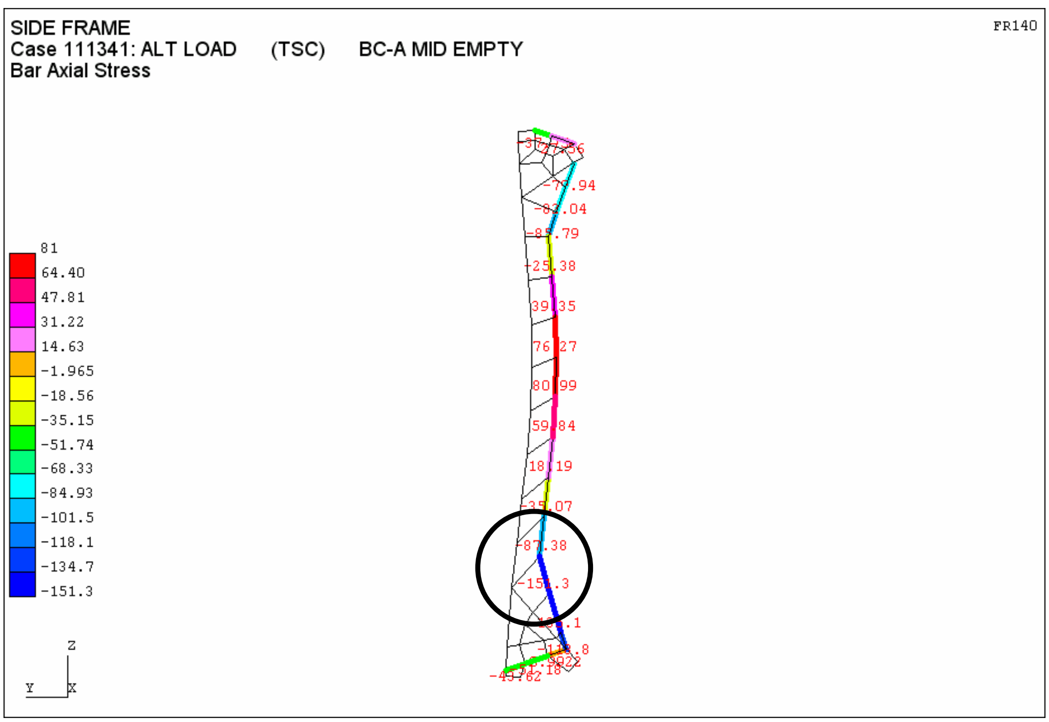
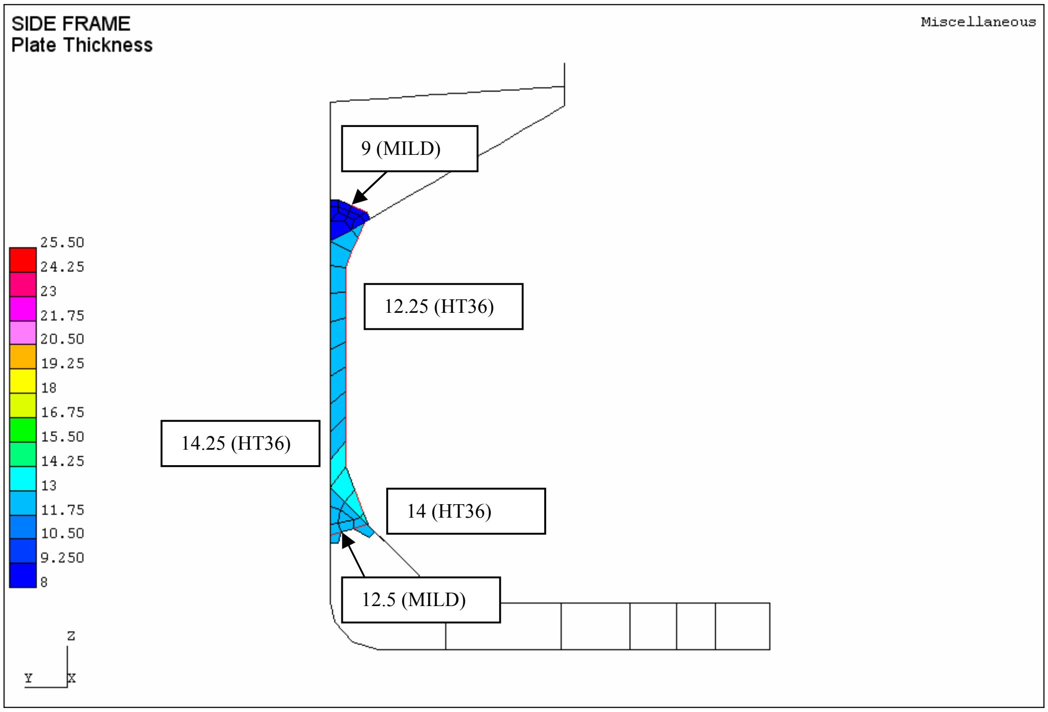


