NATIONAL TECHNICAL UNIVERSITY OF ATHENS
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MASTER THESIS

«Finite Element Analysis of a Bulk Carrier Vessel's Cargo Hold for Yield and Buckling Strength Assessment According to IACS Common Structural Rules»

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Abstract:

The present thesis presents the work carried out to assess the yield and buckling strength of a Bulk Carrier using Finite Element Methods in order to calculate the areas of the central cargo ship exposed to greater stresses. A combination of design methodologies has been considered for the structural analysis of a bulk carrier ship's cargo hold. The validation of the results was made following the guidelines "Common Structural Rules for Bulk Carriers and Oil Tankers" from IACS. The finite element method and finite element analysis software ANSYS Mechanical APDL software was used to analyze static and dynamic load case of the full load condition. This methodology has been applied to analyze some of the mechanical properties of the model such as total deformation, stress- strain distribution, Von Mises stress, Buckling etc.

The work consists of four stages. The first gives the theoretical background, presents the basic principles of the IACS Common Structural Rules. The focus is on the bending analysis of a central tank of the ship, applying the method for Partial Ship Analysis of these regulations. In the second stage, the modeling of the three cargo tanks is presented, but our interest is focused on the central tank. In the third stage, the whole construction is discretized (meshhing) and the limit conditions are entered. Moreover, this stage presents the various charging stages and the way in which these loads are transferred to the discrete model. The Request should not be introduced into the local loads in the form of pressure at suitable nodes and transferred to hull girder beam loads at the ends of the model to enable analysis. In the fourth and last stage you have the results. Finally, the conclusions are presented.

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1. Introduction

The increasing demands placed on Bulk Carrier safety have reinforced the commitment of regulatory bodies to look for higher design standards and to improve the overall approach to design criteria. IACS has developed, for the first time, a unified complete set of Common Structural Rules for Bulk Carriers. New CSR rules implement advanced structural and hydrodynamic computational methods to establish new criteria applied in a consistent manner, which will result not only in a more robust, safer ship, but will also eliminate the possibility of using scantlings and steel weight as a competitive element when selecting a class society to approve a new design.

Nowadays, the use of finite element analysis is a conventional method applied to resolve the majority of problems related to structural calculation. The overall objective of proposed work is to assess the yield and buckling strength of primary members and stiffeners of bulk carrier according to Common Structural Rules for Bulk Carriers. Analyzing ship as a whole is quite tedious and time consuming. Normally studies are carried out on individual primary structural members for various cases. Finite element calculation methods today have reached a certain state of maturity, at least regarding linear analysis. Currently, pre and post-processing programs are developed to make the complex analyses less cumbersome and less time consuming and to minimize the risk of errors.

2. Partial ship structural analysis - Theoretical Background

2.1 Finite element analysis of ship hull structures

Common Structural Rules describe the scope and methods required for structural analysis of ships and the background for how such analyses should be carried out. These IACS guidelines application are based on relevant Rules for Classification of Ships and they are adopted from all class societies.

The objective of these rules is to give a guidance for finite element analyses and assessment of ship hull structures in accordance with Common Structural Rules, to give a general description of relevant finite element analyses and to achieve a reliable design by adopting rational analysis procedures.

2.2 Calculation methods

The Class Guideline provides descriptions for three levels of finite element analyses:

1. Global direct strength analysis to assess the overall hull girder response.
2. Partial ship structural analysis to assess the strength of hull girder structural members, primary supporting structural members and bulkheads.
3. Local structure analysis to assess detailed stress levels in local structural details.

In the present work the analysis will be performed with the second method, 'Partial ship structural analysis' and the following chapter presents this methodology in detail.

2.3 Structural model

As mentioned above, the partial ship structural analysis is used for the strength assessment of scantlings of hull girder structural members, primary supporting members and bulkheads.

The aim of the cargo hold FE analysis is to assess the overall strength of the structure in the evaluation areas. Modelling the ship's plating and stiffener systems with a stiffener spacing mesh size, s x s, is sufficient to carry out yield assessment and buckling assessment of the main hull structures. In our model for more accuracy we use mesh size with half stiffener spacing. For partial ship analysis, the FE model is to extend so that the model boundaries at the models end are adequately remote from the evaluation area. Normally, the longitudinal extent of the cargo hold FE model is to cover three cargo hold lengths. Both port and starboard sides of the ship are to be modelled. The full depth of the ship is to be modelled including primary supporting members above the upper deck. The transverse bulkheads at the ends of the model can be omitted. Typical finite element models representing the midship cargo hold region of different ship type configurations are shown in figure 1.

Shell elements are to be used to represent plates. All stiffeners are to be modelled with beam elements having axial, torsional, bi-directional shear and bending stiffness. The eccentricity of the neutral axis is to be modelled. Alternatively, concentric beams (in NA of the beam) can be used providing that the out of plane bending properties represent the inertia of the combined plating and stiffener. The width of the attached plate is to be taken as ½ + ½ stiffener spacing on each side of the stiffener. The shell element mesh is to follow the stiffening system as far as practicable, hence representing the actual plate panels between stiffeners, i.e. s x s, where s is stiffeners spacing.

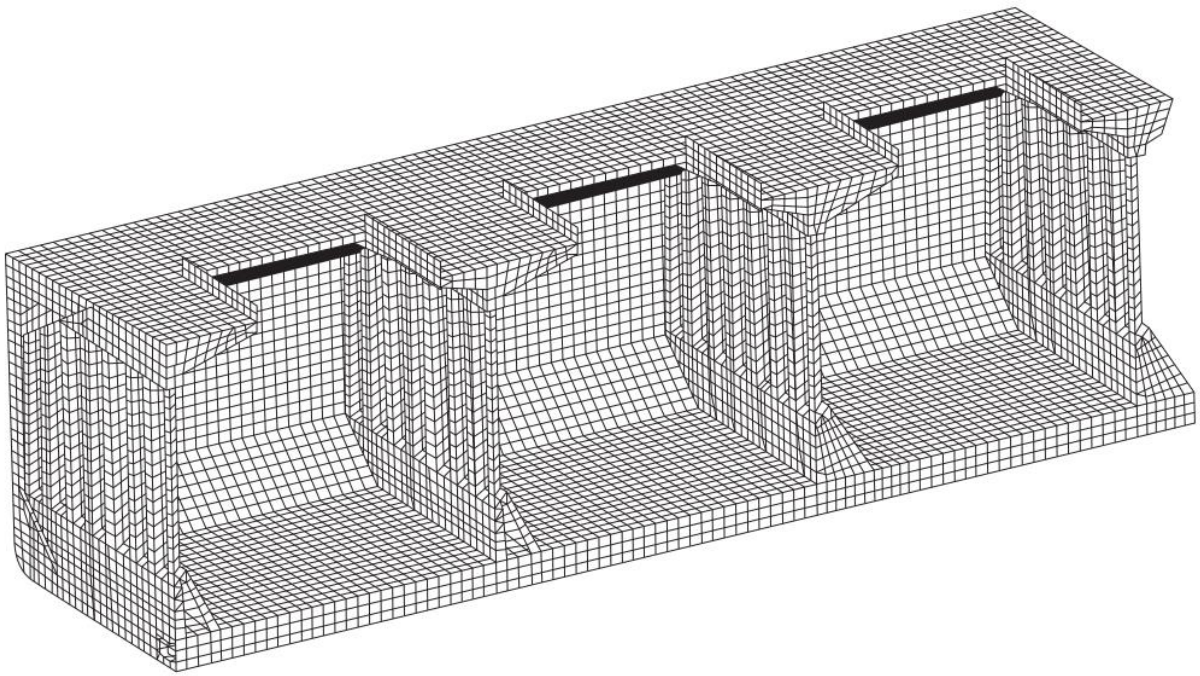


***Figure** 1 - Example of 3 cargo hold model within midship region of a bulk carrier (shows only port side of the full breadth model), IACS Common Structural Rules*

2.4 Boundary conditions

In general, the model needs to be supported at the model's end(s) to prevent rigid body motions and to absorb unbalanced shear forces. The boundary conditions shall not introduce abnormal stresses into the evaluation area. Where relevant, the boundary condition shall enable the adjustment of hull girder loads, such as hull girder bending moments or shear forces. Rigid links in y and z are applied at both ends of the cargo hold model so that the constraints of the model can be applied to the independent points. Rigid links in x-rotation are applied at both ends of the cargo hold model so that the constraint at fore end and required torsion moment at aft end can be applied to the independent point. The x-constraint is applied to the intersection between centreline and inner bottom at fore end to ensure the structure has enough support. The boundary conditions to be applied at the ends of the cargo hold FE model, are given in table 1 and in figure 2 are given the boundary conditions applied at the model end sections.

Location	*Translation*			*Rotation*		
	δ_x	δ_y	δ_z	θ_x	θ_y	θ_z
Aft End						
Independent point	-	Fix	Fix	$M_{T\text{-}end}$ (4)	-	-
Cross section	-	Rigid link	Rigid link	Rigid link	-	-
	End beam					
Fore End						
Independent point	-	Fix	Fix	Fix	-	-
Intersection of centreline and inner bottom (3)	Fix	-	-	-	-	-
Cross section	-	Rigid link	Rigid link	Rigid link	-	-
	End beam					

Note 1: [-] means no constraint applied (free).

Note 2: See Figure

Note 3: Fixation point may be applied on other continuous structures such as outer bottom at centreline. If exists, the fixation point can be applied at any location of longitudinal bulkhead at centreline, except independent point location.

Note 4: hull girder torsional moment adjustment in kNm

Table 1 - Boundary constraints at model ends except the foremost cargo hold models

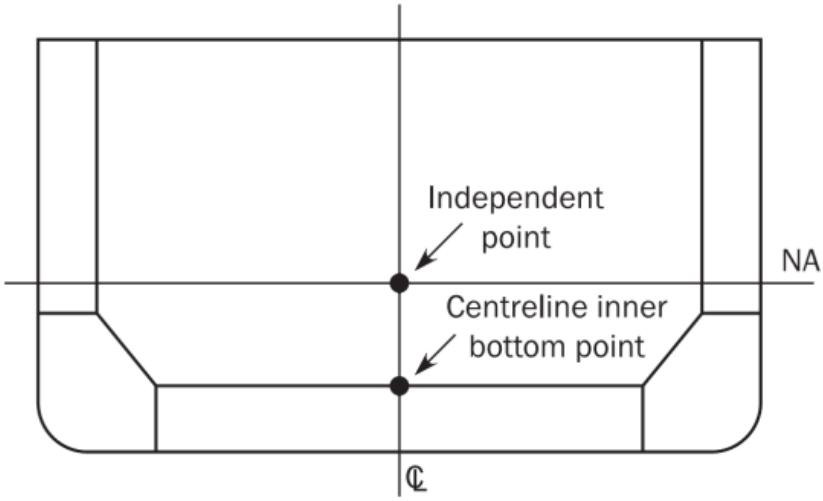


Figure** 2 - **Boundary conditions applied at the model end sections

2.5 F.E. load combinations and load application

Design loads are to provide an envelope of the typical load scenarios anticipated in operation. The combinations of the ship static and dynamic loads which are likely to impose the most onerous load regimes on the hull structure are to be investigated in the partial ship structural analysis. Design loads used for partial ship FE analysis are to be based on the design load scenarios, as given in table 2. For the strength assessment, the principal design load scenarios consist of either S (static) loads or S + D (static + dynamic) loads. In some cases, the letter 'A' prefixes the S or S + D to denote that this is an accidental design load scenario. There are some additional design load scenarios to be considered which relate to impact (I) loads, sloshing (SL) loads and fatigue (F) load.

			Design load scenario				
			1	2	3	4	5
			Normal operations at harbour and sheltered water	*Normal operation at sea*	*Flow through ballast water exchange*	*Overfilling of ballast tanks and tank testing*	*Flooding*
			Static (S)	*Static + dynamic (S+D)*	*Static + dynamic (S+D)*	*Static (S) and (T)*	*Static (S)*
Load component	Hull girder loads	VBM	M_{sw}	$M_{sw} + M_{wv\text{-}LC}$	$M_{sw} + M_{wv\text{-}LC}$	M_{sw}	M_{sw}
		HBM	-	$M_{wh\text{-}LC}$	$M_{wh\text{-}LC}$	-	-
		VSF	Q_{sw}	$Q_{sw} + Q_{wv\text{-}LC}$	$Q_{sw} + Q_{wv\text{-}LC}$	-	-
		TM [2)]	M_{st}	$M_{st} + M_{wt\text{-}LC}$	$M_{st} + M_{wt\text{-}LC}$	M_{st}	M_{st}

				Design load scenario				
				1	2	3	4	5
				Normal operations at harbour and sheltered water	*Normal operation at sea*	*Flow through ballast water exchange*	*Overfilling of ballast tanks and tank testing*	*Flooding*
				Static (S)	*Static + dynamic (S+D)*	*Static + dynamic (S+D)*	*Static (S) and (T)*	*Static (S)*
	Local loads	P_{ex}	Exposed decks	-	P_D	-	-	-
			External shell	P_S	$P_S + P_W$	$P_S + P_W$	P_S	-
			Superstructure sides	-	max(P_W; P_{SI})	-	-	-
			Superstructure end bulkheads and deckhouse walls	-	P_A	-	-	-
		P_{in}	Boundaries of water ballast tanks[1)]	$P_{ts\text{-}3}$	$P_{ts\text{-}1} + P_{td}$	$P_{ts\text{-}2} + P_{td}$	max($P_{ts\text{-}4}$, $P_{ts\text{-}ST}$)	-
			Boundaries of tanks other than water ballast tanks			-	$P_{ts\text{-}ST}$	-
			Watertight boundaries	-	-	-	-	P_{fs}
			Boundaries of bulk cargo holds	P_{bs}	$P_{bs} + P_{bd}$	-	-	-
			Internal structures in tanks	P_{int}		-	-	-
		P_{dt}	Exposed decks and non-exposed decks and platforms	$P_{dt\text{-}s}$	$P_{dt\text{-}s} + P_{dt\text{-}d}$	-	-	-
		F_U	Heavy units on internal and external decks	$F_{U\text{-}s}$	$F_{U\text{-}s} + F_{U\text{-}d}$	-	-	-
		P_{wl}	Decks and hatch covers/RoRo equipment	$P_{wl\text{-}1}$	$P_{wl\text{-}2}$	-	-	-

1) WB cargo hold is considered as ballast tank except for design load scenario 'ballast water exchange'.
2) Hull girder torsion to be considered for ships with large deck openings only.

Table 2 - Principal design load scenarios

2.6 Internal and external loads

Constant pressure, calculated at the element's centroid, is applied to the shell element of the loaded surfaces, e.g. outer shell and deck for the external pressure and tank/hold boundaries for the internal pressure. External pressure is to be calculated for each load case in accordance with the rules. External pressures include static sea pressure, wave pressure and green sea pressure. Internal pressures include static dry and liquid cargo, ballast and other liquid pressure, setting pressure on relief valve and dynamic pressure of dry and liquid cargo, ballast and other liquid pressure due to acceleration.

2.7 Hull girder loads

As partial ship FE model represents a part of the ship, the local loads (i.e. static and dynamic internal and external loads) applied to the model will induce hull girder loads which represent a semi-global effect. The semi global effect may not necessarily reach desired hull girder loads, i.e. hull girder targets. The procedures describe hull girder adjustments to the targets as defined in the rules in order to apply additional forces and moments to the model.

The adjustments are calculated and each hull girder component can be adjusted separately:
a) Hull girder vertical shear force.
b) Hull girder vertical bending moment.
c) Hull girder horizontal bending moment.
d) Hull girder torsional moment

2.7.1 Hull vertical bending moment

The target hull girder vertical bending moment, *Mv-targ*, in kNm, at a longitudinal position for a given FE load combination is taken as:

$$M_{v-targ} = C_{BM-LC}\, M_{sw} + M_{wv-LC}$$

Where:

C_{BM-LC} = *Percentage of permissible still water bending moment applied for the load combination under consideration.*

M_{wv-LC} = *Vertical wave bending moment in kNm, for the dynamic load case under consideration.*

M_{sw} = *Permissible still water bending moments at the considered longitudinal position for seagoing and harbour conditions as defined in the rules.*

In case the target vertical bending moment needs to be reached, an additional vertical bending moment is to be applied at both ends of the cargo hold FE model to generate this target value in the mid-hold of the model. This end vertical bending moment is given as follows:

$$M_{v-end} = M_{v-targ} - M_{v-peak}$$

Where *Additional vertical bending moment, in kNm, to be applied to both ends of FE model.*

$M_{v\text{-}targ}$ = Hogging (positive) or sagging (negative) vertical bending moment, in kNm, as specified above.

$M_{v\text{-}peak}$ = *Maximum or minimum bending moment, in kNm, within the length of the mid-hold due to the local loads and due to the shear force adjustment.*

2.7.2 Hull girder shear force adjustment procedure

The target hull girder vertical shear force at the aft and forward transverse bulkheads of the mid-hold, $Q_{tar\text{-}gaft}$ and $Q_{targ\text{-}fwd}$, in kN, for a given FE load combination is taken as:

If $Q_{fwd} \geq Q_{aft}$ then, the following relationships must be followed:

$$Q_{targ-aft} = C_{SF-LC} \cdot Q_{sw-neg} - \Delta Q_{swa} + f_{\beta}|C_{QW}|Q_{wv-neg}$$

$$Q_{targ-fwd} = C_{SF-LC} \cdot Q_{sw-pos} + \Delta Q_{swf} + f_{\beta}|C_{QW}|Q_{wv-pos}$$

$Q_{fwd} < Q_{aft}$ then, the following relationships must be followed:

$$Q_{targ-aft} = C_{SF-LC} \cdot Q_{sw-pos} + \Delta Q_{swa} + f_{\beta}|C_{QW}|Q_{wv-pos}$$

$$Q_{targ-fwd} = C_{SF-LC} \cdot Q_{sw-neg} - \Delta Q_{swf} + f_{\beta}|C_{QW}|Q_{wv-neg}$$

Where:

Q_{fwd}, Q_{aft} = Vertical shear forces, in kN, due to the local loads respectively at the forward and aft bulkhead position of the mid-hold.

$C_{SF\text{-}LC}$ =	*Percentage of permissible still water shear force. When FE load combinations are specified in the rules.*
$Q_{sw\text{-}pos}$, $Q_{sw\text{-}neg}$ =	*Positive and negative permissible still water shear forces, in kN, at any longitudinal position for seagoing and harbour conditions.*
ΔQ_{swf}, ΔQ_{swa}, =	Shear force correction, in kN, for the considered FE loading pattern at the forward and aft bulkhead respectively taken as minimum of the absolute values of ΔQ_{mdf} as defined in the rules.
$Q_{wv\text{-}pos}$, $Q_{wv\text{-}neg}$ =	*Positive and negative vertical water shear forces, in kN.*

2.8 Analysis criteria

Yield and buckling strength assessment is to be carried out within the evaluation area of the FE model for all modelled structural members. In the mid-hold cargo analysis, the following structural members shall be evaluated:

— All hull girder longitudinal structural members,

— All primary supporting structural members (web frames, cross ties, etc.), and

— Transverse bulkheads, forward and aft of the mid-hold.

Examples of the longitudinal extent of the evaluation areas for a gas carrier and an ore carrier ships are shown in Figure 3.

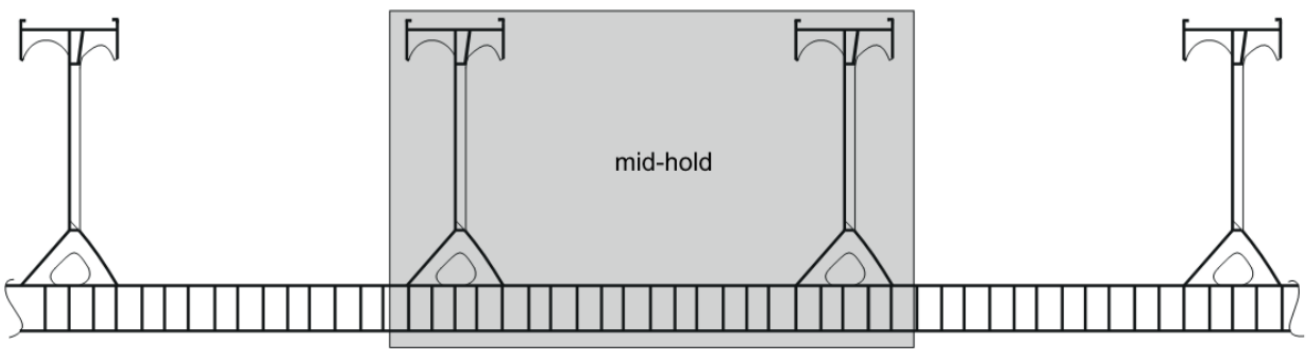


***Figure** 3 - Boundary conditions applied at the model end sections*

2.8.1 Yield strength assessment

Von Mises stresses

For all plates of the structural members within evaluation area, the von Mises stress, *σvm*, in N/mm2, is to be calculated based on the membrane normal and shear stresses of the shell element. The stresses are to be evaluated at the element centroid of the mid-plane (layer), as follows:

$$\sigma_{vm} = \sqrt{\sigma_x^2 - \sigma_x\sigma_y + \sigma_y^2 + 3\tau_{xy}^2}$$

where:

σ_x, σ_y = Element normal membrane stresses, in N/mm^2.

τ_{xy} = Element shear stress, in N/mm^2.

Axial stress in beams and rod elements

For beams and rod elements, the axial stress, *σaxial*, in N/mm^2, is to be calculated based on axial force alone. The axial stress is to be evaluated at the middle of element length. The axial stress is to be calculated for the following members:

—The flange of primary supporting members,

— The intersections between the flange and web of the corrugations, in dummy rod elements, modelled with unit cross sectional properties at the intersection between the flange and web of the corrugation.

Permissible stress

The coarse mesh permissible yield utilization factors, λ_{yperm}, are based on the element types and the mesh size described in this section. Where the geometry cannot be adequately represented in the cargo hold model and the stress exceeds the cargo hold mesh acceptance criteria, a finer mesh may be used for such geometry to demonstrate satisfactory scantlings. If the element size is smaller, stress averaging should be performed. In such cases, the area weighted Von Mises stress within an area equivalent to mesh size required for partial ship model is to comply with the coarse mesh permissible yield utilization factors. Stress averaging is not to be carried across structural discontinuities and abutting structure.

Acceptance criteria - coarse mesh permissible yield utilisation factors

The result from partial ship strength analysis is to demonstrate that the stresses do not exceed the maximum permissible stresses defined as coarse mesh permissible yield utilisation factors, as follows:

$$\lambda_y \leq \lambda_{yperm}$$

where:

λ_y = Yield utilisation factor

= $\frac{\sigma_{vm}}{R_y}$ for shell elements in general

= $\frac{\sigma_{axial}}{R_y}$ for rod or beam elements in general

σ_{vm} = Von Mises stress, in N/mm^2.

σ_{axial} = Axial stress in rod element, in N/mm^2.

λ_{yperm} = Coarse mesh permissible yield utilisation factor, as given in the rules,

2.8.2 Buckling strength assessment

'Buckling' is used as a generic term to describe the strength of structures, generally under in-plane compressions and/or shear and lateral load. The buckling strength or capacity can take into account the internal redistribution of loads depending on the load situation, slenderness and type of structure.

Buckling capacity based on this principle gives a lower bound estimate of ultimate capacity, or the maximum load the panel can carry without suffering major permanent set. Buckling capacity assessment utilizes the positive elastic post-buckling effect for plates and accounts for load redistribution between the structural components, such as between plating and stiffeners. For slender structures, the capacity calculated using this method is typically higher than the ideal elastic buckling stress (minimum Eigen value). Accepting elastic buckling of structural components in slender stiffened panels implies that large elastic deflections and reduced in-plane stiffness will occur at higher buckling utilization levels

2.8.2.1 Buckling creteria

In the present work we will deal with the study of the buckling strength of overall stiffened panels elementary plate panels. The buckling utilization factor of the structural member is equal to the highest utilization factor obtained for the different buckling modes. The maximum plate utilization factor (n_{plate}) is to satisfy the following criterion:

$n_{plate} \leq n_{all}$, *Where* $n_{plate} = \frac{1}{\gamma_c}$

According to IACS rules, Chapter 8, Section 5, the plate limit state is based on the following interaction formulae:

$$\left(\frac{\gamma_{c1}\,\sigma_x\,S}{\sigma'_{cx}}\right)^{e_0} - B\left(\frac{\gamma_{c1}\,\sigma_x\,S}{\sigma'_{cx}}\right)^{e_0/2}\left(\frac{\gamma_{c1}\,\sigma_y\,S}{\sigma'_{cy}}\right)^{e_0/2} + \left(\frac{\gamma_{c1}\,\sigma_y\,S}{\sigma'_{cy}}\right)^{e_0} + \left(\frac{\gamma_{c1}\,|\tau|\,S}{\tau'_c}\right)^{e_0} = 1$$

$$\left(\frac{\gamma_{c2}\,\sigma_x\,S}{\sigma'_{cx}}\right)^{2/\beta_p^{0.25}} + \left(\frac{\gamma_{c2}\,|\tau|\,S}{\tau'_c}\right)^{2/\beta_p^{0.25}} = 1 \quad \text{for } \sigma_x \geq 0$$

$$\left(\frac{\gamma_{c3}\,\sigma_y\,S}{\sigma'_{cy}}\right)^{2/\beta_p^{0.25}} + \left(\frac{\gamma_{c3}\,|\tau|\,S}{\tau'_c}\right)^{2/\beta_p^{0.25}} = 1 \quad \text{for } \sigma_y \geq 0$$

$$\frac{\gamma_{c4}\,|\tau|\,S}{\tau'_c} = 1$$

with

$\gamma_c = min(\gamma_{c1}, \gamma_{c2}, \gamma_{c3}, \gamma_{c4})$

where:

σ_x, σ_y : Applied normal stress to the plate panel, in N/mm^2, to be taken as defined in [2.2.7].

τ : Applied shear stress to the plate panel, in N/mm^2.

σ_{cx}' : Ultimate buckling stress, in N/mm^2, in direction parallel to the longer edge of the buckling panel as defined in [2.2.3].

σ_{cy}' : Ultimate buckling stress, in N/mm^2, in direction parallel to the shorter edge of the buckling panel as defined in [2.2.3].

τ_c' : Ultimate buckling shear stresses, in N/mm^2, as defined in [2.2.3].

γ_{c1}, γ_{c2}, γ_{c3}, γ_{c4}: Stress multiplier factors at failure for each of the above different limit states. γ_{c2} and γ_{c3} are only to be considered when $\sigma_x \geq 0$ and $\sigma_y \geq 0$ respectively.

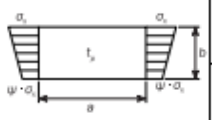
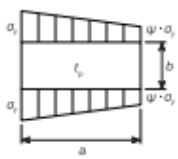
B : Coefficient given in Table 1.

e_0 : Coefficient given in Table 1.

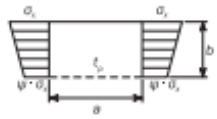
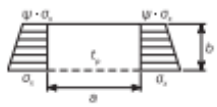
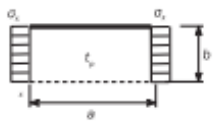
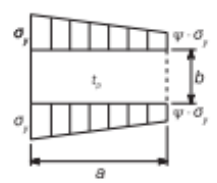
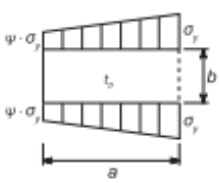
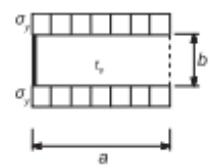
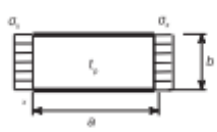
β_p : Plate slenderness parameter taken as:

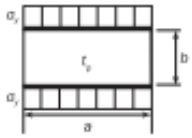
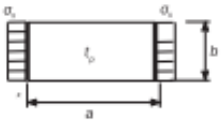
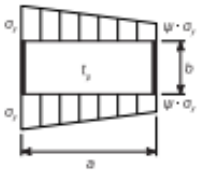
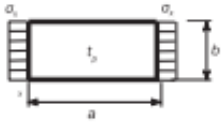
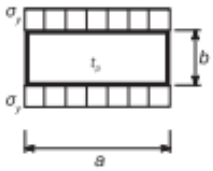
$$\beta_p = \frac{b}{t_p}\sqrt{\frac{R_{eH\_P}}{E}}$$

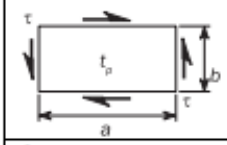
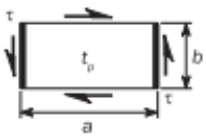
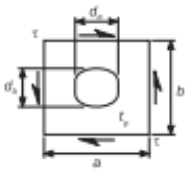
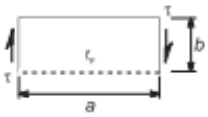
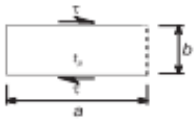
The boundary conditions for plates are to be considered as simply supported, see cases 1, 2 and 15 of Table 3. In this table also we can find buckling and reduction factors for plane plate panels.

