EMship Advanced Design

Structural Design of Transverse Bulkhead of a Handymax Bulk Carrier Built in Steel Sandwich Panels

Student: Martin Markulin

Supervisor: Prof. Maciej Taczała

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Université de Liège

Centrale Nantes

Zachodniopomorski Uniwersytet Technologiczny w Szczecinie

Universität Rostock Traditio et Innovatio

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Classical Ship Structure

Classical/traditional ship structure:

- consists of steel plates with stiffening elements connected to the surface of the plate; ensuring required strength and stiffness
- corrugated stiff structures – self stiffening structures

Classical type of structure properties:

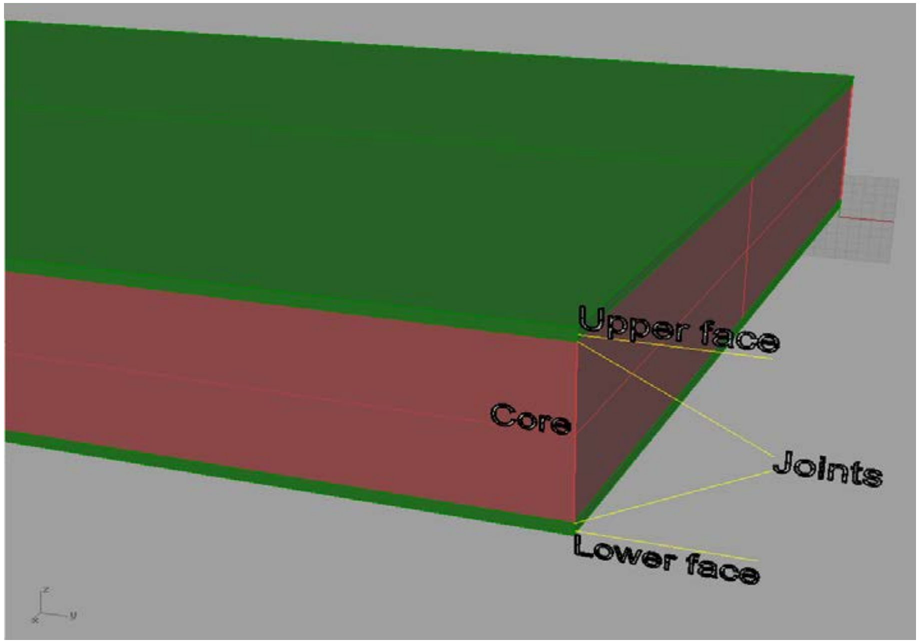
- relatively large structural dimensions and weight;
- it requires certain amount of prefabrications, heat work, reparations and post-outfitting works.

Sandwich Structures

Sandwich concept:

A solid body that consists of following components:

- upper and lower face
- the core
- connection between the core and faces



The main idea:

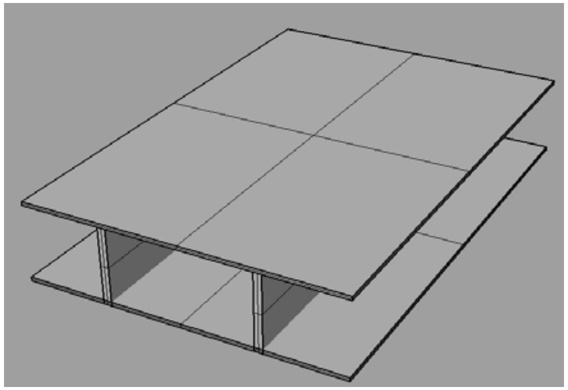
is to keep the faces away from the neutral axis, what has the strong impact on the value of moment of inertia; having the result of high section modulus over the overall mass.

Sandwich Structure Properties

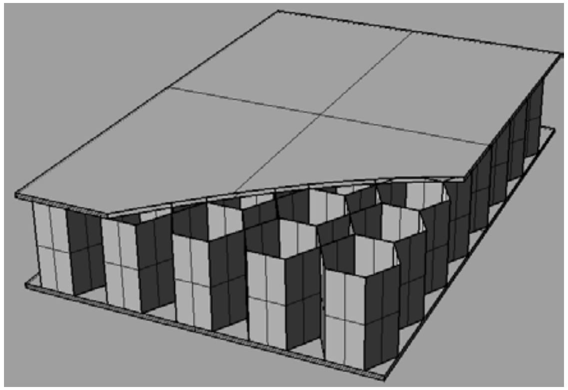
The faces and core materials:

- metallic (Steel, Al-alloys...)
- non-metalic (composite materials, organic materials...)

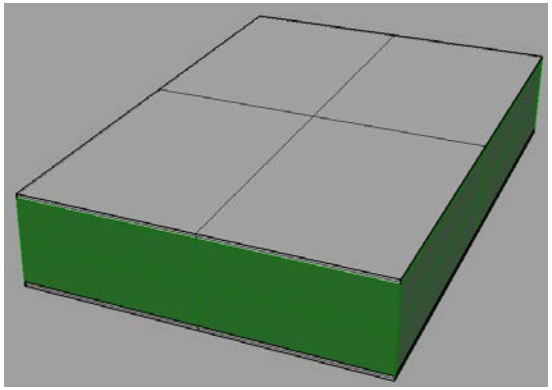
Various topologies of a sandwich panel:



Web-Core



Honeycomb

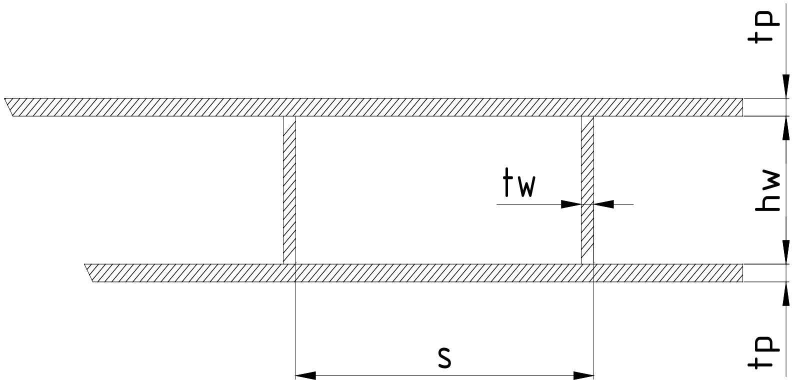


Cellular-Core

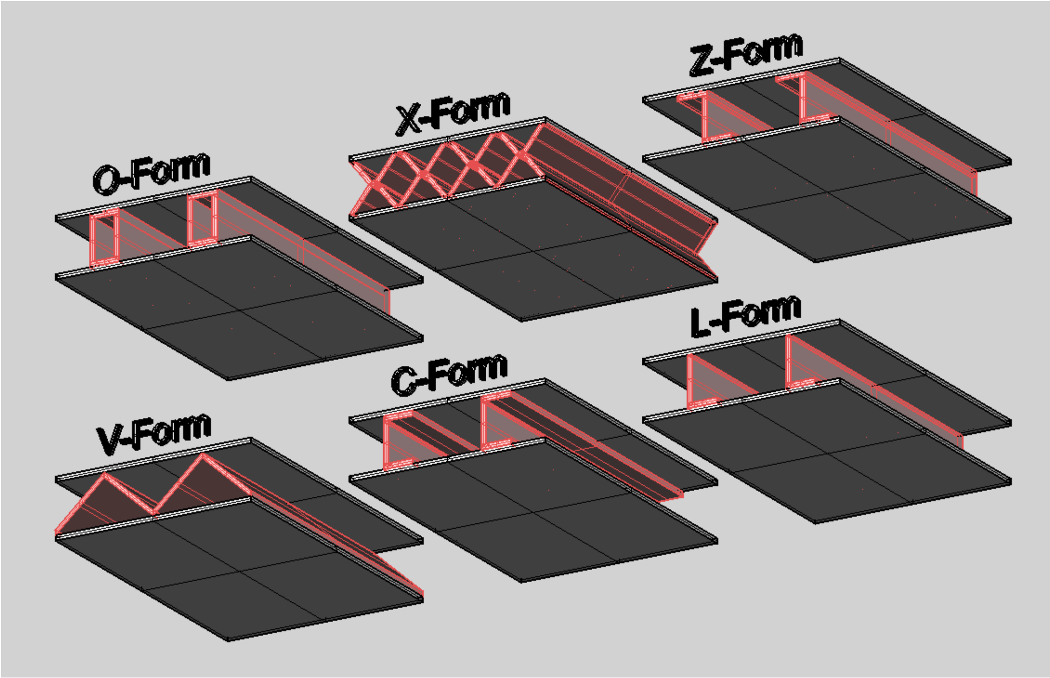
Steel Sandwich Panels

Observed sandwich panel: Web core/Steel sandwich panels (I-core® panel)

Cross-section scantlings:
tp, tw = 1 – 8 mm
hw = 40 – 100 mm
s = 50 – 150 mm (120 mm)



Steel sandwich panel core configurations –
O, X, Z, V, C, L Form



ADVANTAGES

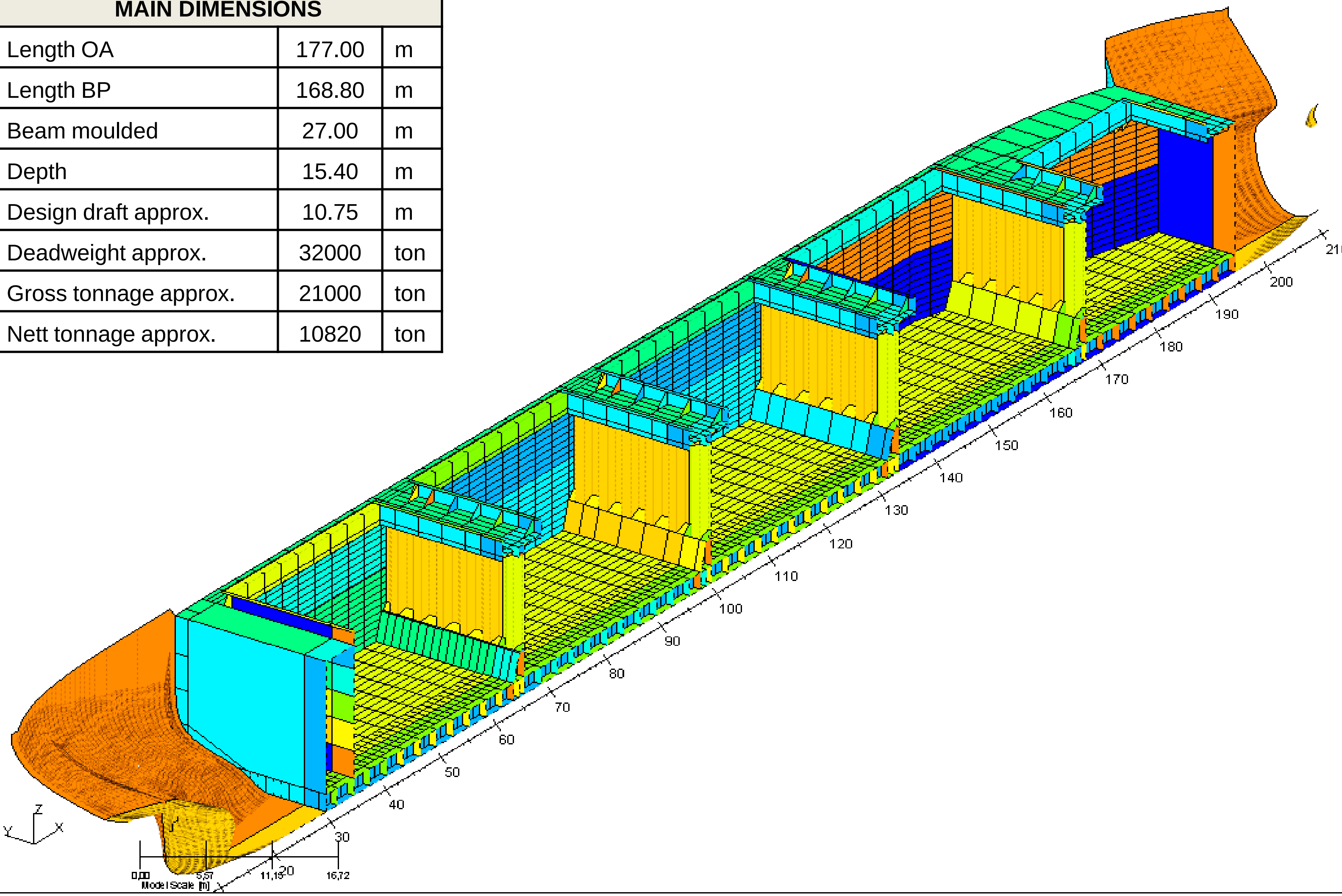
- high structural strength
- improved fire safety and heat insulation
- sound insulation
- corrosion resistance
- high accuracy of assembly
- modular design and ease of assembly
- favourable weight
- fatigue resistance
- structural applicability (ducts and holes)
- explosion and ballistic penetration resistance
- space saving
- energy saving in production

DRAWBACKS

- high investment costs
- no Classification Rules related
- limited applicability
- relatively new material (no feedback)
- not widely used/trusted by the industry
- limited structural inspectability
- ...