Fig.5 (b) Bending Stress in Side Frame in way of Lower Bracket



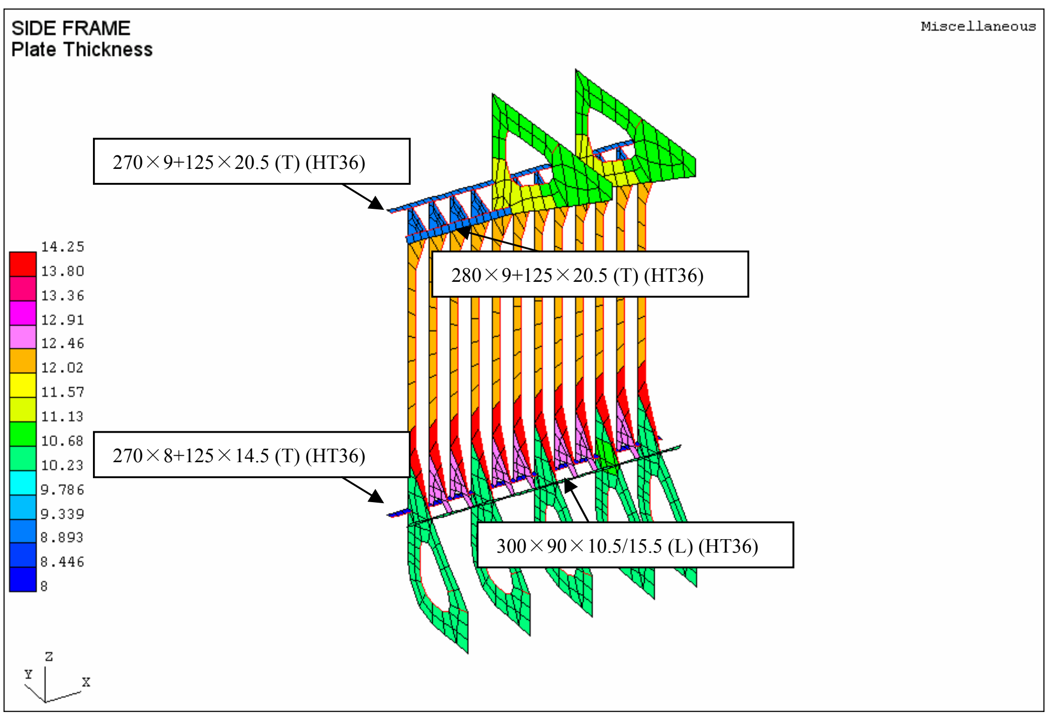


Fig. 6 Net Scantlings Complying with Rule Change Proposal

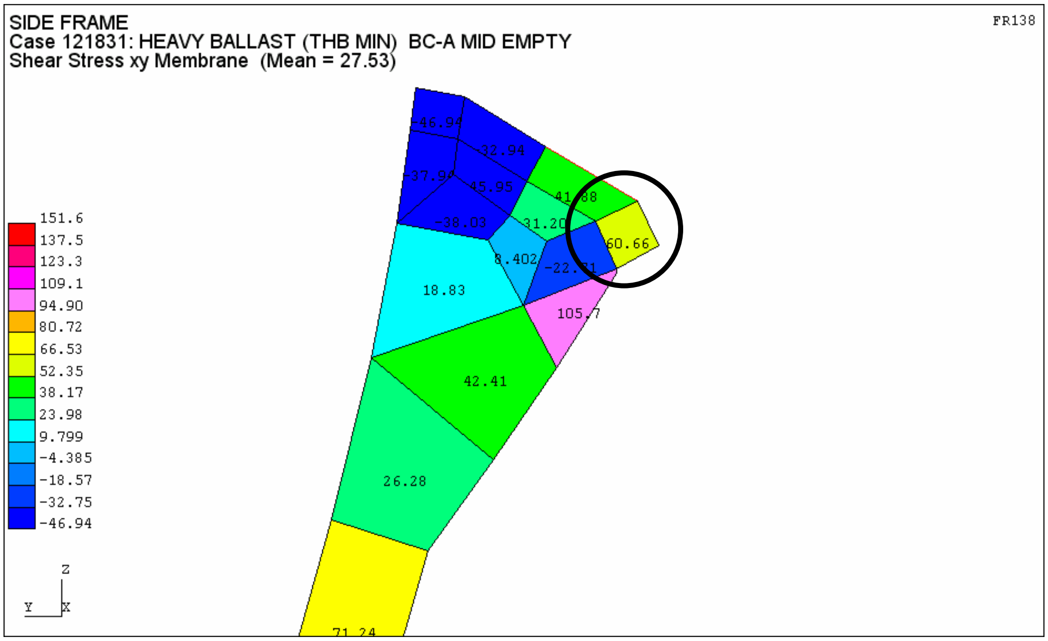


Fig.7 (a) Shear Stress in Supporting Bracket at Longl Stiffener on Topside Sloping Bhd

