ANALYSIS OF SHIP STRUCTURES

Project work:

GLOBAL SHIP HULL STRUCTURAL ANALYSIS BASED ON THE FINITE ELEMENT METHOD

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1. INTRODUCTION

The goal of this project is to develop and analyze a structural model of a tanker midship block using the commercial software Ansys Mechanical ADPL.

The block under consideration is 30 m long and structurally streamlined to accommodate this circumstance study. To enhance the seal, a watertight bulkhead with a cross-section of X=0 m was installed. The stress reaction At the end of the block, at X=30 m, boundary conditions were applied to the nodes, in order to constrain all six degrees of freedom. Five distinct loading circumstances will be evaluated for this analysis: moment of vertical bending, Torsion moment, vertical shear force, horizontal shear force, and horizontal bending moment.

Both vertical load instances are the total of their still water and induced-wave values.

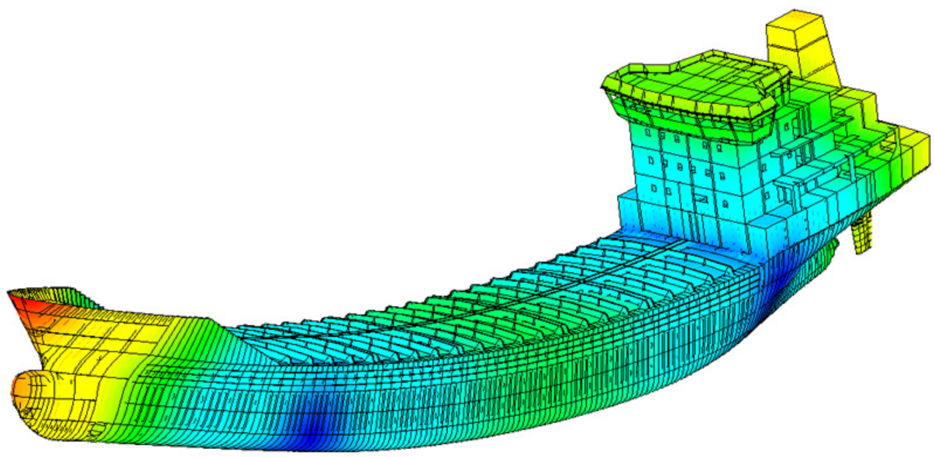
Following the application of all load conditions in the Ansys model, the data produced by the prescribed routes in the center of the block will be analyzed in order to draw conclusions about the structural response.

To simplify things, the equivalent plate thickness was computed and the longitudinal stiffener thicknesses were added to the plate thicknesses. On ANSYS, various plate thicknesses have been allocated to each location. Following the input of the regions, material attributes, and some structural factors, the meshing, boundary condition selection, and force application were carried out. Meshing is the process of separating the geometry's structure into smaller parts in FEM. After meshing the geometry and setting the DOF boundary conditions, the forces may be applied and a solution created.

Only static and linear analyses have been examined in this example, which means that they are not time dependent, and the conclusion is only true if stresses remain within the linear elastic range of the material utilized.

2. FEM analysis

The FEM is a generic numerical approach for solving partial differential equations with two or three variables in space. It is a popular approach for solving engineering issues such as structural analysis (our case study), heat transport, fluid dynamics, and many more.
In order to solve a problem, the FEM breaks a big system into smaller, simpler sections known as finite elements. This is accomplished by a specific space discretization in the space dimensions, which is performed through the development of an object mesh: the numerical domain for the solution, which has a finite number of nodes.
A system of algebraic equations is the end result of the finite element technique formulation of a boundary value issue. Over the domain, the approach approximates the unknown function. The basic equations that represent these finite pieces are then combined into a bigger system of equations that represents the full issue. The FEM then approximates a solution by using the calculus of variations to minimize an associated error function.
This approach is highly useful in our situation of the structural examination of the tanker ship since it allows us to take and display data that would otherwise be quite difficult to achieve using analytical methods. The study was carried out using a quadrangular element mesh, which was a good fit for my ship's proportions and produced a nearly homogeneous mesh.



The mathematical model's response is then thought to be approximated by the discrete model created by linking or assembling the collection of all pieces.
When studying many manmade and natural systems, the disconnection-assembly notion emerges easily. For example, it is straightforward to see an engine, bridge, building, airplane, or skeleton as manufactured from smaller components. Finite elements, unlike finite difference models, do not overlap in space.

A standard finite element analysis using a software system necessitates the necessary data:

1. Nodal point spatial locations (geometry)
2. Elements connecting the nodal points
3. Mass properties
4. Boundary conditions
5. Loading or forcing function details
6. Analysis options

Considering FEM is a discretization approach, a FEM model must have a finite number of degrees of freedom.
They are placed in a matrix form called u, which is also known as the DOF column or state vector.
Mechanical applications use the term nodal displacement vector for u.
Procedures for the FEM Solution Process:

1. Separate the structure into parts (elements with nodes) (discretization/meshing).
2. Connect (assemble) the components at the nodes to build an approximation of the overall structure's system of equations (forming element matrices)
3. Determine the solution to the system of equations involving unknown quantities at the nodes (e.g., displacements)
4. Determine required quantities (for example, strains and stresses) at specified components. FEM studies are extensively utilized in design and engineering offices nowadays since they are a highly strong tool for analyzing ship constructions.

3. Ship's dimensions and geometry

Following the main dimension:

MAIN DIMENSIONS		
Lbp	286,2	[m]
B	46,1	[m]
D	24,1	[m]
d	17,6	[m]
v	15,8	[kn]
Cb	0,84	\
Cw	10,69873528	

Lbp: Length between perpendiculars

B: Breath

D: Drought

d: Draft

Vs: Cruise speed

Cb: Block coefficient

It was slightly modified to ensure that the ship's center of gravity occurred in the lower portion of the draft, as we shall see later, by adding two extra bottom girders.

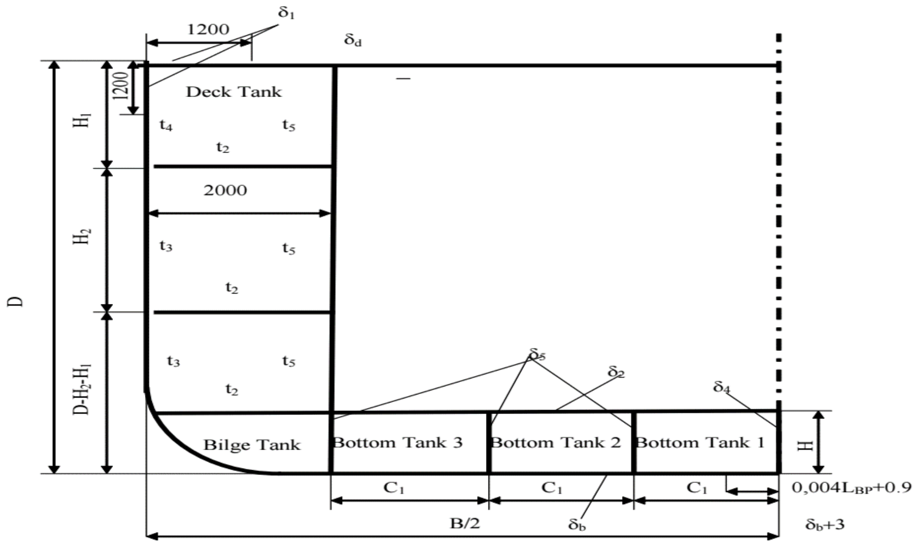


Figure 6 Midship section

COMPARTMENT GEOMETRY			
	Computations	Real	
H	2,57	3	[m]
H1	4,82	5	[m]
H2	7,23	7	[m]
D-H1-H2	12,05	12,1	[m]
C1	3,17	3	[m]
DH		7,1875	[m]

4. Thicknesses

The thicknesses have to be such that the section satisfy the minimum midship section modulus requirement. The first item done was the computation of the minimum thicknesses necessary, therefore it was chosen to compute it, as with the first way.