Design Introduction – The Initial Model

MAIN DIMENSIONS		
Length OA	177.00	m
Length BP	168.80	m
Beam moulded	27.00	m
Depth	15.40	m
Design draft approx.	10.75	m
Deadweight approx.	32000	ton
Gross tonnage approx.	21000	ton
Nett tonnage approx.	10820	ton



Initial Step – Corrugated Bulkhead

As the scantlings of the corrugated bulkheads used on original structure have not been available in initial calculations, the determination of scantlings for these structures will be performed under the scope of this project.

Nomenclature and scantlings calculated according to GL Rules, following values were chosen and verified

$$W = t \cdot d \left(b + \frac{s}{3} \right) \quad [cm^3]$$

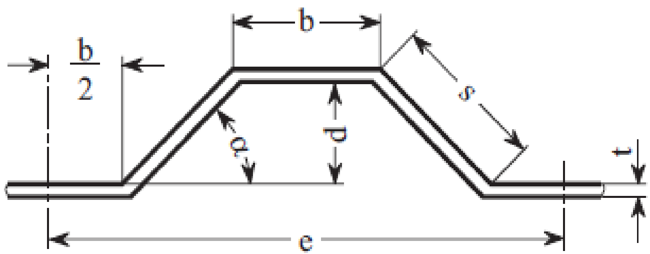


Fig. 11.2 Element of a corrugated bulkhead

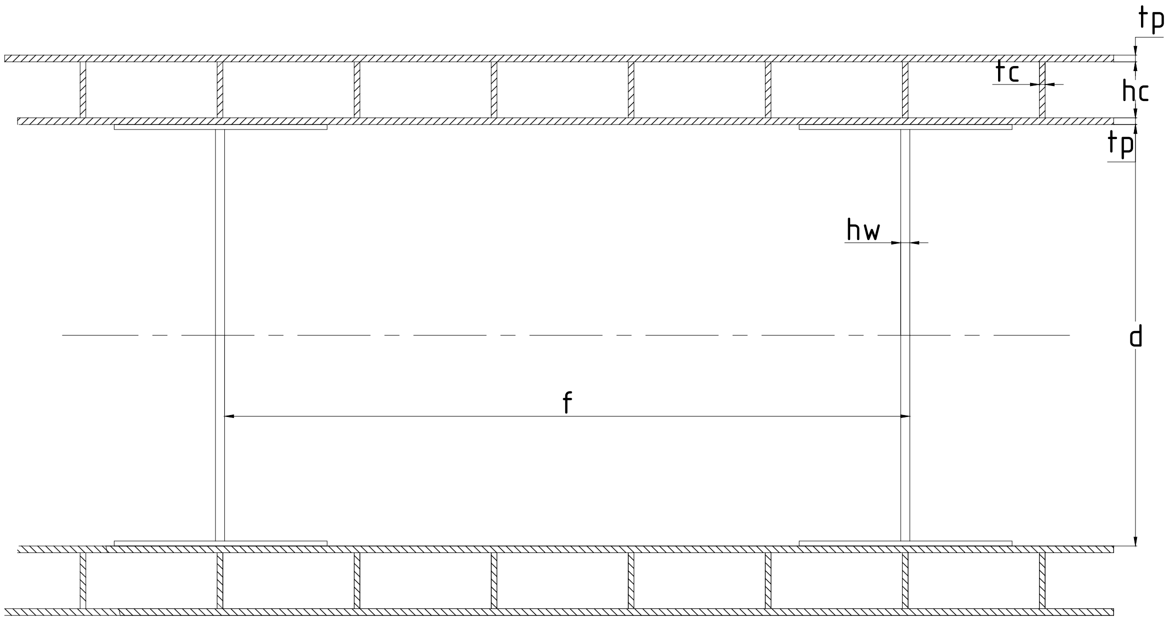
	ReH (N/mm^2)		
	235	315	355
Dimensions	CB2400*700*600*10	CB2400*700*600*8	CB2400*700*600*7
b (mm)	700	700	700
e (mm)	2400	2400	2400
s (mm)	781.02	781.02	781.02
t (mm)	10	8	7
d (mm)	600	600	600
W (cm^3)	5762.05	4609.64	4033.43
kg/m2	2317.80	1483.39	1135.72
Overall mass (t)	227.14	145.37	111.30

Initial Step – Double Sandwich Bulkhead

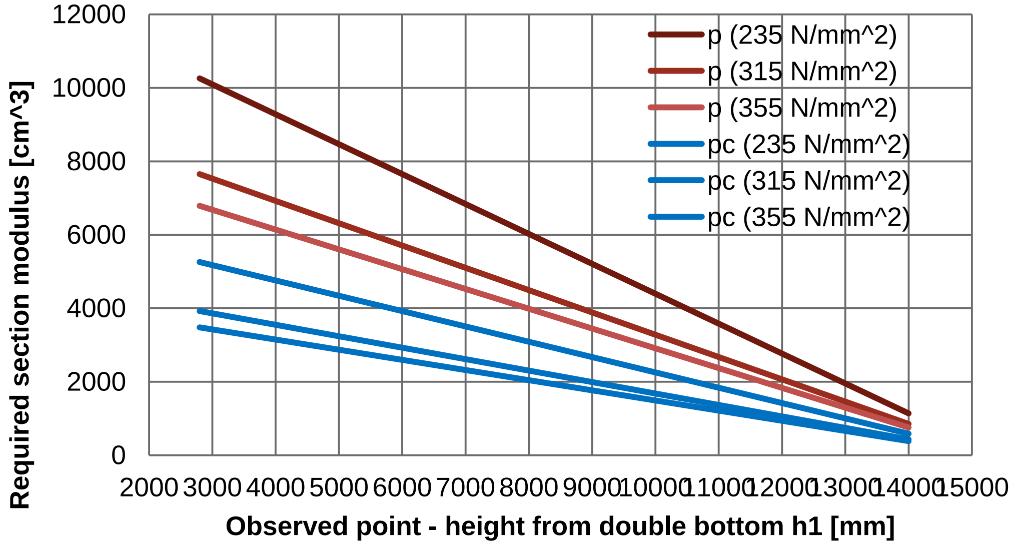
- after calculations of moments of inertia it was observed that single sandwich panel is not offering sufficiently high moment of inertia

- in order to increase the moment of inertia to the value required by the Rules, a new design solution is introduced

- the solution consists of two separated sandwich panels which offer significantly higher section modulus



Corrugated Bulkhead – Sandwich Bulkhead Analogy

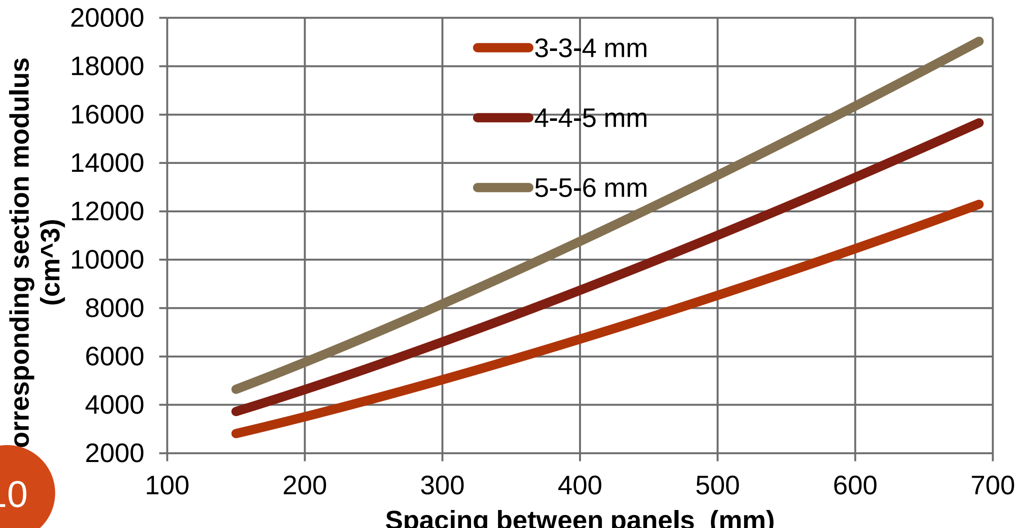


The principle for dimensioning the double sandwich structure:

Required Section Modulus of Corrugated Bulkhead

=

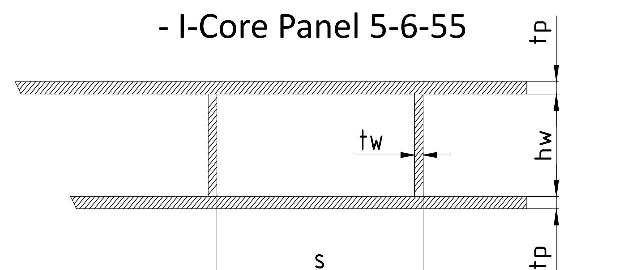
Required Section Modulus of Double Bulkhead



Section Modulus of Double Bulkhead = f(d),

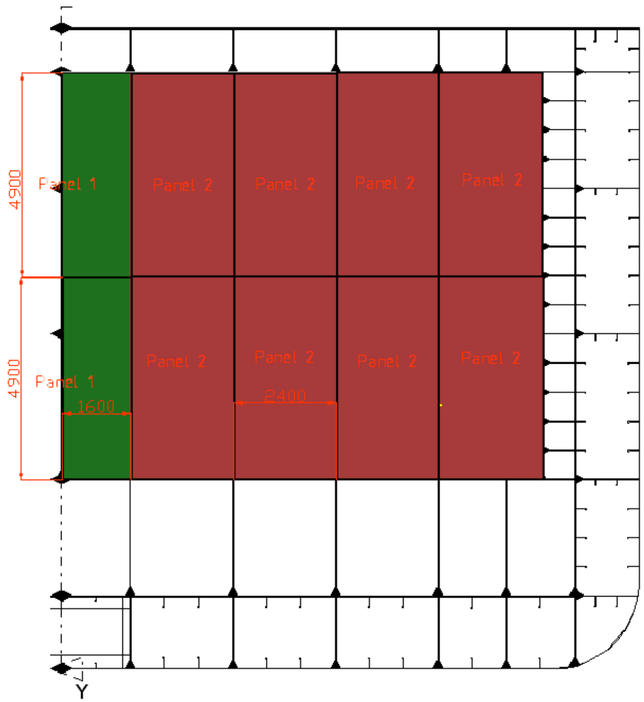
For 3 proposed sandwich panels $t_p - t_w - h_w$:

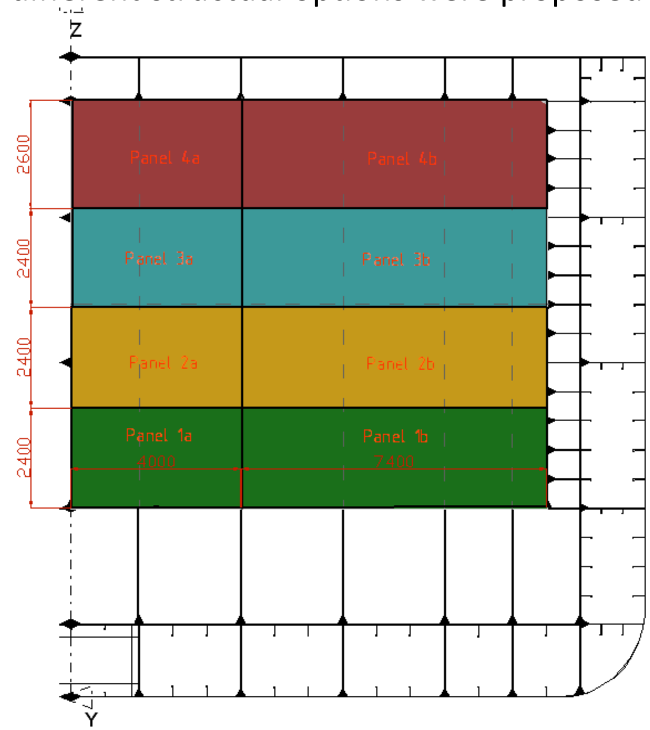
- I-Core Panel 3-4-55
- I-Core Panel 4-5-55
- I-Core Panel 5-6-55



Optimal Design Selection

Following available layout of the surrounding ship structure, 3 different structual options were proposed :





- Vertical panel placement, variable spacing
- Vertical panel placement, constant spacing

- Horisontal panel placement, variable spacing

For each structural proposal, several panel types manufactured from different materials are proposed:

Panel type ($t_p - t_w - h_w$):
- I-Core Panel 3-4-55 mm
- I-Core Panel 4-5-55 mm
- I-Core Panel 5-6-55 mm

Material type:
- R_{eH} = 235 N/mm²
- R_{eH} = 315 N/mm²
- R_{eH} = 355 N/mm²

Weight Comparison (1)

	Dimensions	**Weight (t)**
Corrugated bulkhead CB1	CB2400*700*600*10	227.14
Corrugated bulkhead CB2	CB2400*700*600*8	145.37
Corrugated bulkhead CB3	CV2400*700*600*7	111.30

		for 235 N/mm^2			
		Weight (t)	Reduction for CB1 (%)	Reduction for CB2 (%)	Reduction for CB3 (%)
Panel 3-4-55	Vertical	37.69	83.41	74.07	33.45
	Horizontal	37.34	83.56	74.32	33.23
	Simple	40.42	82.20	72.19	35.14
Panel 4-5-55	Vertical	44.01	80.62	69.73	37.35
	Horizontal	43.73	80.75	69.92	37.18
	Simple	46.12	79.70	68.27	38.66
Panel 5-6-55	Vertical	50.83	77.62	65.04	41.57
	Horizontal	50.82	77.63	65.04	41.56
	Simple	52.73	76.78	63.72	42.75

Weight Comparison (2)

		for 315 N/mm²			
		Weight (t)	Reduction for CB1 (%)	Reduction for CB2 (%)	Reduction for CB3 (%)
Panel 3-4-55	Vertical	35.44	84.40	75.62	68.16
	Horizontal	34.96	84.61	75.95	68.59
	Simple	37.45	83.51	74.24	66.36
Panel 4-5-55	Vertical	41.77	81.61	71.27	62.48
	Horizontal	41.77	81.61	71.27	62.47
	Simple	43.37	80.91	70.16	61.03
Panel 5-6-55	Vertical	48.91	78.47	66.36	56.06
	Horizontal	47.00	79.31	67.67	57.77
	Simple	50.22	77.89	65.46	54.88

		for 355 N/mm²			
		Weight (t)	Reduction for CB1 (%)	Reduction for CB2 (%)	Reduction for CB3 (%)
Panel 3-4-55	Vertical	34.49	84.81	76.27	69.01
	Horizontal	34.03	69.42	76.59	69.42
	Simple	36.30	67.38	75.03	67.38
Panel 4-5-55	Vertical	40.95	63.21	71.83	63.21
	Horizontal	38.92	65.03	73.23	65.03
	Simple	40.95	63.21	71.83	63.21
Panel 5-6-55	Vertical	48.52	56.40	66.62	56.40
	Horizontal	42.45	61.86	70.80	61.86
	Simple	49.53	55.50	65.93	55.50

Design Selection

After the investigation of different sandwich panel possibilities it was observed that there is significant weight reductions (39-83%) compared to classical corr. structures

In the comparison, following objectives were taken under consideration :

- **Weight reduction** (keeping structural capacity)
- **Cost reduction**
  - Structural complexity reduction
  - Reduction of labour
  - Increased use of standard members, better material utilisation

The selected structure for further analisys is:

- I-core PANEL 5-6-55
- Reh = 315 N/mm^2
- Vertical placement of the panels
- Constant inner spacing of the double structure of 390 mm

Analisys of Selected Structure

- Structural response of the structure will be performed using the Finite element method.

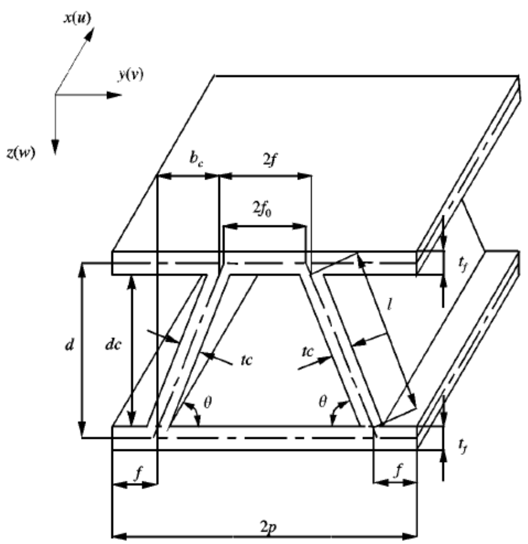
- In order to reduce the high number of elements required for the sandwich panel discretisation, the homogenisation of the panel will be introduced.

- The homogenisation consists of analitical, or another kind of equivalent panel formulation, proposed by different authors.

Equivalent Panel Formulation

- in this case, the homogenisation formulation consists of introducing the orthotropic plate with equivalent properties as corresponding sandwich panel.

- the expressions were formulated by: T. S. Lok, Q. H. Cheng (*Nanyang Technological University, School of Civil and Structural Engineering, Singapore)*



Elastic constants of the truss-core unit derived by the authors are

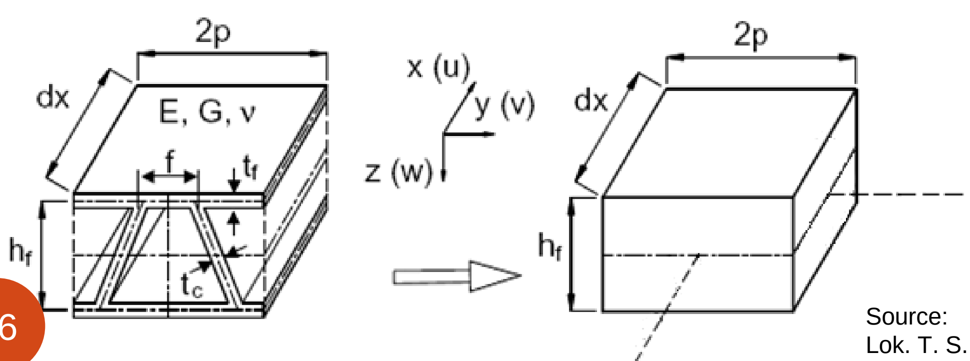
$$D_x = E(I_c + I_f), \qquad D_y = \frac{EI_f}{1 - \nu^2 I_c/(I_c + I_f)}, \tag{2a}$$

$$D_{xy} = GI_f, \qquad \nu_x = \nu, \qquad \nu_y = \nu\frac{D_y}{D_x}, \tag{2b}$$

$$D_{Qx} = Gt_c\frac{\mathrm{d}^2 t_f/plt_c + \frac{1}{6}(\mathrm{d}_c/p)^2}{t_f/t_c + ld_c/3pd}, \qquad D_{Qy} = \frac{1}{(\delta_y^C + \delta_y^F)/d + \delta_z^C/p}, \tag{2c}$$

where δ_y^C, δ_z^C and δ_y^F are deflection parameters described in reference [9]; I_c and I_f are the moments of inertia per unit width of the truss-core cross-section in the yz-plane defined as

$$I_c = \frac{lt_c d_c^2}{12p}, \qquad I_f = \frac{t_f d^2}{2}. \tag{3}$$



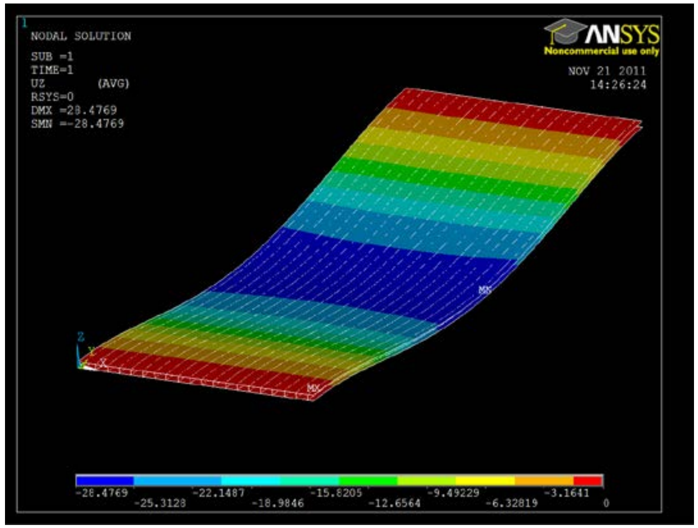
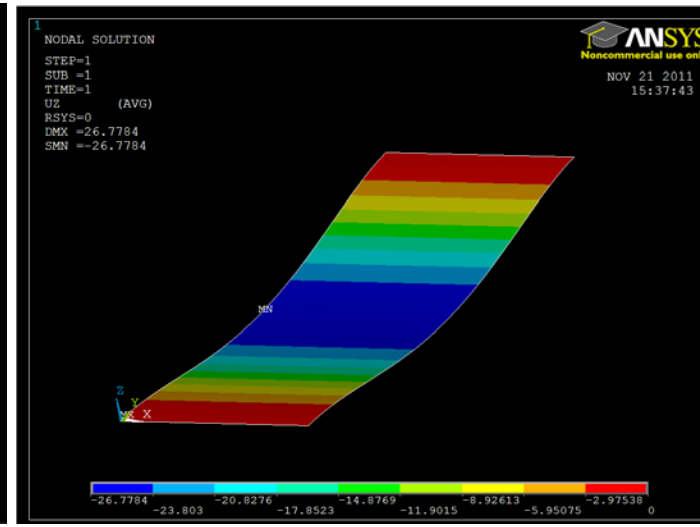
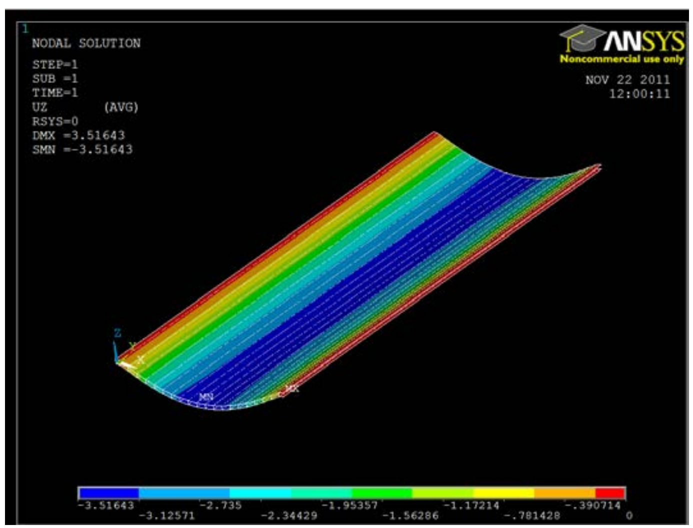
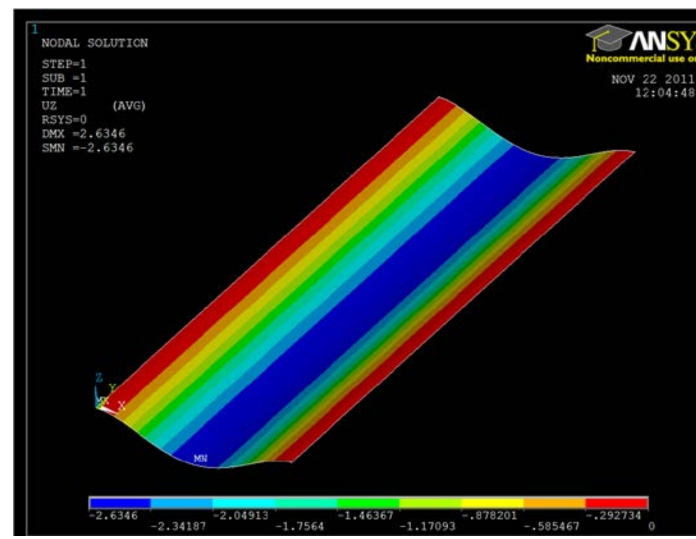
Source:
Lok. T. S. and Cheng. Q. H.. 2000. *Free Vibration Of Clamped Orthotropic Sandwich Panel*. Journal of Sound and vibration (2000) 229(2). 311}327

Sandwich Panel and Equivalent Plate–Comparison

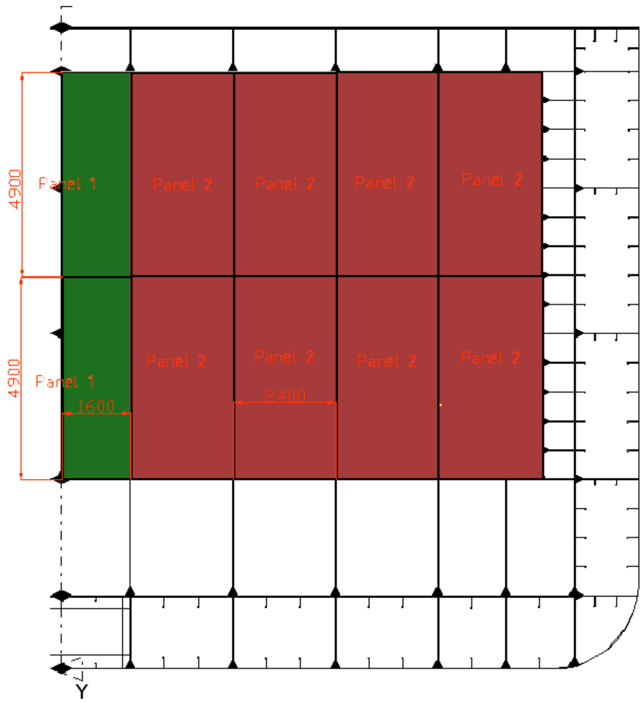
- initial calculations carried out to determine the resemblance in shape and magnitude of displacement for actual panel and equivalent plate
- calculations carried out for different boundary conditions
- resemblance in shape and displacement shown satisfactory
- resemblance in stress distribution unsatisfactory