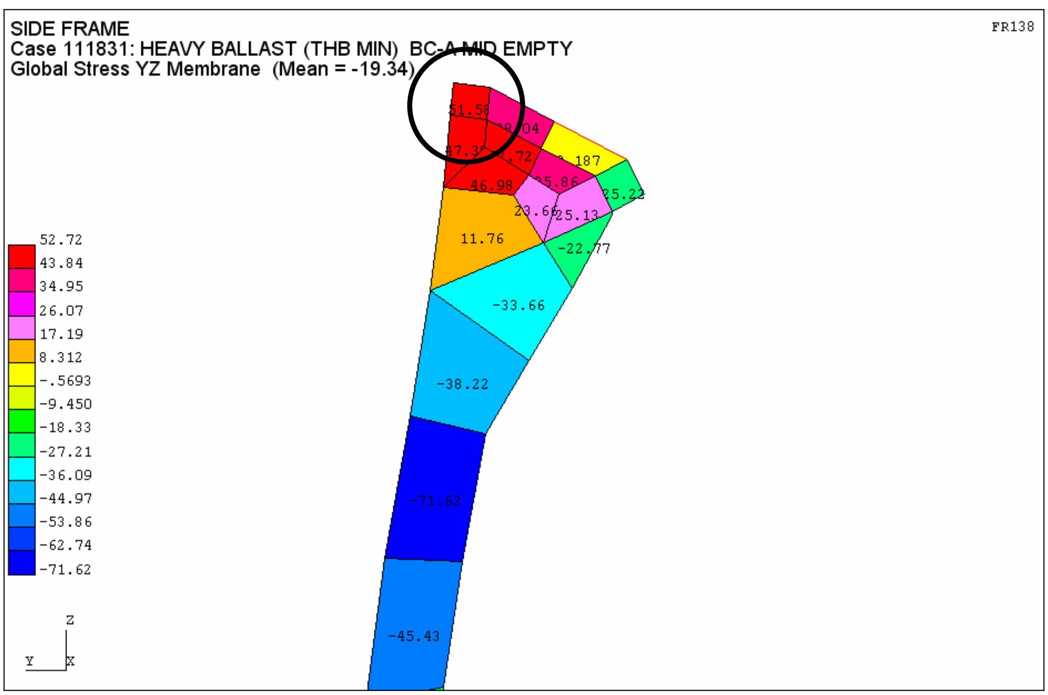


Fig. 7 (b) Shear Stress in Supporting Bracket at Side Shell Longl in Topside Tank

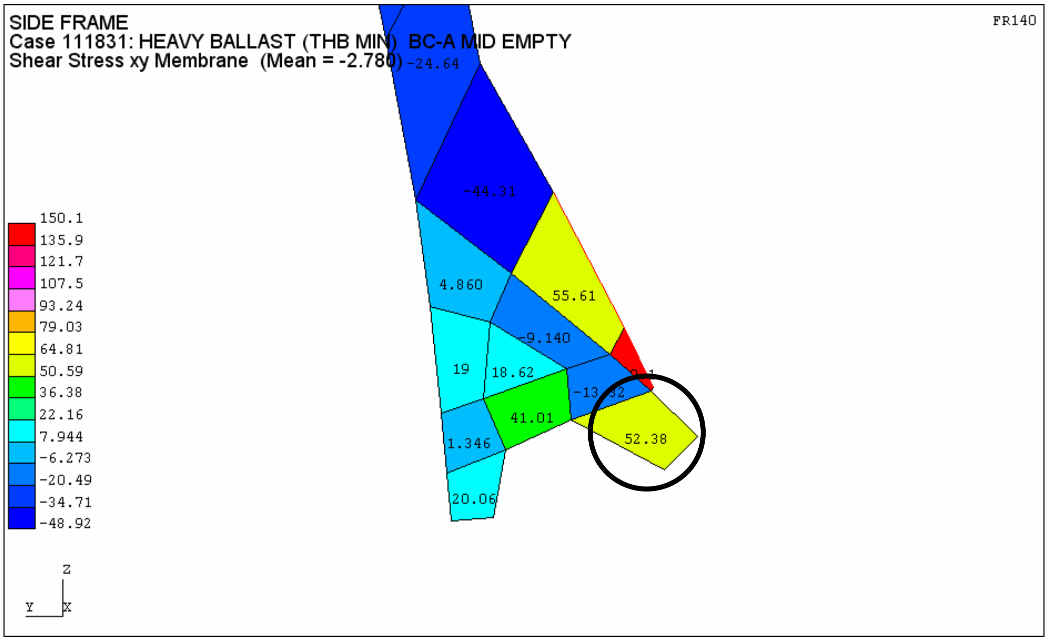


Fig. 7 (c) Shear Stress in Supporting Bracket at Longl Stiffener on Hopper Sloping Bhd