It is as follows:

	ti [mm]
δ_d	36,0721
δ_{1h}	36,0721
δ_{1v}	36,0721
t_4	36,0721
t_{5up}	38,0918
t_{2up}	36,8908
t_{3md}	36,8758
t_{5md}	38,0918
t_{2md}	36,8908
t_{3dw}	36,8758
t_{5dw}	38,0918
t_{2dw}	36,8908
δ_2	36,0721
$\delta_{5\ 6.1}$	39,1133
$\delta_{5\ 6.2}$	39,1133
$\delta_{5\ 6.3}$	39,1133
$\delta_{5\ 6.4}$	39,1133
$\delta_{5\ 6.5}$	39,1133
δ_4	39,1185
δ_b	39,1185
δ_b+3	42,9181

Related to the main formulas used:

$$\delta_d = 0.035L + 5, mm$$

$$\delta_b = 0.04L + 6\ , mm$$

$$t_4 = 1.2\delta_b$$

$$t_3 = 0.8\delta_d$$

$$\delta_5 = \delta_b$$

$$\delta_4 = 0.9\delta_b$$

$$\delta_{bt} = 0.8\delta_{db}$$

$$\delta_{db} = 0.8\delta_d$$

$$\delta_1 = 1.3\delta_d$$

t_5=10mm

The initial thickness calculated values, which were not published because to their limited utility for final sizing, were less than the necessary values for the minimum midship section modulus.

The following was the process for calculating the midship section modulus:

$$b, h, t \;\&\; y_g$$

$$A_i = b * h$$

$$S_{x_i} = A_i * y_g$$

$$A_{tot} = \sum_i^n A_i$$

$$S_{x_{tot}} = \sum_i^n S_{x\,i}$$

$$y_{g_{tot}} = \frac{S_{x_{tot}}}{A_{tot}}$$

$$I_{x_{prop_i}} = \frac{1}{12} * b_i * h_i^3$$

$$I_{x_{tras_i}} = I_{x_{prop_i}} + A_i\left(y_{g_i} - y_{g_{tot}}\right)^2$$

$$I_{x_{tot}} = \sum_i^n (I_{x_{prop_i}} + I_{x_{tras_i}})$$

$$W = \frac{I_{x_{tot}}}{y_{g_{tot}}}$$

Throughout these equations, the following table was calculated:

	ti [mm]	b [mm]	h [mm]	ygi [mm]	A [mm^2]	Sx [mm^3]	Jxp [mm^4]	Jxt [mm^4]	Jxtot [mm^4]	xgi [mm]	Sy [mm^3]	Jyp [mm^4]	Jyt [mm^4]	Jytot [mm^4]
δ_d	36,0721	21850	36	24082	788175	1,90E+10	8,55E+07	1,55E+14	3,11E+14	10925	8,61E+09	3,14E+13	9,41E+13	2,51E+14
δ_{1h}	36,0721	1200	36	24082	43286	1,04E+09	4,69E+06	8,54E+12	1,71E+13	11525	4,99E+08	5,19E+09	5,75E+12	1,15E+13
δ_{1v}	36,0721	36	1200	23464	43286	1,02E+09	5,19E+09	7,80E+12	1,56E+13	23032	9,97E+08	4,69E+06	2,30E+13	4,59E+13
t_4	36,0721	36	3800	21000	137074	2,88E+09	1,65E+11	1,65E+13	3,33E+13	23032	3,16E+09	1,49E+07	7,27E+13	1,45E+14
t_{5up}	38,0918	38	5000	21564	190459	4,11E+09	3,97E+11	2,53E+13	5,14E+13	15862,5	3,02E+09	2,30E+07	4,79E+13	9,58E+13
t_{2up}	36,8908	7000	37	19280	258236	4,98E+09	2,93E+07	2,21E+13	4,41E+13	18500	4,78E+09	1,05E+12	8,84E+13	1,79E+14
t_{3md}	36,8758	37	7000	15582	258131	4,02E+09	1,05E+12	7,93E+12	1,80E+13	23032	5,95E+09	2,93E+07	1,37E+14	2,74E+14
t_{5md}	38,0918	38	7000	15582	266643	4,15E+09	1,09E+12	8,19E+12	1,86E+13	15862,5	4,23E+09	3,22E+07	6,71E+13	1,34E+14
t_{2md}	36,8908	7000	37	12100	258236	3,12E+09	2,93E+07	1,10E+12	2,19E+12	18500	4,78E+09	1,05E+12	8,84E+13	1,79E+14
t_{3dw}	36,8758	37	12100	6032	446197	2,69E+09	5,44E+12	7,17E+12	2,52E+13	23032	1,03E+10	5,06E+07	2,37E+14	4,73E+14
t_{5dw}	38,0918	38	9100	6032	346635	2,09E+09	2,39E+12	5,57E+12	1,59E+13	15862,5	5,50E+09	4,19E+07	8,72E+13	1,74E+14
t_{2dw}	36,8908	7000	37	3000	258236	7,75E+08	2,93E+07	1,28E+13	2,56E+13	18500	4,78E+09	1,05E+12	8,84E+13	1,79E+14
δ_2	36,0721	15000	36	7000	541081	3,79E+09	5,87E+07	5,00E+12	1,00E+13	7500	4,06E+09	1,01E+13	3,04E+13	8,12E+13
$\delta_{5\ 6.1}$	39,1133	39	3000	1500	117340	1,76E+08	8,80E+10	8,56E+12	1,73E+13	15862,5	1,86E+09	1,50E+07	2,95E+13	5,90E+13
$\delta_{5\ 6.2}$	39,1133	39	3000	1500	117340	1,76E+08	8,80E+10	8,56E+12	1,73E+13	12000	1,41E+09	1,50E+07	1,69E+13	3,38E+13
$\delta_{5\ 6.3}$	39,1133	39	3000	1500	117340	1,76E+08	8,80E+10	8,56E+12	1,73E+13	9000	1,06E+09	1,50E+07	9,50E+12	1,90E+13
$\delta_{5\ 6.4}$	39,1133	39	3000	1500	117340	1,76E+08	8,80E+10	8,56E+12	1,73E+13	6000	7,04E+08	1,50E+07	4,22E+12	8,45E+12
$\delta_{5\ 6.5}$	39,1133	39	3000	1500	117340	1,76E+08	8,80E+10	8,56E+12	1,73E+13	3000	3,52E+08	1,50E+07	1,06E+12	2,11E+12
δ_4	39,1185	39	3000	1500	117356	1,76E+08	8,80E+10	8,56E+12	1,73E+13	0	0,00E+00	1,50E+07	0,00E+00	2,99E+07
δ_b	39,1185	21005	39	0	821693	0,00E+00	1,05E+08	8,28E+13	1,66E+14	12547,4	1,03E+10	3,02E+13	1,29E+14	3,19E+14
δ_b+3	42,9181	2045	43	0	87759	0,00E+00	1,35E+07	8,84E+12	1,77E+13	1022,4	8,97E+07	3,06E+10	9,17E+10	2,45E+11

yg [mm]	10039
xg[mm]	0

To maintain the problem as realistic as possible, with all simplifications, putting the additional two bottom girders means adding weight below the lower middle section part of the ship, which would drop the true center of gravity further lower, making the deck the most stressed area (as the real examples suggest to us).