Output results	Total Displacement (mm)		Difference (%)
	Sandwich panel	Orthotropic plate	
Case 1	28.4761	26.7784	5.96
Case 2	3.51643	2.6246	25.36

Sandwich Panel and Equivalent Plate – Comparison (2)

	Actual panel	Equivalent plate
Case 1		
Case 2		

Equivalent Panels and Actual Structure



Structure consists of the following elements:
- Panel 1: 3200x4900 mm
- Panel 2: 2400x4900 mm

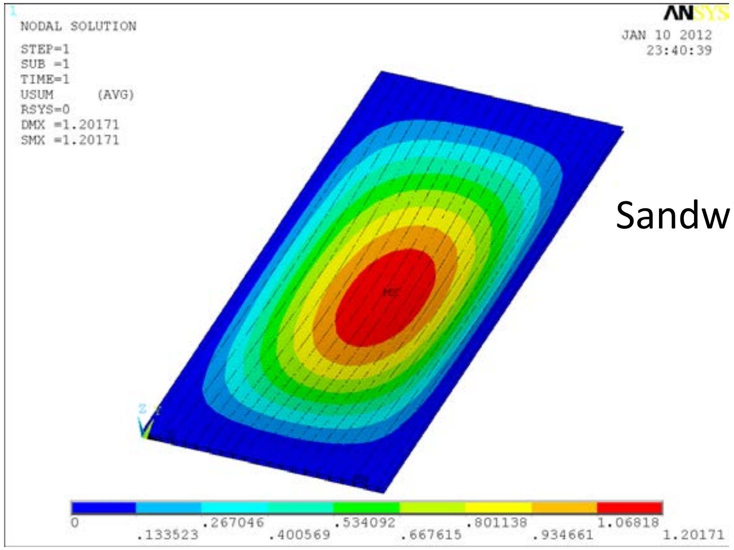
The panels used in actual structure will be observed as clamped on all edges.

The result for this is complete revision of behaviour of previously commented consisting equivalent panels.

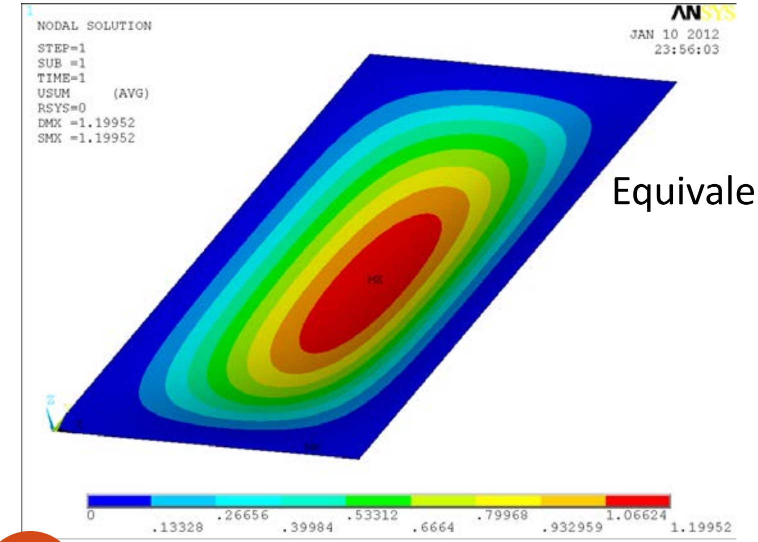
The procedure:
Increasing the load used in the analysis of the actual plate (0.005 MPa) and apply it on the corresponding equivalent plate until the same order of magnitude of a stress is achieved.

$$k = \frac{Increased\ load\ (equivalent\ plate)}{Original\ load\ (sandwich\ panel)} = \frac{load}{0.005}$$

Correction Factor – An Example



Sandwich panel



Equivalent plate

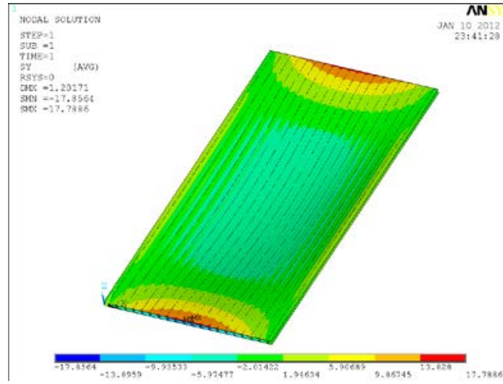
Correction factor obtained for maximal nodal displacement resemblance for this case is k = 8.4

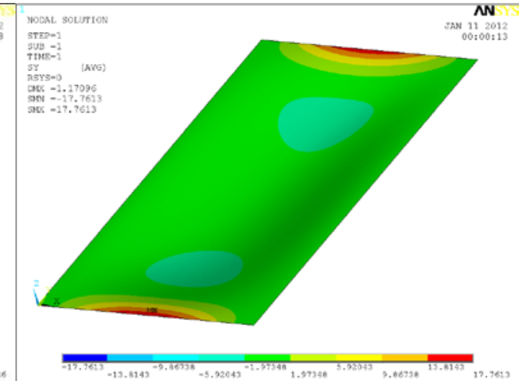
Equivalent Plates for Panel 2400x4900– Preview

Sandwich panel

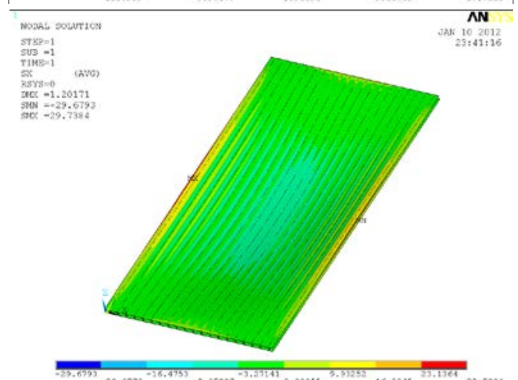
Equivalent plate

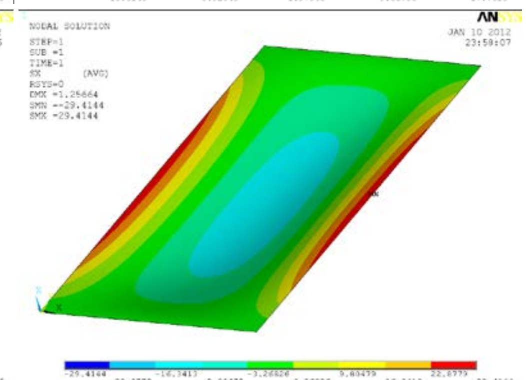
Longitudinal stress distribution



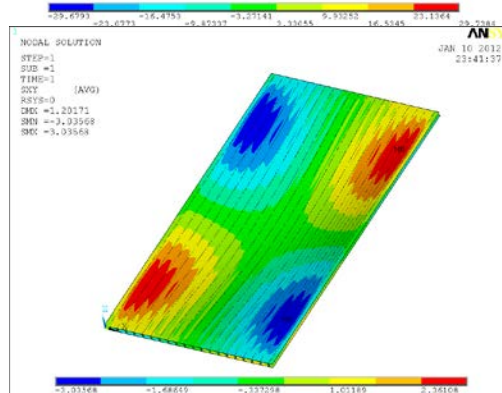


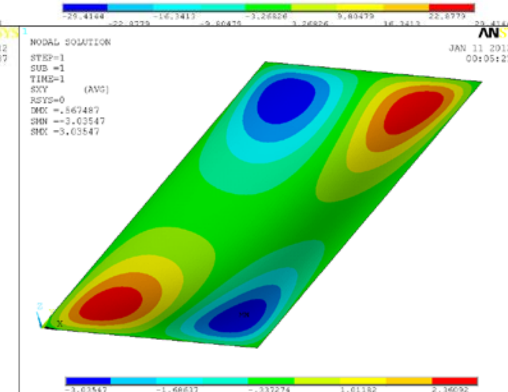
Transversal stress distribution





Shear stress distribution





Correction Factors – Preview

	Panel 2 (3200x4900)		**Panel 1 (2400x4900)**	
	Corrected Load (MPa)	Correction factor	Corrected Load (MPa)	Correction factor
Total displacement	0.0223	4.46	0.042	8.40
(trans. stress) σ_x	0.0285	5.70	0.044	8.80
(long. stress) σ_y	0.0275	5.50	0.041	8.20
(shear stress) σ_{xy}	0.01298	2.60	0.019	3.80

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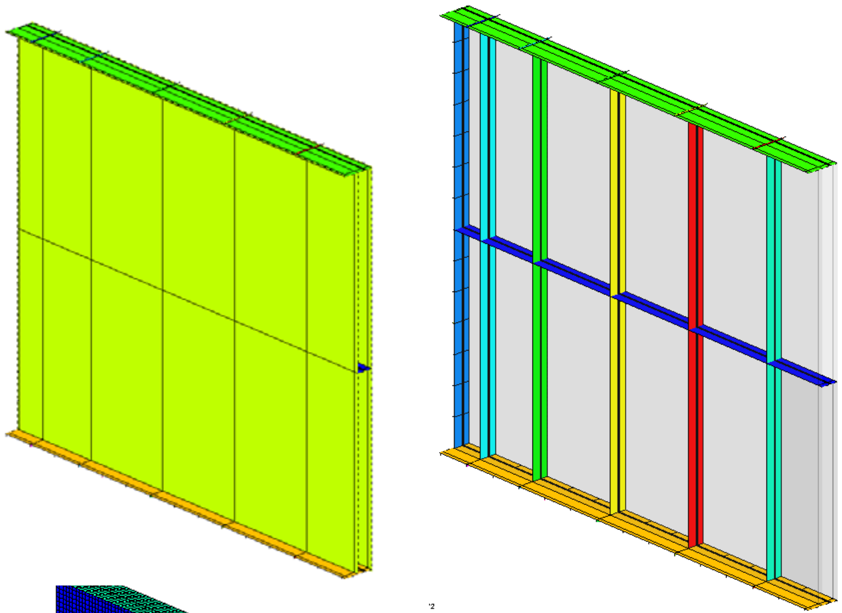
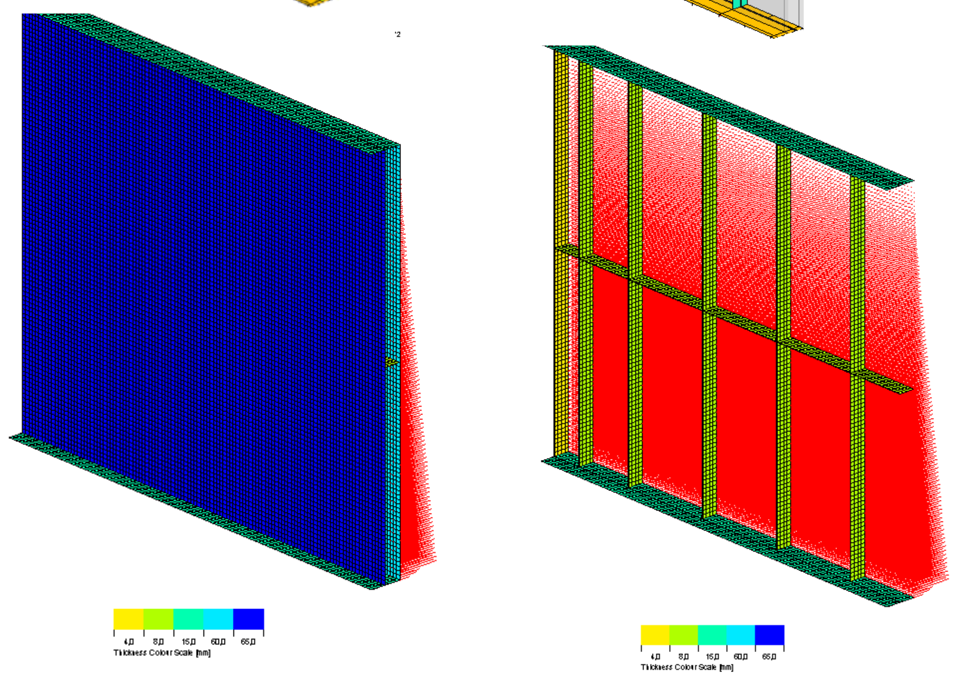
Double Sandwich Panel Bulkhead – Isolated Structure