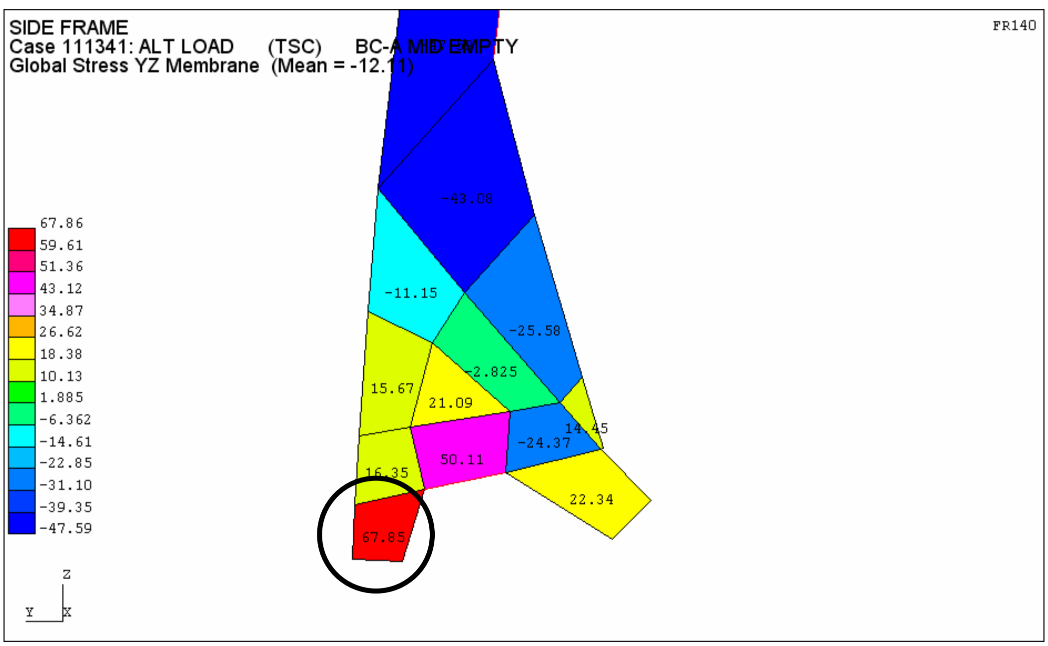


Fig.7 (d) Shear Stress in Supporting Bracket at Side Shell Longl in Hopper Side Tank