$$W_{DECK} - W_{REQUIRED}$$

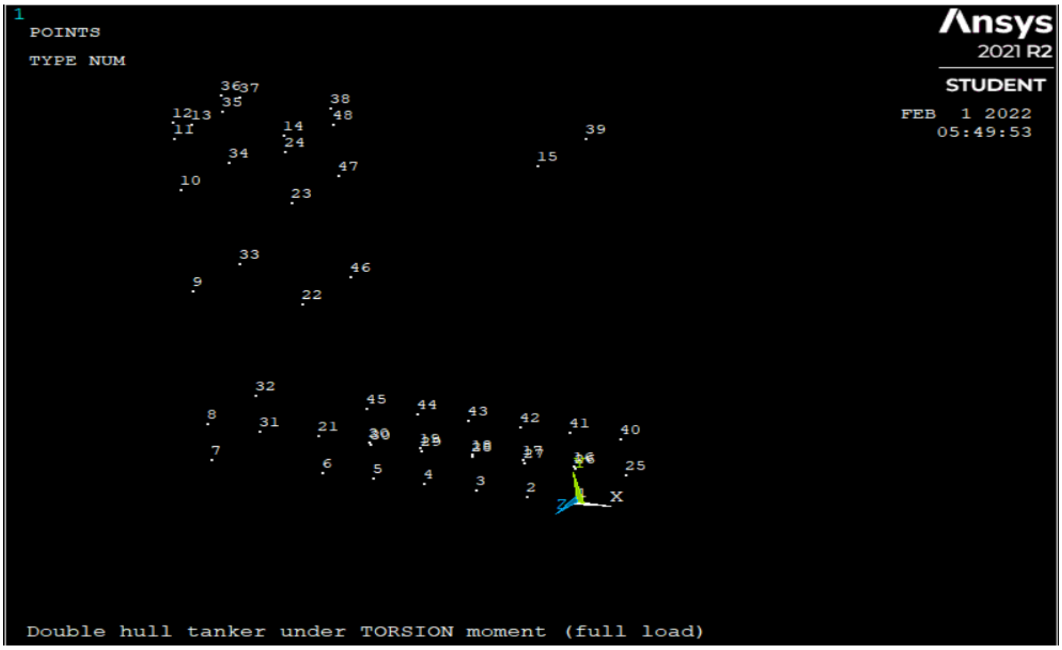
It was chosen not to make this difference equal to zero, but rather to make it significant or equal to the previously stated number in order to allow the program to select the optimal option with a little safety margin and flexibility in the outcomes.
To find the best solution for the ship, has been decided to put on some constraints:

$$\delta_d \leq \delta_1$$
$$t_4 \leq \delta_1$$
$$\delta_b = \delta_b + 3$$
$$t_{2_i} \; equals \; in \; all \; double \; side$$
$$t_{3_i} \; equals \; in \; all \; external \; side$$
$$t_{5_i} \; equals \; in \; all \; external \; side$$
$$\delta_{5_i} \; equals \; in \; all \; bottom$$
$$33[mm] \leq t_i \leq 37[mm]$$
$$t_i \; integers$$

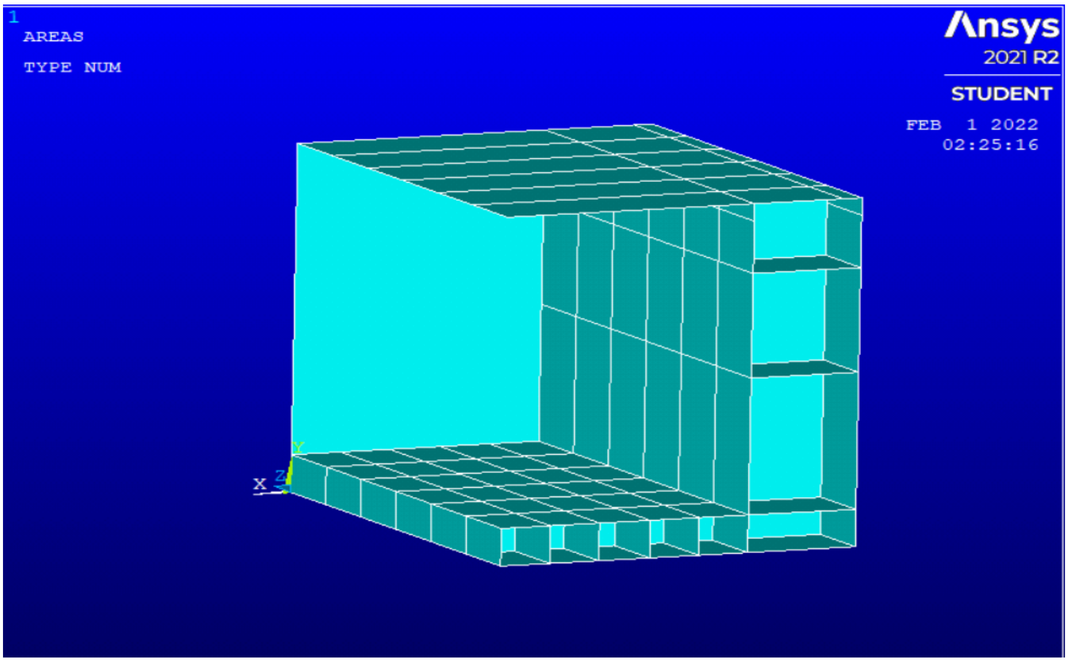
Both are selected to have the fewest and simplest geometry modifications feasible. It isn't the most realistic solution because, for example, the external side of the ship requires a plate whose thickness increases with draft due to increased hydrostatic pressure, but, as stated in the first section of the report, all decisions are made in order to have the simplest geometry possible in accordance with the most realistic solution.

5. Structure

It has been decided to begin construction on the section's left side.The initial step was to number the nodes of the section as they changed and intersected with the different structural features. The result was as follows, duplicating the first section to the *z=-5 [m]:*



The next phase was to identify and produce the transversal and longitudinal regions between these two parts, keeping in mind to generate the major bulkhead as well.



The next phase was to define the properties of the steel utilized in the structure and to decide which element to employ.The element chosen is Shell93, and its properties include Poisson's ratio and Young's modulus, which are 0.3 and 200e9 Pa, respectively, as well as the various thicknesses employed for the plates and their use in various regions.