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
1 	$1 \geq \psi \geq 0$		$K_x = F_{long} \dfrac{8.4}{\psi + 1.1}$	When $\sigma_x \leq 0$: $C_x = 1$ When $\sigma_x > 0$: $C_x = 1$ for $\lambda \leq \lambda_o$ $C_x = c\left(\dfrac{1}{\lambda} - \dfrac{0.22}{\lambda^2}\right)$ for $\lambda > \lambda_o$ where: $c = (1.25 - 0.12\psi) \leq 1.25$ $\lambda_o = \dfrac{c}{2}\left(1 + \sqrt{1 - \dfrac{0.88}{c}}\right)$
	$0 > \psi > -1$		$K_x = F_{long}\,[7.63 - \psi\,(6.26 - 10\psi)]$	
	$\psi \leq -1$		$K_x = F_{long}\,[5.975(1 - \psi)^2]$	
2 	$1 \geq \psi \geq 0$		$K_y = F_{tran} \dfrac{2\left(1 + \dfrac{1}{\alpha^2}\right)^2}{1 + \psi + \dfrac{(1-\psi)}{100}\left(\dfrac{2.4}{\alpha^2} + 6.9 f_1\right)}$	When $\sigma_y \leq 0$: $C_y = 1$ When $\sigma_y > 0$: $C_y = c\left(\dfrac{1}{\lambda} - \dfrac{R + F^2\,(H - R)}{\lambda^2}\right)$ where: $c = (1.25 - 0.12\psi) \leq 1.25$ $R = \lambda(1 - \lambda/c)$ for $\lambda < \lambda_o$ $R = 0.22$ for $\lambda \geq \lambda_o$ $\lambda_o = 0.5c\,(1 + \sqrt{1 - 0.88/c})$ $F = \left[1 - \left(\dfrac{K}{0.91} - 1\right)/\lambda_p^2\right] c_1 \geq 0$ $\lambda_p^2 = \lambda^2 - 0.5$ for $1 \leq \lambda_p^2 \leq 3$ c_1 as defined in [2.2.3] $H = \lambda - \dfrac{2\lambda}{c\,(T + \sqrt{T^2 - 4})} \geq R$ $T = \lambda + \dfrac{14}{15\lambda} + \dfrac{1}{3}$
		$\alpha \leq 6$	$f_1 = (1 - \psi)(\alpha - 1)$	
		$\alpha > 6$	$f_1 = 0.6\left(1 - \dfrac{6\psi}{\alpha}\right)\left(\alpha + \dfrac{14}{\alpha}\right)$ but not greater than $14.5 - \dfrac{0.35}{\alpha^2}$	
	$0 > \psi \geq 1 - \dfrac{4\alpha}{3}$		$K_y = \dfrac{200 F_{tran}(1 + \beta^2)^2}{(1 - f_3)(100 + 2.4\beta^2 + 6.9 f_1 + 23 f_2)}$	
		$\alpha > 6(1 - \psi)$	$f_1 = 0.6\left(\dfrac{1}{\beta} + 14\beta\right)$ but not greater than $14.5 - 0.35\beta^2$ $f_2 = f_3 = 0$	
		$3(1 - \psi) \leq \alpha \leq 6(1 - \psi)$	$f_1 = \dfrac{1}{\beta} - 1$ $f_2 = f_3 = 0$	

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
		$1.5(1-\psi) \le \alpha < 3(1-\psi)$	$f_1 = \frac{1}{\beta} - (2-\omega\beta)^4 - 9(\omega\beta - 1)\left(\frac{2}{3} - \beta\right)$ $f_2 = f_3 = 0$	
		$1-\psi \le \alpha < 1.5(1-\psi)$	• For $\alpha > 1.5$: $f_1 = 2\left(\frac{1}{\beta} - 16\left(1 - \frac{\omega}{3}\right)^4\right)\left(\frac{1}{\beta} - 1\right)$ $f_2 = 3\beta - 2$ $f_3 = 0$ • For $\alpha \le 1.5$: $f_1 = 2\left(\frac{1.5}{1-\psi} - 1\right)\left(\frac{1}{\beta} - 1\right)$ $f_2 = \frac{\psi(1 - 16f_4^2)}{1-\alpha}$ $f_3 = 0$ $f_4 = (1.5 - Min(1.5;\alpha))^2$	
		$0.75(1-\psi) \le \alpha < 1-\psi$	$f_1 = 0$ $f_2 = 1 + 2.31(\beta - 1) - 48\left(\frac{4}{3} - \beta\right)f_4^2$ $f_3 = 3f_4(\beta - 1)\left(\frac{f_4}{1.81} - \frac{\alpha - 1}{1.31}\right)$ $f_4 = (1.5 - Min(1.5;\alpha))^2$	
	$\psi < 1 - \frac{4\alpha}{3}$		$K_y = 5.972F_{tran}\frac{\beta^2}{1-f_3}$ where: $f_3 = f_5\left(\frac{f_5}{1.81} + \frac{1+3\psi}{5.24}\right)$ $f_5 = \frac{9}{16}(1 + Max(-1;\psi))^2$	

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
3 	$1 \geq \psi \geq 0$		$K_x = \dfrac{4\,(0.425 + 1/\alpha^2)}{3\psi + 1}$	$C_x = 1$ for $\lambda \leq 0.7$ $C_x = \dfrac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
	$0 > \psi \geq -1$		$K_x = 4(0.425 + 1/\alpha^2)\,(1 + \psi) - 5\psi\,(1 - 3.42\psi)$	
4 	$1 \geq \psi \geq -1$		$K_x = \left(0.425 + \dfrac{1}{\alpha^2}\right)\dfrac{3 - \psi}{2}$	
5 	–	$\alpha \geq 1.64$	$K_x = 1.28$	
		$\alpha < 1.64$	$K_x = \dfrac{1}{\alpha^2} + 0.56 + 0.13\alpha^2$	
6 	$1 \geq \psi \geq 0$		$K_y = \dfrac{4(0.425 + \alpha^2)}{(3\psi + 1)\alpha^2}$	$C_y = 1$ for $\lambda \leq 0.7$ $C_y = \dfrac{1}{\lambda^2 + 0.51}$ for $\lambda > 0.7$
	$0 > \psi \geq -1$		$K_y = 4(0.425 + \alpha^2)(1 + \psi)\dfrac{1}{\alpha^2} - 5\psi(1 - 3.42\psi)\dfrac{1}{\alpha^2}$	
7 	$1 \geq \psi \geq -1$		$K_y = (0.425 + \alpha^2)\dfrac{(3 - \psi)}{2\alpha^2}$	
8 	–		$K_y = 1 + \dfrac{0.56}{\alpha^2} + \dfrac{0.13}{\alpha^4}$	
9 	–		$K_x = 6.97$	$C_x = 1$ for $\lambda \leq 0.83$ $C_x = 1,13\left(\dfrac{1}{\lambda} - \dfrac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
10 	–		$K_y = 4 + \frac{2.07}{\alpha^2} + \frac{0.67}{\alpha^4}$	$C_y = 1$ for $\lambda \le 0.83$ $C_y = 1,13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
11 	–	$\alpha \ge 4$	$K_x = 4$	$C_x = 1$ for $\lambda \le 0.83$ $C_x = 1,13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
		$\alpha < 4$	$K_x = 4 + 2.74\left[\frac{4-\alpha}{3}\right]^4$	
12 	–		$K_y = K_y$ determined as per case 2	For $\alpha < 2$: $C_y = C_{y2}$ For $\alpha \ge 2$: $C_y = \left(1.06 + \frac{1}{10\alpha}\right)C_{y2}$ where: C_{y2} : C_y determined as per case 2
13 	–	$\alpha \ge 4$	$K_x = 6.97$	$C_x = 1$ for $\lambda \le 0.83$ $C_x = 1,13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$
		$\alpha < 4$	$K_x = 6.97 + 3.1\left[\frac{4-\alpha}{3}\right]^4$	
14 	–		$K_y = \frac{6.97}{\alpha^2} + \frac{3.1}{\alpha^2}\left[\frac{4-1/\alpha}{3}\right]^4$	$C_y = 1$ for $\lambda \le 0.83$ $C_y = 1.13\left(\frac{1}{\lambda} - \frac{0.22}{\lambda^2}\right)$ for $\lambda > 0.83$

Case	Stress ratio ψ	Aspect ratio α	Buckling factor K	Reduction factor C
15 	–		$K_\tau = \sqrt{3}\left[5.34 + \frac{4}{\alpha^2}\right]$	$C_\tau = 1$ for $\lambda \le 0.84$ $C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$
16 	–		$K_\tau = \sqrt{3}\left\{5.34 + Max\left[\frac{4}{\alpha^2}\ ;\ \frac{7.15}{\alpha^{2.5}}\right]\right\}$	
17 	–		$K_\tau = K_{roboe16}\, r$ $K_{roboe16}$: K_τ according to case 15 r : Opening reduction factor taken as: $r = \left(1 - \frac{d_a}{a}\right)\left(1 - \frac{d_b}{b}\right)$ with $\frac{d_a}{a} \le 0.7$ and $\frac{d_b}{b} \le 0.7$	
18 	–		$K_\tau = \sqrt{3}(0.6 + 4/\alpha^2)$	$C_\tau = 1$ for $\lambda \le 0.84$ $C_\tau = \frac{0.84}{\lambda}$ for $\lambda > 0.84$
19 	–		$K_\tau = 8$	

Edge boundary conditions:

- - - - - - - - - Plate edge free.

———————— Plate edge simply supported.

▬▬▬▬▬▬▬▬ Plate edge clamped.

Note 1: Cases listed are general cases. Each stress component (σ_x, σ_y) is to be understood in local coordinates.

[CORR1 to 01 JAN 2015]

Table 3 - Boundary conditions, buckling factors and reduction factors for plane plate panels.

3. Model Configuration

3.1 CAD model preparation

3.1.1 Principal ship characteristics

In this analysis, a bulk carrier vessel has been selected with principle specifications as given in Table 4. The vessel selected as base case to present the buckling assessment relating to CSR-BC by direct finite element analysis is a Kamsarmax bulk carrier. The bulk carrier has seven cargo holds. The number 1 of cargo hold is in the fore of the ship and No. 7 is in the aft of the ship. The distance between top side webs is 3.72 m and the distance between bottom floors is 2.79m. The watertight bulkheads are located at the end of every cargo tank, with a distance equal to 25.11 m. Figure 4 shows the general arrangement of the corresponding bulk carrier and the location of the cargo tanks examined. The midship section is shown in Figure 5.

LENGTH O.A. LOA =	228.99	m
LENGTH B.P. LBP =	225.10	m
BREADTH MLD BMLD =	32.26	m
DEPTH MLD DMLD =	20.00	m
DESIGN LOAD DRAFT MLD =	12.20	m
FULL LOAD DRAFT EXTREME=	14.429	m
NAVIGATION AREA:	OCEAN GOING	
DEAD WEIGHT =	81922	mt
DISPLACEMENT =	94361	mt
LIGHT WEIGHT =	12439	mt
L.C.G after Midship =	10.08	m
V.C.G. above Base Line =	11.02	m
T.C.G. from center line =	0.01	m
CARGO HOLD CAPACITY (GRAIN	97246.7	m^3
SERVICE SPEED =	14.50	KTS
CB =	0.88	

Table 4 – Principle particulars of the subject vessel

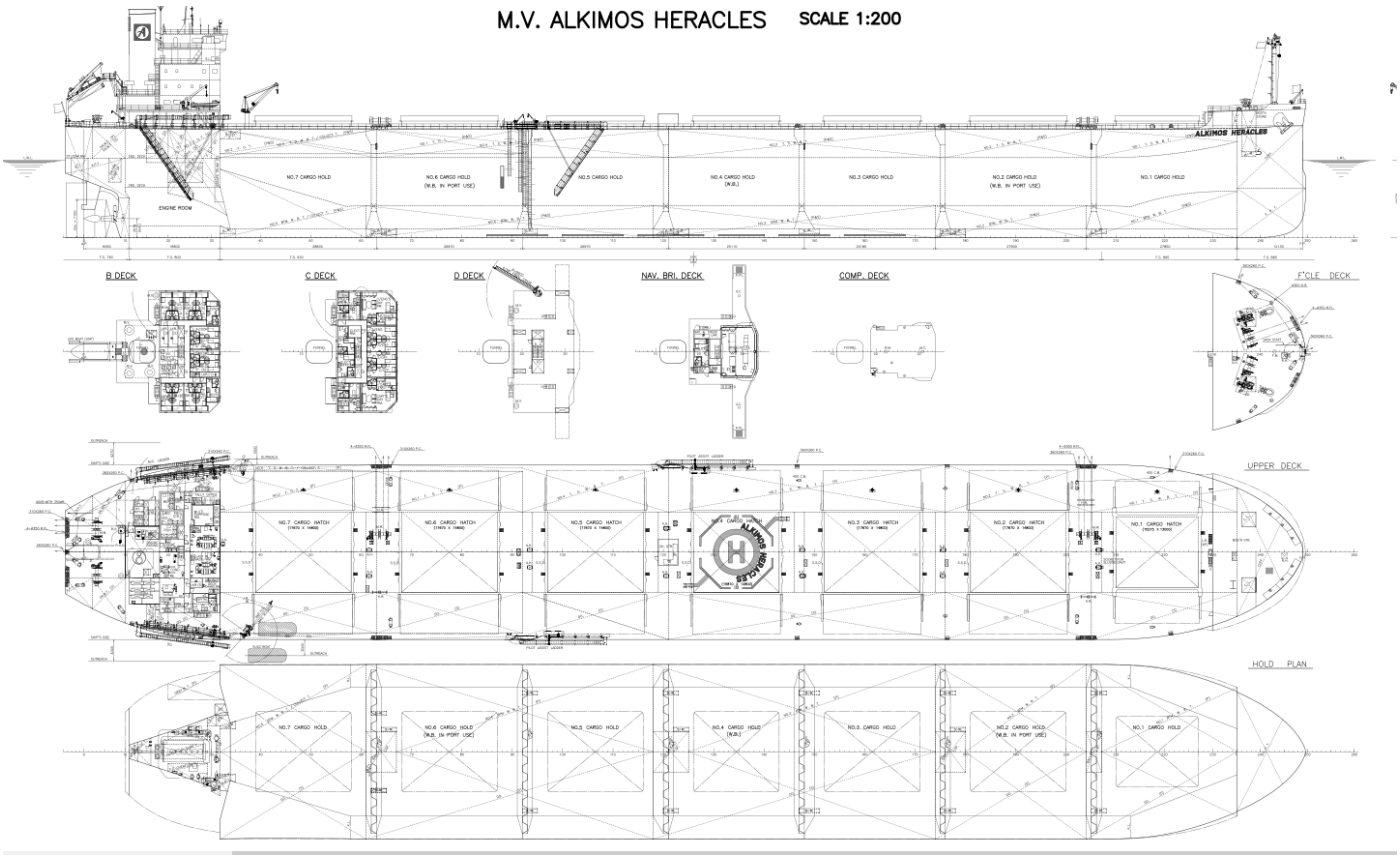


***Figure** 4 – General arrangement*

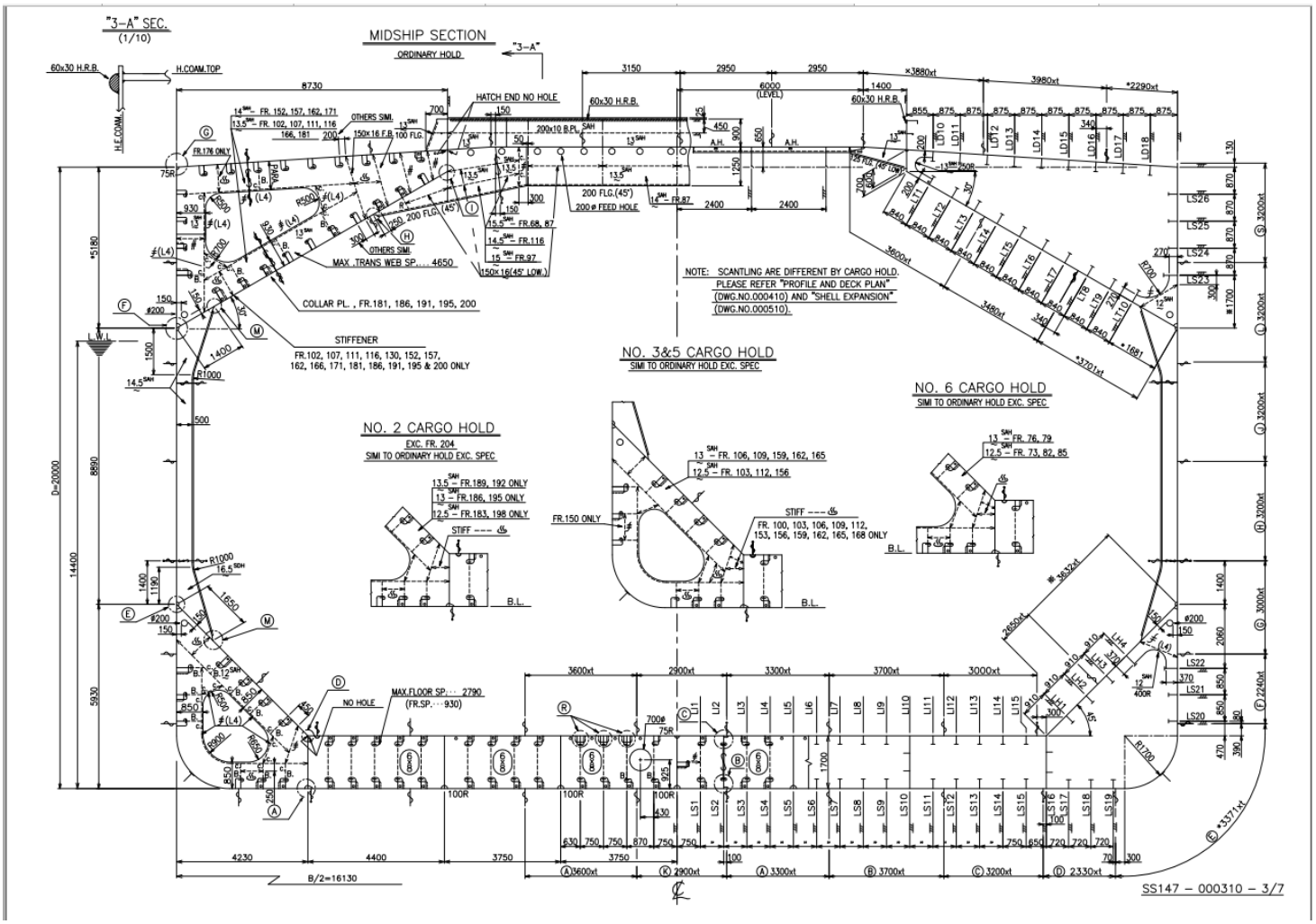


***Figure** 5 – Mid ship section*

3.1.2 Geometric model

In order to create a proper and easy-to-use geometric model, the suitability of the surfaces forming the ship form should be checked first. Preparation of CAD model is the base for FE model preparation, as it is one of the most time consuming process other than FE model generation. To modeling a complicated, massive structure like ship it is vital to choose a correct software tool for model preparation. The geometry design is carried out using the Rhinoceros cad software and has been verified according to the drawings and corrected for the shape, thickness, material and cutouts of structural elements. It is also ensured that all the longitudinal members are present with correct properties. These members are vital for the hull girder strength.

Normally, the longitudinal extent of the cargo hold FE model is to cover three cargo hold lengths. The model on which the structural analyses have been carried out, is selected to be the holds lying within the frame number 92 to frame number 177. In between these frame numbers there are 3 cargo holds and in order to apply the partial ship analysis method, our interest is focused in the middle hold, cargo hold No4, which is approximately located in the middle of the ship.

The modeling process begins with the ship form, which is the basis of our geometric model. The ship form is divided in all its longitudinal and transverse lines. Then, first of all the deck and after that the longitudinal members are modeled. Therefore, we will have all the boundaries when we would like to create web frames. Finally, by using these boundaries we can model the elements on web frames and complete the geometric modeling quickly. The steps below summarise the process:

- ✓ Divide the ship form in frames
- ✓ If there are stiffener lines on the outer cover, divide the ship form over these lines
- ✓ Divide the ship from the deck lines and create the deck areas
- ✓ Divide the deck areas from frame, longitudinal elements and stiffener lines
- ✓ Create all longitudinal elements on the decks and ship form
- ✓ Divide all-longitudinal elements from the frame lines
- ✓ Create all transverse structural elements including web frames

Figure 6 shows the half section of the longitudinal extent of geometric model witch to be cover three cargo holds and two transverse bulkheads, together with their associated stools. Figure 7 shows the double bottom floors and girders of the full breadth model. Both ends of the model are to form vertical planes and to include any transverse web frames on the planes. The transverse bulkheads at the ends of the model can be omitted.

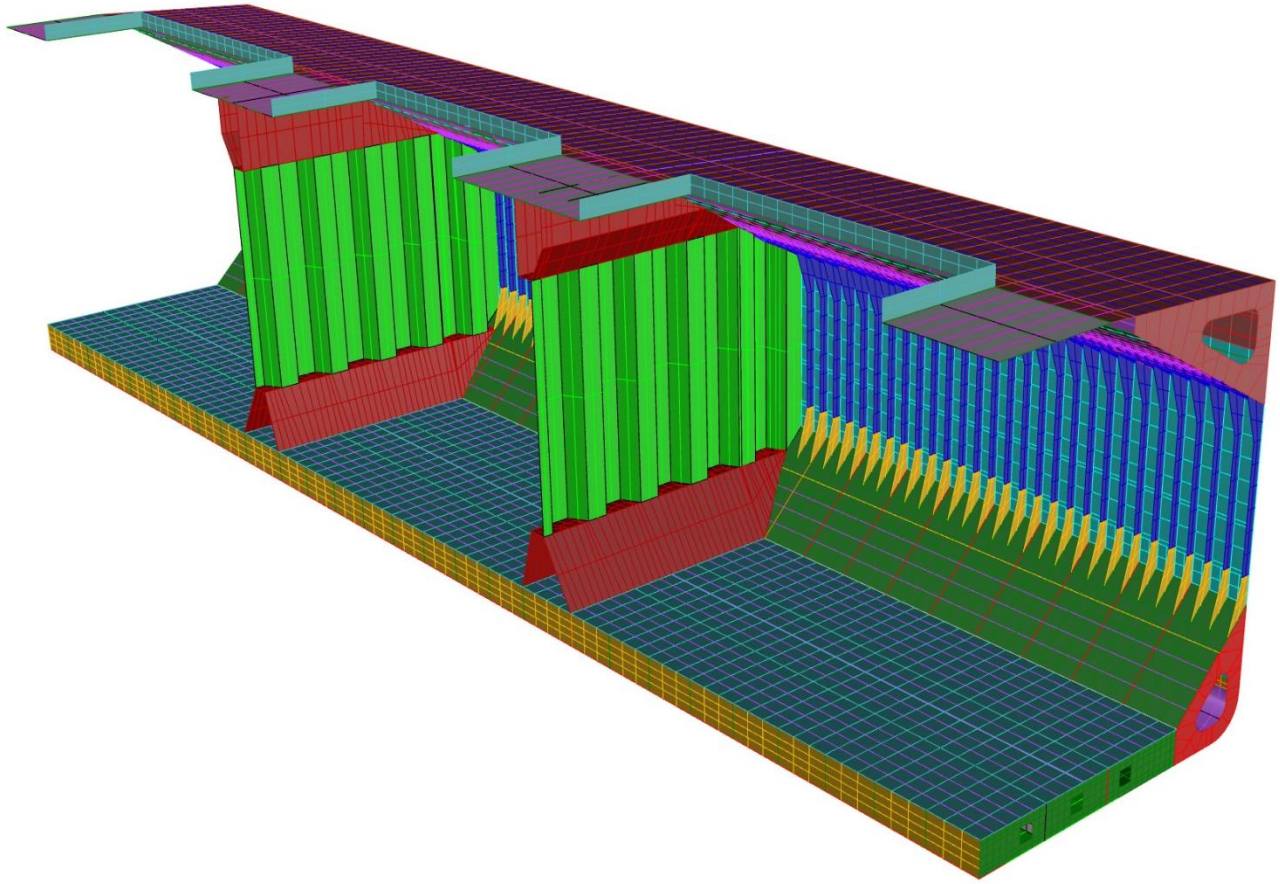


***Figure** 6 – Geometrical model for Partial Ship Analysis (shows only port side of the full breadth model)*

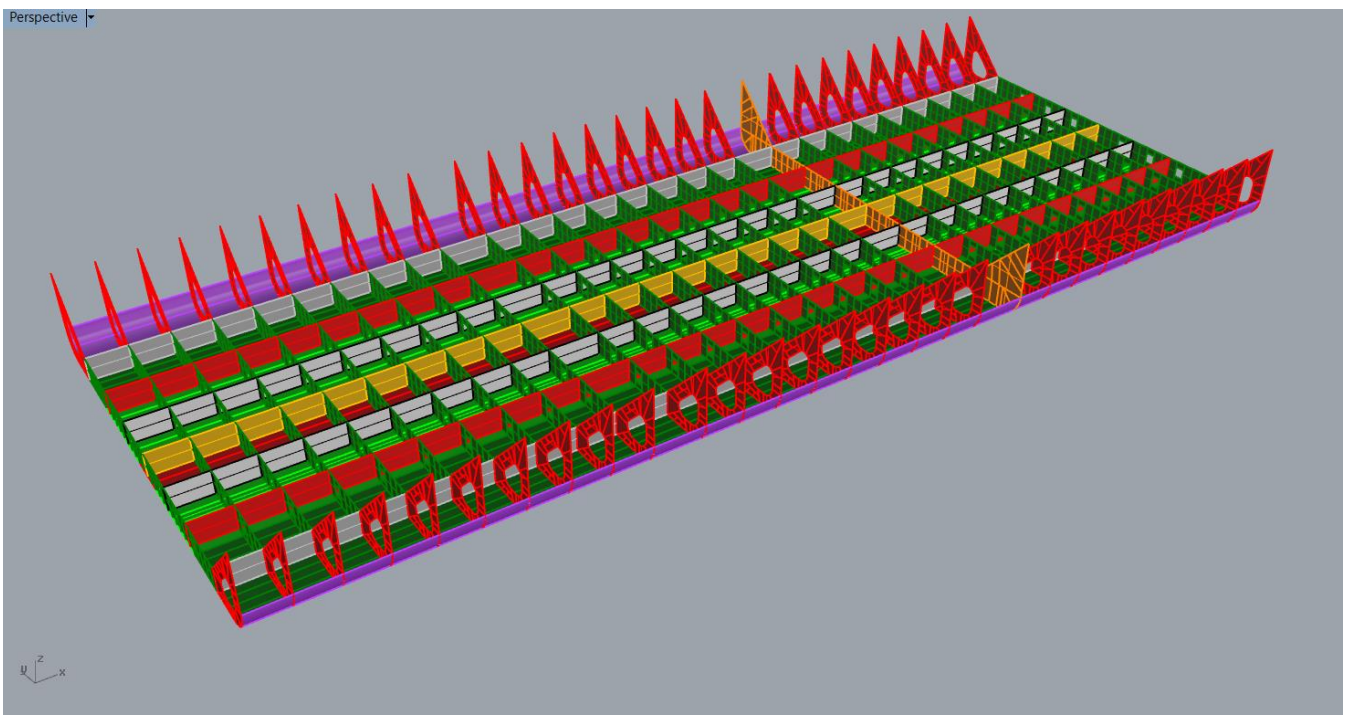


***Figure** 7 – Geometrical model for Partial Ship Analysis, shows the double bottom floors and girders of the full breadth model.*

3.2 Material model

The material properties used in the analysis are based on nominal properties of steel used in the fabrication of bulk carrier. This steel has been selected is because it has the same mechanical properties as used in the naval industry, at the same time this steel conforms the requirements established by IACS (2012) in regards to material properties. The material properties of the steel selected are displayed in Table 3.

Item	Value
Tensile yield strength	315 MPa
Compressive yield strength	315 MPa
Density	7850 kg/m^3

Table 5 – Mechanical properties structural steel

3.3 Finite elements model preparation

3.3.1 Finite elements model preparation in ANSYS Mechanical APDL

Ship is a structure which consisting of sheet metal is defined by shell elements. Primary structural elements such as hull, decks, transverse web frames and longitudinal girders can be defined as shell elements. Secondary structural elements, such as stiffeners placed onto hull, decks or bulkheads, flat bars on primary members, can be defined by beams elements. Once the modeling process is finished, it is necessary to define appropriate shell sections for the areas and beam sections for the lines.