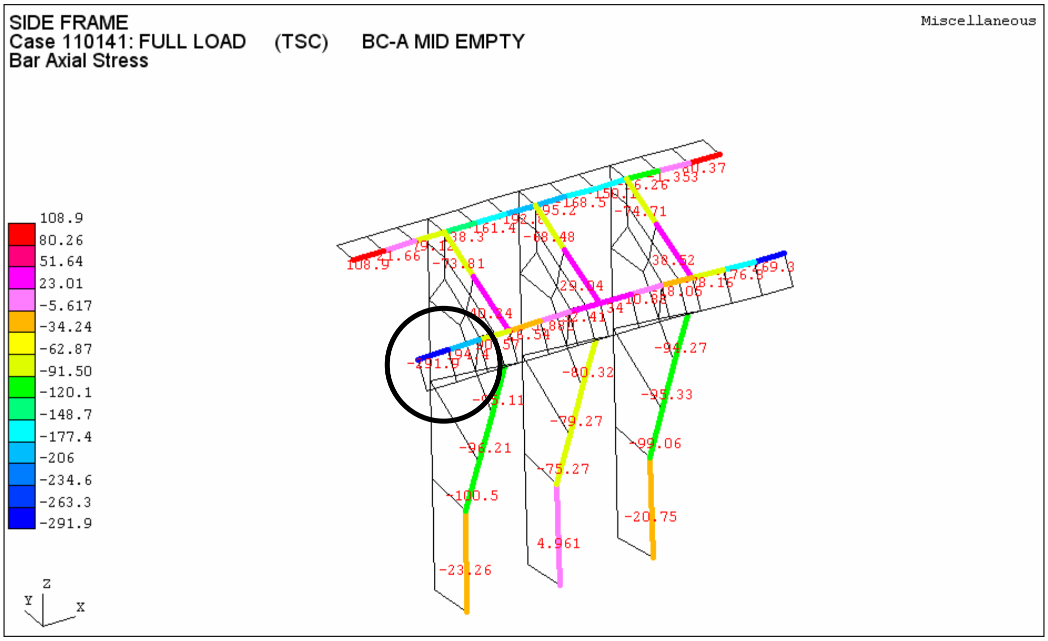


Fig. 8(a) Longl Stress in Longl Stiffener on Topside Sloping Bhd

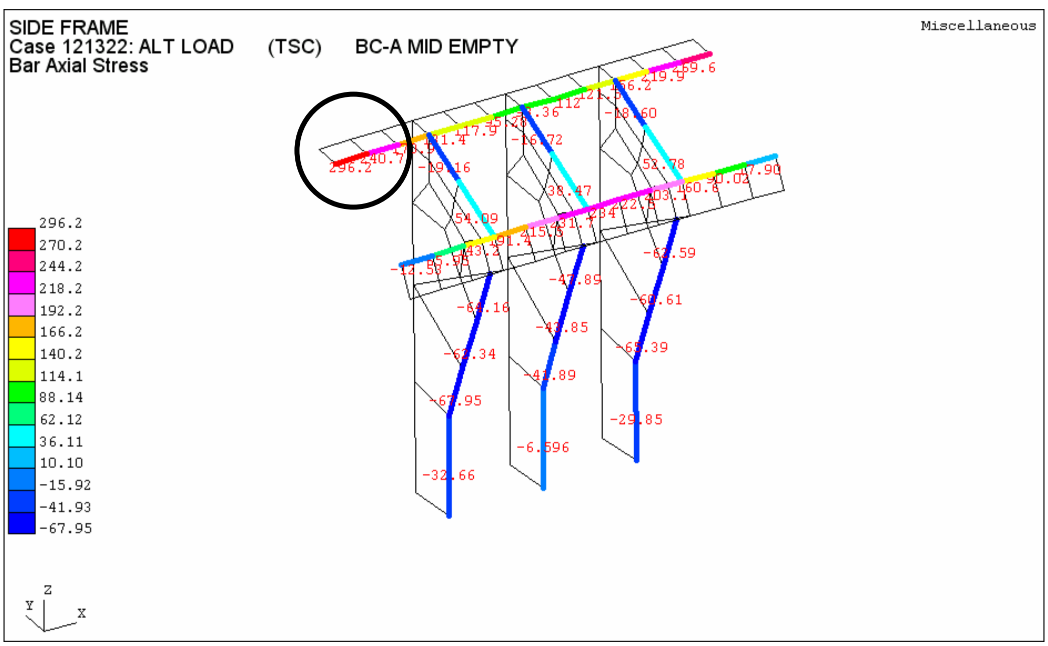


Fig. 8 (b) Longl Stress in Side Shell Longl in Topside Tank

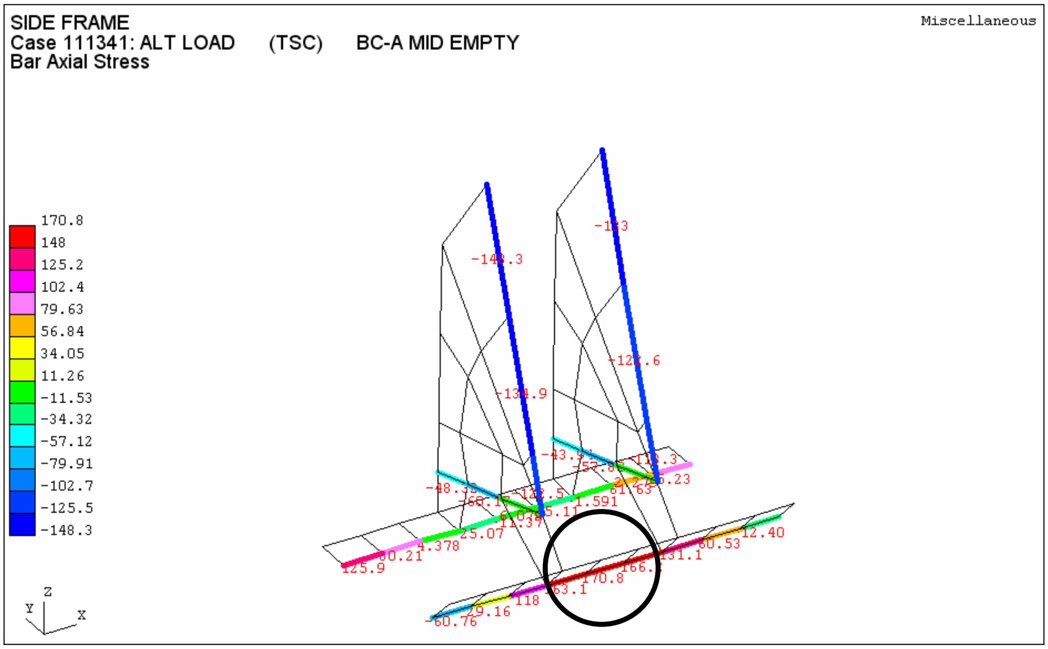


Fig. 8 (c) Longl Stress in Longl Stiffener on the Hopper Sloping Bhd

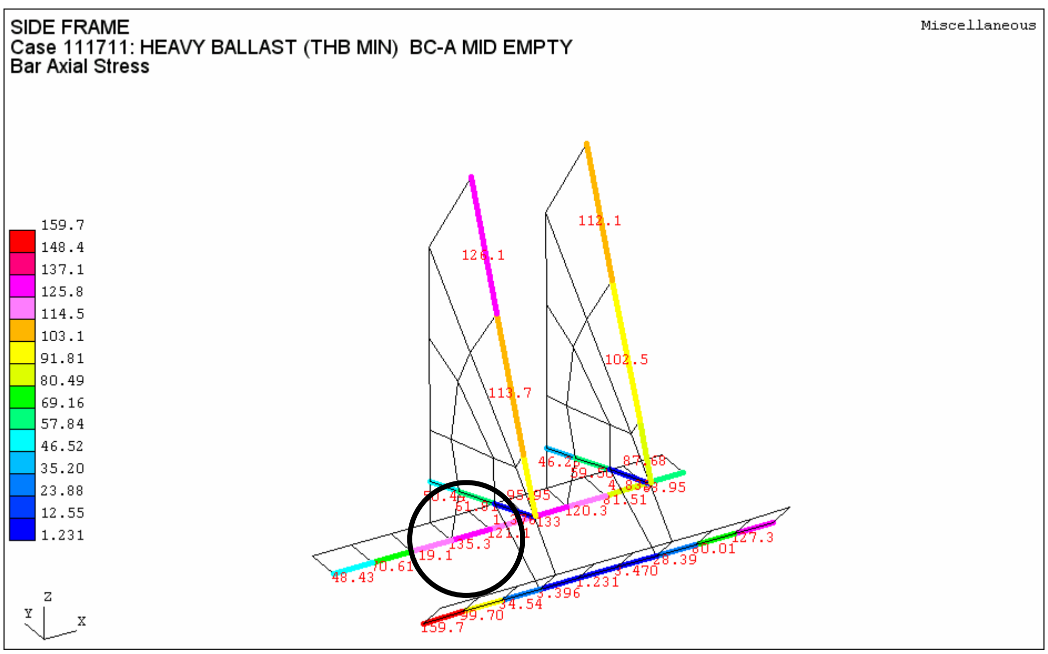