Resistence steel	normal	H32	H36
$\sigma_{yelding}$ [Mpa]	235	315	355
$\sigma_{ammisible}$ [Mpa]	175	236	266

Elements	t [mm]
R1	36
R2	37
R3	38
R4	50
R5	39
R6	43

Afterwards when, the modeling is nearly finished.

The final phases entail the production, reflection, and joining of all regions, while keeping in mind that the main bulkhead is not included in the sections to be reproduced each time.

Finally, the model was mesh by mesh with a size of 1.0 mm.

The structural model is now complete.

The findings are not displayed for the entire section, but just for the bottom, inner bottom, left side, and deck in the transversal direction in the center of the model, and another on the deck in the longitudinal direction on the symmetry plane.

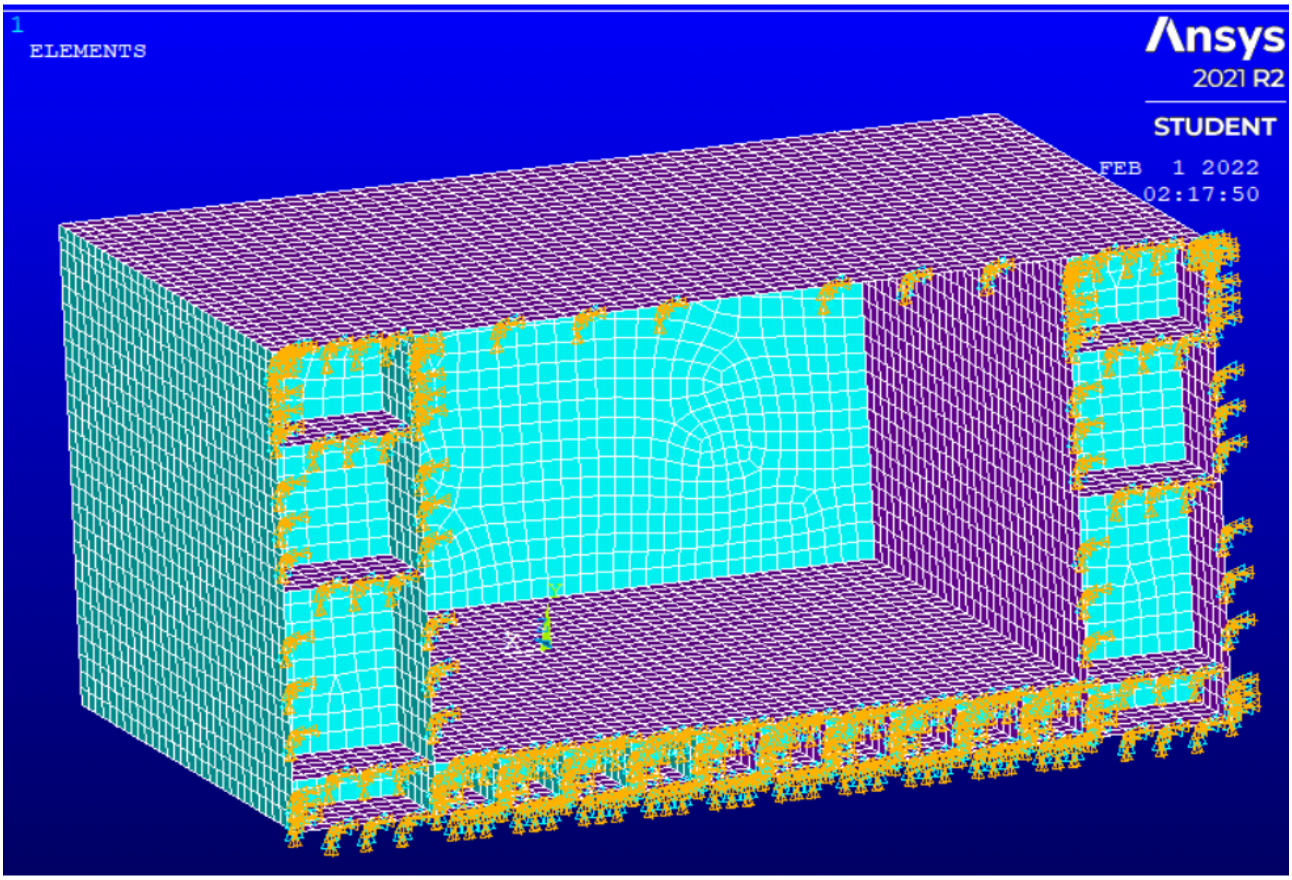
As a result, pathways have been created for each item, and the stress distribution is presented along these paths.

6. Load condition

The minimum loading requirements for bending moments, shear forces, and torsion that a ship must bear are determined in the Load conditions sections, using the project description as a reference, in line with the DNV classification society standards.

The material under consideration for the plate is a naval construction steel with a yield stress of 235 MPa and a young modulus of 200 GPa.

Before applying the loads, the boundary conditions were defined to restrain the displacement and rotation in all directions of the coordinate system, in all the nodes belonging to the section X = 30 m. To define the boundary condition, even though a transversal is fixed, all nodes on this side are clamped to prevent movement in any degree of freedom.



7. Vertical bending moments

Since one transversal is fixed, all nodes on this side are clamped to prevent movement in any degree of freedom.

- Still water

$$M_{SO} = -0.065 C_w L^2 B (C_b + 0.7) \text{ [kNm], in sagging}$$

$$M_{SO} = C_w L^2 B (0.1225 - 0.015 C_b) \text{ [kNm], in hogging}$$

$$M_S = K_{sm} M_{SO}$$

For our case $K_{sm} = 1$

- Wave induced

$$M_{WO} = -0.11 C_w L^2 B (C_b + 0.7) \text{ [kNm], in sagging}$$

$$M_{WO} = 0.19 C_w L^2 B (C_b + 0.7) \text{ [kNm], in hogging}$$

$$M_W = K_{wm} M_{WO}$$

For our case $K_{wm} = 1$

	Sagging	Hogging	
Ms	-4043959	4439871	[kN*m]
Mw	-6843622	1,2E+07	[kN*m]
Mt	-1,1E+07	1,6E+07	[kN*m]
σ_{deck}	-175000	261364	[kN/m^2]
	-175,00	261,36	[Mpa]

Thanks to the hogging condition that was chosen because it is the worst, the findings are as follows:

This moment has been applied as a force to each node of the opposing segment fixed by the following formulas:

$$F_i = \sigma_{Zi} A_i \quad \text{[kN] i-node}$$

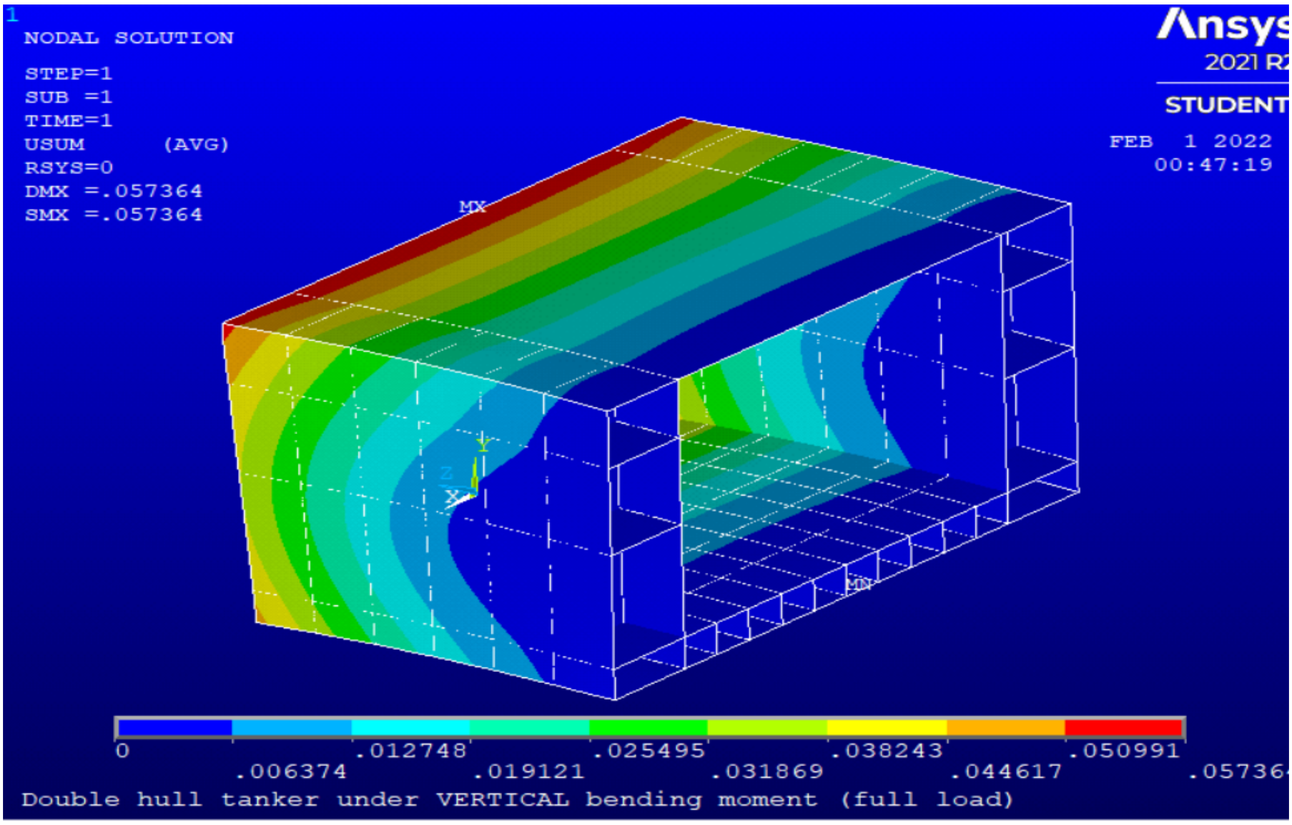
With A_i area linked at i-node and σ_{Zi} the stress in Z direction linked at i-node.

$$\sigma_{Zi} = 1000 M_{TOT} / (\frac{I_X}{Y_i - Y_G}) \text{ [N/m}^2\text{] i-node}$$

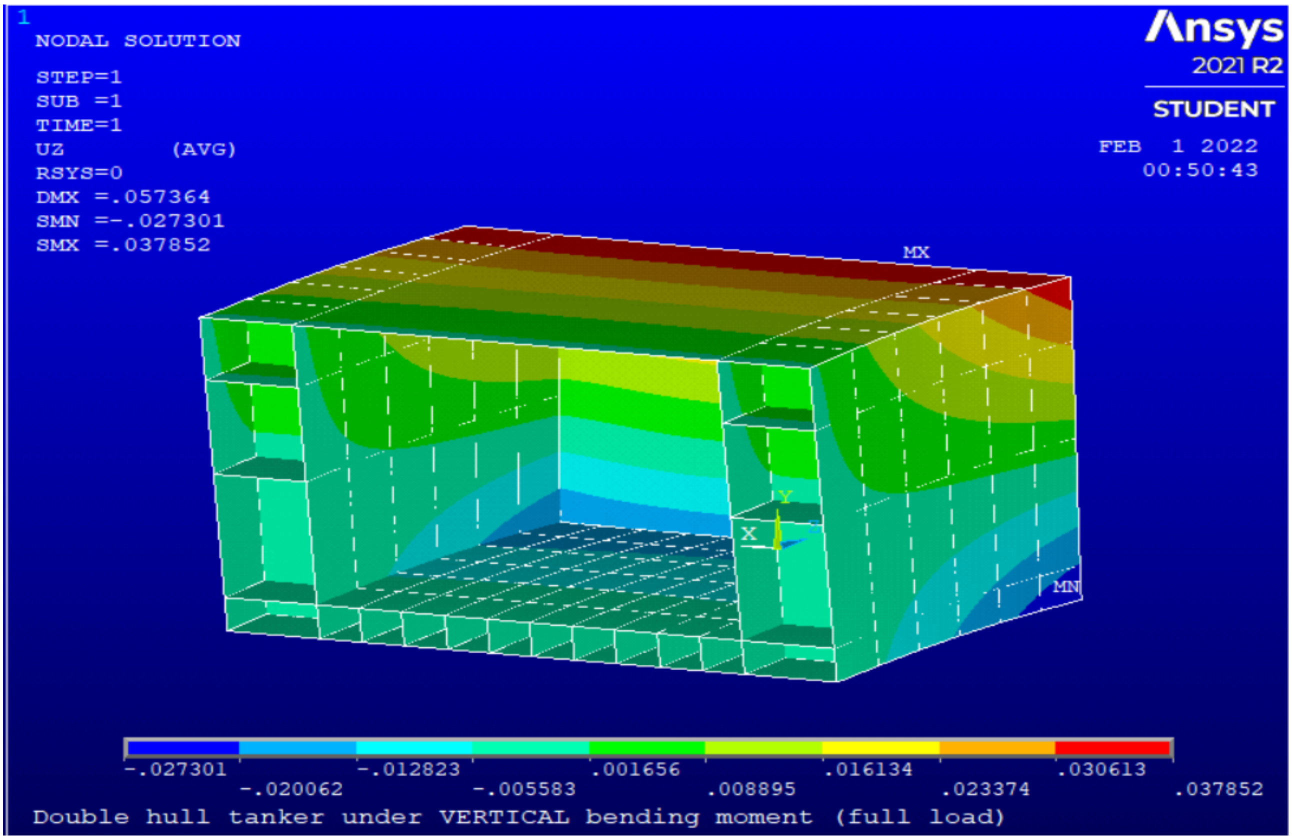
Y_i and Y_G are respectively vertical coordinate of i-node and neutral axes.