When the tree hold structure model is prepared, the plates, stiffeners and other structures are then meshed individually. Selection of element size, shape and element divisions are the final steps before meshing. A complete FE mesh model is generated by selecting and repeating the mesh process for every part of the model separately. The number of element and degrees of freedoms associated with the structure is properly controlled as it is most important to control the solution time. A ship's structure is assumed as a thin wall box which is stiffened by beams and subjected to shear and torsion loads. Plate shell element is the ideal FE technique for modeling such a structure. The elements type selected for a ship's structural analysis must be tested for convergence and consistency. One dimensional truss elements having axial stiffness can be used to model stiffeners in ship analysis, whereas 1D beam elements having axial, shear, bending and torsional stiffness are used for modeling beam structures.

After the completion of the model in Rhinoceros CAD, each of the plates, stiffeners and other structures has its own layer and therefore can be independently selected and exported in IGES format in order to insert in ANSYS APDL. Ship structure modeling with all details is time consuming and difficult. ANSYS APDL and macros decreases a lot of modeling manual errors and time consumption during ship modeling. Then, real constants are attached in the tabular form. This process can also be automated with the help of APDL and ANSYS macros. Shell elements used for modeling of hull plates are SHELL 281, whereas beam elements used for modeling of hull stiffeners are BEAM189.

SHELL281 is suitable for analyzing thin to moderately-thick shell structures. The element has eight nodes with six degrees of freedom at each node: translations in the x, y, and z axes, and rotations about the x, y, and z-axes. (When using the membrane option, the element has translational degrees of freedom only.). It is well-suited for linear, large rotation, and/or large strain nonlinear applications. Change in shell thickness is accounted for in nonlinear analyses. The element accounts for follower (load stiffness) effects of distributed pressures. It may be used for layered applications for modeling composite shells or sandwich construction. The accuracy in modeling composite shells is governed by the first-order shear-deformation theory (usually referred to as Mindlin-Reissner shell theory). The element formulation is based on logarithmic strain and true stress measures. The element kinematics allow for finite membrane strains (stretching). However, the curvature changes within a time increment are assumed to be small. The following figure 8 shows the geometry, node locations, normal direction, and multilayer construction for this element. The element is defined by shell section information and by eight nodes (I, J, K, L, M, N, O and P). Mid-side nodes may not be removed from this element. See

Quadratic Elements (Midside Nodes) in the Modeling and Meshing Guide for more information about the use of midside nodes. A triangular-shaped element may be formed by defining the same node number for nodes K, L and O.

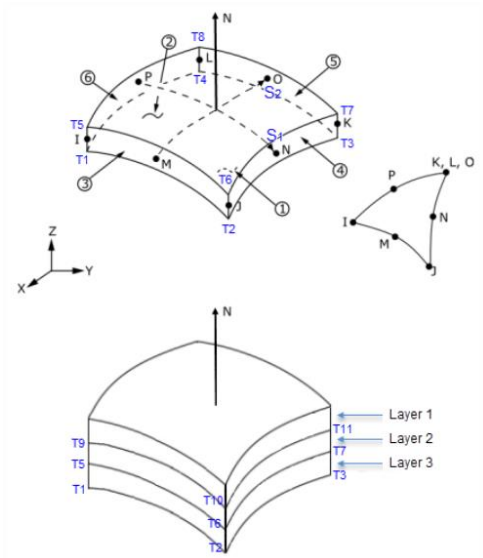


***Figure** 8 – SHELL281 Geometry*

The BEAM189 element is suitable for analyzing slender to moderately stubby/thick beam structures. The element is based on Timoshenko beam theory which includes shear-deformation effects. The element provides options for unrestrained warping and restrained warping of cross-sections. The element is a quadratic three-node beam element in 3-D. With default settings, six degrees of freedom occur at each node; these include translations in the x, y, and z directions and rotations about the x, y, and z directions. An optional seventh degree of freedom (warping magnitude) is available. The element is well-suited for linear, large rotation, and/or large-strain nonlinear applications. The element includes stress stiffness terms, by default, in any analysis. The provided stress-stiffness terms enable the elements to analyze flexural, lateral, and torsional stability problems. Elasticity, plasticity, creep and other nonlinear material models are supported. A cross-section associated with this element type can be a built-up section referencing more than one material. Added mass, hydrodynamic added mass and loading, and buoyant loading are available. The following figure 9, shows the geometry, node locations and normal direction for this element

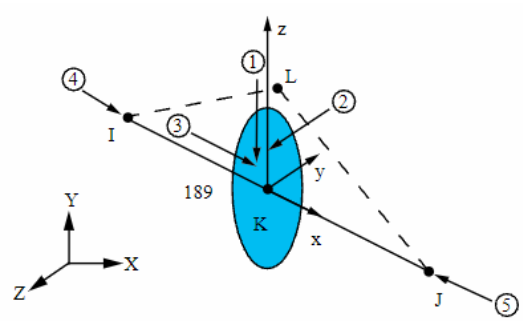


***Figure** 9 – BEAM189 Geometry*

3.5.2 Mesh generation

As mentioned above, the geometry design, mesh generation and load application for buckling assessment are all carried out using the ANSYS Mechanical APDL pre-processor (ANSYS Parametric Design Language). The Finite Element code of Ansys APDL software was used to analyze the structure by developing macros in APDL. The mesh size is 420mm. The generated number of nodes was equal to 336995 and 140411 elements. Figure 10 shows the mesh generated.

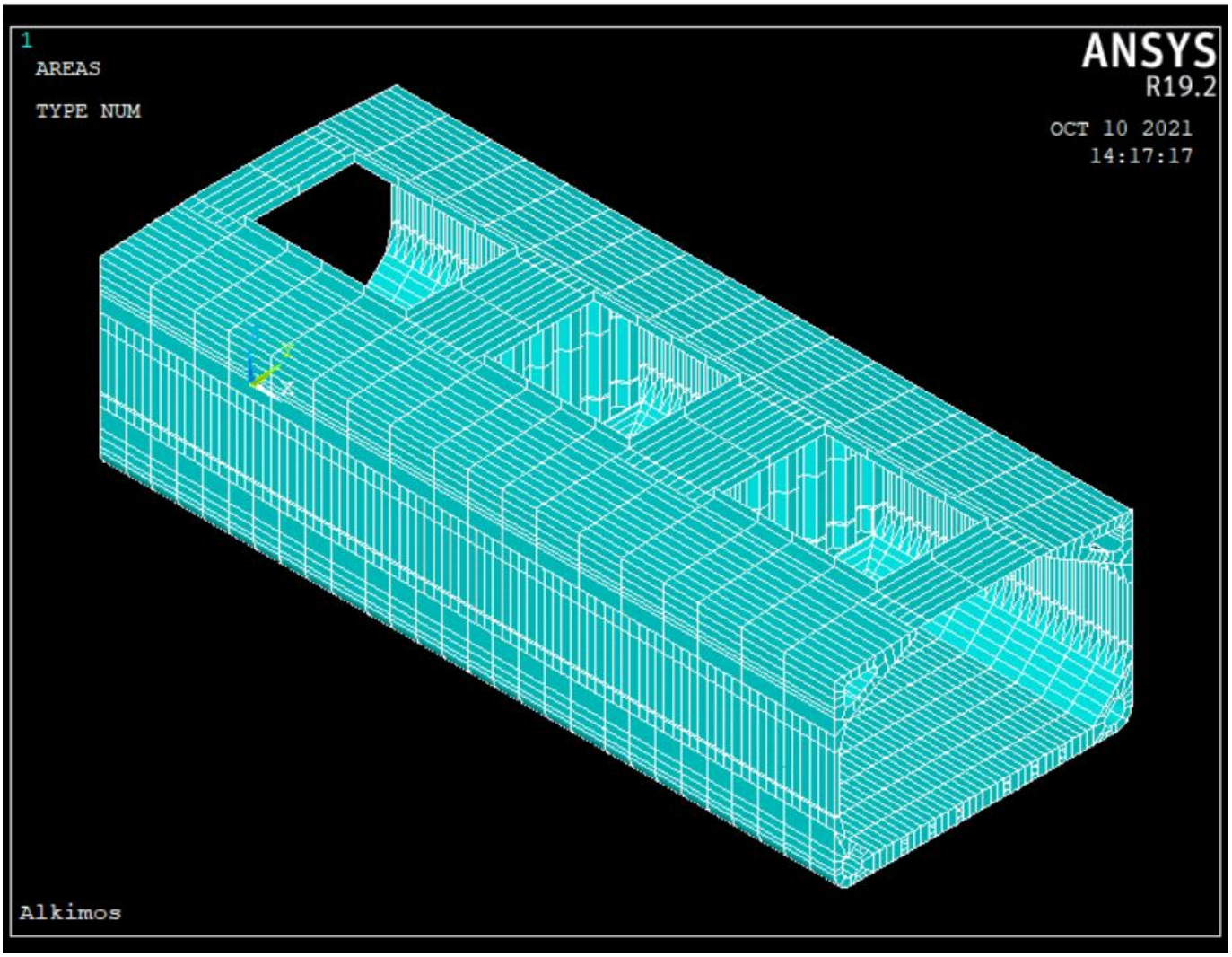


Figure** 10 – **Meshing

3.4 Boundary conditions

The boundary conditions have been applied at the rigid links on the cargo ends, point constraints and end-beams. Following the instructions specified in IACS "Common structural rules for double hull tanks". Rigid links connect the nodes on the longitudinal members at the model ends.

In FE methods, boundary conditions are applied at different supports by selecting the relevant nodes to constrain their translational and rotations movement. For the global analysis, it is necessary to avoid the rigid body motion of the model which is normally controlled by 6-DOF. The translational supports are placed away from the areas of interest. A balance load is generated at translational supports to eliminate the forces of constrained node. In some analyses, symmetric boundary conditions are helpful and are related to load application and structural arrangements. Symmetric boundary conditions for the half breadth model are applied with respect to center line. In case of uniform lateral loads, symmetric boundary conditions are applied at the ends of the model and stresses generated by the global hull are overlapped into the results. On the contrary, stress and displacement generated due to hull girder bending and shearing forces can be set at the end cross sections. Different boundary conditions are required for a hull module under hull girder loads. For hull girder vertical bending, these are applied at transverse bulkhead. Whereas, in the case of vertical shearing forces, symmetric boundary conditions are placed at the ends of the cargo hold model. When a ship is assumed under vertical shearing forces and only half breadth of the ship is considered, then symmetric boundary conditions can be applied along the center line of ship.

As discussed before in section 2.4, rigid links in y and z are applied at both ends of the cargo hold model so that the constraints of the model can be applied to the independent points. Rigid links in x-rotation are applied at both ends of the cargo hold model so that the constraint at fore end and required torsion moment at aft end can be applied to the independent point. The x-constraint is applied to the intersection between centreline and inner bottom at fore end to ensure the structure has enough support. The boundary conditions to be applied at the ends of the cargo hold FE model, are given in table 1 The whole three dimensional model assumed to be fixed at the both end. At the free end section, rigid constraint conditions are to be applied to all nodes located on longitudinal members, in such a way that the transverse section remains plane after deformation. The boundary conditions applied on the structure are presented in the following figure 11.

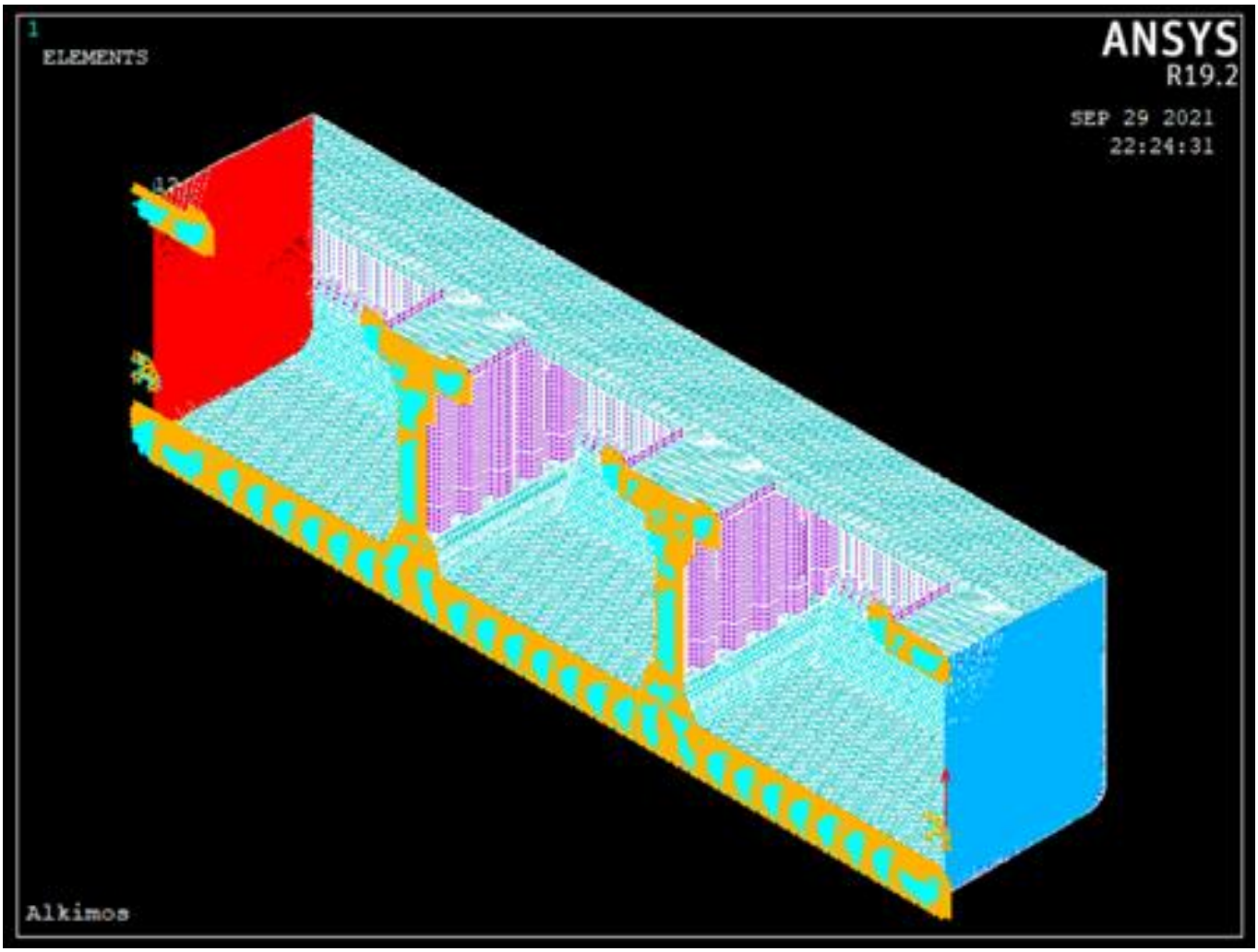


***Figure** 11 – Boundary conditions applying to the model*

3.5 Load analysis

The hydrostatic water pressure is to be applied to the outside hull with increasing the gravity as acceleration calculated from related class rules. For cargo hold, cargo load weight are to be applied increasing the gravity same as sea pressure. Global bending moment and sheering forces are to be applied at the end of the model in order to ensure maximum bending moment at the middle of the ship. The value of bending moment and share force is taken from the rules.
For the calculation of results the following types of loads have been considered:

- Cargo load
- Hydrostatic pressure
- Still water bending moment
- Shear force
- Wave load

The load combination factors for HSM, HSA and FSM load cases for strength assessment are found in table 6. In our case HSM-1 load component has been selected and it will be used in the calculations of loads that follow in next steps.

Load component		LCFs	HSM-1	HSM-2	HAS-1	HAS-2	FSM-1	FSM-2
Hull girder loads	M_{WV}	C_{WV}	-1	1	-0.7	0.7	-1	1
	Q_{WV}	C_{QW}	-1	1	-0.6	0.6	-1	1
	M_{WH}	C_{WH}	0	0	0	0	0	0
	M_{WT}	C_{WT}	0	0	0	0	0	0
Longitudinal accelerations	a_{surge}	C_{XS}	0.1	-0.1	0.2	-0.2	-0.2	0.2
	$a_{pitch\text{-}x}$	C_{XP}	-0.7	0.7	-1	1	0.15	-0.15
	$g \sin\phi$	C_{XG}	0.6	-0.6	0.8	-0.8	-0.2	0.2
Transverse accelerations	a_{sway}	C_{YS}	0	0	0	0	0	0
	$a_{roll\text{-}y}$	C_{YR}	0	0	0	0	0	0
	$g \sin\theta$	C_{YG}	0	0	0	0	0	0
Vertical accelerations	a_{heave}	C_{ZH}	0.35	-0.35	0.4	-0.4	0	0
	$a_{roll\text{-}z}$	C_{ZR}	0	0	0	0	0	0
	$a_{pitch\text{-}z}$	C_{ZP}	-0.7	0.7	-1	1	0.15	-0.15

Table 6 – Load combination factors for HSM, HSA and FSM load cases - strength assessment

3.5.1 Ship Motions and Accelerations

The ship motions and accelerations are assumed to be sinusoidal. The motion values defined by the formulae in this section are single amplitudes, i.e. half of the 'crest to trough' height.

a_0 =	0.35		*acceleration parameter*
R =	10.00		*vertical coordinate, in m, of the ship rotation centre*
f_β =	1.00		*heading correction factor*
f_{ps} =	1.00		
f_r =	1.00		
f_{fa} =	0.90		
f_T =	1.00		*ratio between draught at a loading condition and scantling draught*

Roll Motion

T_θ =	18.43	Sec	*Roll period*
θ =	23.48	deg	
$f_{p,s}$ =	1.00		*for strength assessment*
$f_{p,f}$ =	0.20		*for fatigue assessment*
f_{BK} =	1.00		
k_r =	12.58	m	
$GM_{calculation}$ =	2.48	m	
GM_{actual} =	2.48	m	*Full loading condition No21*
g =	9.81	m/s^2	

Pitch Motion

T_ϕ =	13.15	Sec	*Pitch period*
λ_ϕ =	270.12		
ϕ =	10.02	deg	*The pitch angle*
$f_{p,s}$ =	1.00		*for strength assessment*

$f_{p,f}$ =	0.21		*for fatigue assessment*

Ship accelerations at the centre of gravity

α_{surge} =	1.12	m/s^2	*The longitudinal acceleration due to surge*
$f_{p,s}$ =	1.00		*for strength assessment*
$f_{p,f}$ =	0.20		*for fatigue assessment*
α_{sway} =	1.87	m/s^2	*The transverse acceleration due to sway*
$f_{p,s}$ =	1.00		*for strength assessment*
$f_{p,f}$ =	0.20		*for fatigue assessment*
α_{heave} =	3.47	m/s^2	*The vertical acceleration due to heave*
v =	5.00		
$f_{p,s}$ =	1.00		*for strength assessment*
$f_{p,f}$ =	0.23		*for fatigue assessment*
α_{roll} =	0.05	rad/s^2	*The roll acceleration*
$f_{p,s}$ =	1.00		*for strength assessment*
$f_{p,f}$ =	0.20		*for fatigue assessment*
α_{pitch} =	0.05	rad/s^2	*The pitch acceleration*
$f_{p,s}$ =	1.00		*for strength assessment*
$f_{p,f}$ =	0.23		*for fatigue assessment*
x =	112.55	m	*longitudinal position along the ship*
f_{lp} =	1		*factor depending on longitudinal position along the ship*

Accelerations for dynamic load cases

Longitudinal acceleration

The longitudinal acceleration at any position for each dynamic load case, shall be taken as:

α_x =	-1.27	m/s^2	
z =	20	m	*the considered point with respect to the coordinate system*

Transverse acceleration

The transverse acceleration at any position for each dynamic load case, shall be taken as:

α_y = 0 m/s²

Vertical acceleration

The vertical acceleration at any position for each dynamic load case, shall be taken as:

α_z = 1.62 m/s²

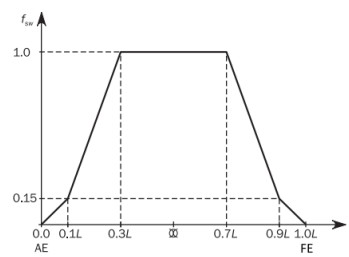
y= 10 m

3.5.2 Hull Girder Load

Still water hull girder loads

Cw = 10.10 m *wave coefficient, for 90 <=L <=300*

Vertical still water bending moment



Still water bending moment in seagoing condition

Hogging conditions:

$M_{sw\text{-}h\text{-}min}$ = 1700897.2 kNm

Sagging conditions:

$M_{sw\text{-}s\text{-}min}$ = -1347127.2 kNm

$M_{wv\text{-}h\text{-}min}$ = 2756509.0 *vertical wave bending moment in kN, amidships in hogging condition*

$M_{wv\text{-}s\text{-}min}$ = -2872550.7 *vertical wave bending moment in kN, amidships in sagging condition*

fsw = 1 *distribution factor along the ship length*

Vertical still water shear force

Still water shear force

$Q_{sw\text{-}pos\text{-}min}$ = 30224.74 kN *the hull girder positive vertical still water shear force*

$Q_{sw\text{-}neg\text{-}min}$ = -30224.74 kN *the hull girder negative vertical still water shear force*

$M_{sw\text{-}min}$ = 1700897.21 *absolute maximum of* $M_{sw\text{-}h\text{-}min}$ and $M_{sw\text{-}s\text{-}min}$ with f_{sw} = 1.0

fqs = 0.8 *distribution factor along the ship length*

Dynamic hull girder loads

Vertical wave bending moment

The vertical wave bending moments at any longitudinal position, in kNm, shall be taken as:

Hogging conditions:

$M_{wv\text{-}h}$ = 2756509.025 kNm

Sagging conditions:

$M_{wv\text{-}s}$ =	-2872550.685	kNm

$f_{n\ell\text{-}vh}$ =	1	*coefficient considering non-linear effects applied to hogging*
$f_{n\ell\text{-}vs}$ =	1.04	*for strength assessment*
	1	*for fatigue assessment*
f_p =	1.00	*for strength assessment*
	0.25	*for fatigue assessment*
f_{vib} =	1.14	
f_m =	1	*distribution factor for vertical wave bending moment along the ship's length*

Vertical wave shear force

The vertical wave shear forces at any longitudinal position, in kN, shall be taken as:

$Q_{wv\text{-}pos}$ =	24447.81148	*Positive permissible still water shear forces, in kN, at any longitudinal position*
$Q_{wv\text{-}neg}$ =	-24447.81148	*Negative permissible still water shear forces, in kN, at any longitudinal position*

f_p =	1.00	*for strength assessment*
	0.24	*for fatigue assessment*
$f_{q\text{-}pos}$ =	0.73	
$f_{q\text{-}neg}$ =	0.73	

Horizontal wave bending moment

The horizontal wave bending moment at any longitudinal position, in kNm, shall be taken as:

M_{wh} =	2883281.02	kNm

f_p =	1.00	*for strength assessment*
	0.22	*for fatigue assessment*

Wave torsional moment

The wave torsional moment at any longitudinal position with respect to the ship baseline, in kNm, shall be taken as:

M_{wt} =	316223.9	kNm
M_{wt1} =	166808.4	kNm
M_{wt2} =	149415.5	kNm
f_{t1} =	0.57	
f_{t2} =	0.33	
x=	112.55	m

f_p =	1.00	*for strength assessment*
	0.18	*for fatigue assessment*

Hull girder loads for dynamic load cases

Vertical wave bending moment

$M_{wv\text{-}LC}$ = -2872550.7 kNm

C_{WV} = -1 *load combination factor for vertical wave bending moment shall be taken as specified in "Motions & Accelerations" table*

Vertical wave shear force

$Q_{wv\text{-}LC}$ = 24447.81 kN

C_{QW} = -1 *load combination factor for vertical wave shear force, shall be taken as specified in "Motions & Accelerations" table*

Horizontal wave bending moment

$M_{wh\text{-}LC}$ = 0.0 kNm

C_{WH} = 0 *load combination factor for horizontal wave bending moment shall be taken as specified in "Motions & Accelerations" table*

Wave torsional moment

$M_{wt\text{-}LC}$ = 0.0 kNm

C_{WT} = 0

load combination factor for wave torsional moment shall be taken as specified in "Motions & Accelerations" table

Hull girder targets

Procedure to adjust vertical bending moment for midship cargo hold region

As we have already discussed earlier, in case the target vertical bending moment needs to be reached, an additional vertical bending moment is to be applied at both ends of the cargo hold FE model to generate this target value in the mid-hold of the model. In our case the shear force adjustment is not requested because after applying the local loads, the shear forces at both bulkheads are lower to the target values as we may notice from the below figure 12. And thus this end vertical bending moment is corrected only by applying only the $M_{V\text{-}FEM}$ correction (figure 13), which is the vertical bending moment, in kNm, at position x, due to the local loads.

$M_{v\text{-}targ}$ = -2022102.08 kNm

$C_{BM\text{-}LC}$ = 0.5

$M_{v\text{-}end}$ = -1748102.08 kNm

$M_{v\text{-}peak}$ = $M_{v\text{-}FEM}$ = -274000 kNm

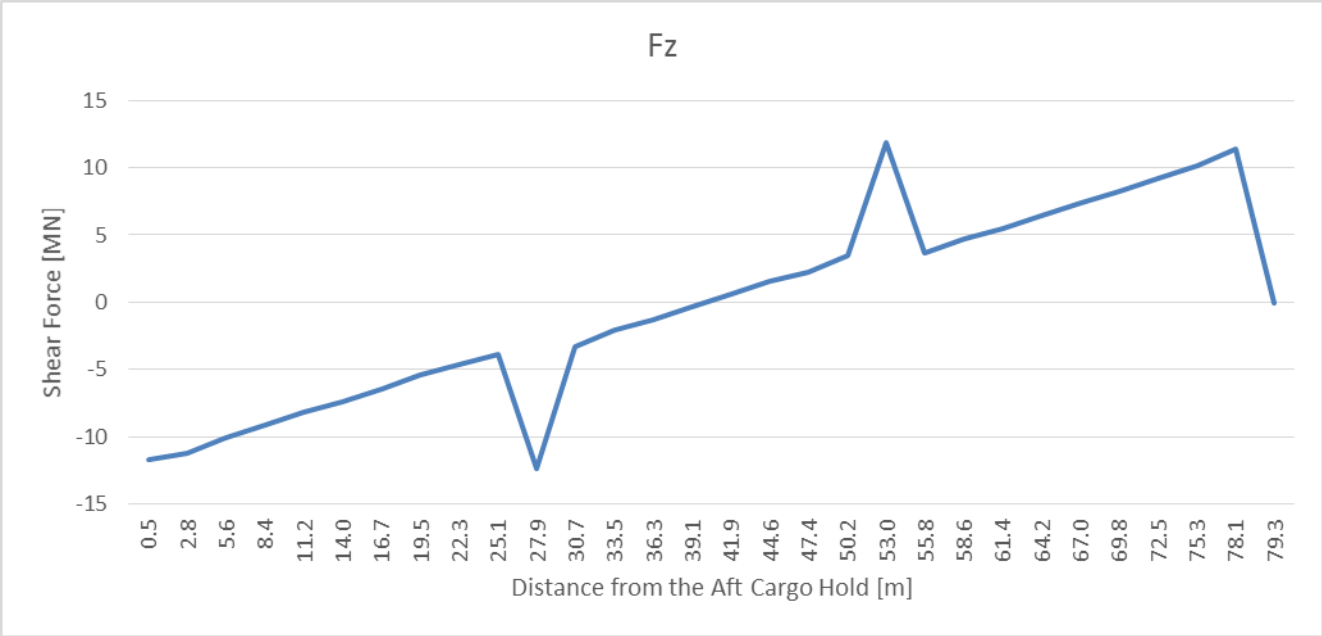


***Figure** 12 – Shear forces diagram due to local loads*

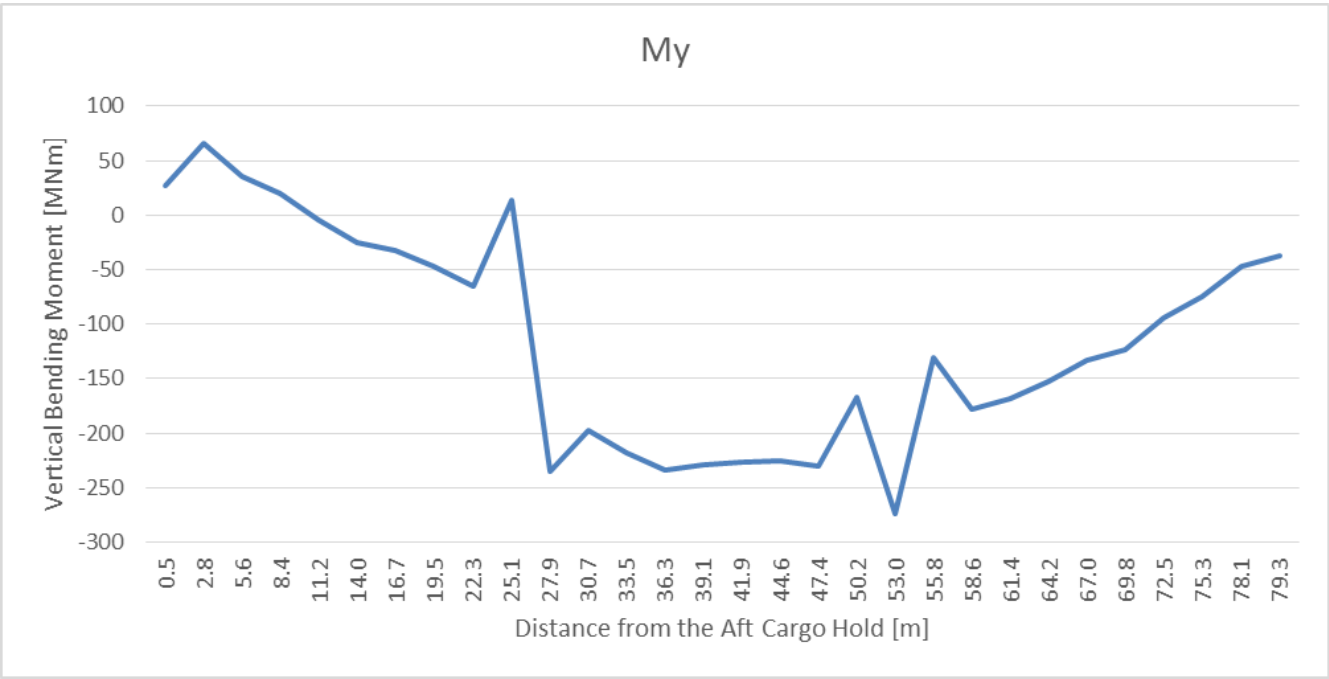


***Figure** 13 – Bending moment diagram due to local loads*

Target hull girder shear force

$Q_{targ\text{-}aft}$ =	-56191.61	*The target hull girder vertical shear force in kN at the aft transverse bulkhead of the mid-hold*
$Q_{targ\text{-}fore}$ =	56191.61	*The target hull girder vertical shear force in kN at the forward transverse bulkhead of the mid-hold*
ΔQ_{swa} =	1519.06	kN
ΔQ_{swf} =	1519.06	kN
C_{QW} =	-1	
$C_{SF\text{-}LC}$ =	1	

$\Delta Q_{mdf,\ aft\ end}$ =	1519.06
$\Delta Q_{mdf,\ fore\ end}$ =	-1519.06
$\Delta Q_{mdf,\ mid}$ =	1519.06

$C_{d,a}$ =	-1	*distribution coefficient at the aft end of the considered cargo hold*
$C_{d,f}$ =	1	*distribution coefficient at the fore end of the considered cargo hold*
α =	1255.12	
M =	11000	t
B_H =	32.26	
l_H =	25.11	
l_0 =	32.26	
b_0 =	25.11	
ϕ =	3.37	

3.6 Solution

The final step of the modeling presses is solution. A number of 1921122 mathematical equations are solved in order to have our results ready to use for the next step: “Results and Analysis”.