Fig.8 (d) Longl Stress in Side Shell Longl in Hopper Side Tank

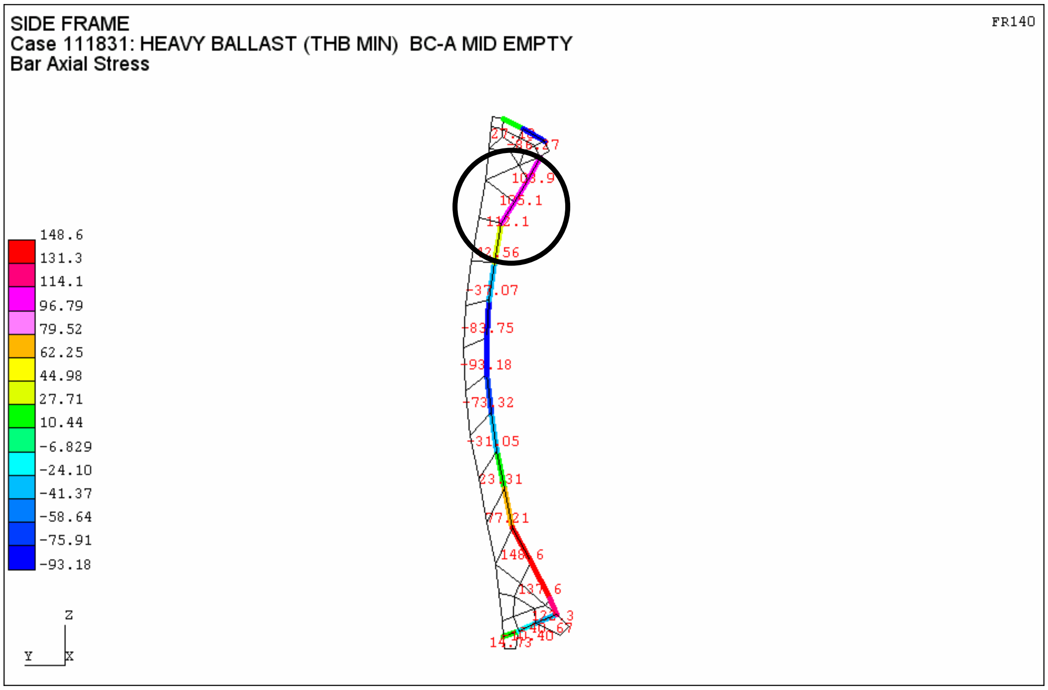


Fig. 9 (a) Bending Stress in Side Frame in way of Upper Bracket

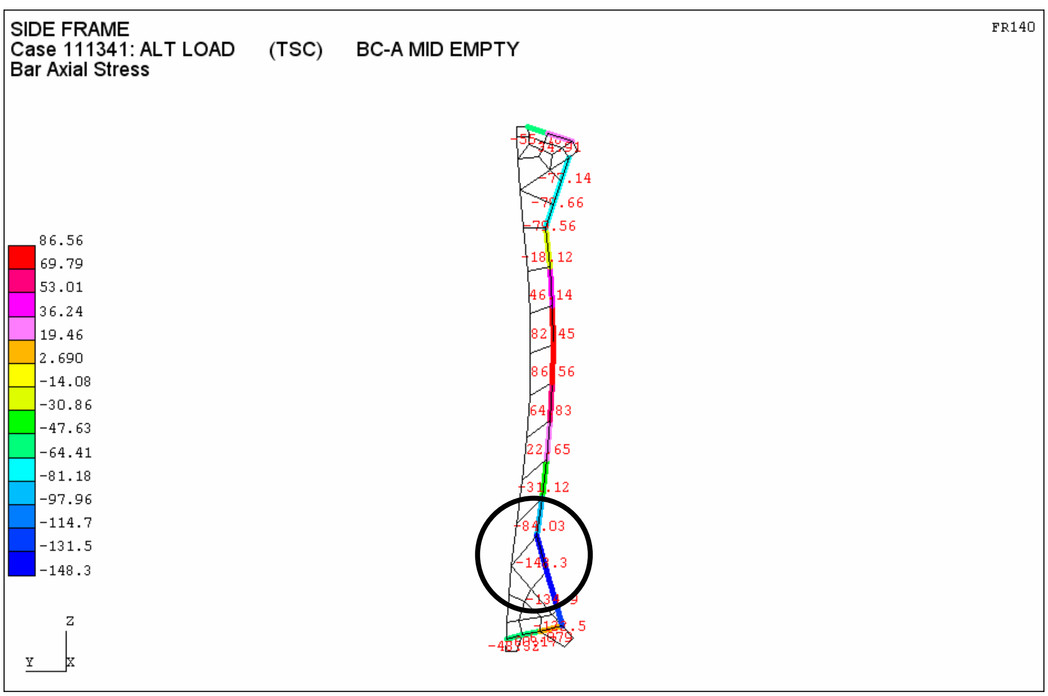


Fig. 9 (b) Bending Stress in Side Frame in way of Lower Bracket

Computation of upper and lower connection of side frames of single side bulk carriers