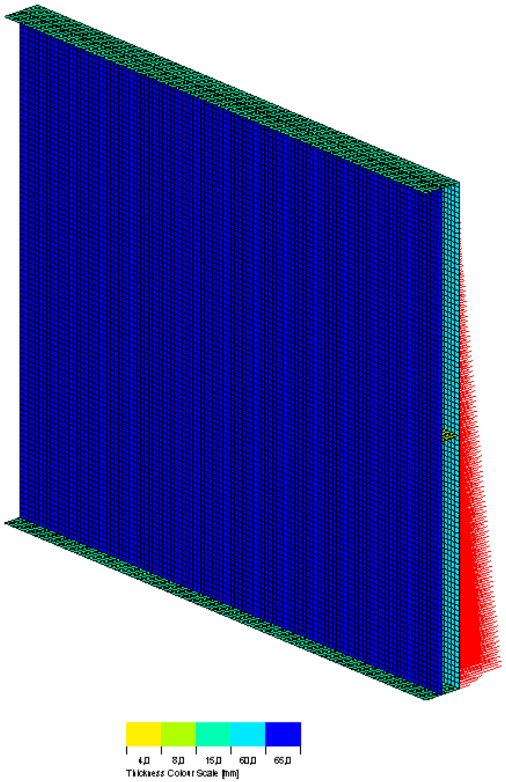


3D Model

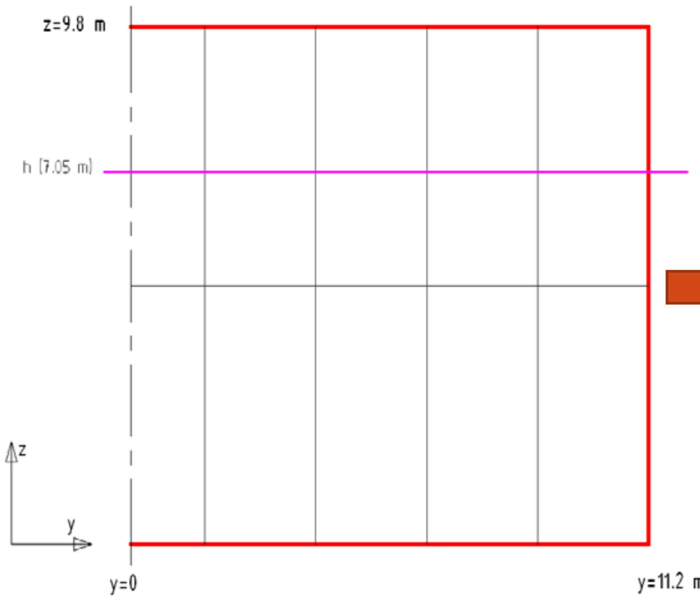


FE Model and nodal forces

Calculation Procedure



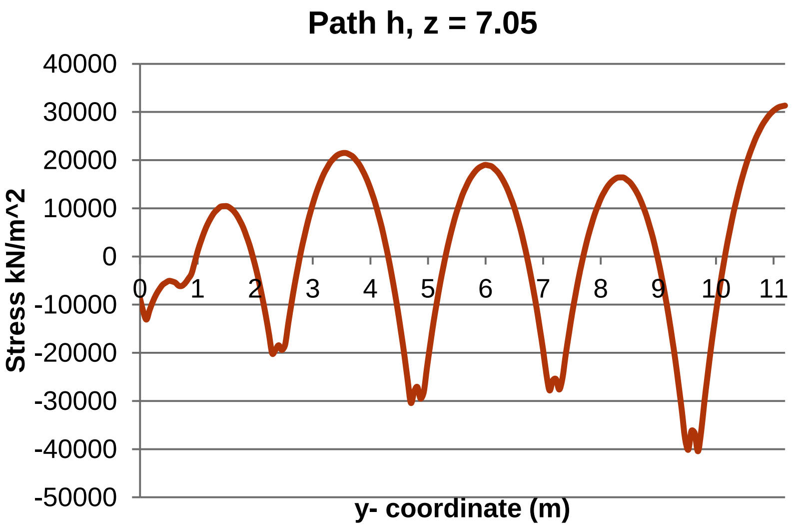
FE Model and nodal forces



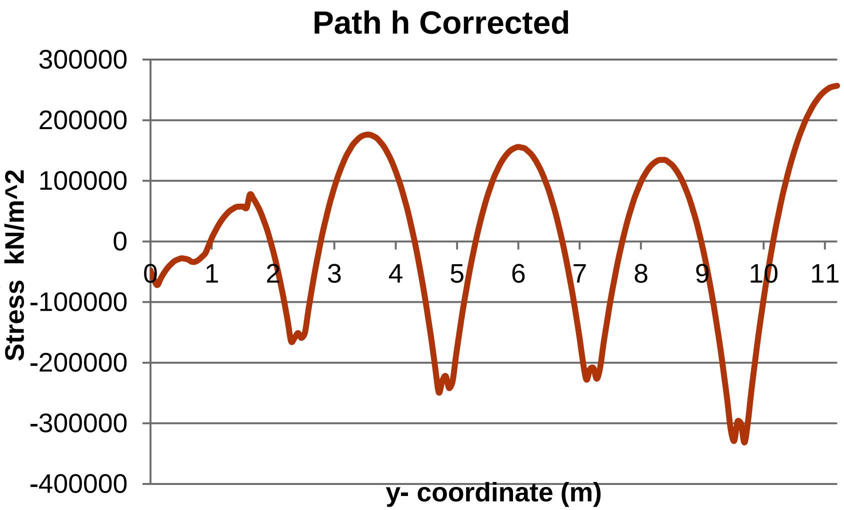
A Cross-section picked

Calculation Procedure – Stress Distribution

Multiplied with corresponding k



Output results from structural analysis



Corrected results

Calculation Procedure of Equivalent Stress

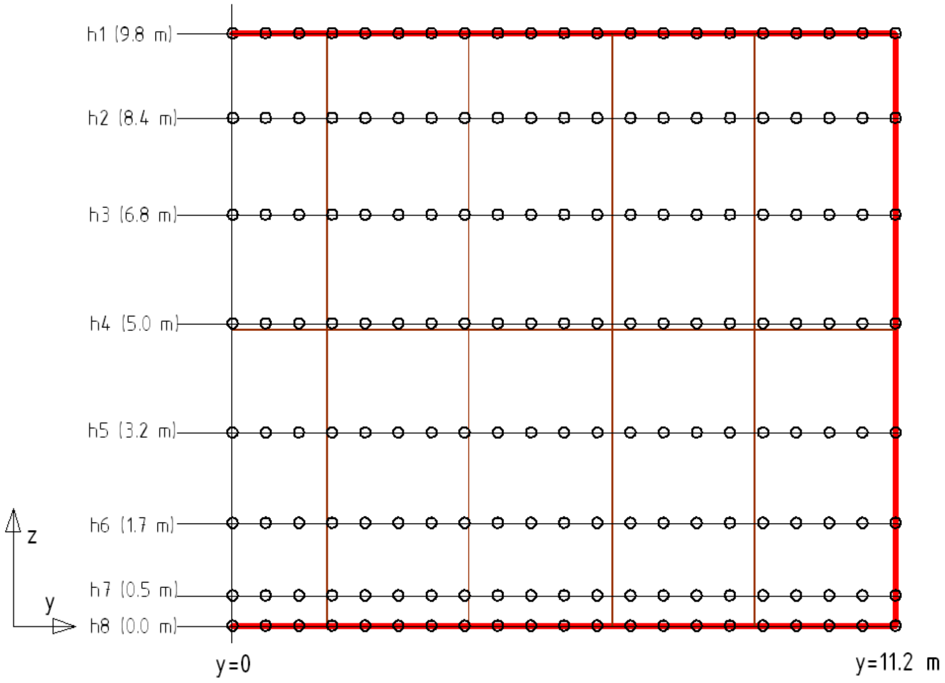
- Following this technique, more realistic values of all stresses in homogenised orthotropic plate can be obtained.

- The structure is divided in 8 horizontal cross-sections on the lower and upper bulkhead edge and vertical positions of 0.5, 1.7, 3.2, 5.0, 6.8 and 8.4 m.

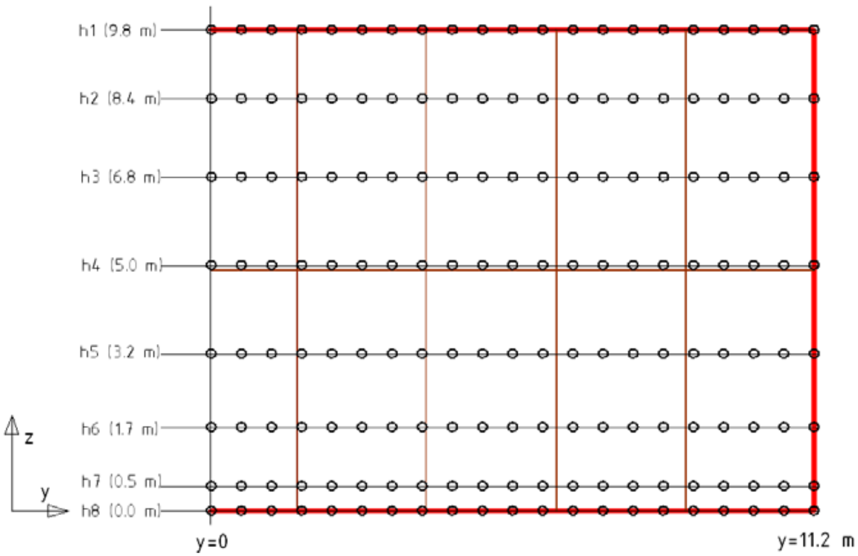
- Each section consists of 20 equally distributed points, forming the grid of distributed points across the surface of the structure.

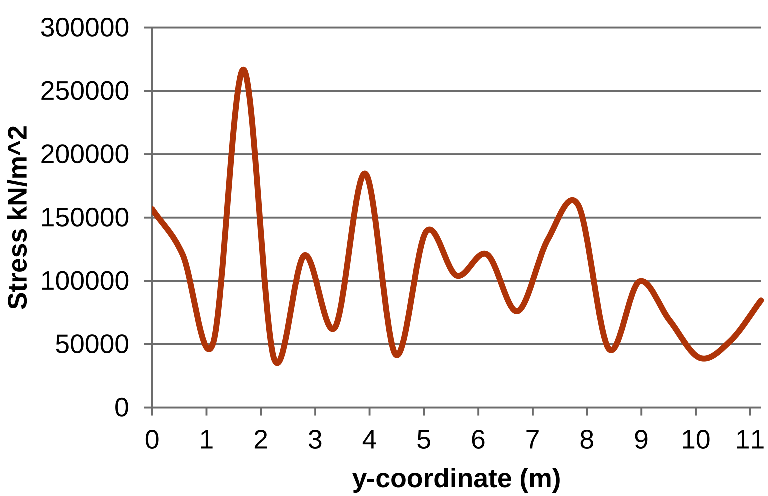
- The positions of points at the horizontal cross-sections from which the values of stresses are acquired for calculation of von Mises equivalent stresses

$$\sigma_e = \sqrt{\sigma_y^2 + \sigma_z^2 - \sigma_y \sigma_z + 3\sigma_{yz}^2}$$



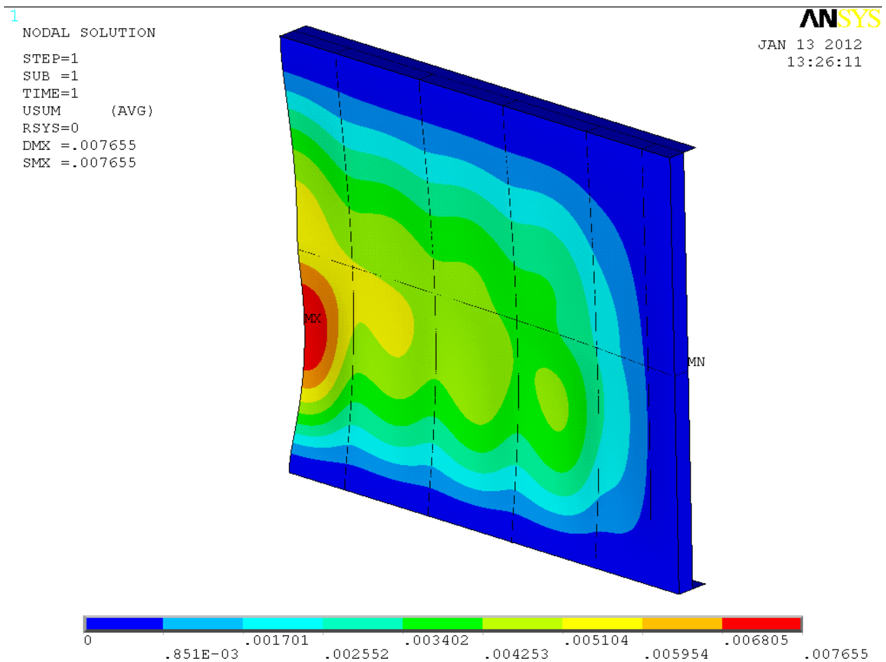
Overview of Equivalent Stresses for Isolated Structure