Plotting results:

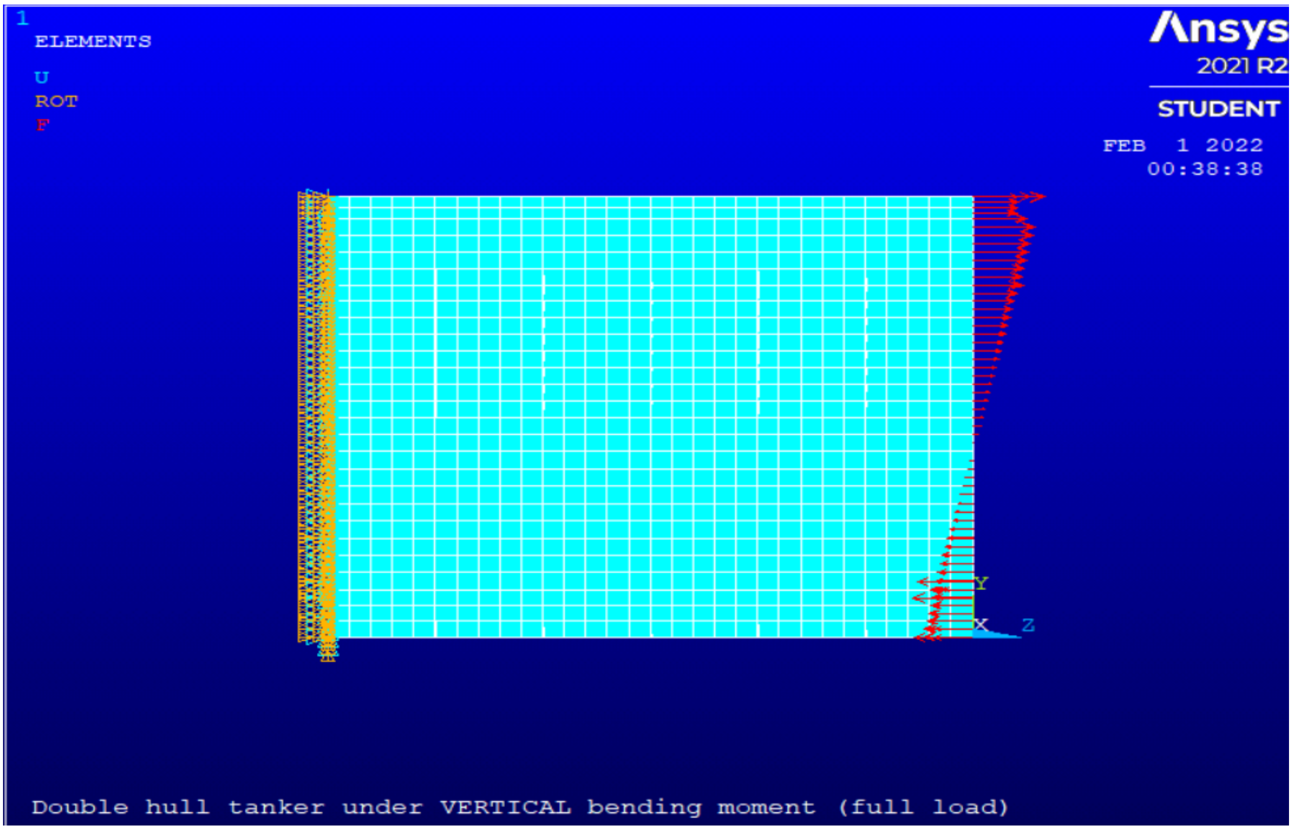
Displacement summary



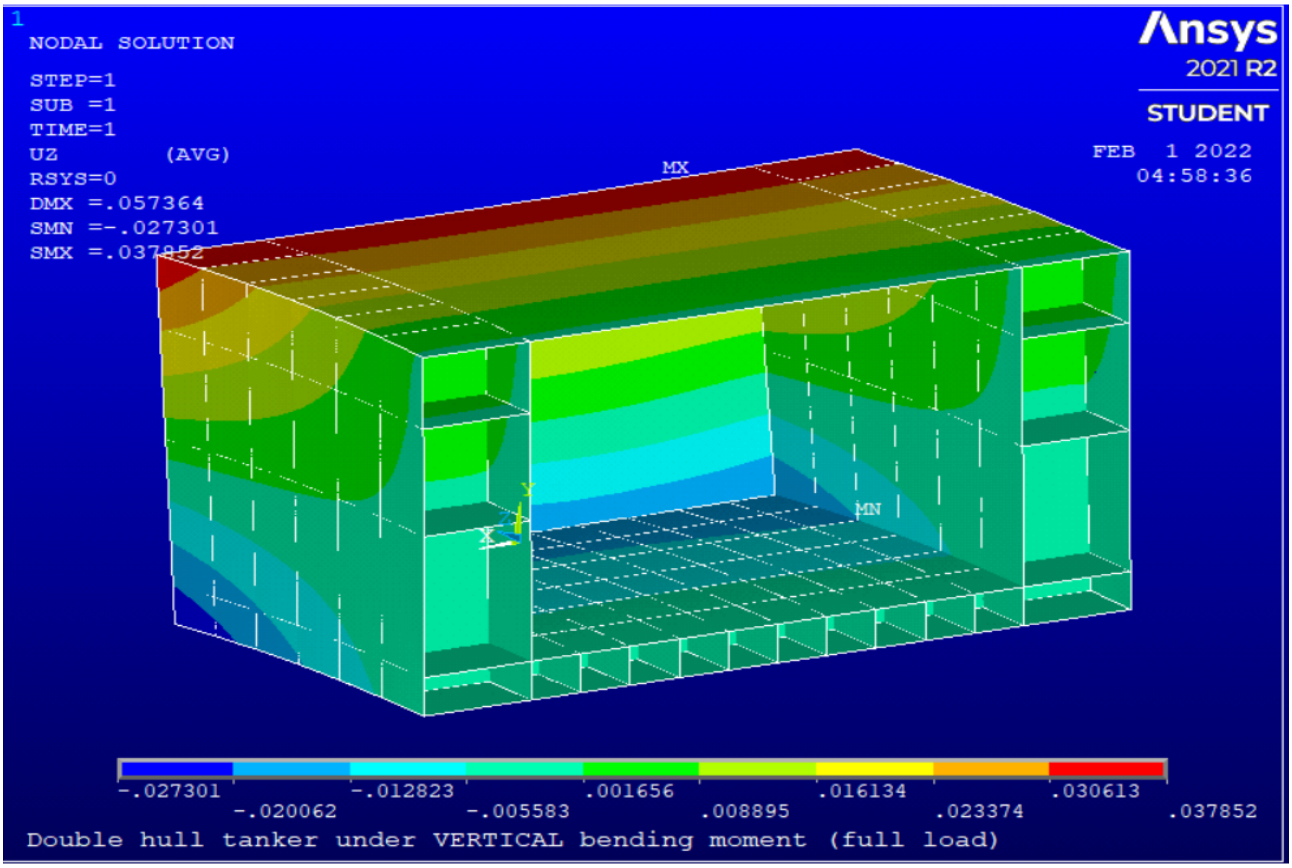
Displacament in Z direction