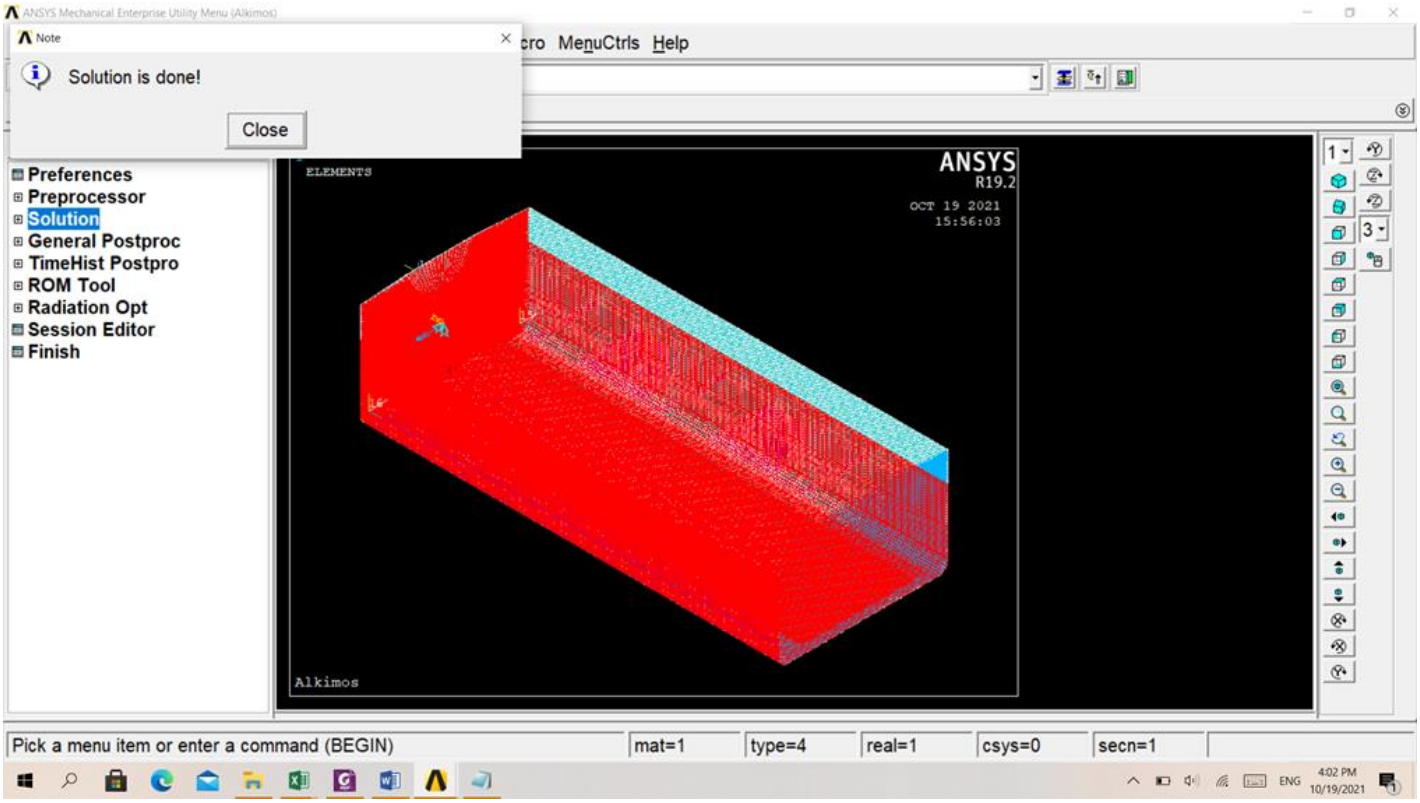


Figure** 14 – **Solution of the full model

4. Results and analysis

4.1 Yield strength assessment

The total deformation occurred due to the applied load on the model is shown in the following figures. The maximum displacement vector summary deformation is 42.86mm. It is seen from the Fig. 18 that the maximum deformation is occurring at the aft and fwd hatch coaming plates. It occurs because we omit the transverse bulkheads at the ends of the model.

It is interesting in the present analysis to see how the solution changes depending on whether we choose an element solution or a nodal solution. As we can see in the pictures that follow, in the element solution, greater stresses occur than in the nodal solution. ANSYS displays stresses in two ways: a)Element stress solution and b) Nodal stress solution. In element stresses solution, the element stresses are displayed within individual elements. They are non-averaged stresses. The stress distribution is unique to an individual element. From the other side, in nodal stress solutions, the stresses are in averaged form at each global node. The stress value at a global node is average of all the local-node-stress-values of all the elements sharing that global node.

Going back to the finite element theory, we will see that this theory is based on an energy equilibrium, by applying the method of displacements, solving a mathematical model of the equations in order to come to energy balance and the overall problem is solved in terms of global nodes. Once displacement vector is computed we can compute strain components using the spatial derivatives of the displacement. Once strain at each node (global as well as local nodes) is known we can compute stress σ at each node, find the displacements and by extension the modes at each node. These modes are calculated for each node and thus constitute a continuous field. Our goal, however, is to calculate the stresses to see if we are within the limit values set by the regulations.

All the above drive to large deviations in the points where different structural components (ex. inner bottom with hopper plate or/and stool plate) are joined. Exactly at these points we notice that we have discontinuous type of stress and stresses overpass the limits. The discontinuous type of stress distribution in element solution only indicates that mesh refinement is needed. Refining the mesh, the element solution approaches the nodal solution. However here our goal is partial ship analysis and not local and by using a meshing with element size 420 mm which is much more less than a half of the frame space (930mm), we consider that our whole approach is considered satisfactory.