The following note is extracted from the WP/S background document for UR S12 revision 4. This version of the UR was neither officially released, but is the basis for the requirements of the IACS Common Structural Rules for bulk carriers.
This note is related to the calculation of the longitudinals that support the lower and upper connecting brackets of the side shell frames in hopper and topside tanks.
The relevant requirements are provided in Ch 6, Sec 2, [3.4] of IACS CSR for bulk carriers.

The technical background document has been modified to adopt the symbols and notations of the Common structural rules for bulk carriers Chapter 6, Section 2, in order to facilitate the reading. For the meaning of the symbols not defined hereunder, please refer to the text of the Common Structural Rules.

Checking of section modulus of the longitudinals in Ch 6, Sec 2 [3.4.1]

The section modulus of the longitudinals is required to have sufficient bending strength to support the end fixing moment of the side frame about the intersection point of the sloping bulkhead and the side shell.
The end fixing moment of the side frame is that induced by the external sea pressure acting on the side frame (end brackets excluded) and the deflection and rotation of the end support due to the loading on the hopper and the double bottom.
The sea pressure loading on the end brackets is not included because the sea pressure loading on this and on the connecting structure of the hopper and topside tank are assumed to cancel.

The end fixing moment, M_{ef}, of the side frame about the intersection point of the sloping bulkhead and the side shell in Nm is given as:

$$M_{ef} = \alpha_T \cdot (p_S + p_W) \cdot s \cdot l^2 \qquad (1)$$

The end fixing moment, M_{ef}, gives rise to line loads on the connected side and sloping bulkhead stiffeners, q_{efi}, in N/m such that:

$$\frac{M_{ef}}{s} = \sum_i q_{efi} \cdot d_i \qquad (2)$$

The line load, q_{efi}, gives rise to plastic bending moments in the connected side and sloping bulkhead stiffeners, M_{ci}, in Nm given as:

$$M_{ci} = \frac{q_{efi}\ \ell_I^2}{16} \qquad (3)$$

Hence, assuming an allowable stress equal to yield, the section modulus requirement for a connected side or sloping bulkhead longitudinal in cm^3 becomes:

$$w_i = \frac{M_{ci}}{R_Y} \qquad (4)$$

Injecting the expression of M_{ci} from (4) into (3) and putting q_{efi} in (2), we obtain:

$$\sum_i w_i \cdot d_i = \frac{M_{ef} \cdot l_l^2}{16 \cdot s \cdot R_Y} = \alpha_T \cdot \frac{(p_S + p_W) \cdot l^2 \cdot l_l^2}{16 \cdot R_Y} \qquad (5)$$

The above expression allows the required section modulus of the connected longitudinals to be determined and is given under [3.4.1] of Common Structural Rules for bulk carriers, Chapter 6, Section 2.

Checking of connection area in Ch 6, Sec 2 [3.4.2]

The connecting force Q_{efi} in N is transferred through shear between the brackets and the longitudinals, with:

$$Q_{efi} = s \cdot q_{efi} \qquad (6)$$

Assuming an allowable shear stress equal to 0.5 R_Y, we have, with Ai in cm^2 the connection area between bracket and longitudinal:

$$\frac{R_{Ybkt}}{2} = \frac{10^{-2} \cdot Q_{efi}}{A_i} = \frac{10^{-2} \cdot s \cdot q_{efi}}{A_i} \qquad (7)$$

Injecting q_{efi} from (3) and (4) inside (7), we obtain:

$$A_i = [0.32] \cdot \frac{w_i \cdot s \cdot R_{Y\lg}}{l_l^2 \cdot R_{Ybkt}} \qquad (8)$$

The above expression provides the required connection area and is given with the coefficient 0.32 rounded up to 0.4 and introducing the material factors for bracket and stiffener to replace the yield strengths ratio, under [3.4.2] of Common Structural rules for bulk carriers, Chapter 6, Section 2.

Technical background of the requirement of Supporting Structure of Side Frame in Ch 6 Sec 2, [3.4.1] and [3.4.2]

1. Checking of section modulus of the longitudinals in Ch 6, Sec 2 [3.4.1]

The section modulus of the longitudinals is required to have sufficient bending strength to support the end fixing moment of the side frame about the intersection point of the sloping bulkhead and the side shell.

The end fixing moment of the side frame is that induced by the external sea pressure acting on the side frame (end brackets excluded) and the deflection and rotation of the end support due to the loading on the hopper and the double bottom.

The sea pressure loading on the end brackets is not included because the sea pressure loading on this and on the connecting structure of the hopper and topside tank are assumed to cancel.