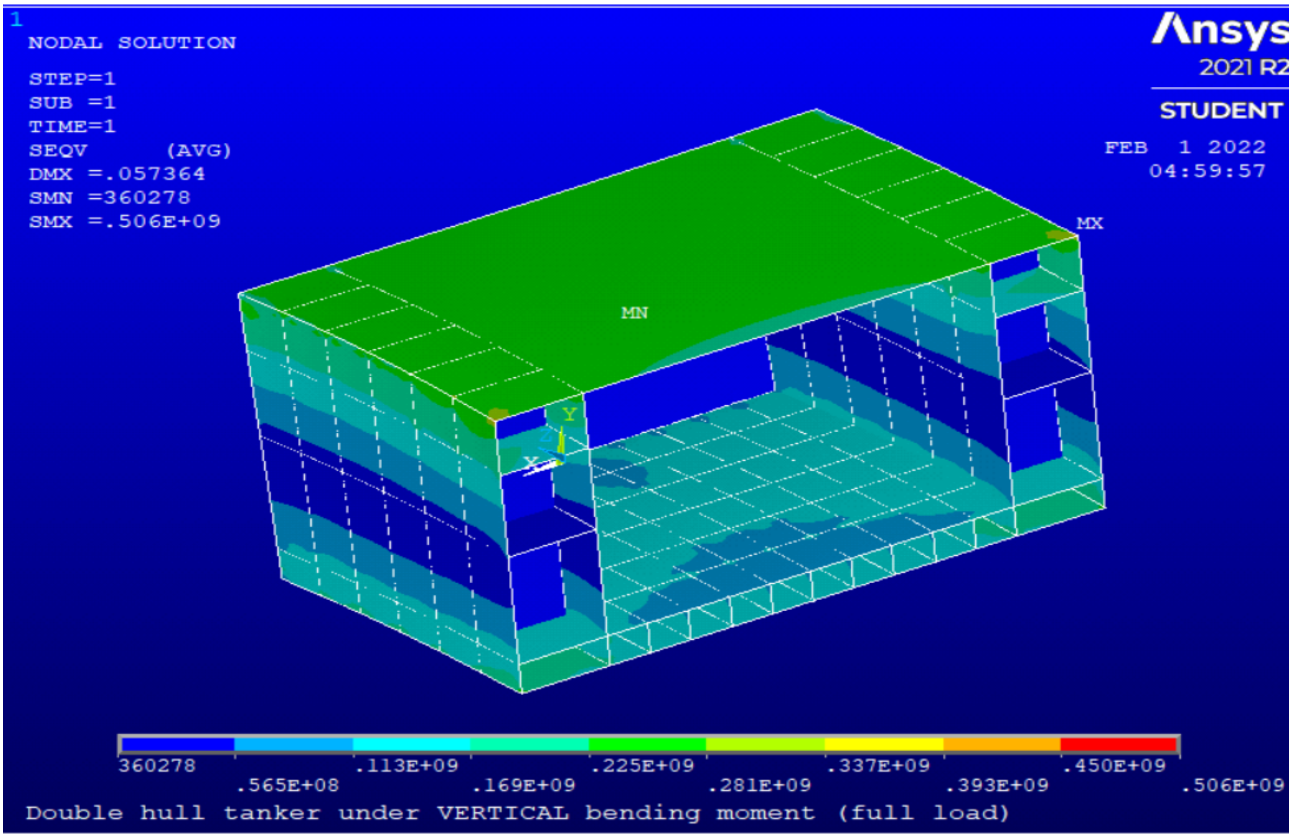
General mash representing the vertical bending moment:



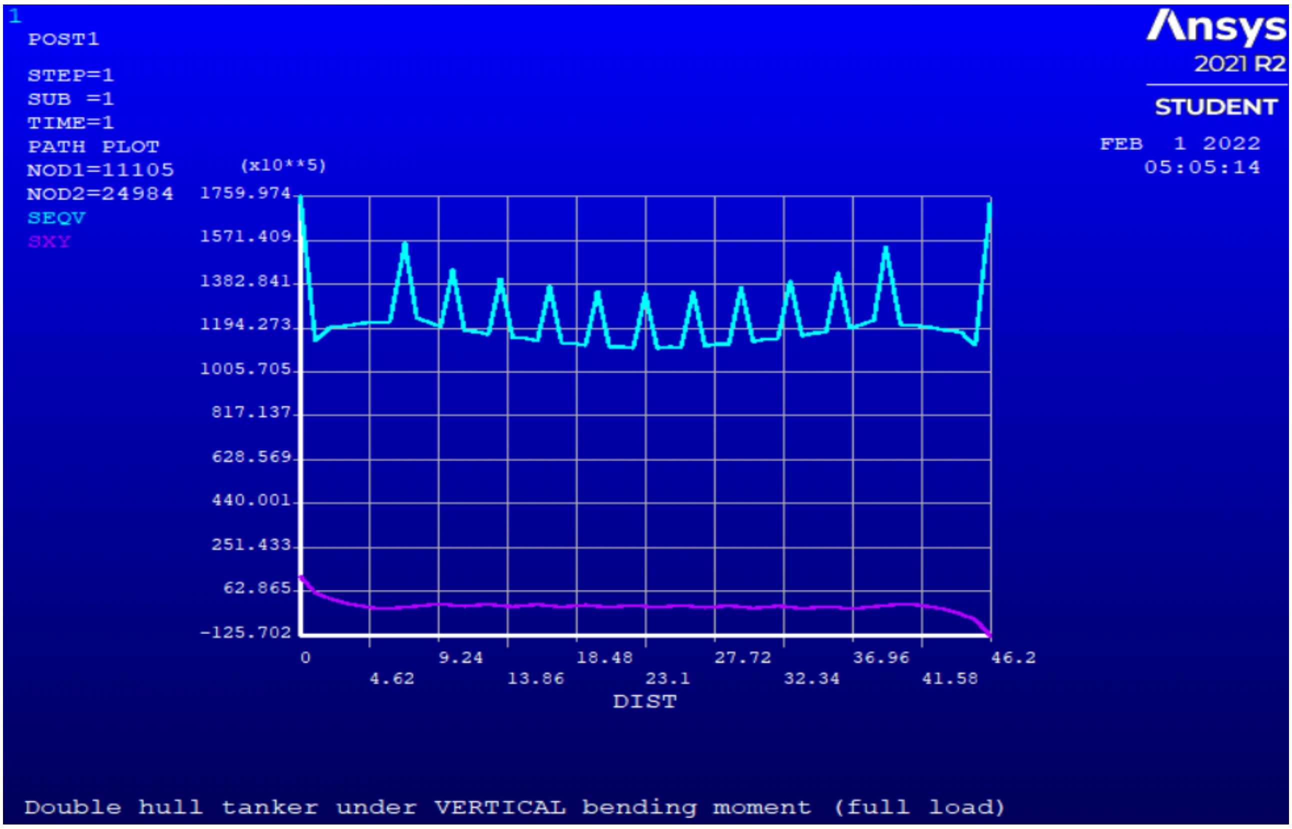
Vertical bending moment applying the path conditions