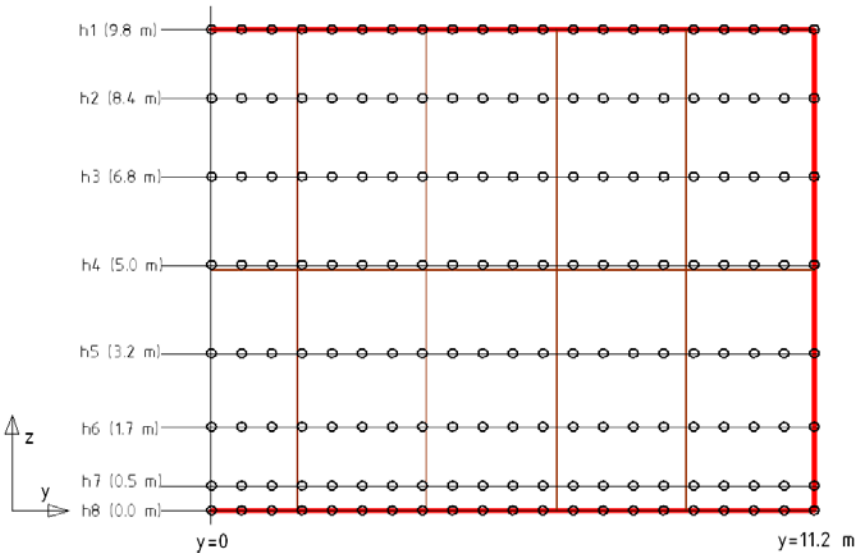


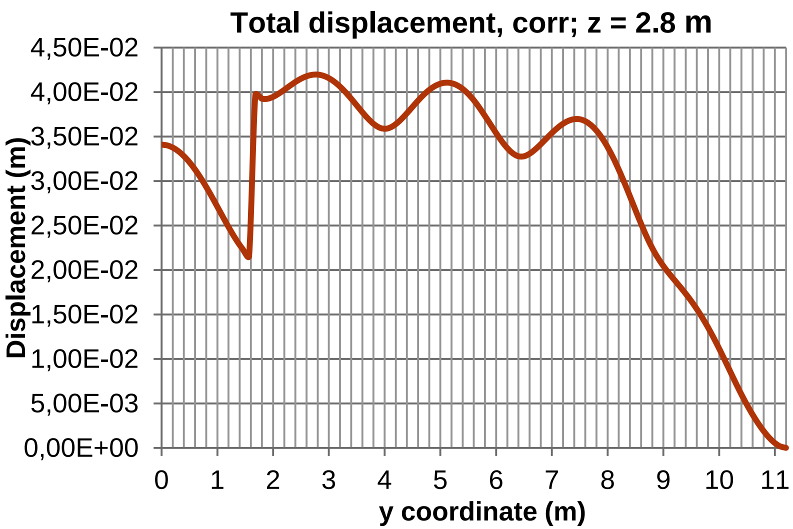
VON-MISES STRESSES (kN/m²)								
y	h1 (9.8 m)	h2 (8.4 m)	h3 (6.8 m)	h4 (5.0 m)	h5 (3.2 m)	h6 (1.7 m)	h7 (0.5 m)	h8 (0.0 m)
0	30993.7	31205.93	56700.33	83698.16	138242.8	156639.1	60535.53	140849.1
0.56	29294.5	28859.92	41834.15	68931.39	99998.01	120833.3	55739.89	125625.9
1.12	29861.8	30591.29	17554.88	34027.69	27827.14	50699.73	54525.2	92998.11
1.68	67178.39	47439.25	112563.5	34850.71	259281.2	266812.3	77887.61	141075.7
2.24	32610.62	31338.65	14121.15	32549.64	10156.51	38889.31	29444.89	113929.4
2.8	28460	29312.02	43411.93	50770.03	93248.12	120178.4	35687.89	127931.6
3.36	30653.5	31542.17	19446.22	39184.77	34916.47	63015.39	30614.9	114724.5
3.92	58120.04	38882.97	80924.87	34361.58	171893.6	184722.6	74116.84	127363.6
4.48	34393.34	34649.6	16990.08	37195.42	6338.596	41732.54	47342.11	112508.1
5.04	28546.46	33225.16	51046.24	61332.43	113712	138931.7	39970.75	132062
5.6	28150.2	30809.89	38245.7	54273.36	80656.9	104177.7	33888.64	123334.1
6.16	42165.88	34191.52	48382.81	28039.69	111134.4	120939.7	70317.24	110590
6.72	37541.97	32029.36	29916.74	34517.91	66785.43	76036.88	66369.82	108212.5
7.28	27900.05	34636.2	55276.36	67096.88	112754.2	132863.6	39147.16	128988.5
7.84	26037.53	38131.34	69072.07	73968.92	142582.3	159678.7	44709.08	131371.8
8.4	25728.52	30954.89	23489.84	46248.63	30801.28	46352.66	53446.7	100409.3
8.96	31296.12	14708.99	25582.27	30099.85	77947.34	99488.48	48121.4	90381.11
9.52	12286.35	20160.19	33957.06	44647.93	60134.56	68741.27	32037.11	72367.67
10.08	6273.479	14521.67	13218.27	48933.15	28005.95	39105.81	41698.58	51142.79
10.64	2788.822	11468.43	43193.71	49131.42	74512.49	52720.22	16725.12	19398.44
11.2	913.7253	20578.88	60987.28	149909.2	110051	84593.51	29321.66	1995.969

Total Nodal Displacement for Isolated Structure



Nodal displacement output results, uncorrected

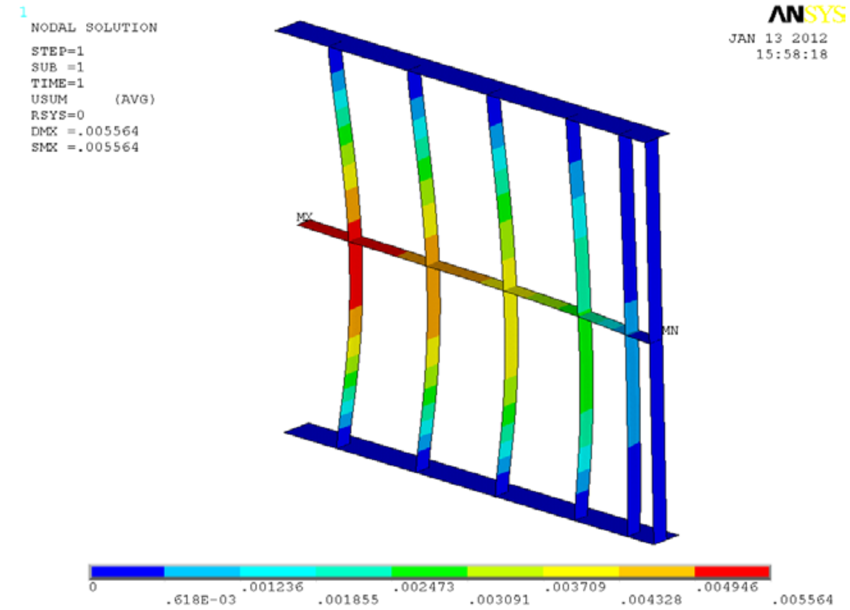




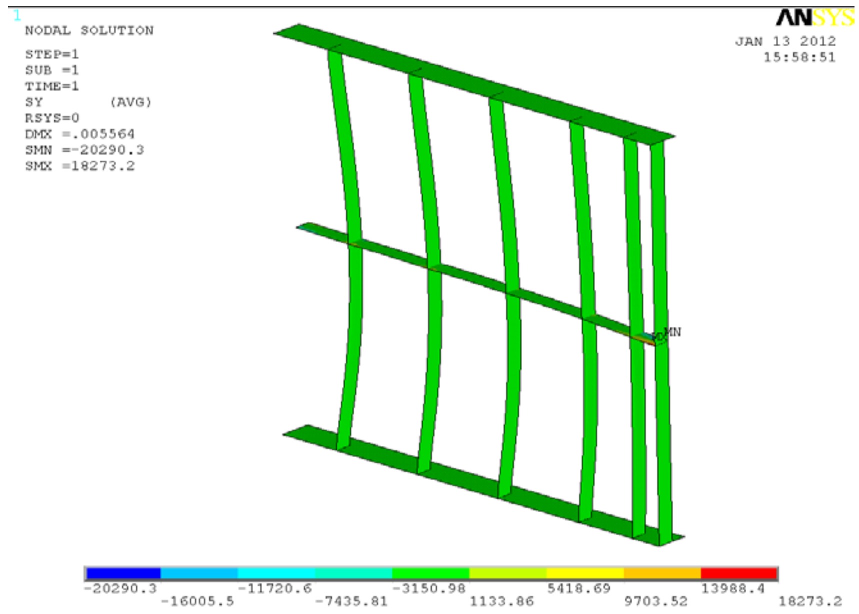
Corrected output results

Distribution of Stresses in the Internal Double Sandwich Bulkhead Structure (1)

Total nodal displacements for internal structure

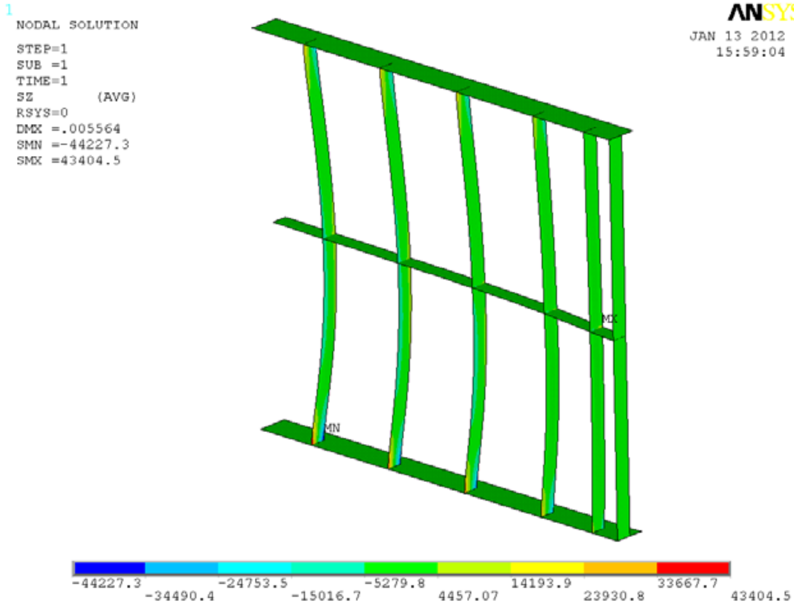


Transversal normal stress distribution for internal structure

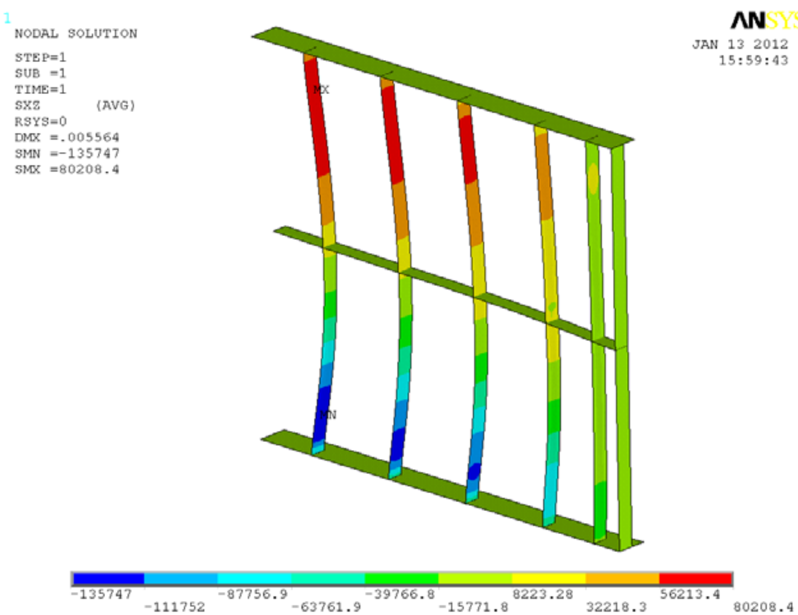


Distribution of Stresses in the Internal Double Sandwich Bulkhead Structure (2)