The end fixing moment, M_{ef}, of the side frame about the intersection point of the sloping bulkhead and the side shell in Nm is given as:

$$M_{ef} = \alpha_T \cdot (p_S + p_W) \cdot s \cdot l^2 \tag{1}$$

Where

α_T : the coefficient determined by the results of FEA considering the moments transferred from the topside structure or bilge hopper structure.

p_s, p_w : Pressures, in kN/m^2, at the mid-span of the side frame to be considered, in intact condition.

s, l : the space and span, in m, of the side frame

The end fixing moment, M_{ef}, gives rise to line loads on the connected side and sloping bulkhead stiffeners, q_{efi}, in N/m such that:

$$\frac{M_{ef}}{s} = \sum_i q_{efi} \cdot d_i \tag{2}$$

Where,

d_i : Distance, in m, of the i-th longitudinal stiffener from the intersection point of the side shell and topside/bilge hopper tank.

The line load, q_{efi}, gives rise to plastic bending moments in the connected side and sloping bulkhead stiffeners, M_{ci}, in Nm given as:

$$M_{ci} = \frac{q_{efi}\ \ell_l^2}{16} \tag{3}$$

Where,

λ_l : spacing, in m, of transverse supporting webs in topside / bilge hopper tank.

Hence, assuming an allowable stress equal to yield, $R_{Y,lg,i}$, the section modulus requirement, $w_{i,r}$, which is not the net modulus offered, for a connected side or sloping bulkhead longitudinal in cm^3 becomes:

$$w_{i,r} = \frac{M_{ci}}{R_{Y,\lg,i}} \tag{4}$$

Injecting the expression of M_{ci} from (4) into (3) and putting q_{efi} in (2), we obtain:

$$\sum_i w_{i,r} \cdot d_i \cdot R_{Y,\lg,i} = \frac{M_{ef} \cdot l_l^2}{16 \cdot s} = \alpha_T \cdot \frac{(p_S + p_W) \cdot l^2 \cdot l_l^2}{16} \tag{5}$$

The above expression allows the required section modulus of the connected longitudinals to be determined and is given under [3.4.1] of Common Structural Rules for bulk carriers, Chapter 6, Section

2.

$$\sum_i w_i \cdot d_i \cdot R_{Y,\lg,i} \geq \sum_i w_{i,r} \cdot d_i \cdot R_{Y,\lg,i} = \alpha_T \cdot \frac{(p_S + p_W) \cdot l^2 \cdot l_l^2}{16} \qquad \text{(5-a)}$$

Where,

w_i : The net modulus offered, in cm^3, of the i-th longitudinal stiffener

Where, the coefficient α_T was determined conservatively based on the results of 3D FEA carried out by WP/S, i.e.

α_T.=150 for the longitudinal stiffeners supporting the lower connecting brackets is rounded from 135 obtained from the results of FEA.

α_T.=75 for the longitudinal stiffeners supporting the upper connecting brackets is based on the FEA results.

If the same allowable stress, $R_{Y,lg}$, is applied to all of the connected longitudinals, the formula (5-a) can be changed to:

$$\sum_i w_i \cdot d_i \geq \alpha_T \cdot \frac{(p_S + p_W) \cdot l^2 \cdot l_l^2}{16 \cdot R_{Y,\lg}} \qquad \text{(5-a)}$$

2. Checking of connection area in Ch 6, Sec 2 [3.4.2]

The connecting force Q_{efi} in N is transferred through shear between the brackets and the longitudinals, with:

$$Q_{efi} = s \cdot q_{efi} \qquad (6)$$

Assuming an allowable shear stress equal to $0.5R_{Y,bi}$ which is safe side comparing with the ultimate shear stress $R_{eH} / \sqrt{3} \cong 0.577 R_{eH}$, we have, with $A_{i,r}$ in cm^2 the connection area requirement between bracket and longitudinal (which is not the connection area offered):

$$\frac{R_{Y,bkt}}{2} = \frac{10^{-2} \cdot Q_{efi}}{A_{i,r}} = \frac{10^{-2} \cdot s \cdot q_{efi}}{A_{i,r}} \qquad (7)$$

Injecting q_{efi} from (3) and (4) inside (7), we obtain:

$$A_{i,r} = 0.32 \cdot \frac{w_{i,r} \cdot s \cdot R_{Y,\lg,i}}{l_l^2 \cdot R_{Y,bkt}} \qquad (8)$$

Because $w_{i,r}$ and $A_{i,r}$ can not be obtained, the formula (8) should be changed to:

$$\sum A_{i,r} \cdot d_i = \sum 0.32 \cdot \frac{w_{i,r} \cdot s \cdot R_{Y,\lg,i}}{l_l^2 \cdot R_{Y,bkt}} \cdot d_i = \frac{0.32s}{l_l^2 \cdot R_{Y,bkt}} \sum w_{i,r} \cdot d_i \cdot R_{Y,\lg,i} = 0.02\alpha_T \cdot \frac{(p_S + p_W) \cdot s \cdot l^2}{R_{Y,bkt}}$$

$$\sum_i A_i \cdot d_i \geq 0.02 \cdot \alpha_T \cdot \frac{(p_S + p_W) \cdot s \cdot l^2}{R_{Y,bkt}} \qquad \text{(8-a)}$$

Where,

A_i : The net connection area offered, in cm^2, between bracket and longitudinal