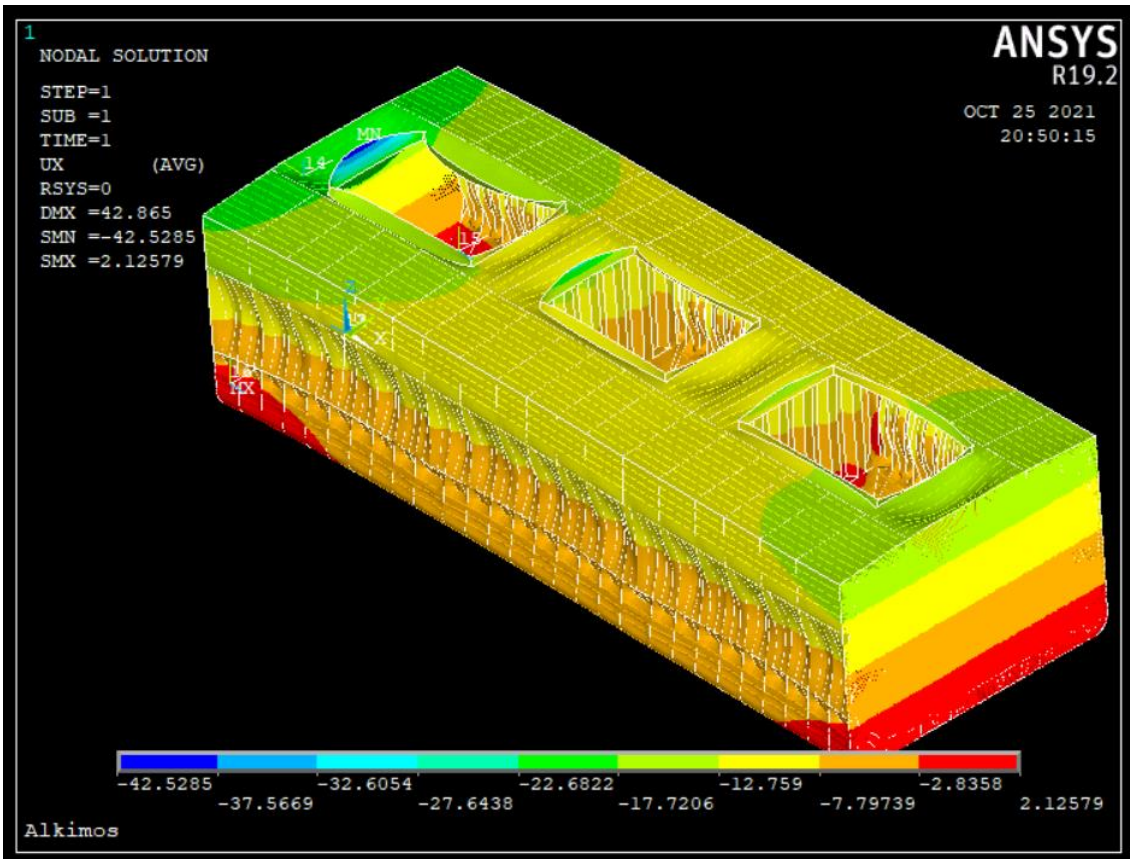


***Figure** 15 – X-Component of Displacement*

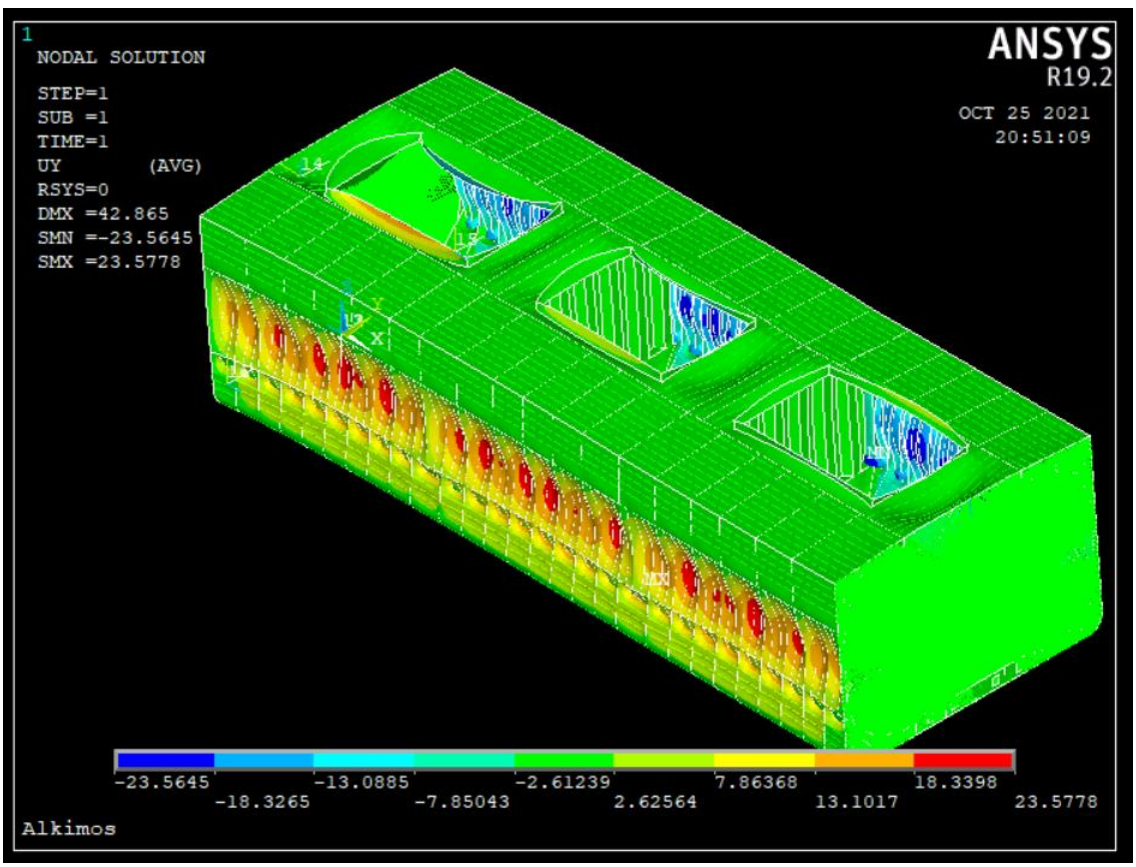


***Figure** 16 – Y-Component of Displacement*

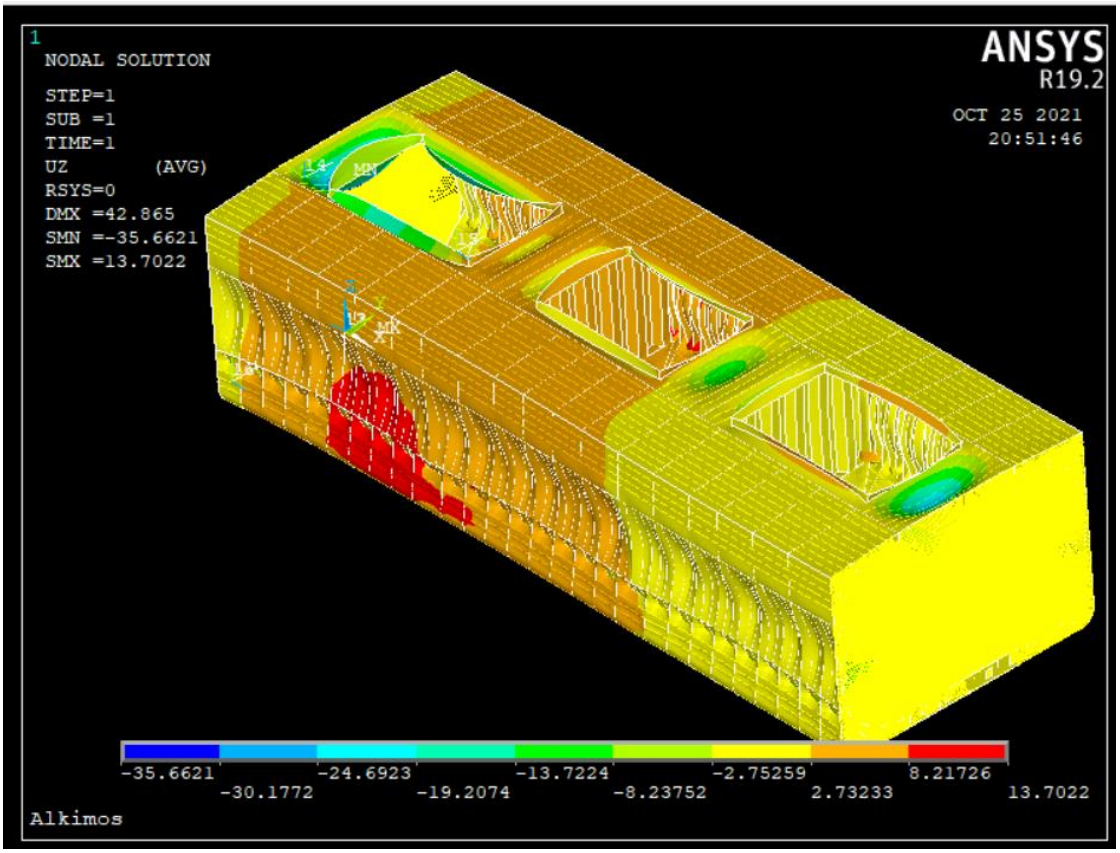


***Figure** 17 – Z-Component of Displacement*

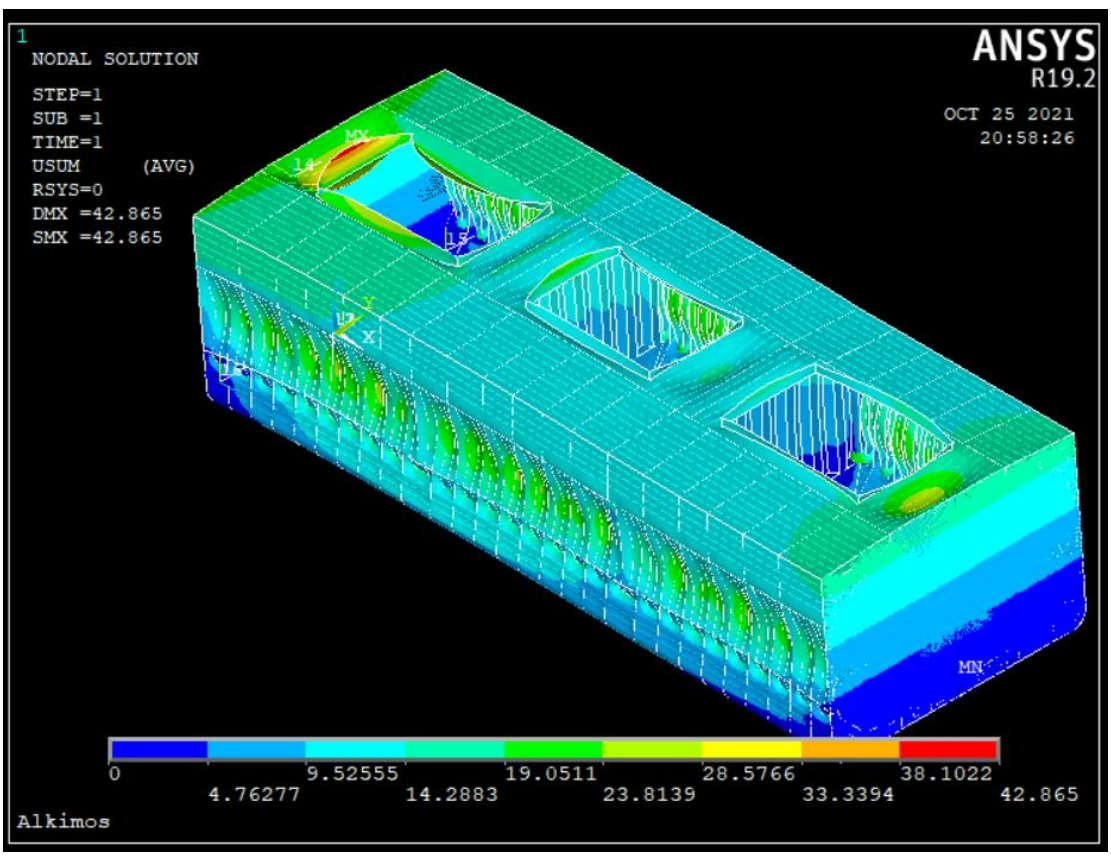


***Figure** 18 –Displacement Vector Summary*

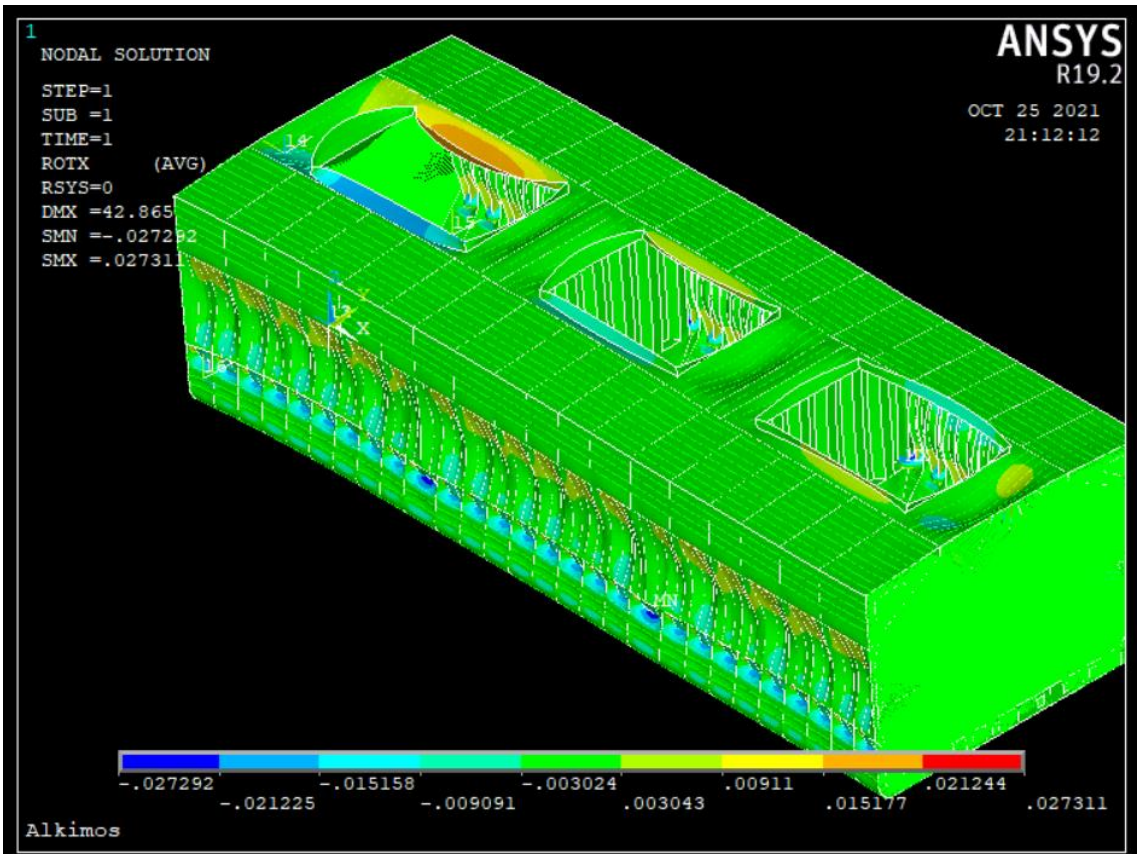


***Figure** 19 – X-Component of Rotation*

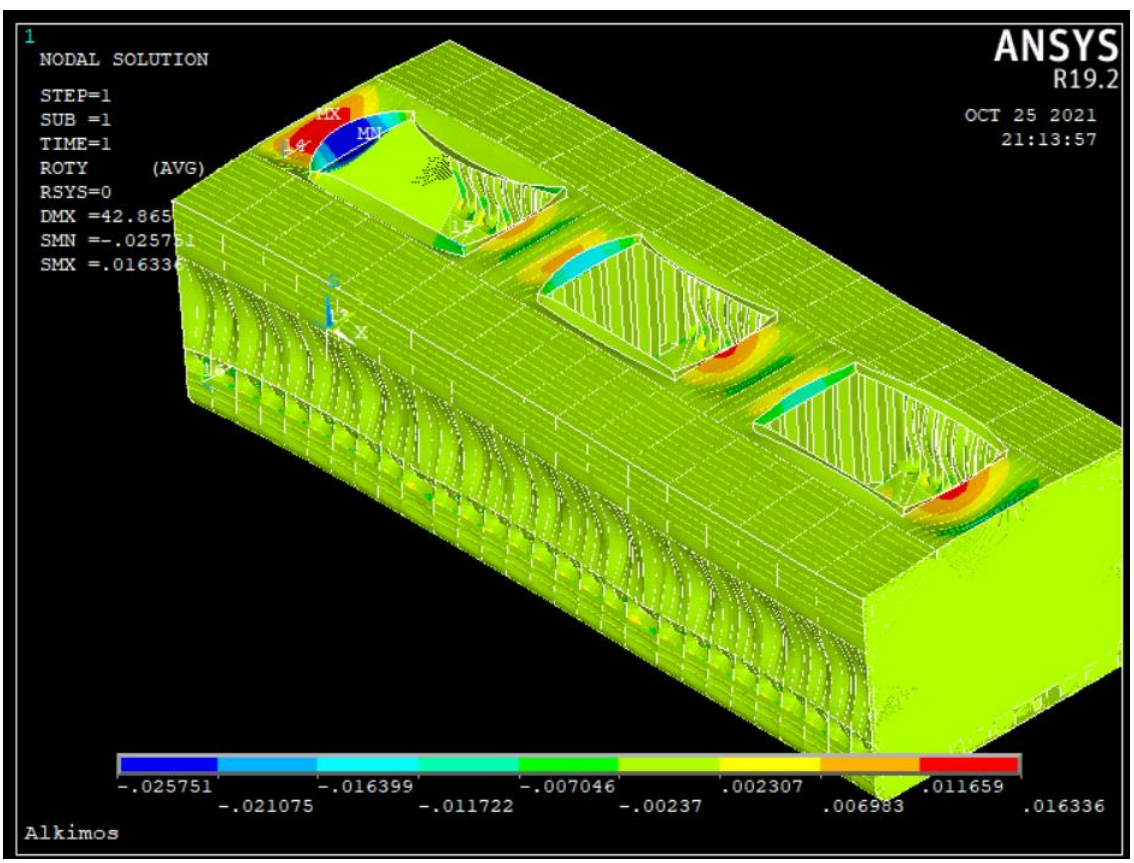


***Figure** 20 – Y-Component of Rotation*

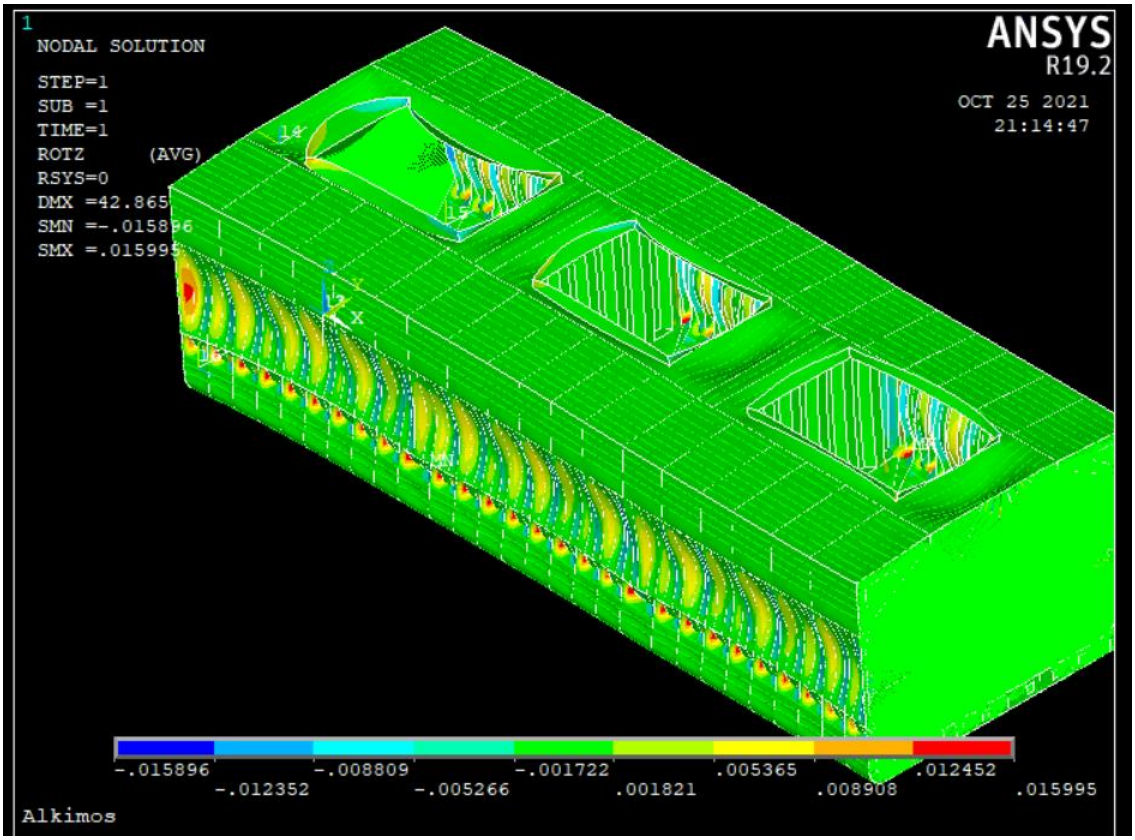


***Figure** 21 – Z-Component of Rotation*

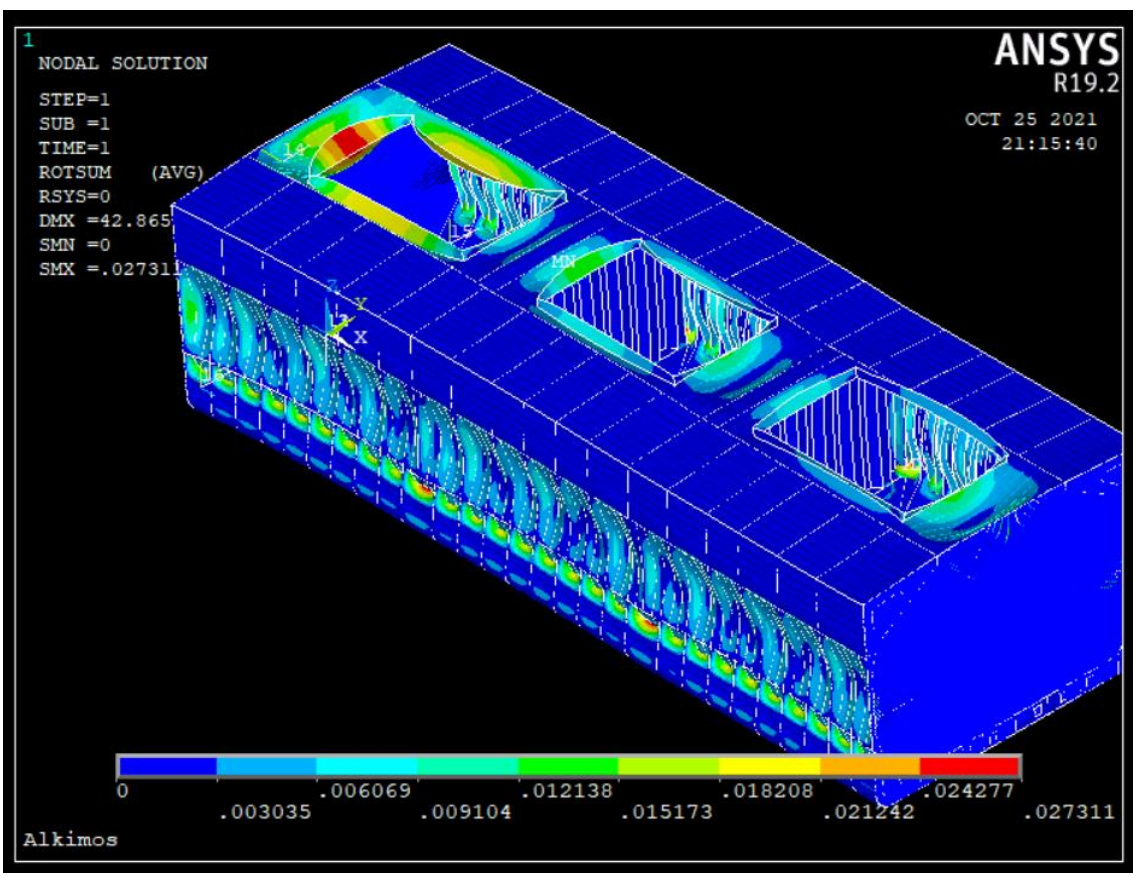


***Figure** 22 –Rotation Vector Summary*

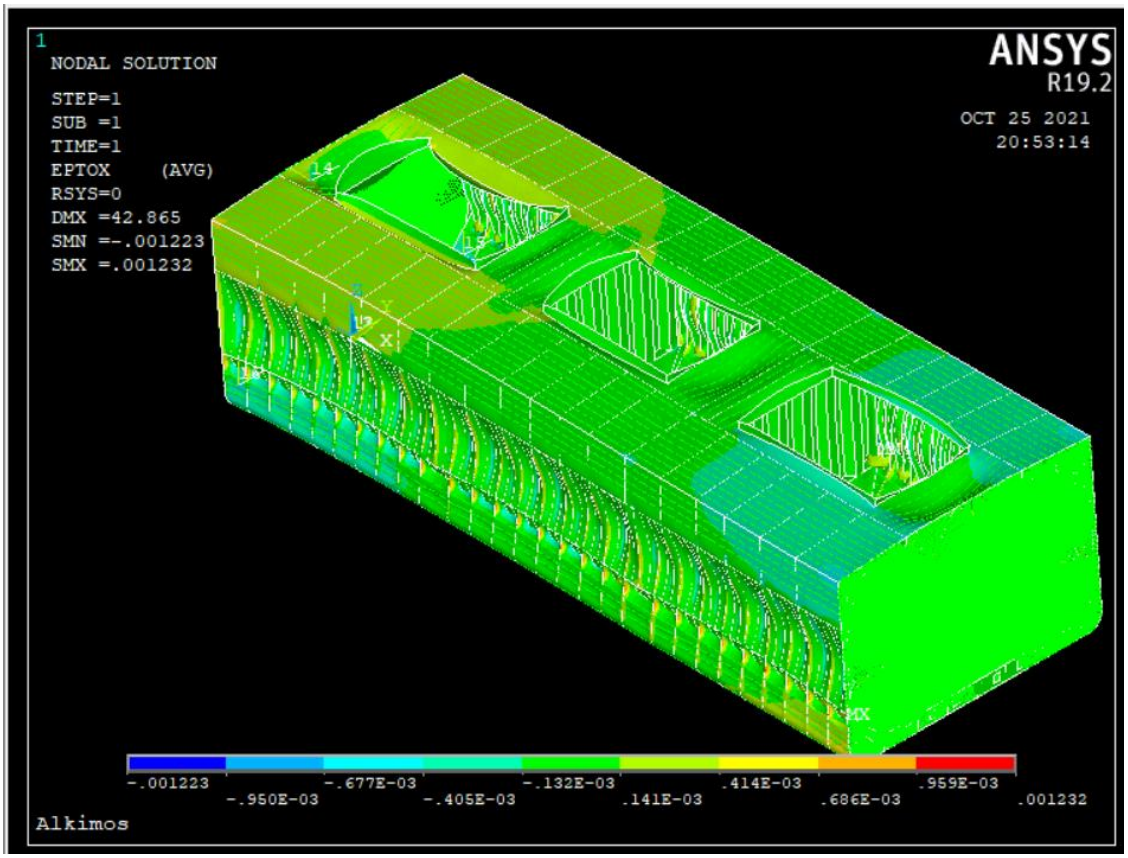


***Figure** 23 – X-Component of Total Mechanical Strain*

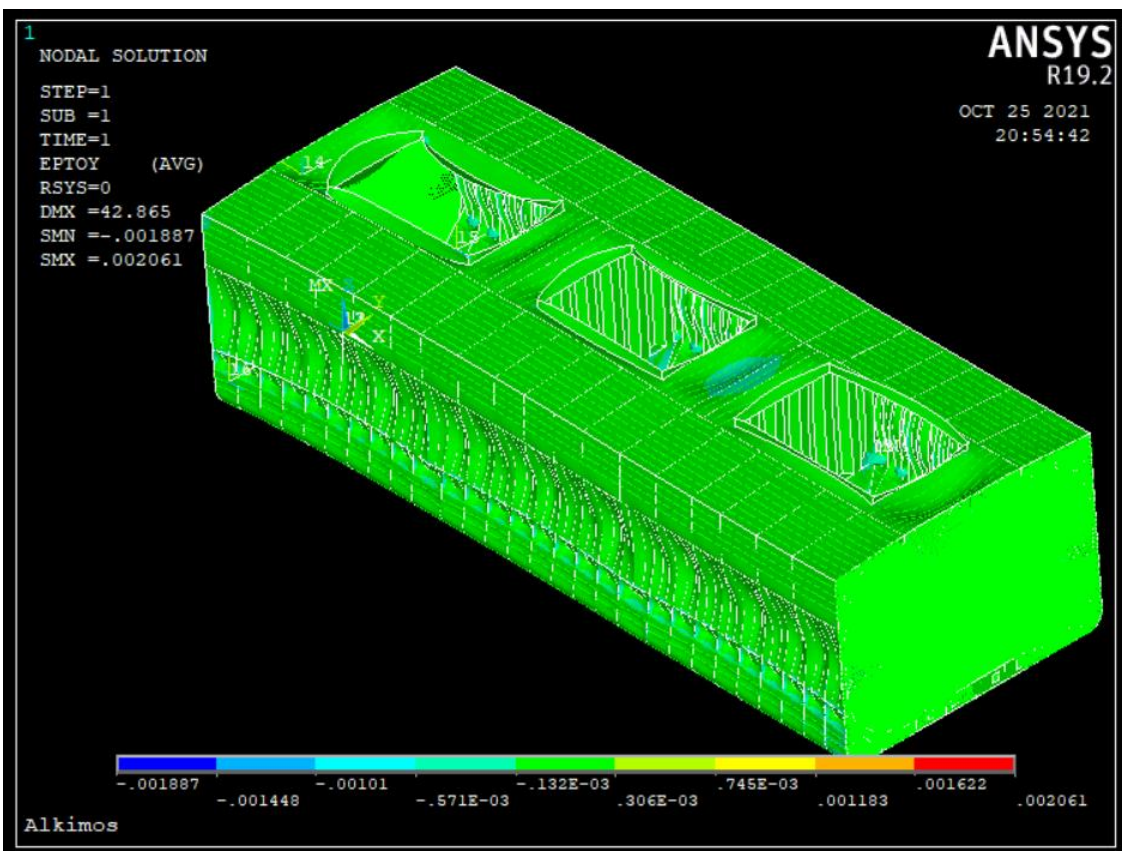


***Figure** 24 – Y-Component of Total Mechanical Strain*

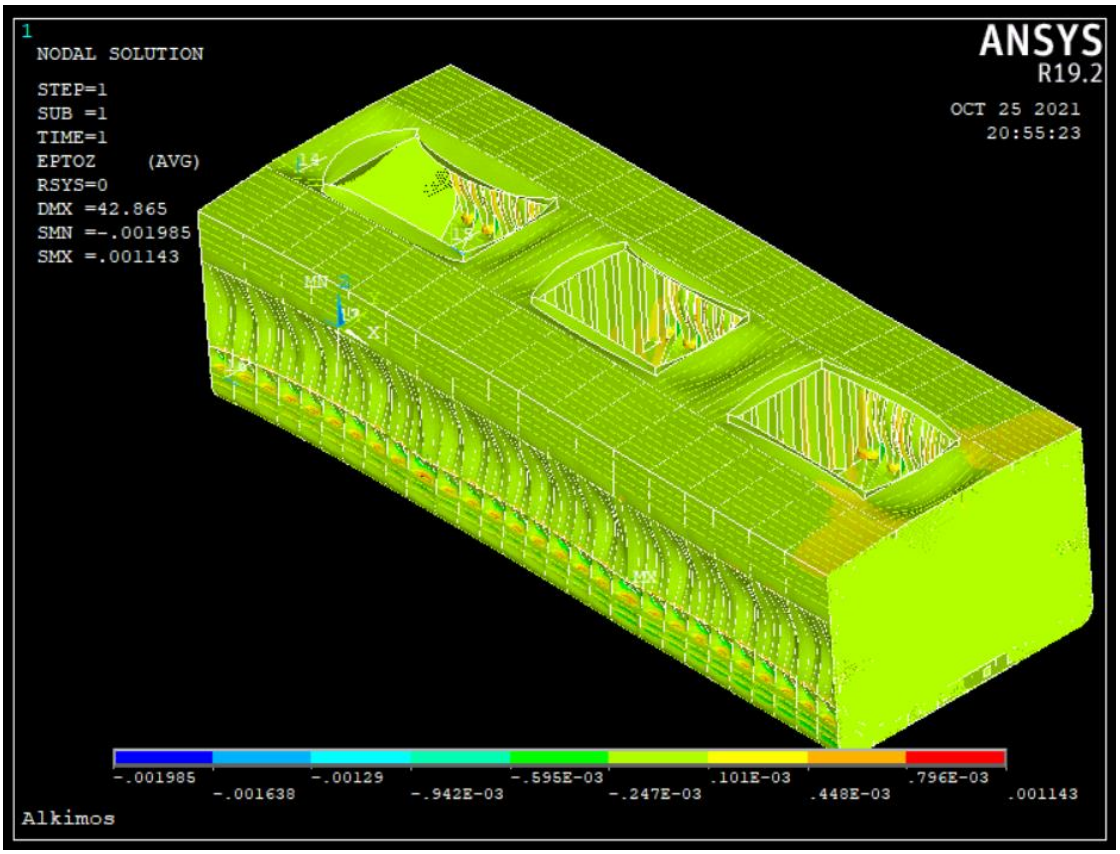


***Figure** 25 – Z-Component of Total Mechanical Strain*

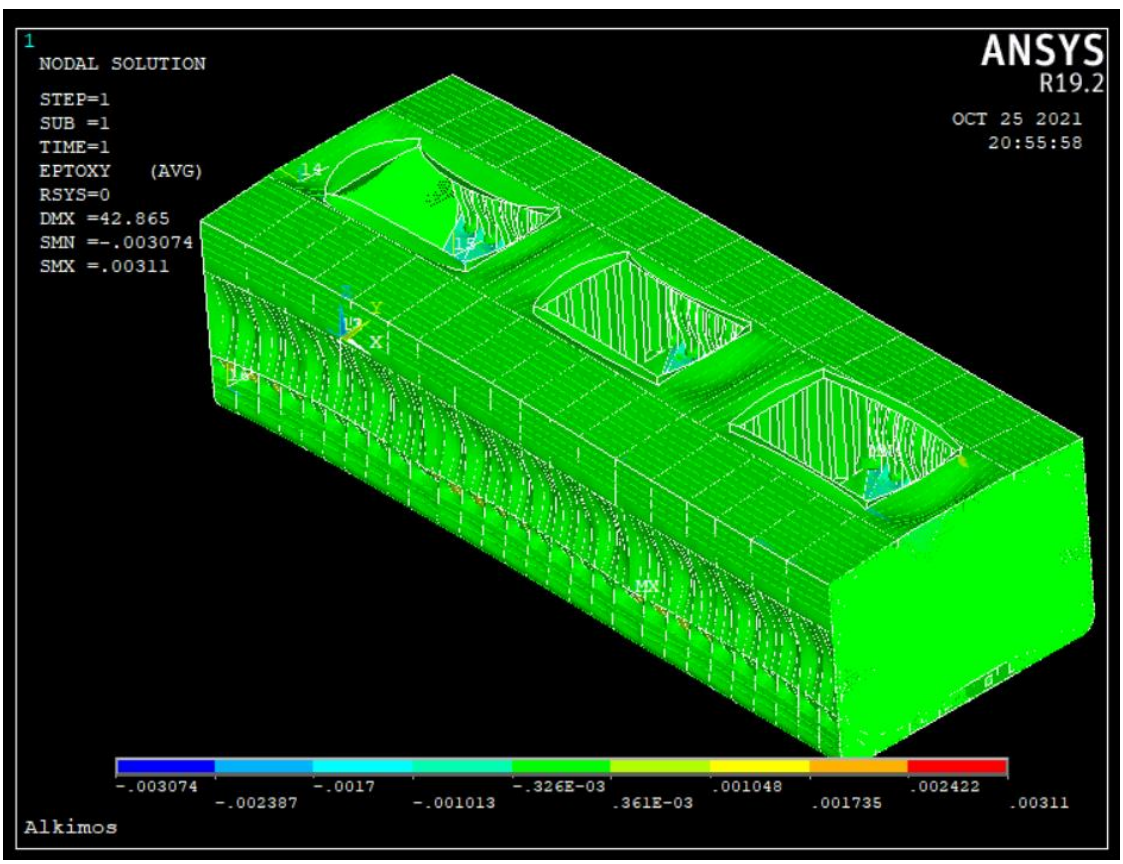


***Figure** 26 – XY-Shear Total Mechanical Strain*

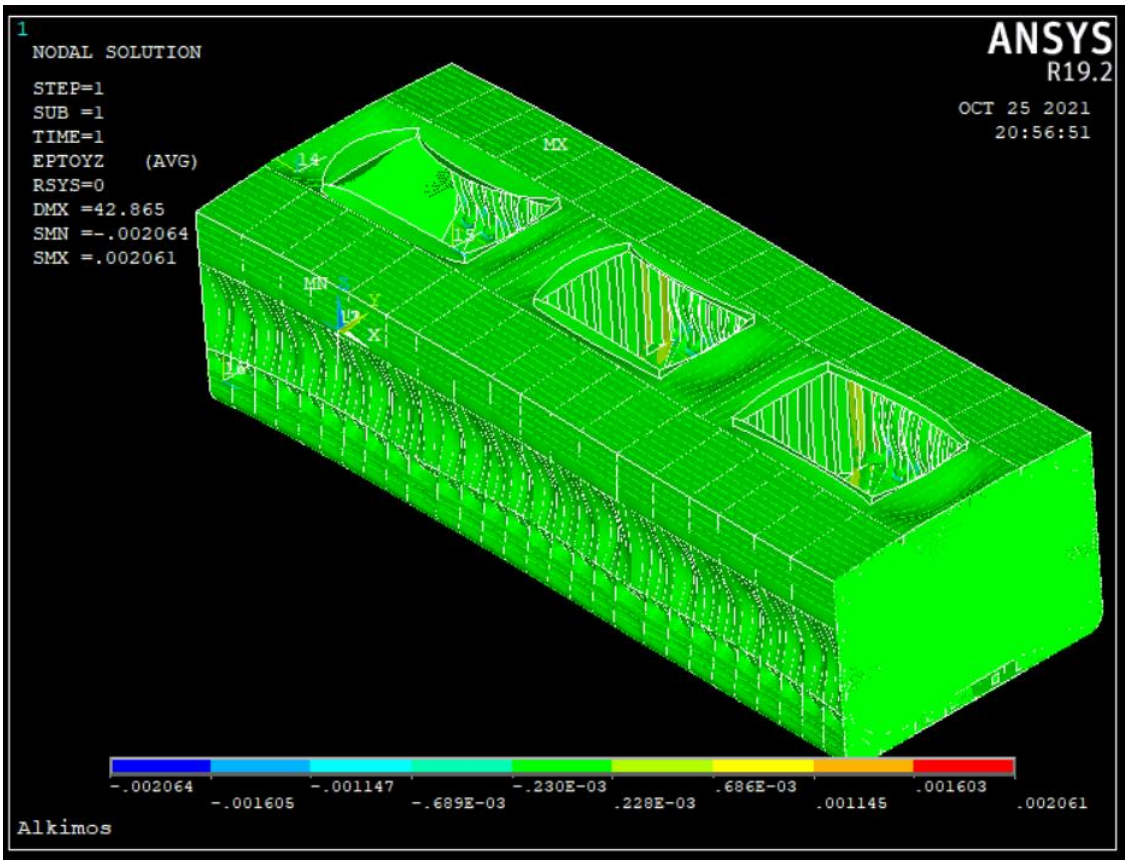


***Figure** 27 – YZ-Shear Total Mechanical Strain*

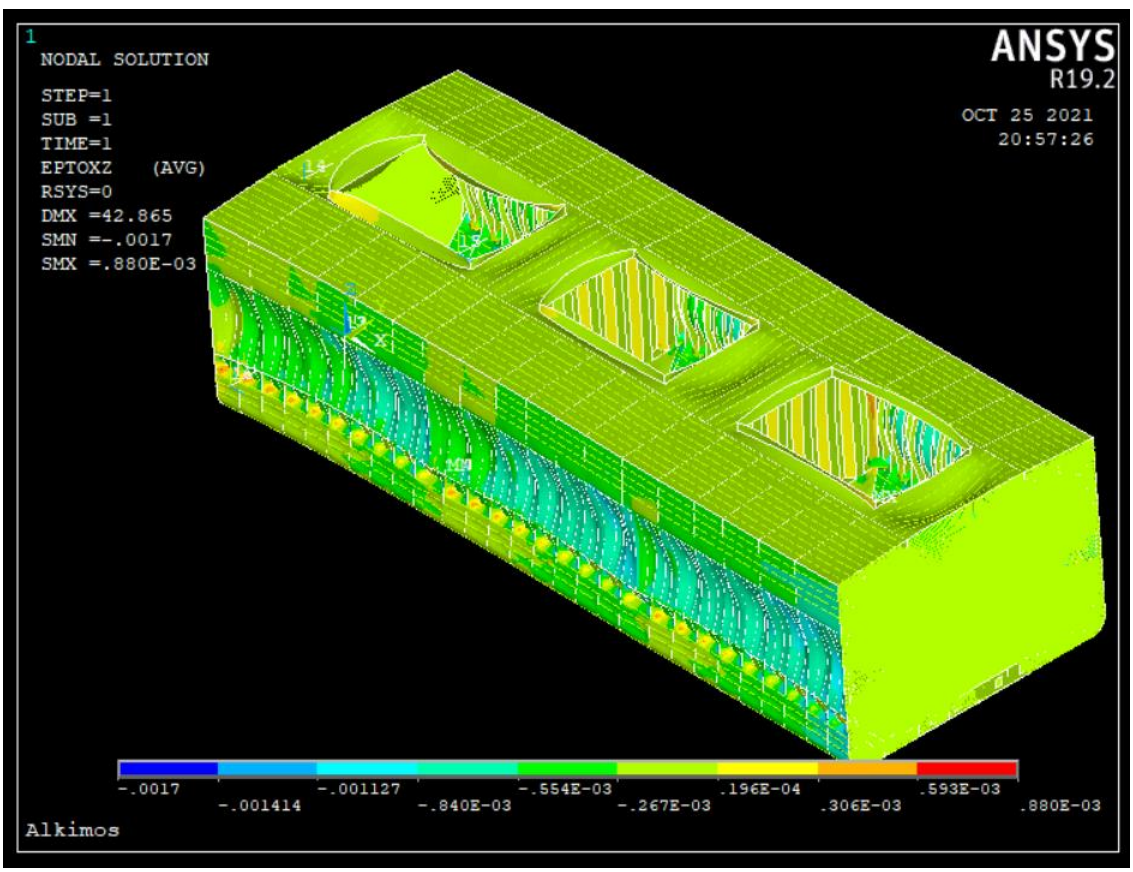


***Figure** 28 – XZ-Shear Total Mechanical Strain*

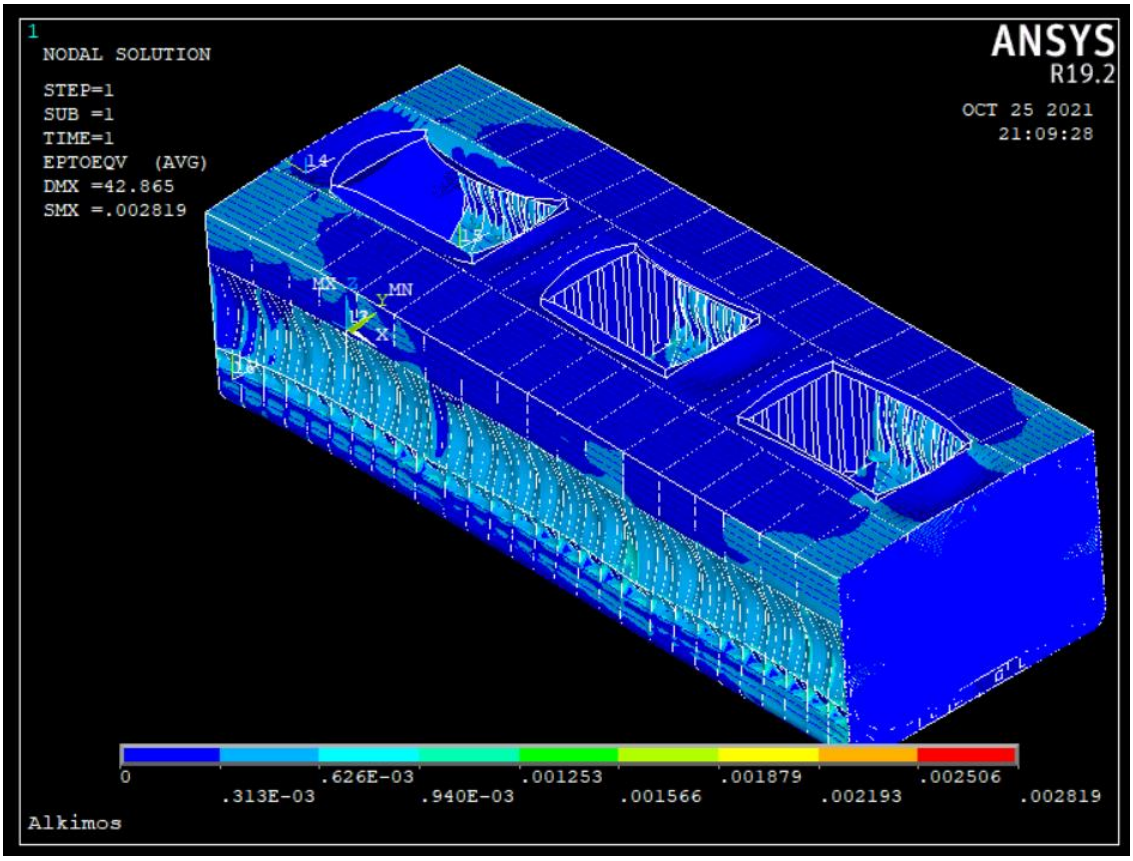


***Figure** 29 – Von Misses Total Mechanical Strain*

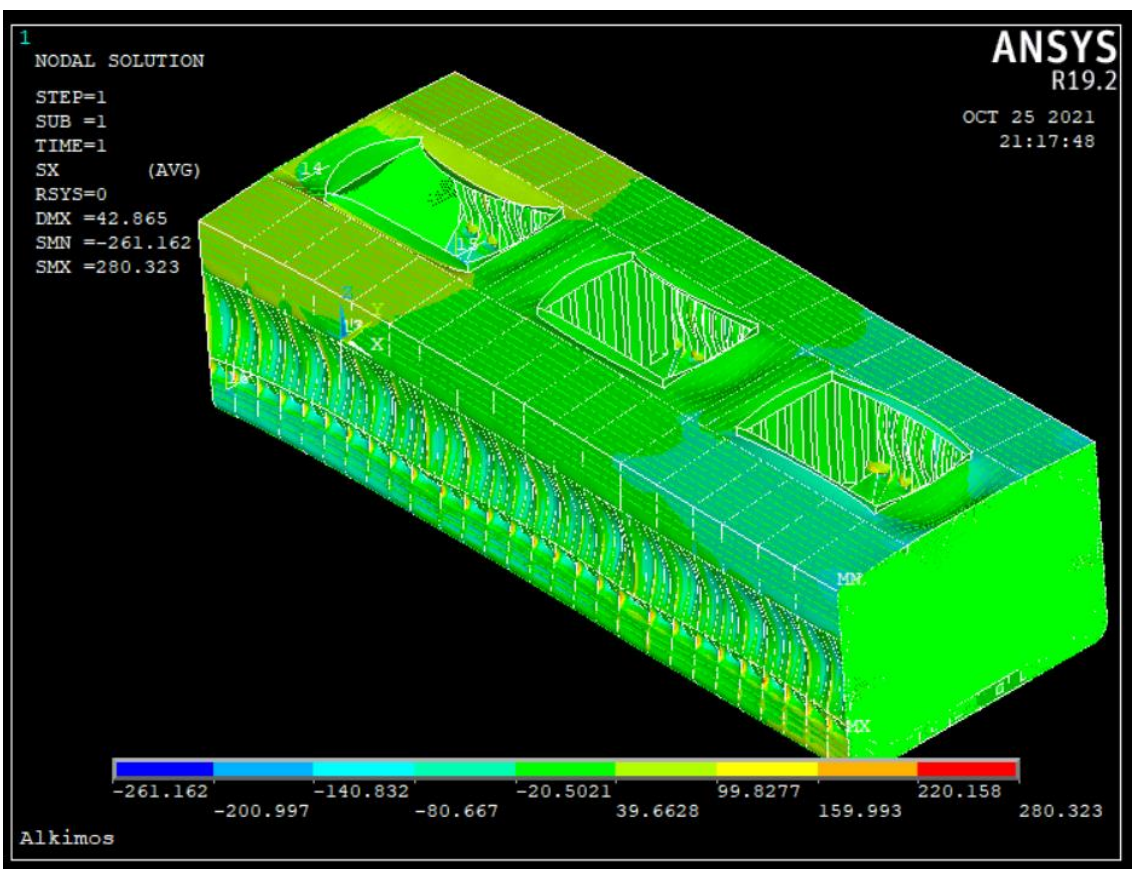


***Figure** 30 – X-Component of Stress / Nodal Solution*

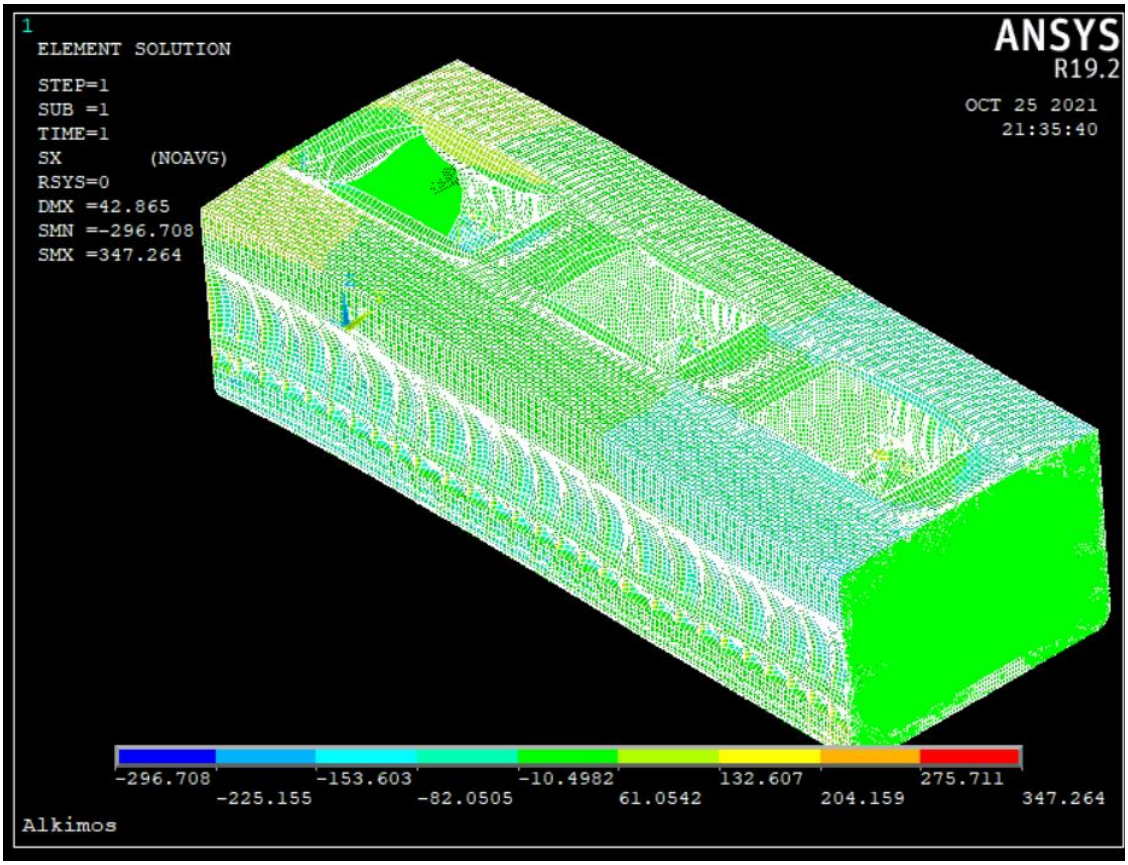


***Figure** 31 – X-Component of Stress / Element Solution*

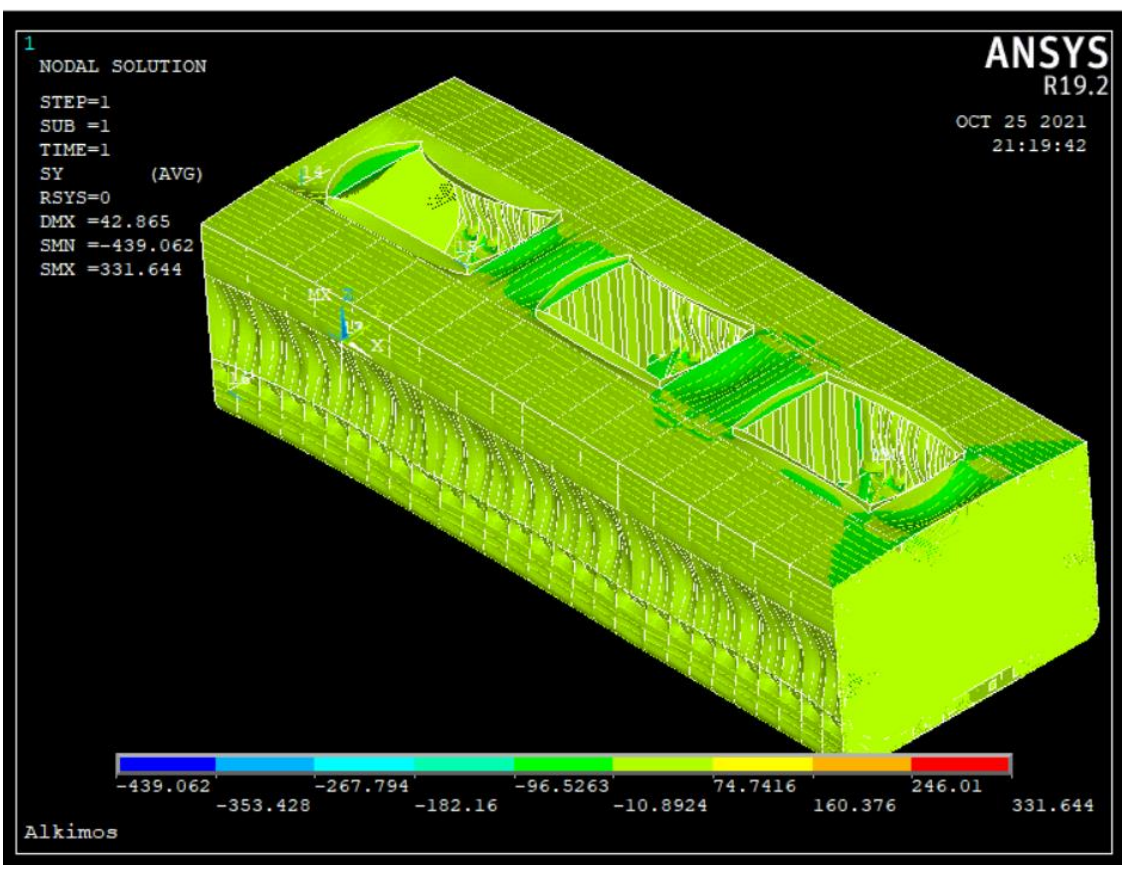


***Figure** 32 – Y-Component of Stress / Nodal Solution*

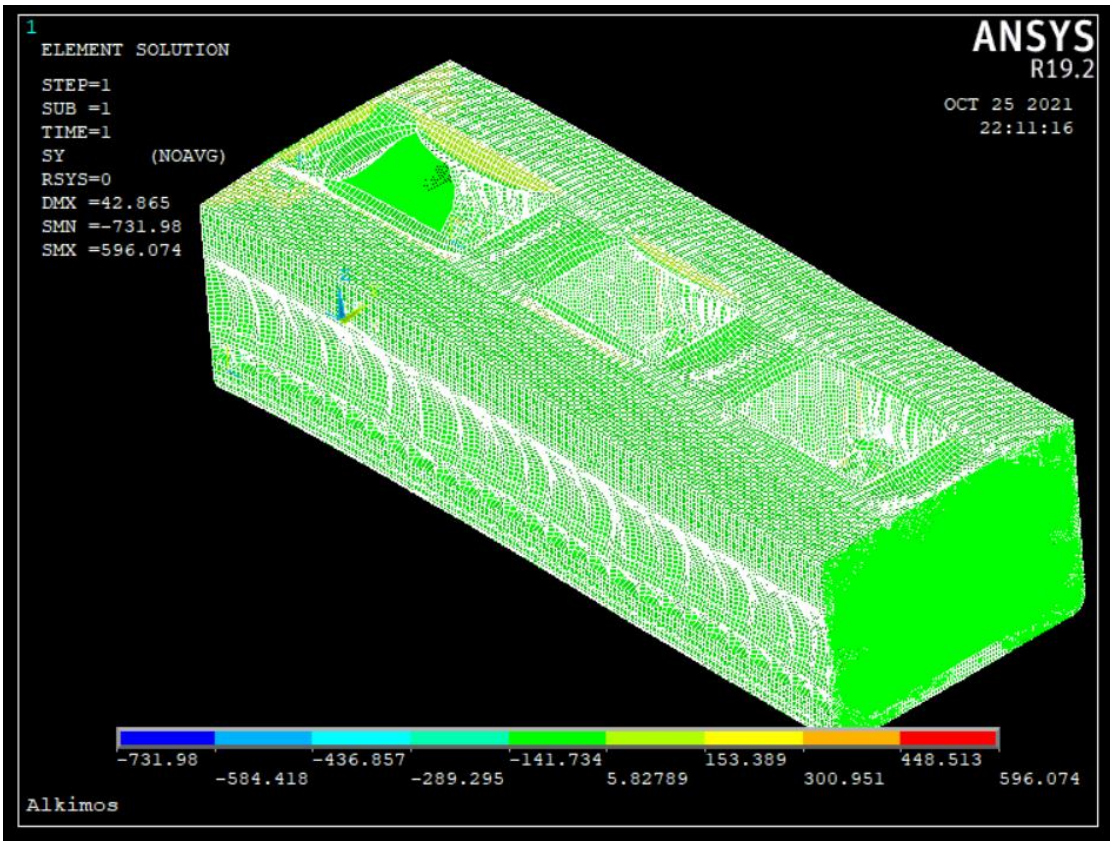


***Figure** 33 – Y-Component of Stress / Element Solution*

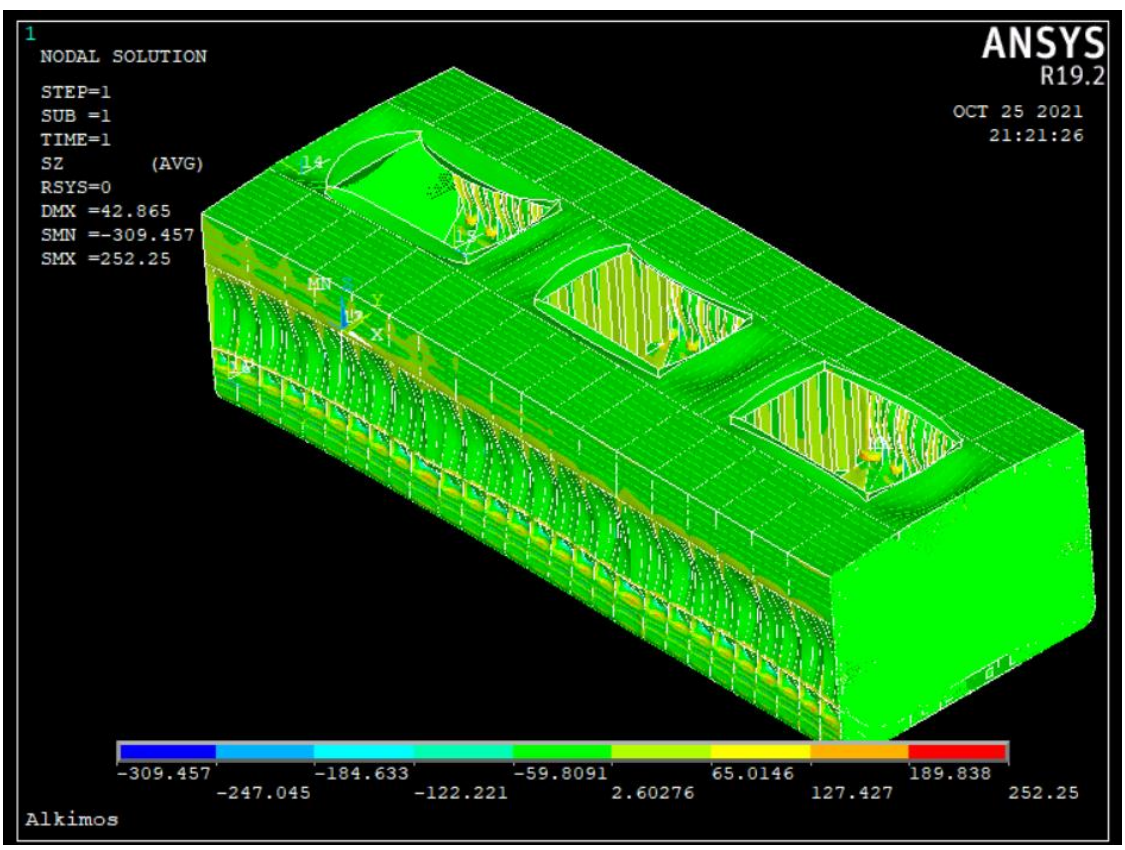


***Figure** 34 – Z-Component of Stress / Nodal Solution*

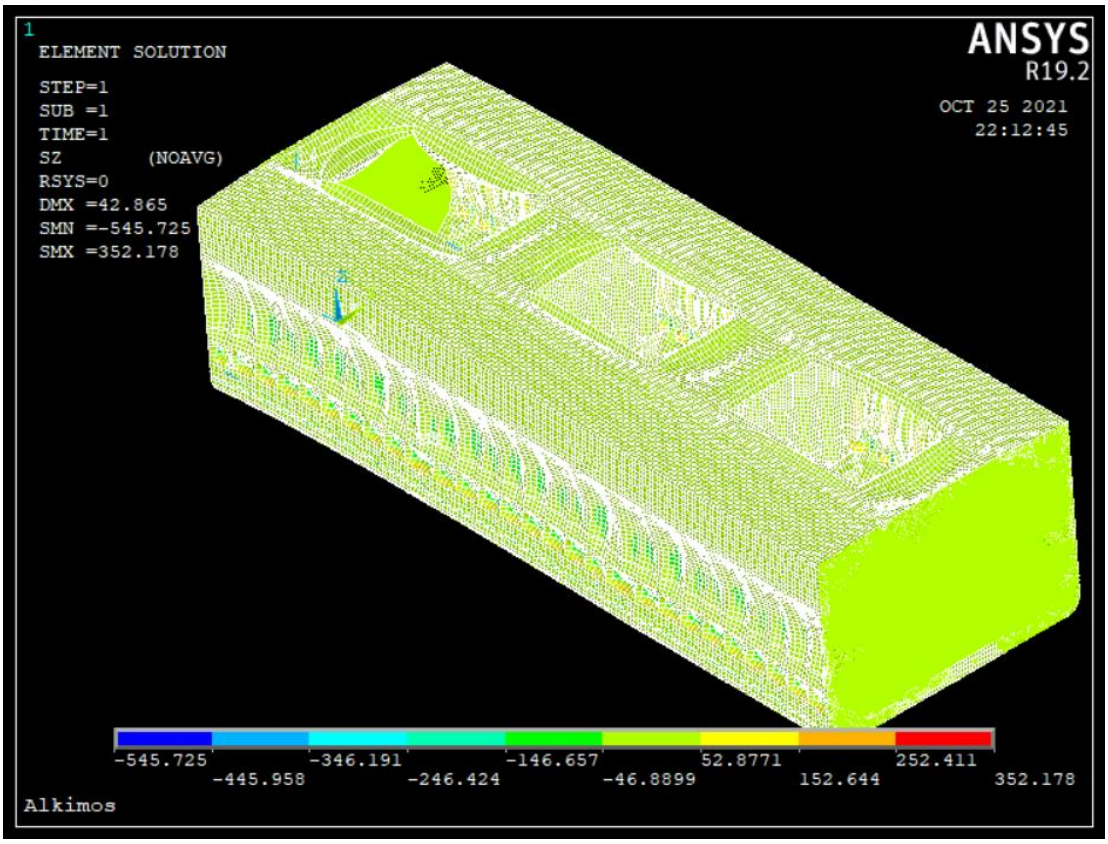


***Figure** 35 – Z-Component of Stress / Element Solution*

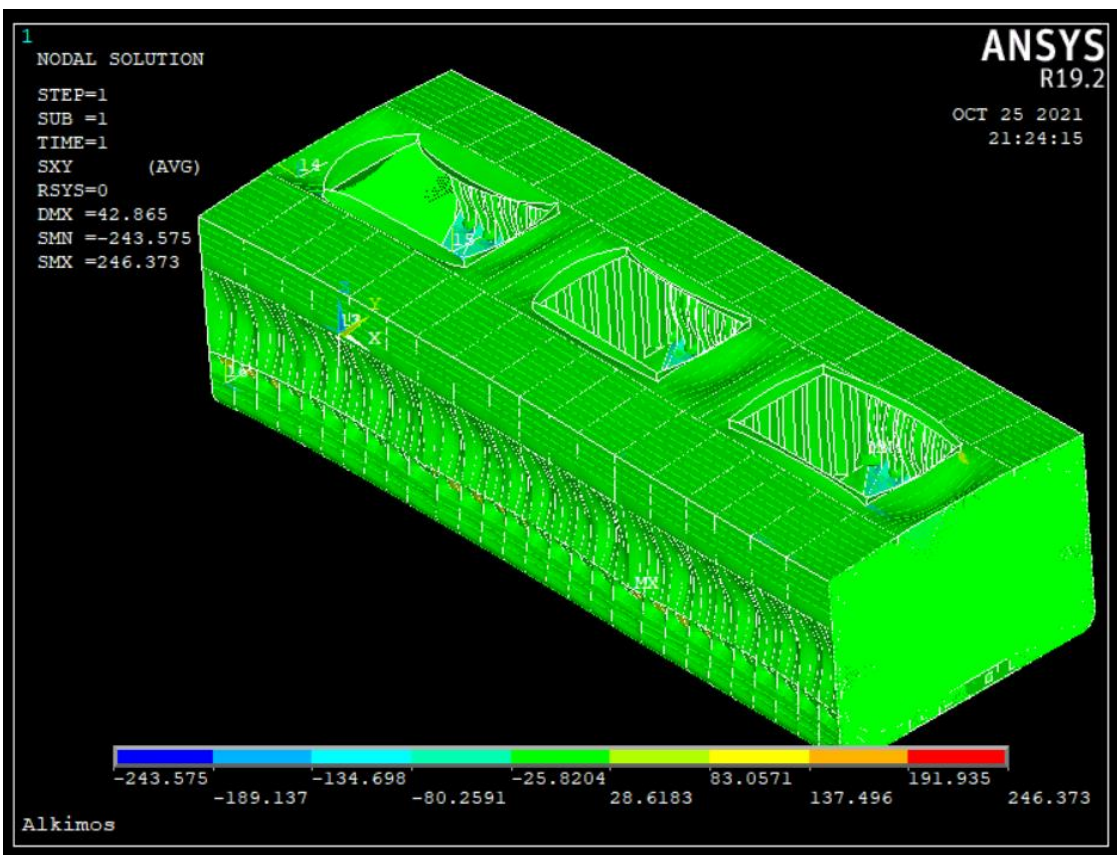


***Figure** 36 – XY-Shear Stress / Nodal Solution*

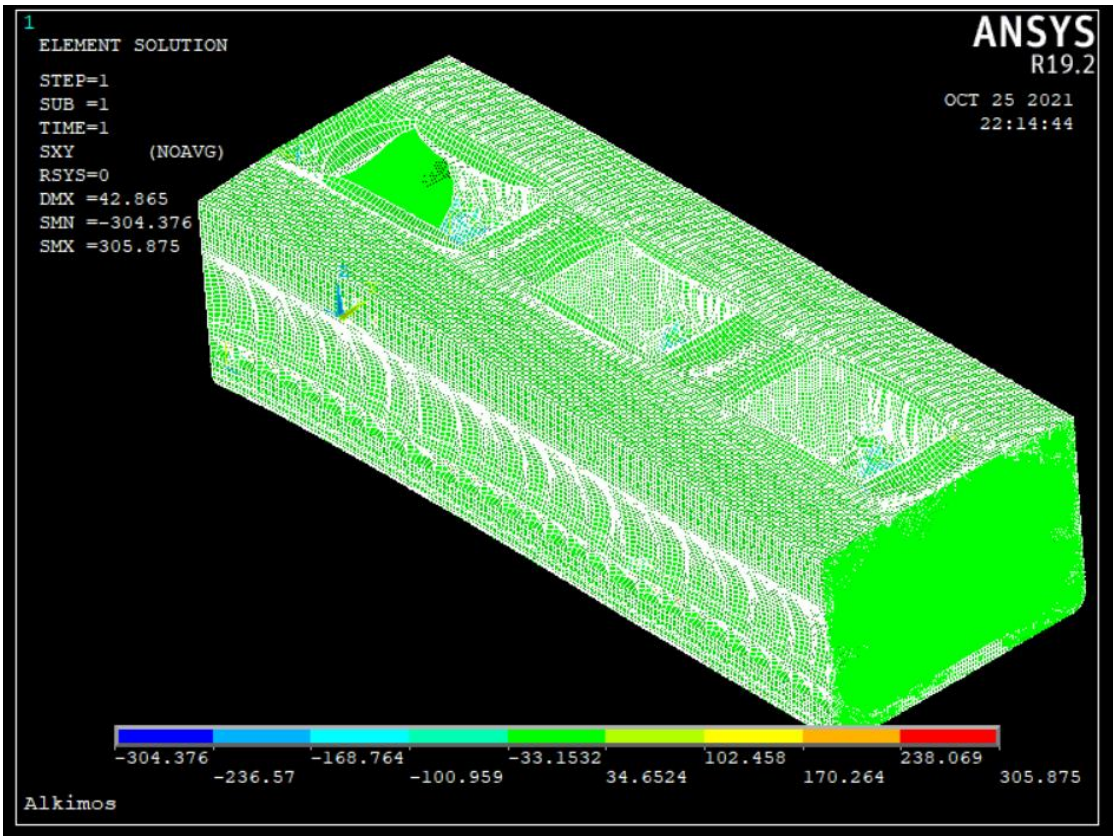


***Figure** 37 – XY-Shear Stress / Element Solution*

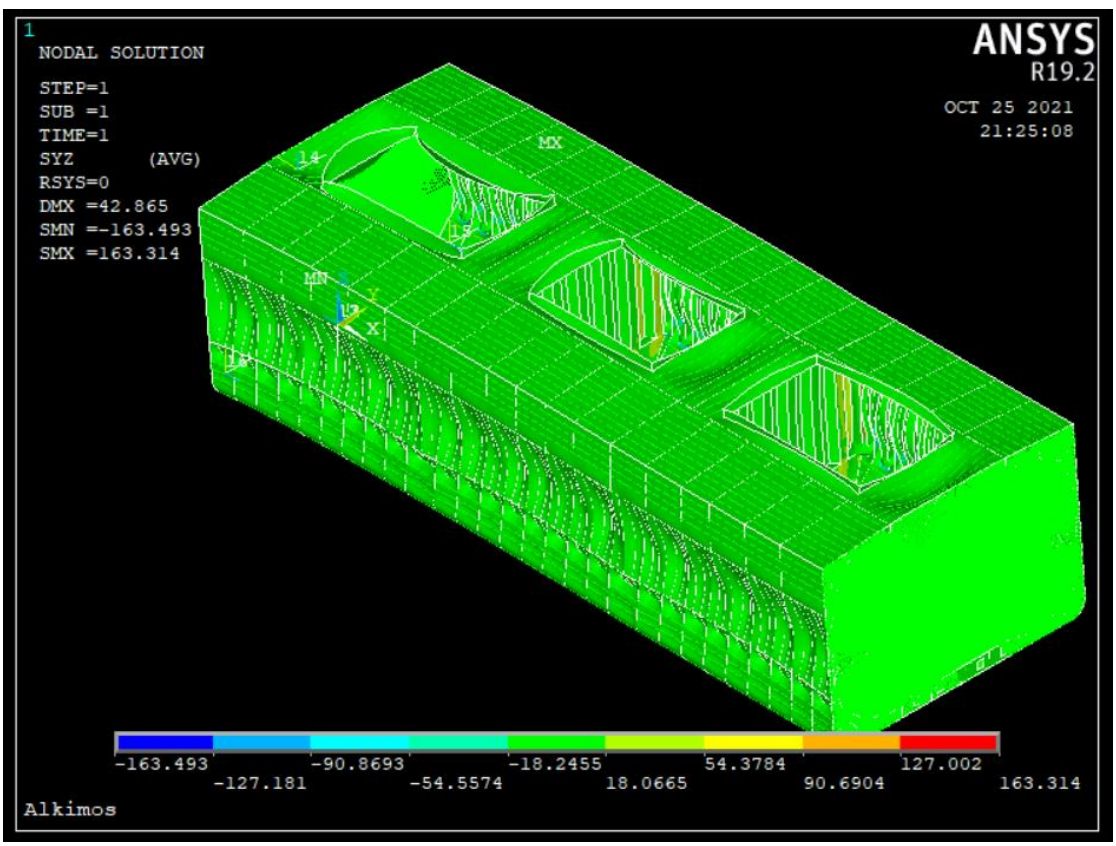


***Figure** 38 – YZ-Shear Stress / Nodal Solution*

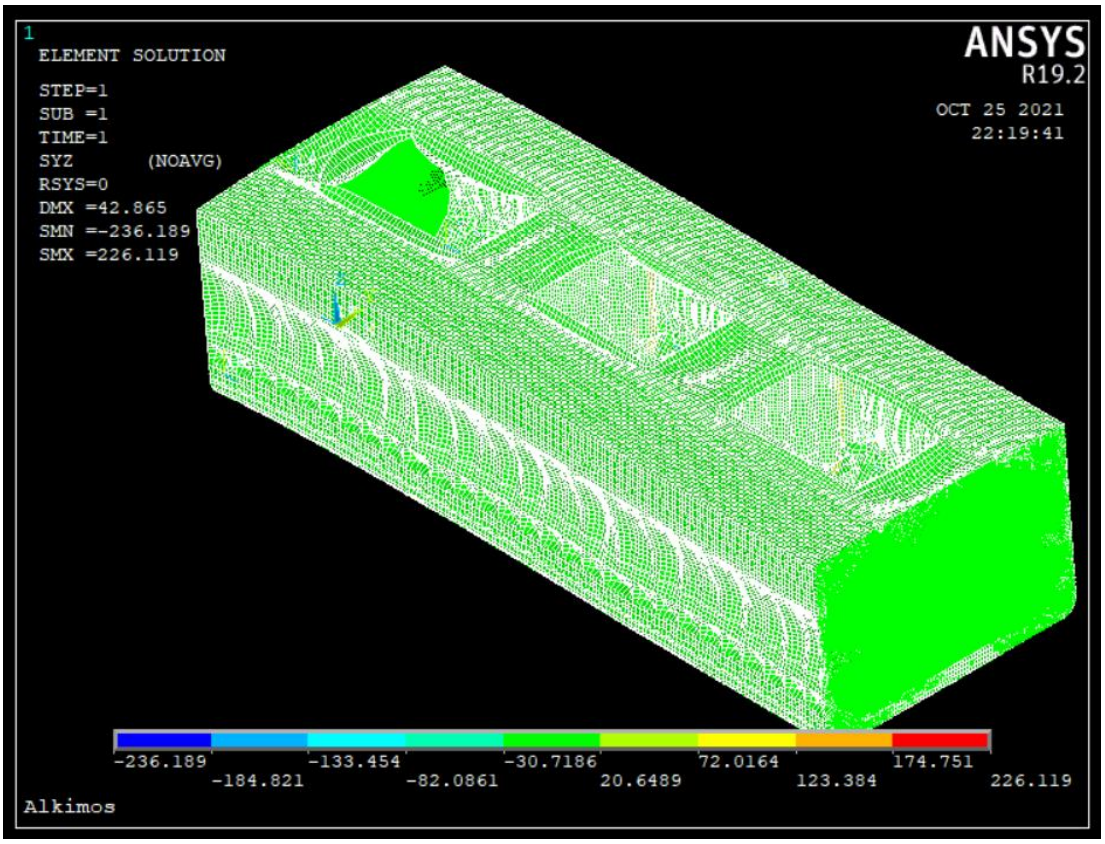


***Figure** 39 – YZ-Shear Stress / Element Solution*

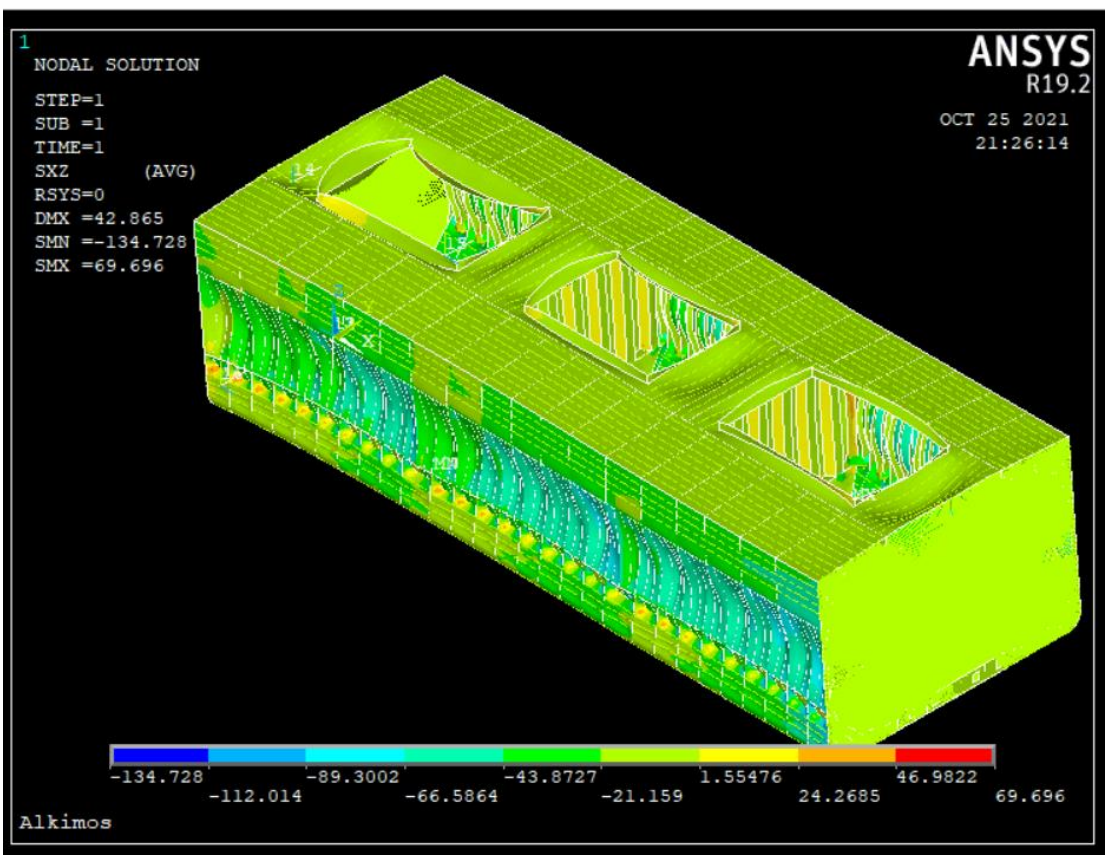


***Figure** 40 – XZ-Shear Stress / Nodal Solution*

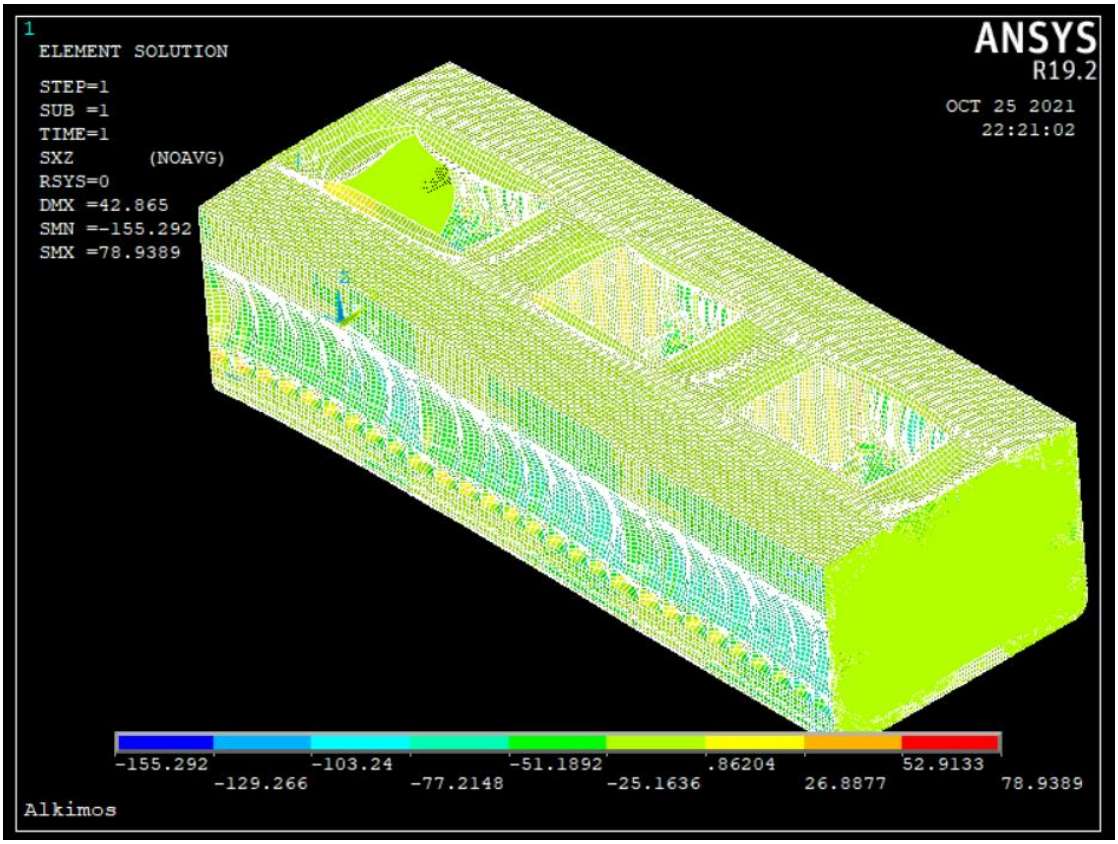


***Figure** 41 – XZ-Shear Stress / Element Solution*

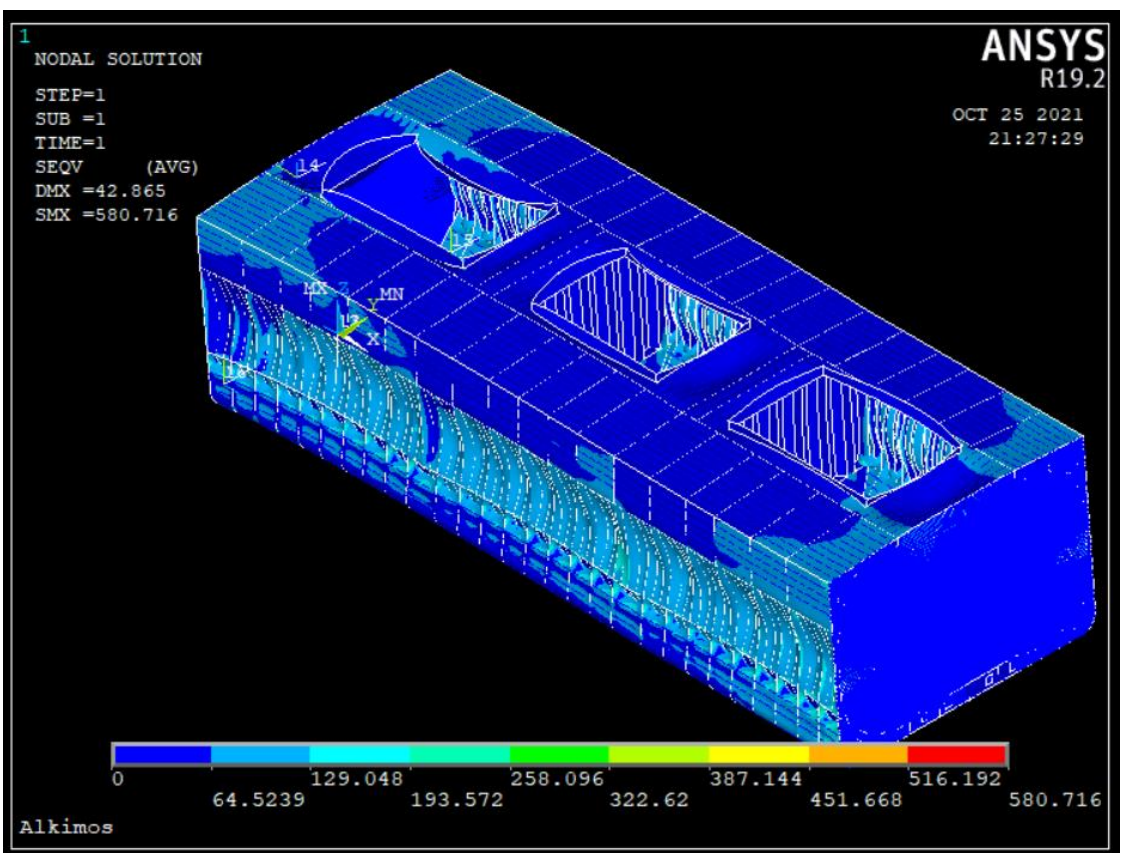


***Figure** 42 – Von Misses Stress / Nodal Solution*

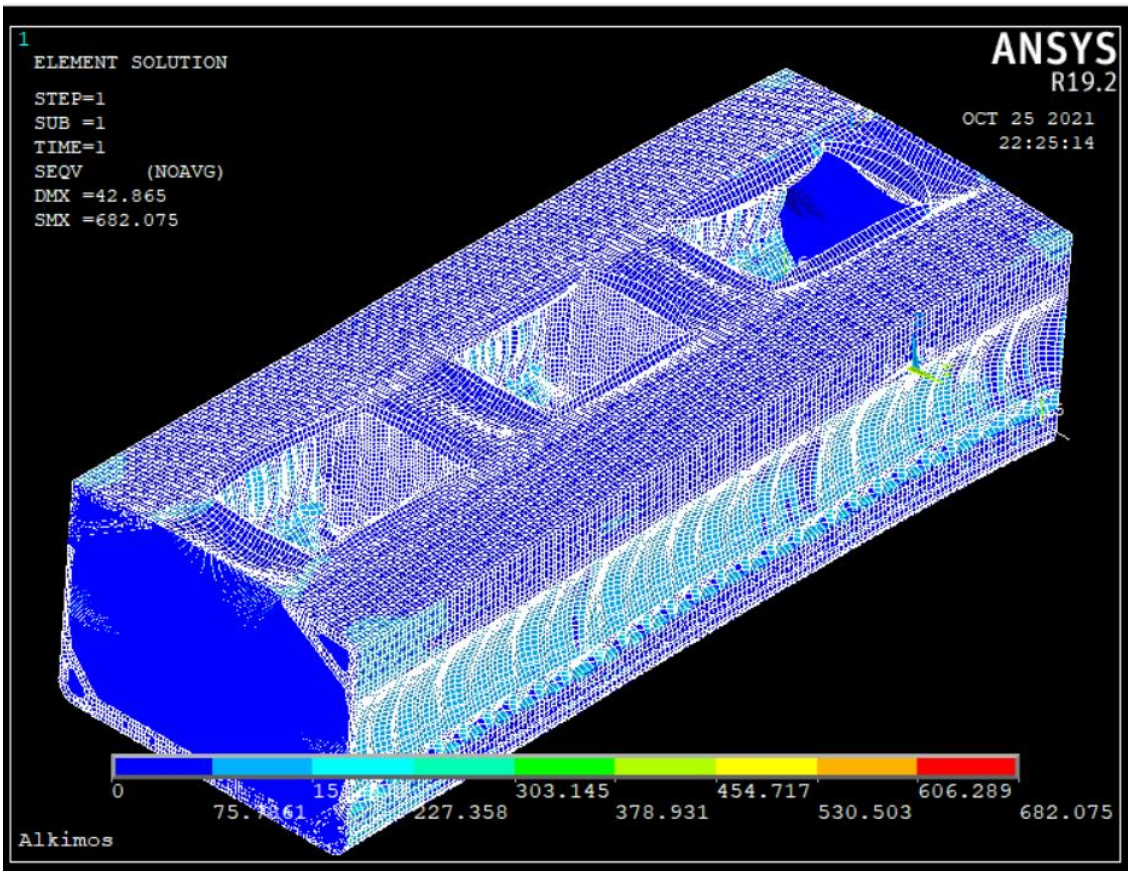


***Figure** 43 – Von Misses Stress / Element Solution*

4.2 Buckling strength assessment

4.2.1 Bottom plate

By applying the method described above in section 2.7.2 we manage to calculate the buckling utilization factors of each structural member of bottom plate as shown in the following tables. Each panel has length the bottom floor spacing in the longitudinal direction and in the transverse direction the width is between bottom longitudinals. We start with plates "BPL_A" at the aft part of the mid cargo hold from side shell to center line (BPL_A 1 is in side shell where BPL_A 19 is in center line) and continue with BPL_B to BPL_J. As we can see all buckling utilization factors are between 0.4 and 0.6 and so we consider that the buckling strength is satisfied.

PANNEL		BPL_A1	BPL_A2	BPL_A3	BPL_A4	BPL_A5	BPL_A6	BPL_A7	BPL_A8	BPL_A9	BPL_A10	BPL_A11	BPL_A12	BPL_A13	BPL_A14	BPL_A15	BPL_A16	BPL_A17	BPL_A18	BPL_A19
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	16	16	16	16	16	16	16	17	17	17	17	17	17.5	17.5	17.5	17.5	17.5	19	19
β_p		1.76	1.83	1.83	1.83	1.83	1.83	1.83	1.73	1.73	1.73	1.73	1.73	1.68	1.68	1.68	1.68	1.68	1.54	1.54
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-139.71	-142.66	-190	-140	-142.6	-138.5	-131.7	-132.3	-130.6	-127.6	-132.89	-131.6	-135.7	-132.6	-131.3	-128.2	-123.5	-120.5	-119.2
σ_y	Mpa	-52.8	-80.3	-55.6	-80	-80.5	-82.6	-66.4	-70.5	-69.8	-68.2	-75.5	-65	-64.2	-62.9	-61.3	-60.5	-69.2	-67.6	-58.6
τ	Mpa	23.6	22.2	10.6	20.2	17.2	21.6	21.9	16.3	17.1	15.2	-22.16	15.1	17.2	14.7	14.4	14	10.2	10.1	5.6