Vertical normal stress distribution for internal structure

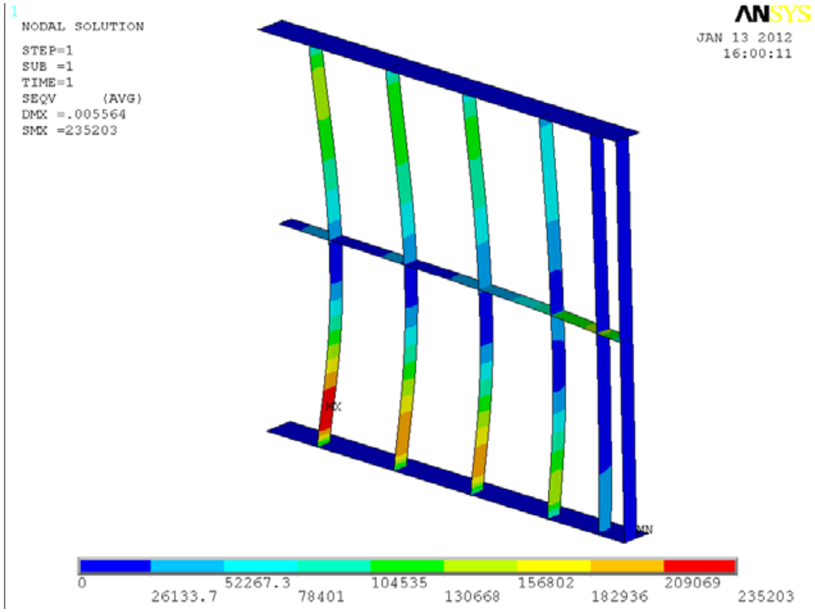


Shear stress distribution for internal structure

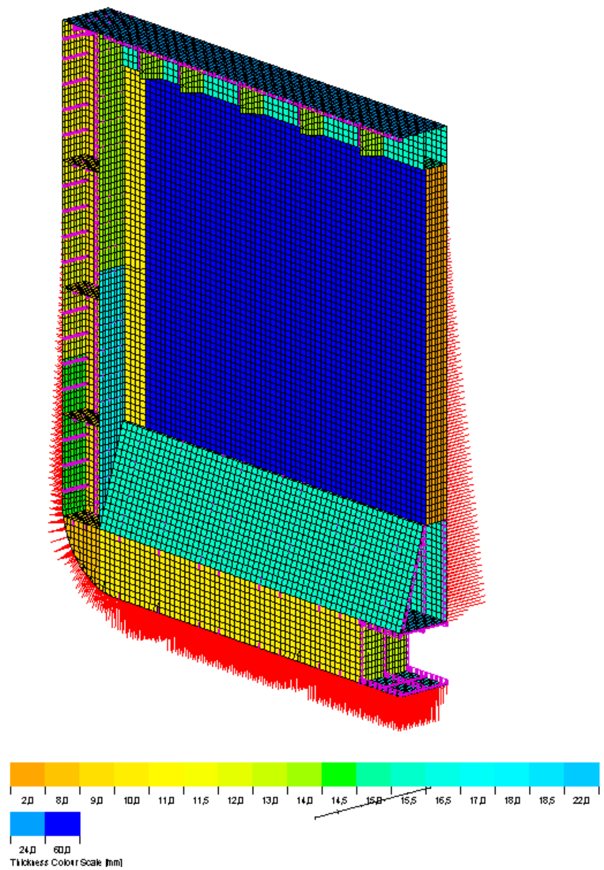


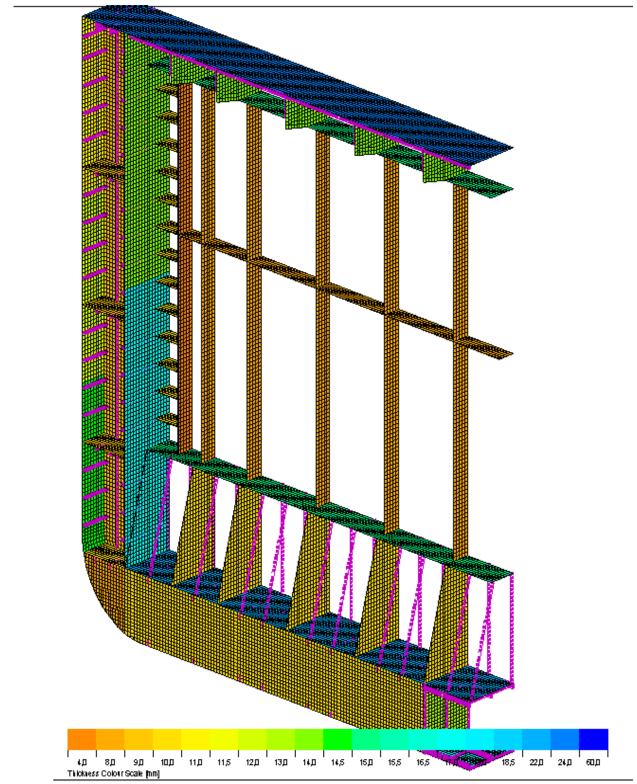
Distribution of Stresses in the Internal Double Sandwich Bulkhead Structure (3)

Von Mises equivalent stress distribution for internal structure



Double Sandwich Bulkhead as a Part of Transversal Bulkhead Structure





Transversal bulkhead structure FE model

ReH (N/mm^2)	k	Permissible stresses (N/mm^2)		
		Normal stress	Shear stress	Von Mises
235	1.00	150.00	100.00	229.13
315	0.75	201.06	134.04	307.13
355	0.66	226.60	151.06	346.13

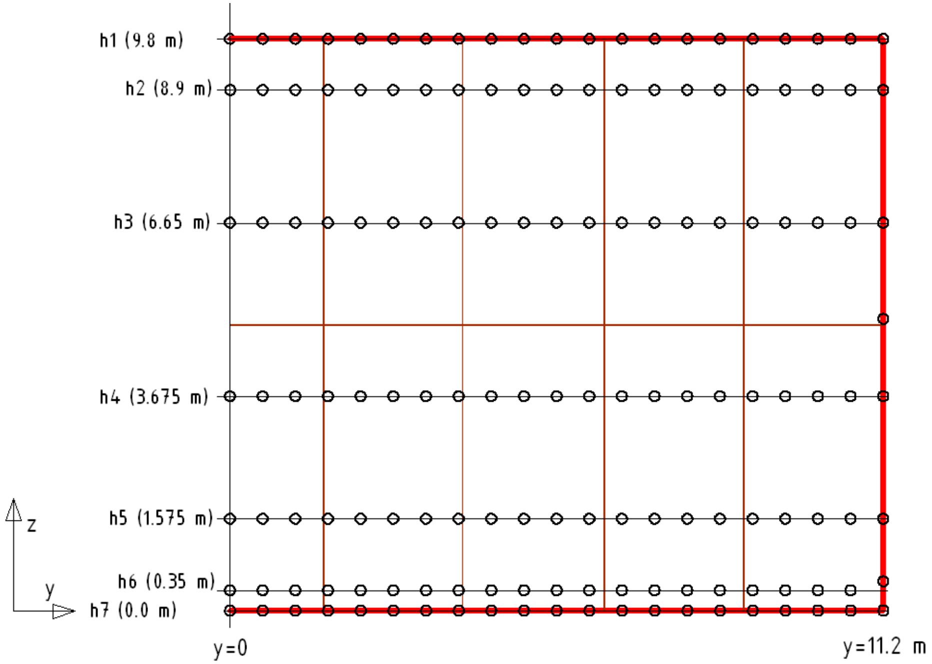
Double Sandwich Bulkhead as a Part of Transversal Bulkhead Structure
The Division

-The structure is divided in 7 horizontal cross-sections on the lower and upper bulkhead edge and vertical positions of 0.35, 1.575, 3.675, 6.65 and 8.9 m.

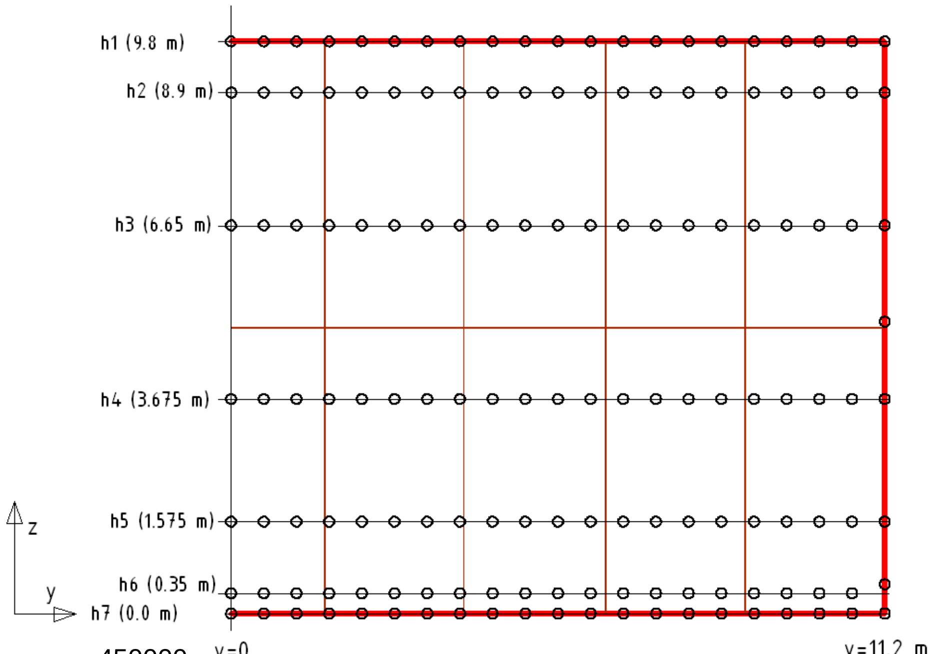
-Each section consists of 20 equally distributed points, forming the grid of distributed points across the surface of the structure.

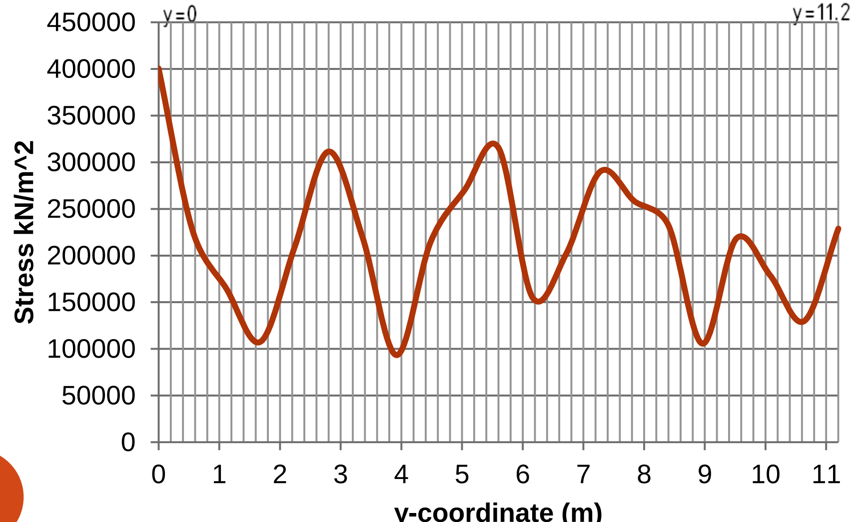
- The positions of points on horizontal cross-sections from which the values of stresses , and are acquired for calculation of von Mises equivalent stresses will be presented

$$\sigma_e = \sqrt{\sigma_y^2 + \sigma_z^2 - \sigma_y\sigma_z + 3\sigma_{yz}^2}$$



Double Sandwich Bulkhead as a Part of Transversal Bulkhead Structure
Distribution of Equivalent Stress

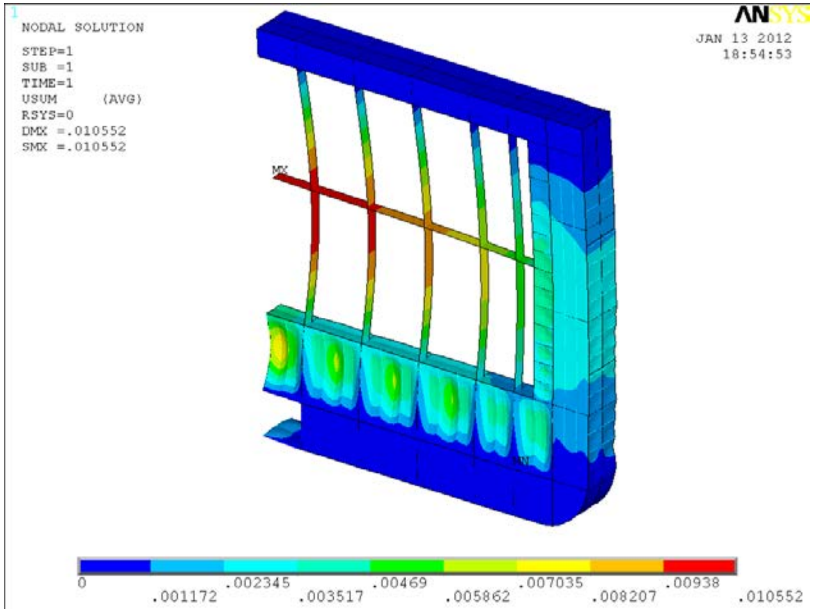




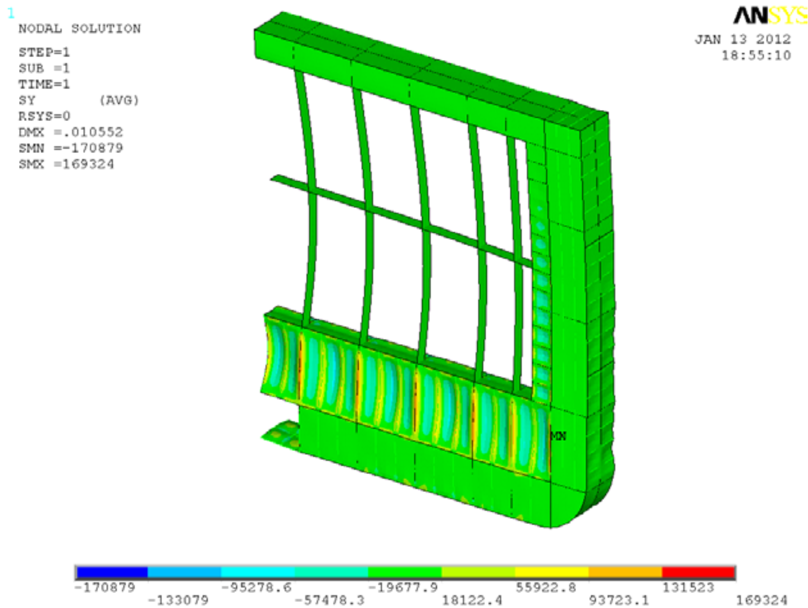
VON MISES STRESSES (kN/m²)							
y	h1 (9.8 m)	h2 (8.925 m)	h3 (6.65m)	h4 (3.675 m)	h5 (1.575 m)	h6 (0.35 m)	h7 (0 m)
0	18847.98	25417.51	53358	106366.9	149512.5	136834.5	400689
0.56	20508.56	42926.17	38224.18	90017.88	128771.9	136773.9	226817.2
1.12	37443.3	70644.3	43064.45	87092.27	118923.9	175545.3	164220.1
1.68	83637.88	38524.71	139045.8	241428.8	272888.1	51071.61	107602.1
2.24	29062.76	50155.91	60101.42	67732.16	66821.55	153109.8	208724.4
2.8	8667.23	8741.473	54474.08	86477.19	107695.1	85444.08	311528.9
3.36	25425.41	45363.31	51571.45	65199.9	66586.32	153947.1	219725
3.92	73675.93	33763.5	111424.4	182073	199159.3	67194.64	93265.81
4.48	38483.33	68520.66	67999.8	68644.65	91790.78	172621.1	214232.7
5.04	10677.94	26605.05	59099.18	94769.26	131070.9	104986.7	270125.7
5.6	15346.49	31830.18	45107.56	82102.98	99057.88	125724.1	315666.3
6.16	69150.1	68238.11	96093.31	157380.5	178045.8	154223.8	155208.1
6.72	53471.54	76641.4	89044.08	115912.4	142449.1	169481.4	202346.5
7.28	14288.17	41718.86	57434.71	82868.17	131181.3	109497.6	290269.5
7.84	11676.16	32139.84	59751.66	113596.1	154095.4	102004.2	258288.7
8.4	36281.93	62424.95	40010.74	94232.55	89467.84	180165.6	232476.6
8.96	39368.56	27247.55	86222.7	130906.1	128547	51832.92	105549.9
9.52	20941.41	14863	55538.12	77264.15	71333.53	56721.14	218310.7
10.08	34800.06	36964.22	50262.36	82080.9	68276.58	113830.4	178485.6
10.64	20985.16	13010.82	48090.06	77452.97	44933.99	19371.91	129826.9
11.2	55670.68	29099.19	120009.5	202154.9	183766.5	274622.7	228864.4

Double Sandwich Bulkhead as a Part of Transversal Bulkhead Structure Distribution of Stresses (1)

Total nodal displacements for internal structure

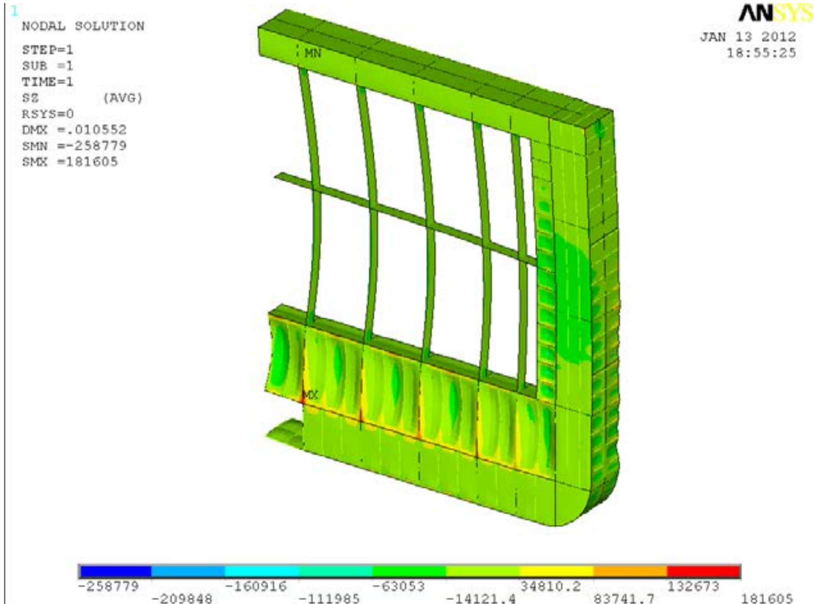


Transversal normal stress distribution for
internal structure

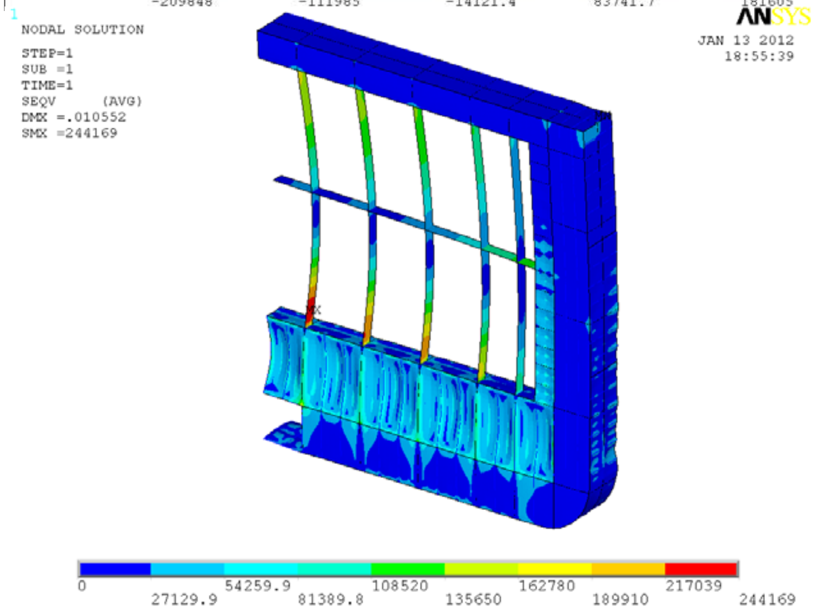


Double Sandwich Bulkhead as a Part of Transversal Bulkhead Structure
Distribution of Stresses (2)

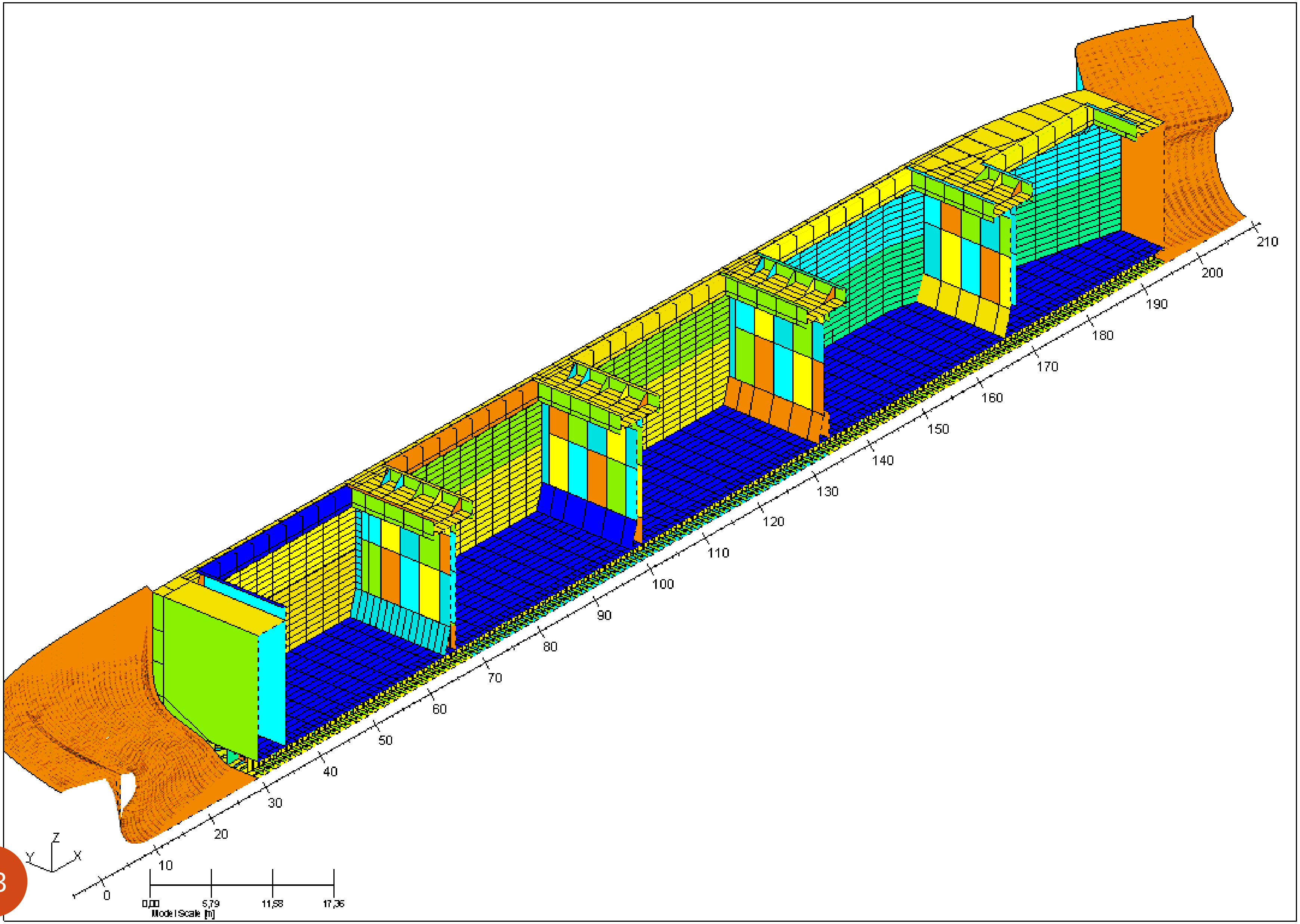
Vertical normal stress distribution for internal structure



Equivalent stress distribution for internal structure



The Preview of the Entire Structure



Conclusion

- Sonsiderable simplification of the problem. Many effects as dynamic analysis, fatigue analysis, cost analysis, manufacturability etc. were not taken under consideration under scope of this project;

- Structural connections between panels and their influence are not taken into consideration.

- Sulkhead observed strictly as an isolated part. The influence of global stress distribution not taken into consideration

- Souble bulkhead structure is slightly over-dimensioned: the equivalent stress mostly under the values permitted by Rules.

- Local excessive stresses should be additionally observed and several design improvements introduced to reduce the effect

- Preliminary design performed as an initial step in design loop. Room for structural improvements and/or optimisation process.

- No Rules for sandwich structures available – rules for dimensioning corrugated structure used instead

- Homogenisation and analysis results should be justified by feedback from an experiment or actual structure (no similar project available)

Thank you for your attention!
Merci pour votre attention!
Dziękuję za uwagę!
Hvala na pozornosti!
¡Gracias por su atención!
en Dank für Ihre Aufmerksamkeit!
Grazie per la vostra attenzione!
أشكركم على اهتمامكم!
感谢您的关注
आप अपना ध्यान के लिए धन्यवाद