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
τ_c'	Mpa	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		2.13	2.11	1.61	2.17	2.15	2.17	2.28	2.32	2.34	2.41	2.25	2.34	2.26	2.33	2.35	2.41	2.52	2.58	2.64
γ_{c4}		6.78	7.21	15.09	7.92	9.30	7.41	7.31	9.82	9.36	10.53	7.22	10.60	9.30	10.88	11.11	11.43	15.69	15.84	28.57
γ_c		2.13	2.11	1.61	2.17	2.15	2.17	2.28	2.32	2.34	2.41	2.25	2.34	2.26	2.33	2.35	2.41	2.52	2.58	2.64
η_{act}		0.47	0.47	0.62	0.46	0.46	0.46	0.44	0.43	0.43	0.41	0.44	0.43	0.44	0.43	0.43	0.41	0.40	0.39	0.38

PANNEL		BPL_B1	BPL_B2	BPL_B3	BPL_B4	BPL_B5	BPL_B6	BPL_B7	BPL_B8	BPL_B9	BPL_B10	BPL_B11	BPL_B12	BPL_B13	BPL_B14	BPL_B15	BPL_B16	BPL_B17	BPL_B18	BPL_B19
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	16	16	16	16	16	16	16	17	17	17	17	17	17.5	17.5	17.5	17.5	17.5	19	19
β_p		1.76	1.76	1.83	1.83	1.83	1.83	1.83	1.73	1.73	1.73	1.73	1.73	1.68	1.68	1.68	1.68	1.68	1.54	1.54
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-137.67	-133.6	-131.5	-135.6	-132.5	-131.2	-128.9	-125.1	-121.7	-120.1	-135.6	-132.4	-128.5	-124.9	-121.8	-120.3	-125.2	-122.2	-118.7
σ_y	Mpa	-105.3	-102.8	-100.8	-106.7	-103.8	-102.7	-106	-103.2	-100.3	-99.1	-103.5	-101.4	-102.55	-99.7	-98.5	-96.4	-101.6	-98.8	-96.9
τ	Mpa	-36.85	-36	-32.3	-32.3	-31.5	-30.6	-34.575	-33.9	-33.1	-32.6	-22.16	-21.9	-22.03	-21.6	-21.3	-20.7	-21.88	-21.5	-21
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
τ_c'	Mpa	184	184	195	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		1.95	2.16	2.25	2.02	2.07	2.10	2.06	2.12	2.17	2.20	2.13	2.18	2.22	2.28	2.33	2.36	2.26	2.32	2.38
γ_{c4}		4.25	9.32	9.56	4.95	5.08	5.23	4.63	4.72	4.83	4.91	7.22	7.31	7.26	7.41	7.51	7.73	7.31	7.44	7.62
γ_c		1.95	2.16	2.25	2.02	2.07	2.10	2.06	2.12	2.17	2.20	2.13	2.18	2.22	2.28	2.33	2.36	2.26	2.32	2.38
η_{act}		0.51	0.46	0.44	0.50	0.48	0.48	0.49	0.47	0.46	0.45	0.47	0.46	0.45	0.44	0.43	0.42	0.44	0.43	0.42

PANNEL		BPL_C1	BPL_C2	BPL_C3	BPL_C4	BPL_C5	BPL_C6	BPL_C7	BPL_C8	BPL_C9	BPL_C10	BPL_C11	BPL_C12	BPL_C13	BPL_C14	BPL_C15	BPL_C16	BPL_C17	BPL_C18	BPL_C19
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	16	16	16	16	16	16	16	17.5	17.5	17.5	17.5	17.5	18.5	18.5	18.5	18.5	18.5	19	19
β_p		1.76	1.76	1.83	1.83	1.83	1.83	1.83	1.68	1.68	1.68	1.68	1.68	1.59	1.59	1.59	1.59	1.59	1.54	1.54
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-108.73	-106.5	-104	-102.9	-100.9	-99.4	-131.7	-105.63	-103.6	-100.9	-101.9	-99.2	-113	-111.6	-110.3	-109.1	-112.6	-110	-108.9
σ_y	Mpa	-103.8	-101.2	-57.3	-55.6	-54.7	-53.6	-79.7	-78	-76.1	-74.6	-66.35	-64.8	-77.15	-76.1	-73.8	-71.7	-71.225	-69.3	-67.3
τ	Mpa	-32.65	23.1	15.2	14.9	14.7	14.3	-8.875	-8.7	-8.5	-8.3	-22.16	-21.9	-22.03	-21.4	-20.8	-20.6	-21.78	-21.2	-20.9
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
τ_c'	Mpa	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		2.28	2.46	2.92	2.95	3.01	3.06	2.36	2.85	2.91	2.98	2.82	2.88	2.56	2.60	2.64	2.68	2.60	2.66	2.69
γ_{c4}		4.90	6.93	10.53	10.74	10.88	11.19	18.03	18.39	18.82	19.28	7.22	7.31	7.26	7.48	7.69	7.77	7.35	7.55	7.66
γ_c		2.28	2.46	2.92	2.95	3.01	3.06	2.36	2.85	2.91	2.98	2.82	2.88	2.56	2.60	2.64	2.68	2.60	2.66	2.69
n_{act}		0.44	0.41	0.34	0.34	0.33	0.33	0.42	0.35	0.34	0.34	0.36	0.35	0.39	0.38	0.38	0.37	0.39	0.38	0.37

PANNEL		BPL_D1	BPL_D2	BPL_D3	BPL_D4	BPL_D5	BPL_D6	BPL_D7	BPL_D8	BPL_D9	BPL_D10	BPL_D11	BPL_D12	BPL_D13	BPL_D14	BPL_D15	BPL_D16	BPL_D17	BPL_D18	BPL_D19
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	16	16	16	16	16	16	16	17.5	17.5	17.5	17.5	17.5	18.5	18.5	18.5	18.5	18.5	19	19
β_p		1.76	1.76	1.83	1.83	1.83	1.83	1.83	1.68	1.68	1.68	1.68	1.68	1.59	1.59	1.59	1.59	1.59	1.54	1.54
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-111.6	-109.2	-106.6	-105.2	-102.3	-99.9	-108.7	-105.9	-103	-101.7	-111	-109.7	-99.6	-98.4	-96.8	-94.4	-105.2	-103.2	-101.6
σ_y	Mpa	-108.6	-106.3	-104	-101.4	-98.5	-95.7	-105	-103.7	-102.1	-100.6	-101.1	-98.4	-102.8	-101.7	-99.7	-97.6	-101.4	-99.7	-97.8
τ	Mpa	-37.53	-36.6	-36.1	-35.3	-34.3	-33.4	-36.415	-35.8	-35.3	-34.3	-22.16	-21.9	-22.03	-21.7	-21.1	-20.7	-21.93	-21.7	-21.3
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
τ_c'	Mpa	180	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		2.14	2.20	2.24	2.29	2.35	2.42	2.21	2.26	2.30	2.34	2.42	2.47	2.54	2.57	2.62	2.68	2.49	2.53	2.58
γ_{c4}		4.17	4.37	4.43	4.53	4.66	4.79	4.39	4.47	4.53	4.66	7.22	7.31	7.26	7.37	7.58	7.73	7.30	7.37	7.51
γ_c		2.14	2.20	2.24	2.29	2.35	2.42	2.21	2.26	2.30	2.34	2.42	2.47	2.54	2.57	2.62	2.68	2.49	2.53	2.58
n_{act}		0.47	0.46	0.45	0.44	0.42	0.41	0.45	0.44	0.43	0.43	0.41	0.41	0.39	0.39	0.38	0.37	0.40	0.39	0.39

PANNEL		BPL_E1	BPL_E2	BPL_E3	BPL_E4	BPL_E5	BPL_E6	BPL_E7	BPL_E8	BPL_E9	BPL_E10	BPL_E11	BPL_E12	BPL_E13	BPL_E14	BPL_E15	BPL_E16	BPL_E17	BPL_E18	BPL_E19
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	16	16	16	16	16	16	16	17.5	17.5	17.5	17.5	17.5	18.5	18.5	18.5	18.5	18.5	19	19
β_p		1.76	1.76	1.83	1.83	1.83	1.83	1.83	1.68	1.68	1.68	1.68	1.68	1.59	1.59	1.59	1.59	1.59	1.54	1.54
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-90.7	-88.8	-87.4	-85.8	-83.7	-81.7	-95	-92.2	-91.2	-89.4	-88.9	-87.7	-128.5	-102.3	-100.8	-98.6	-90.1	-88.2	-86.1
σ_y	Mpa	-105.9	-102.9	-100.8	-97.9	-96.6	-94.3	-101.9	-100	-97.3	-95.7	-98.3	-95.6	-98.8	-96.6	-94.9	-92.7	-97.45	-94.8	-92.4
τ	Mpa	-38.76	-37.7	-36.6	-36.1	-35	-34.5	-37.43	-36.6	-35.8	-35.3	-22.16	-21.5	-21.83	-21.3	-20.9	-20.6	-21.73	-21.3	-20.8
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
τ_c'	Mpa	180	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		2.28	2.36	2.41	2.46	2.52	2.57	2.33	2.38	2.43	2.48	2.70	2.77	2.24	2.58	2.63	2.68	2.71	2.78	2.85
γ_{c4}		4.04	4.24	4.37	4.43	4.57	4.64	4.27	4.37	4.47	4.53	7.22	7.44	7.33	7.51	7.66	7.77	7.36	7.51	7.69
γ_c		2.28	2.36	2.41	2.46	2.52	2.57	2.33	2.38	2.43	2.48	2.70	2.77	2.24	2.58	2.63	2.68	2.71	2.78	2.85
n_{act}		0.44	0.42	0.41	0.41	0.40	0.39	0.43	0.42	0.41	0.40	0.37	0.36	0.45	0.39	0.38	0.37	0.37	0.36	0.35

PANNEL		BPL_F1	BPL_F2	BPL_F3	BPL_F4	BPL_F5	BPL_F6	BPL_F7	BPL_F8	BPL_F9	BPL_F10	BPL_F11	BPL_F12	BPL_F13	BPL_F14	BPL_F15	BPL_F16	BPL_F17	BPL_F18	BPL_F19
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	16	16	16	16	16	16	16	17.5	17.5	17.5	17.5	17.5	18.5	18.5	18.5	18.5	18.5	19	19
β_p		1.76	1.76	1.83	1.83	1.83	1.83	1.83	1.68	1.68	1.68	1.68	1.68	1.59	1.59	1.59	1.59	1.59	1.54	1.54
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-105.9	-103.4	-101.9	-100.3	-98.6	-96.4	-103.1	-100.3	-98.1	-95.5	-99.45	-97.2	-99.3	-96.8	-94.6	-92.2	-98.125	-95.3	-93.1
σ_y	Mpa	-109.8	-107.2	-104.4	-102.1	-99.5	-97.2	-105.95	-102.8	-100.4	-98.2	-101.15	-98.5	-102.075	-99.7	-98.6	-96.2	-100.425	-98	-95.2
τ	Mpa	-40.1	-39.2	-38.4	-38	-37.6	-36.8	-39.05	-38.5	-37.7	-37	-22.16	-21.5	-21.83	-21.4	-21.1	-20.5	-21.78	-21.3	-21.1
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
τ_c'	Mpa	180	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		2.13	2.19	2.24	2.28	2.32	2.37	2.21	2.26	2.31	2.37	2.55	2.62	2.55	2.61	2.65	2.72	2.58	2.65	2.72
γ_{c4}		3.90	4.08	4.17	4.21	4.26	4.35	4.10	4.16	4.24	4.32	7.22	7.44	7.33	7.48	7.58	7.80	7.35	7.51	7.58
γ_c		2.13	2.19	2.24	2.28	2.32	2.37	2.21	2.26	2.31	2.37	2.55	2.62	2.55	2.61	2.65	2.72	2.58	2.65	2.72
n_{act}		0.47	0.46	0.45	0.44	0.43	0.42	0.45	0.44	0.43	0.42	0.39	0.38	0.39	0.38	0.38	0.37	0.39	0.38	0.37

PANNEL		BPL_G1	BPL_G2	BPL_G3	BPL_G4	BPL_G5	BPL_G6	BPL_G7	BPL_G8	BPL_G9	BPL_G10	BPL_G11	BPL_G12	BPL_G13	BPL_G14	BPL_G15	BPL_G16	BPL_G17	BPL_G18	BPL_G19
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	16	16	16	16	16	16	16	17	17	17	17	17	17	17	17	17	17	18.5	18.5
β_p		1.76	1.76	1.83	1.83	1.83	1.83	1.83	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.59	1.59
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-94.6	-92.1	-89.9	-87.4	-85.6	-84.5	-87.9	-86.8	-85.8	-83.4	-100.2	-99.2	-97.2	-96.1	-94.2	-92.7	-90.6	-89.4	-88.1
σ_y	Mpa	-99.8	-97	-95.4	-94.2	-92.1	-89.9	-97	-95.2	-93.5	-92.6	-93.65	-92	-94.8	-92	-90.6	-88.3	-92.825	-91.4	-89.5
τ	Mpa	-39.27	-38.4	-37.9	-37.4	-37	-36.6	-38.335	-37.3	-36.3	-35.4	-22.16	-21.9	-22.03	-21.4	-20.8	-20.6	-21.78	-21.2	-20.9
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
τ_c'	Mpa	180	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		2.30	2.38	2.42	2.46	2.51	2.55	2.41	2.46	2.51	2.56	2.63	2.66	2.66	2.71	2.76	2.82	2.77	2.81	2.86
γ_{c4}		3.99	4.17	4.22	4.28	4.32	4.37	4.17	4.29	4.41	4.52	7.22	7.31	7.26	7.48	7.69	7.77	7.35	7.55	7.66
γ_c		2.30	2.38	2.42	2.46	2.51	2.55	2.41	2.46	2.51	2.56	2.63	2.66	2.66	2.71	2.76	2.82	2.77	2.81	2.86
n_{act}		0.43	0.42	0.41	0.41	0.40	0.39	0.41	0.41	0.40	0.39	0.38	0.38	0.38	0.37	0.36	0.35	0.36	0.36	0.35

PANNEL		BPL_H1	BPL_H2	BPL_H3	BPL_H4	BPL_H5	BPL_H6	BPL_H7	BPL_H8	BPL_H9	BPL_H10	BPL_H11	BPL_H12	BPL_H13	BPL_H14	BPL_H15	BPL_H16	BPL_H17	BPL_H18	BPL_H19
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	16	16	16	16	16	16	16	17	17	17	17	17	17	17	17	17	17	18.5	18.5
β_p		1.76	1.76	1.83	1.83	1.83	1.83	1.83	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.73	1.59	1.59
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-90.1	-87.7	-85.2	-83.7	-81.3	-79.3	-83.6	-81.7	-80.7	-79.8	-102.3	-101.1	-98.1	-95.5	-93.7	-92	-96.2	-93.8	-92.4
σ_y	Mpa	-101.56	-99.4	-96.9	-94.9	-93.8	-91.2	-98.23	-96.2	-95.1	-92.6	-95	-92.2	-95.415	-93.3	-90.9	-89	-94.15	-93	-90.5
τ	Mpa	-36.9	-35.9	-35.5	-35.1	-34.5	-33.9	-36	-35.6	-35.2	-34.8	-22.16	-21.6	-21.88	-21.4	-20.8	-20.3	-21.78	-21.3	-21.1
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
τ_c'	Mpa	180	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		2.36	2.44	2.49	2.53	2.58	2.64	2.48	2.52	2.55	2.60	2.59	2.64	2.64	2.70	2.77	2.82	2.68	2.73	2.79
γ_{c4}		4.24	4.46	4.51	4.56	4.64	4.72	4.44	4.49	4.55	4.60	7.22	7.41	7.31	7.48	7.69	7.88	7.35	7.51	7.58
γ_c		2.36	2.44	2.49	2.53	2.58	2.64	2.48	2.52	2.55	2.60	2.59	2.64	2.64	2.70	2.77	2.82	2.68	2.73	2.79
n_{act}		0.42	0.41	0.40	0.39	0.39	0.38	0.40	0.40	0.39	0.38	0.39	0.38	0.38	0.37	0.36	0.35	0.37	0.37	0.36

PANNEL		BPL_I1	BPL_I2	BPL_I3	BPL_I4	BPL_I5	BPL_I6	BPL_I7	BPL_I8	BPL_I9	BPL_I10	BPL_I11	BPL_I12	BPL_I13	BPL_I14	BPL_I15	BPL_I16	BPL_I17	BPL_I18	BPL_I19
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	16	16	16	16	16	16	16	16.5	16.5	16.5	16.5	16.5	17	17	17	17	17	17.5	17.5
β_p		1.76	1.76	1.83	1.83	1.83	1.83	1.83	1.78	1.78	1.78	1.78	1.78	1.73	1.73	1.73	1.73	1.73	1.68	1.68
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-77.9	-75.9	-74.7	-73.9	-72.3	-70.8	-49.3	-48.3	-47.6	-46.9	-82.6	-81.3	-81.03	-78.9	-78.1	-76.7	-75.8	-73.9	-71.8
σ_y	Mpa	-101.63	-98.8	-96.7	-94	-92.1	-91.2	-97.815	-96.3	-93.4	-91.4	-94.2	-93.1	-94.6075	-92.6	-90.8	-89.4	-93.4	-91.8	-90.3
τ	Mpa	-38.75	-37.9	-37.2	-36.5	-36	-34.9	-37.625	-36.8	-36.4	-36	-22.16	-21.5	-21.83	-21.5	-20.9	-20.4	-21.83	-21.4	-21.1
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
τ_c'	Mpa	180	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		2.40	2.48	2.53	2.58	2.63	2.68	2.57	2.62	2.68	2.73	2.83	2.88	2.85	2.84	2.97	3.02	2.92	2.98	3.04
γ_{c4}		4.04	4.22	4.30	4.38	4.44	4.58	4.25	4.35	4.40	4.44	7.22	7.44	7.33	7.44	7.66	7.84	7.33	7.48	7.58
γ_c		2.40	2.48	2.53	2.58	2.63	2.68	2.57	2.62	2.68	2.73	2.83	2.88	2.85	2.84	2.97	3.02	2.92	2.98	3.04
n_{act}		0.42	0.40	0.40	0.39	0.38	0.37	0.39	0.38	0.37	0.37	0.35	0.35	0.35	0.35	0.34	0.33	0.34	0.34	0.33

PANNEL		BPL_J1	BPL_J2	BPL_J3	BPL_J4	BPL_J5	BPL_J6	BPL_J7	BPL_J8	BPL_J9	BPL_J10	BPL_J11	BPL_J12	BPL_J13	BPL_J14	BPL_J15	BPL_J16	BPL_J17	BPL_J18	BPL_J19
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	16	16	16	16	16	16	16	16.5	16.5	16.5	16.5	16.5	17	17	17	17	17	17.5	17.5
β_p		1.76	1.76	1.83	1.83	1.83	1.83	1.83	1.78	1.78	1.78	1.78	1.78	1.73	1.73	1.73	1.73	1.73	1.68	1.68
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-73.8	-71.8	-70.3	-69.1	-68.2	-66.4	-48.7	-47.9	-46.8	-45.6	-82.6	-81	-81.03	-79.4	-78.5	-77.1	-76.2	-74.9	-72.7
σ_y	Mpa	-166.2	-161.8	-158.9	-154.2	-152.6	-150.4	-160.2	-156.1	-154.3	-150.9	-154.35	-151.2	-155.55	-152.7	-148.7	-146.1	-153.525	-150.1	-147.4
τ	Mpa	-36.2	-35.3	-34.4	-33.6	-33.2	-32.3	-34.9	-33.9	-33	-32.4	-22.16	-21.8	-21.98	-21.6	-21.2	-20.6	-21.88	-21.3	-21.1
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
τ_c'	Mpa	180	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184	184
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		1.74	1.79	1.83	1.88	1.90	1.93	1.78	1.82	1.85	1.89	1.97	2.01	1.96	1.99	2.05	2.08	1.98	2.03	2.06
γ_{c4}		4.32	4.53	4.65	4.76	4.82	4.95	4.58	4.72	4.85	4.94	7.22	7.34	7.28	7.41	7.55	7.77	7.31	7.51	7.58
γ_c		1.74	1.79	1.83	1.88	1.90	1.93	1.78	1.82	1.85	1.89	1.97	2.01	1.96	1.99	2.05	2.08	1.98	2.03	2.06
n_{act}		0.58	0.56	0.55	0.53	0.53	0.52	0.56	0.55	0.54	0.53	0.51	0.50	0.51	0.50	0.49	0.48	0.50	0.49	0.48

4.2.2 Inner bottom plate

By applying the method described above in section 2.7.2 we manage to calculate the buckling utilization factors of each structural member of inner bottom plate as shown in the following tables. Again, each panel has length the bottom floor spacing in the longitudinal direction and in the transverse direction the width is between bottom longitudinals. We start with plates "IN.B_A" at the aft part of the mid cargo hold from side shell to center line (IN.B_A_1 is in side shell where IN.B_A_16 is in center line) and continue with IN.B_B to IN.B_H. As we can see all buckling utilization factors are between 0.4 and 0.8 and so we consider that the buckling strength is satisfied.

PANNEL		IN.B_A1	IN.B_A2	IN.B_A3	IN.B_A4	IN.B_A5	IN.B_A6	IN.B_A7	IN.B_A8	IN.B_A9	IN.B_A10	IN.B_A11	IN.B_A12	IN.B_A13	IN.B_A14	IN.B_A15	IN.B_A16
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
β_p		1.41	1.41	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-65.3	-63.8	-83.6	-95.4	-94	-91.5	-89.6	-87.4	-84.9	-84	-99.3	-97	-94.3	-92.7	-95.6	-61.3
σ_y	Mpa	63.2	68.9	76.3	65.3	66.8	70.1	72.3	68.9	57.6	62.3	63.4	68.9	58.9	59.6	62.3	61.3
τ	Mpa	37.2	36.78	36.3	35.7	27.8	15.9	12.6	12.3	12	11.9	15.6	15.3	12.4	12	11.8	11.6
σ_E	Mpa	119.94	119.94	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53
Ψ		-0.62	-0.50	-0.85	-0.58	-0.67	-0.45	-0.52	-0.55	-0.53	-0.58	-0.58	-0.57	-0.59	-0.63	-0.58	-0.54
ky	Mpa	1.84	1.80	1.98	1.84	1.89	1.78	1.81	1.83	1.82	1.84	1.84	1.84	1.85	1.87	1.84	1.82
λ		1.20	1.21	1.20	1.24	1.23	1.27	1.25	1.25	1.25	1.24	1.24	1.24	1.24	1.23	1.24	1.25
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	163	160	162	153	156	149	151	152	152	153	153	153	154	155	153	152
τ_c'	Mpa	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		1.57	1.48	1.30	1.32	1.35	1.30	1.30	1.36	1.53	1.47	1.36	1.31	1.46	1.47	1.40	1.64
γ_{c3}		2.03	1.86	1.73	1.89	1.94	1.82	1.81	1.91	2.26	2.12	2.07	1.90	2.24	2.23	2.12	2.14
γ_{c4}		4.79	4.85	4.91	4.99	6.41	11.21	14.15	14.49	14.86	14.98	11.43	11.65	14.38	14.86	15.11	15.37
γ_c		1.57	1.48	1.30	1.32	1.35	1.30	1.30	1.36	1.53	1.47	1.36	1.31	1.46	1.47	1.40	1.64
n_{act}		0.64	0.68	0.77	0.76	0.74	0.77	0.77	0.74	0.65	0.68	0.73	0.76	0.69	0.68	0.71	0.61

PANNEL		IN.B_B1	IN.B_B2	IN.B_B3	IN.B_B4	IN.B_B5	IN.B_B6	IN.B_B7	IN.B_B8	IN.B_B9	IN.B_B10	IN.B_B11	IN.B_B12	IN.B_B13	IN.B_B14	IN.B_B15	IN.B_B16
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
β_p		1.41	1.41	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-65.6	-64.2	-62.8	-61.6	-61	-60.1	-63.6	-61.8	-60.4	-58.8	-61.4	-59.8	-61.2	-59.6	-58.2	-57.2
σ_y	Mpa	52.3	55.6	47.8	49.3	35.6	66.2	62.1	41.3	36.8	40.3	52.8	36.9	37.8	35.6	34.9	36.5
τ	Mpa	37.8	35.8	34.9	34.5	32.2	16.9	12.3	11.8	11.5	11.2	14.3	14	11.8	11.7	11.4	11.1
σ_E	Mpa	119.94	119.94	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53
Ψ		-0.57	-0.48	-0.56	-0.50	-0.66	-0.48	-0.53	-0.54	-0.54	-0.58	-0.52	-0.53	-0.48	-0.61	-0.53	0.46
ky	Mpa	1.81	1.79	1.83	1.80	1.89	1.79	1.82	1.82	1.82	1.84	1.81	1.82	1.79	1.86	1.82	1.31
λ		1.20	1.21	1.25	1.26	1.23	1.26	1.25	1.25	1.25	1.24	1.25	1.25	1.26	1.24	1.25	1.48
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	161	159	153	151	156	150	152	152	152	153	151	152	150	154	152	117
τ_c'	Mpa	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		1.74	1.69	1.82	1.78	2.18	1.53	1.60	2.12	2.28	2.20	1.80	2.28	2.22	2.36	2.39	2.00
γ_{c3}		2.24	2.23	2.44	2.36	3.14	1.94	2.10	3.13	3.50	3.24	2.44	3.44	3.37	3.66	3.67	2.75
γ_{c4}		4.72	4.98	5.11	5.17	5.54	10.55	14.49	15.11	15.50	15.92	12.47	12.73	15.11	15.24	15.64	16.06
γ_c		1.74	1.69	1.82	1.78	2.18	1.53	1.60	2.12	2.28	2.20	1.80	2.28	2.22	2.36	2.39	2.00
n_{act}		0.58	0.59	0.55	0.56	0.46	0.65	0.62	0.47	0.44	0.45	0.55	0.44	0.45	0.42	0.42	0.50

PANNEL		IN.B_C1	IN.B_C2	IN.B_C3	IN.B_C4	IN.B_C5	IN.B_C6	IN.B_C7	IN.B_C8	IN.B_C9	IN.B_C10	IN.B_C11	IN.B_C12	IN.B_C13	IN.B_C14	IN.B_C15	IN.B_C16
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
β_p		1.41	1.41	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-63.7	-62	-65.4	-63.5	-62.2	-60.4	-63.6	-62.5	-61.6	-60.2	-62.35	-60.6	-61.9	-61.3	-59.6	-58.3
σ_y	Mpa	53.6	48.9	46.9	51.2	37.5	62.8	61.3	42.3	38.2	41.6	53.1	35.2	39.1	36.6	33.5	35.2
τ	Mpa	32.5	28.9	28.5	28	27.8	14.9	11.8	11.7	11.4	2.3	-7.9	-7.7	-4.2	-4.1	-4.1	-4
σ_E	Mpa	119.94	119.94	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53
Ψ		-0.56	-0.50	-0.66	-0.48	-0.53	-0.54	-0.56	-0.50	-0.66	-0.48	-0.53	-0.54	-0.54	-0.58	-0.58	-0.54
ky	Mpa	1.81	1.80	1.89	1.79	1.82	1.82	1.83	1.80	1.89	1.79	1.82	1.82	1.82	1.84	1.84	1.82
λ		1.21	1.21	1.23	1.26	1.25	1.25	1.25	1.26	1.23	1.26	1.25	1.25	1.25	1.24	1.24	1.25
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	161	160	156	150	152	152	153	151	156	150	152	152	152	153	153	152
τ_c'	Mpa	165	186	184	184	184	184	184	184	184	184	184	184	184	184	184	184
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		1.71	1.87	1.85	1.74	2.10	1.61	1.62	2.06	2.24	2.13	1.80	2.35	2.20	2.31	2.46	2.40
γ_{c3}		2.24	2.54	2.57	2.33	3.00	2.07	2.14	3.02	3.44	3.13	2.47	3.70	3.37	3.63	3.96	3.74
γ_{c4}		4.41	5.60	5.61	5.71	5.76	10.74	13.56	13.68	14.04	69.57	20.25	20.78	38.10	39.02	39.02	40.00
γ_c		1.71	1.87	1.85	1.74	2.10	1.61	1.62	2.06	2.24	2.13	1.80	2.35	2.20	2.31	2.46	2.40
n_{act}		0.58	0.54	0.54	0.57	0.48	0.62	0.62	0.48	0.45	0.47	0.55	0.43	0.45	0.43	0.41	0.42

PANNEL		IN.B_D1	IN.B_D2	IN.B_D3	IN.B_D4	IN.B_D5	IN.B_D6	IN.B_D7	IN.B_D8	IN.B_D9	IN.B_D10	IN.B_D11	IN.B_D12	IN.B_D13	IN.B_D14	IN.B_D15	IN.B_D16
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
β_p		1.41	1.41	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-67.2	-65.5	-64.6	-63	-62.2	-60.6	-66.8	-65.9	-65.2	-63.3	-62.3	-60.5	-65.6	-64.7	-63	-61.7
σ_y	Mpa	35.1	32.5	36.1	32.3	31.6	36.4	35.2	34.1	32.5	31.5	35.2	34.3	37.9	41.2	40.2	32.1
τ	Mpa	13.5	13.2	12.8	12.5	12.2	12	13	-5.2	-5.1	-5	-4.3	-4.2	-4.25	-4.1	-4	-3.9
σ_E	Mpa	119.94	119.94	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53
Ψ		-0.62	-0.56	-0.50	-0.66	-0.48	-0.53	-0.54	-0.54	-0.56	-0.50	-0.66	-0.48	-0.53	-0.54	-0.54	-0.58
ky	Mpa	1.84	1.83	1.80	1.89	1.79	1.82	1.82	1.82	1.83	1.80	1.89	1.79	1.82	1.82	1.82	1.84
λ		1.20	1.20	1.26	1.23	1.26	1.25	1.25	1.25	1.25	1.26	1.23	1.26	1.25	1.25	1.25	1.24
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	163	162	151	156	150	152	152	152	153	151	156	150	152	152	152	153
τ_c'	Mpa	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		2.30	2.42	2.23	2.43	2.43	2.29	2.23	2.31	2.39	2.44	2.36	2.38	2.19	2.10	2.15	2.47
γ_{c3}		3.85	4.13	3.51	4.03	3.97	3.52	3.62	3.85	4.06	4.13	3.83	3.79	3.47	3.20	3.28	4.14
γ_{c4}		13.20	13.50	13.93	14.26	14.61	14.86	13.71	34.28	34.95	35.65	41.46	42.44	41.94	43.48	44.57	45.71
γ_c		2.30	2.42	2.23	2.43	2.43	2.29	2.23	2.31	2.39	2.44	2.36	2.38	2.19	2.10	2.15	2.47
n_{act}		0.43	0.41	0.45	0.41	0.41	0.44	0.45	0.43	0.42	0.41	0.42	0.42	0.46	0.48	0.46	0.40

PANNEL		IN.B_E1	IN.B_E2	IN.B_E3	IN.B_E4	IN.B_E5	IN.B_E6	IN.B_E7	IN.B_E8	IN.B_E9	IN.B_E10	IN.B_E11	IN.B_E12	IN.B_E13	IN.B_E14	IN.B_E15	IN.B_E16
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
β_p		1.41	1.41	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-53.8	-53.9	-53.2	-51.8	-50.9	-50.3	-52.8	-52.1	-50.6	-49.7	-51.5	-50.9	-51.25	-50.3	-49.1	-47.7
σ_y	Mpa	53.8	53.9	53.2	51.8	50.9	50.3	52.8	52.1	50.6	49.7	51.5	50.9	51.25	50.3	49.1	47.7
τ	Mpa	16.8	16.4	16.2	16	15.6	15.1	16.4	-3.2	-3.2	-3.1	-6.8	-6.7	-6.75	-6.7	-6.5	-6.3
σ_E	Mpa	119.94	119.94	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53
Ψ		-0.62	-0.56	-0.50	-0.66	-0.48	-0.53	-0.54	-0.54	-0.56	-0.50	-0.66	-0.48	-0.53	-0.54	-0.54	-0.58
ky	Mpa	1.84	1.83	1.80	1.89	1.79	1.82	1.82	1.82	1.83	1.80	1.89	1.79	1.82	1.82	1.82	1.84
λ		1.20	1.20	1.26	1.23	1.26	1.25	1.25	1.25	1.25	1.26	1.23	1.26	1.25	1.25	1.25	1.24
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	163	162	151	156	150	152	152	152	153	151	156	150	152	152	152	153
τ_c'	Mpa	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		1.93	1.93	1.86	1.95	1.94	1.98	1.88	1.94	2.00	2.02	1.99	1.96	1.96	2.00	2.05	2.12
γ_{c3}		2.55	2.54	2.40	2.55	2.50	2.56	2.44	2.53	2.62	2.63	2.62	2.55	2.56	2.62	2.68	2.78
γ_{c4}		10.61	10.87	11.00	11.14	11.43	11.81	10.87	55.71	55.71	57.50	26.21	26.61	26.41	26.61	27.42	28.30
γ_c		1.93	1.93	1.86	1.95	1.94	1.98	1.88	1.94	2.00	2.02	1.99	1.96	1.96	2.00	2.05	2.12
n_{act}		0.52	0.52	0.54	0.51	0.52	0.51	0.53	0.52	0.50	0.50	0.50	0.51	0.51	0.50	0.49	0.47

PANNEL		IN.B_F1	IN.B_F2	IN.B_F3	IN.B_F4	IN.B_F5	IN.B_F6	IN.B_F7	IN.B_F8	IN.B_F9	IN.B_F10	IN.B_F11	IN.B_F12	IN.B_F13	IN.B_F14	IN.B_F15	IN.B_F16
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
β_p		1.41	1.41	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-63.2	-61.5	-66.5	-53.6	-58.8	-57.8	-57.9	-63.2	-58.7	-57.8	-56.3	-93.2	-61.6	-56.2	-50.1	-49.7
σ_y	Mpa	33.5	34.8	36.2	33.2	32.5	34.2	35.1	29.8	29.6	31.6	32.9	33.2	36.8	32.5	34.7	34.9
τ	Mpa	11.6	11.3	11.2	10.9	10.7	10.4	15.2	15	14.6	14.4	5.2	5.1	-2.3	-2.7	-2.7	-2.6
σ_E	Mpa	119.94	119.94	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53
Ψ		-0.56	-0.50	-0.66	-0.48	-0.53	-0.54	-0.54	-0.58	-0.66	-0.48	-0.53	-0.54	-0.54	-0.58	-0.58	-0.54
ky	Mpa	1.81	1.80	1.89	1.79	1.82	1.82	1.82	1.84	1.89	1.79	1.82	1.82	1.82	1.84	1.84	1.82
λ		1.21	1.21	1.23	1.26	1.25	1.25	1.25	1.24	1.23	1.26	1.25	1.25	1.25	1.24	1.24	1.25
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	161	160	156	150	152	152	152	153	156	150	152	152	152	153	153	152
τ_c'	Mpa	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		2.42	2.40	2.24	2.53	2.47	2.43	2.37	2.49	2.61	2.49	2.53	1.94	2.29	2.57	2.59	2.58
γ_{c3}		4.02	3.87	3.64	3.82	3.94	3.77	3.59	4.19	4.29	3.92	3.98	3.96	3.59	4.09	3.84	3.78
γ_{c4}		15.37	15.78	15.92	16.35	16.66	17.14	11.73	11.88	12.21	12.38	34.28	34.95	77.50	66.02	66.02	68.56
γ_c		2.42	2.40	2.24	2.53	2.47	2.43	2.37	2.49	2.61	2.49	2.53	1.94	2.29	2.57	2.59	2.58
n_{act}		0.41	0.42	0.45	0.40	0.40	0.41	0.42	0.40	0.38	0.40	0.40	0.51	0.44	0.39	0.39	0.39

PANNEL		IN.B_G1	IN.B_G2	IN.B_G3	IN.B_G4	IN.B_G5	IN.B_G6	IN.B_G7	IN.B_G8	IN.B_G9	IN.B_G10	IN.B_G11	IN.B_G12	IN.B_G13	IN.B_G14	IN.B_G15	IN.B_G16
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
β_p		1.41	1.41	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	-56.3	-58.4	-47.6	-53.2	-39.8	-37.6	-52.6	-48.9	-49.9	-52.3	-59.8	-49.9	-63.2	-52.3	-63.2	-52.6
σ_y	Mpa	42.6	51.4	46.8	48.9	47.9	46.7	50.85	50.3	48.8	48.2	49.1	48.2	49.525	48.5	47.1	45.9
τ	Mpa	16.1	15.7	15.5	15	14.8	14.6	15.55	15.1	6.1	6	5.3	5.2	3.3	3.3	3.2	3.2
σ_E	Mpa	119.94	119.94	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53
Ψ		-0.56	-0.50	-0.56	-0.50	-0.66	-0.48	-0.53	-0.54	-0.54	-0.56	-0.50	-0.66	-0.48	-0.53	-0.54	-0.54
ky	Mpa	1.81	1.80	1.83	1.80	1.89	1.79	1.82	1.82	1.82	1.83	1.80	1.89	1.79	1.82	1.82	1.82
λ		1.21	1.21	1.25	1.26	1.23	1.26	1.25	1.25	1.25	1.25	1.26	1.23	1.26	1.25	1.25	1.25
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	161	160	153	151	156	150	152	152	152	153	151	156	150	152	152	152
τ_c'	Mpa	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205
e_0		2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00	2.00
B		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
γ_{c1}		2.20	1.93	2.12	1.97	2.21	2.22	1.93	1.99	2.05	2.05	1.92	2.11	1.87	2.03	1.95	2.11
γ_{c3}		3.14	2.63	2.75	2.61	2.75	2.72	2.53	2.57	2.70	2.74	2.66	2.80	2.63	2.72	2.80	2.88
γ_{c4}		11.07	11.35	11.50	11.88	12.04	12.21	11.46	11.81	29.22	29.71	33.63	34.28	54.02	54.02	55.71	55.71
γ_c		2.20	1.93	2.12	1.97	2.21	2.22	1.93	1.99	2.05	2.05	1.92	2.11	1.87	2.03	1.95	2.11
n_{act}		0.45	0.52	0.47	0.51	0.45	0.45	0.52	0.50	0.49	0.49	0.52	0.47	0.53	0.49	0.51	0.47

PANNEL		IN.B_H1	IN.B_H2	IN.B_H3	IN.B_H4	IN.B_H5	IN.B_H6	IN.B_H7	IN.B_H8	IN.B_H9	IN.B_H10	IN.B_H11	IN.B_H12	IN.B_H13	IN.B_H14	IN.B_H15	IN.B_H16
E	Mpa	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000	206000
R_{eH_p}	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
S		1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15	1.15
a	mm	3720	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790	2790
b	mm	720	720	750	750	750	750	750	750	750	750	750	750	750	750	750	750
α		5.17	3.88	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72	3.72
t_p	mm	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20
β_p		1.41	1.41	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47	1.47
n		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
σ_x	Mpa	92.23	90.1	89	87.1	85.6	83.2	89.665	87.2	84.8	83	86.4	84.7	86.3325	84.7	83.5	91.7
σ_y	Mpa	47.8	49.3	35.6	34.2	30.7	58.9	55.6	39.5	29.8	36.5	58.2	55.6	35.8	32.6	31.8	30.8
τ	Mpa	12.4	12.1	11.9	11.7	11.5	11.4	11.8	11.6	11.3	11	1.2	3.5	2.35	2.3	2.3	2.3
σ_E	Mpa	119.94	119.94	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53	110.53
Ψ		-0.53	-0.52	-0.57	-0.58	-0.67	-0.45	-0.52	-0.55	-0.56	-0.50	-0.66	-0.48	-0.53	-0.54	-0.54	-0.58
ky	Mpa	1.79	1.81	1.84	1.84	1.89	1.78	1.81	1.83	1.83	1.80	1.89	1.79	1.82	1.82	1.82	1.84
λ		1.21	1.20	1.24	1.24	1.23	1.27	1.25	1.25	1.25	1.26	1.23	1.26	1.25	1.25	1.25	1.24
σ_{xc}'	Mpa	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315	315
σ_{yc}'	Mpa	160	161	153	153	156	149	151	152	153	151	156	150	152	152	152	153
τ_c'	Mpa	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205	205
e_0		1.84	1.84	1.82	1.82	1.82	1.82	1.82	1.82	1.82	1.82	1.82	1.82	1.82	1.82	1.82	1.82
B		0.68	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67	0.67
γ_{c1}		2.47	2.46	2.79	2.87	3.02	2.15	2.21	2.70	3.04	2.86	2.25	2.27	2.89	3.04	3.09	2.93
γ_{c3}		2.82	2.76	3.58	3.73	4.19	2.17	2.32	3.24	4.23	3.47	2.33	2.34	3.68	4.04	4.15	4.32
γ_{c4}		14.38	14.73	14.98	15.24	15.50	15.64	15.11	15.37	15.78	16.21	148.55	50.93	75.86	77.50	77.50	77.50
γ_c		2.47	2.46	2.79	2.87	3.02	2.15	2.21	2.70	3.04	2.86	2.25	2.27	2.89	3.04	3.09	2.93
n_{act}		0.40	0.41	0.36	0.35	0.33	0.47	0.45	0.37	0.33	0.35	0.44	0.44	0.35	0.33	0.32	0.34

5. Conclusions

A lot of effort has been put into modeling and verification of modeling. The use of finite elements for ship structure requires deep knowledge of finite element theory in order to design and modelling the structure in an efficient and optimum manner and to achieve accurate results. APDL and ANSYS macro played a major role in expanding the scope of finite elements analysis for various operating conditions. Nevertheless, as we have seen, some assumptions must be made in order to take accurate results and to properly evaluate the response of the entire construction to the various load combinations.

The loads which have been calculated in detail by the regulations were applied to the model. Initially, the hydrostatic pressures were imposed on the outer shell platting in combination with the weights of the ship construction and the cargo load. Hydrostatic pressures and weights were calculated based on the regulations from the loading condition and the dynamic load case HSM-1, which causes in the under study vessel maximum bending moment in sagging condition. Subsequently, some additional bending moments were applied at the edges of the model to correct the shear and bending force distributions resulting from the above local loads in order to achieve some desired-target values.

Yield and buckling strength assessment is carried out within the evaluation area of the FE model for all modelled structural members. All hull girder longitudinal structural members, all primary supporting structural members (web frames, cross ties, etc.), and all transverse bulkheads, forward and aft of the mid-hold have been examined and found in satisfactory condition.

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