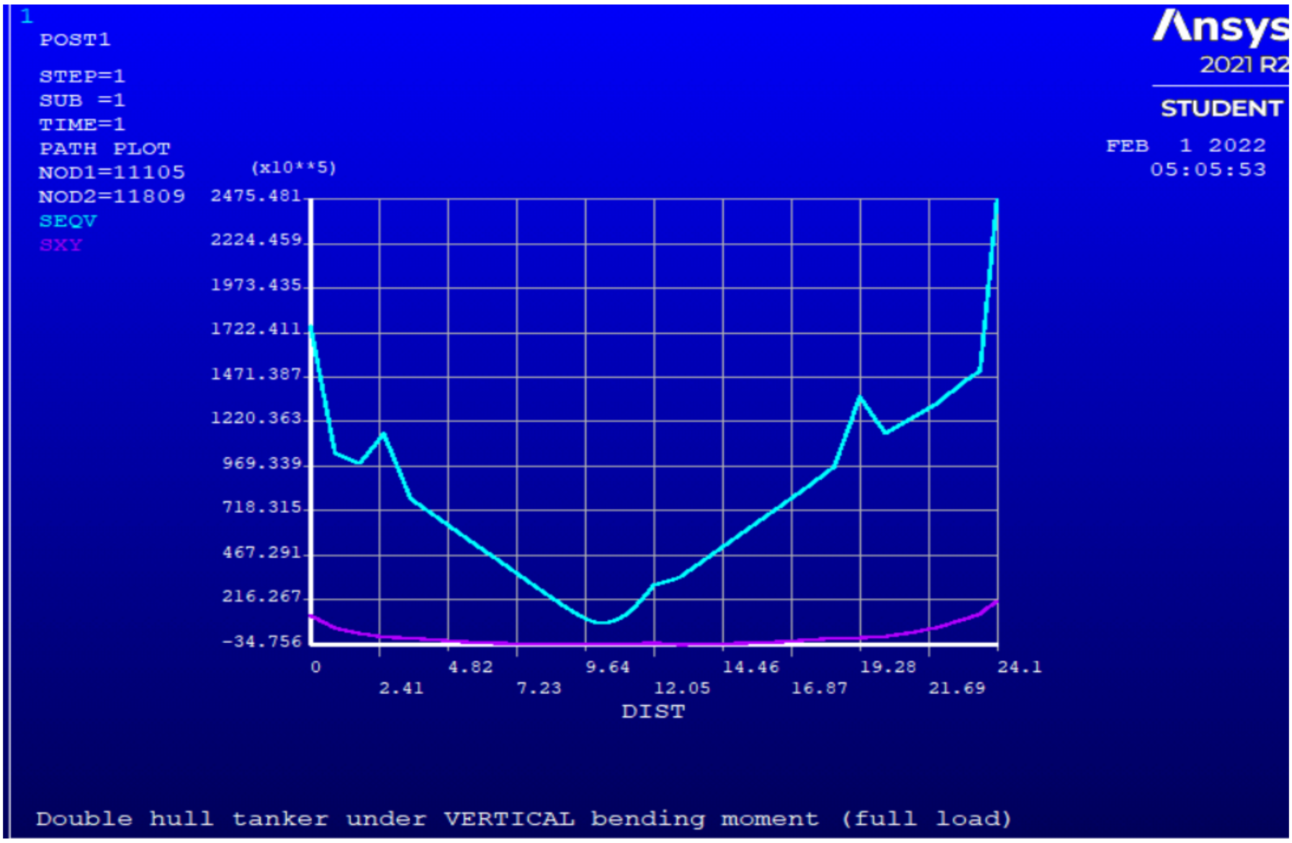
Von Mises mash of stresses:



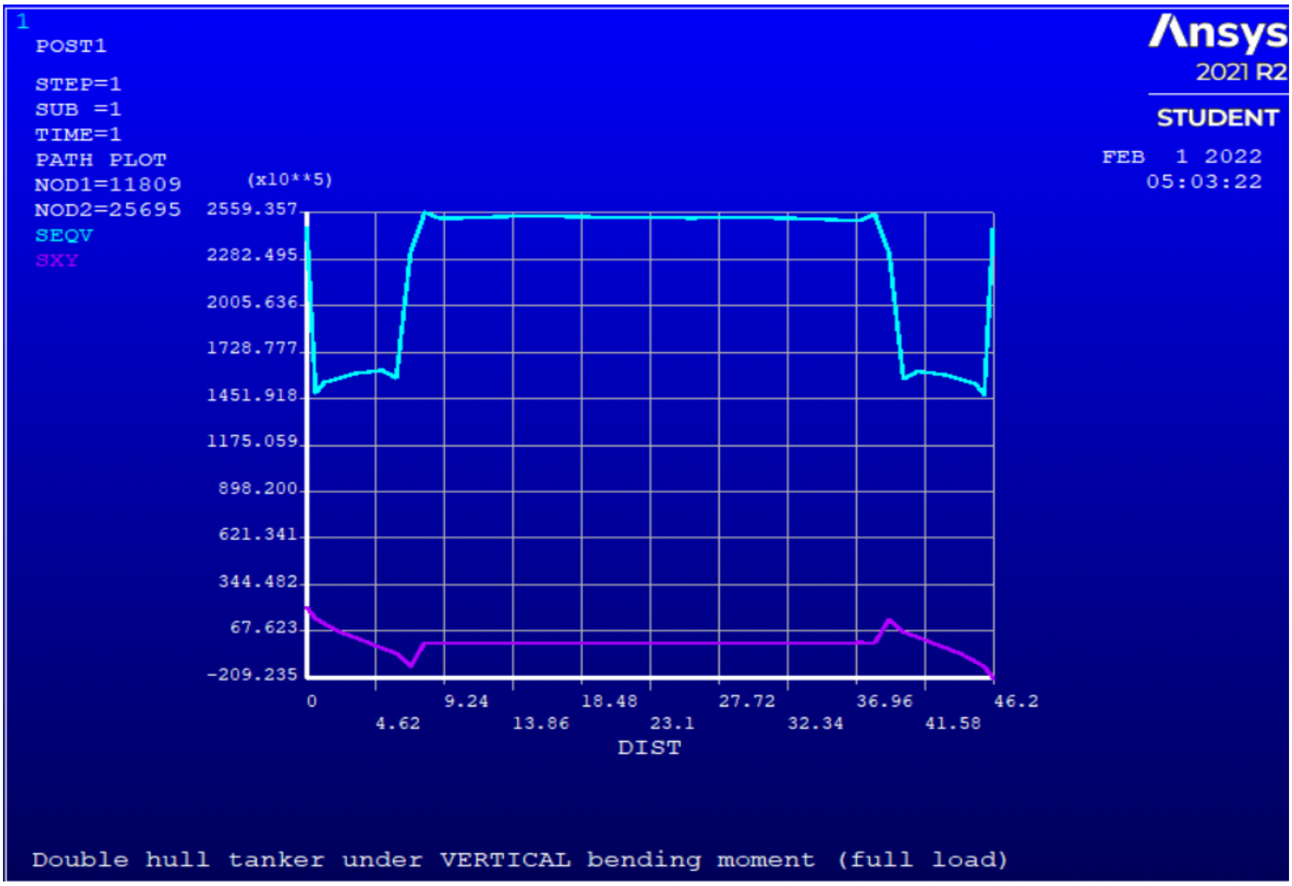
Bottom representation of Von Misess stresses:



Portside representation:



Deck representation:



8. Horizontal bending moment

The horizontal bending moment is caused by waves and may be calculated using the following formula:

$$M_{WH} = 0.22L^{9/4}(T + 0.3B)C_b(1 - \cos(360 * \frac{x}{L}))\ \ [\text{kNm}]$$

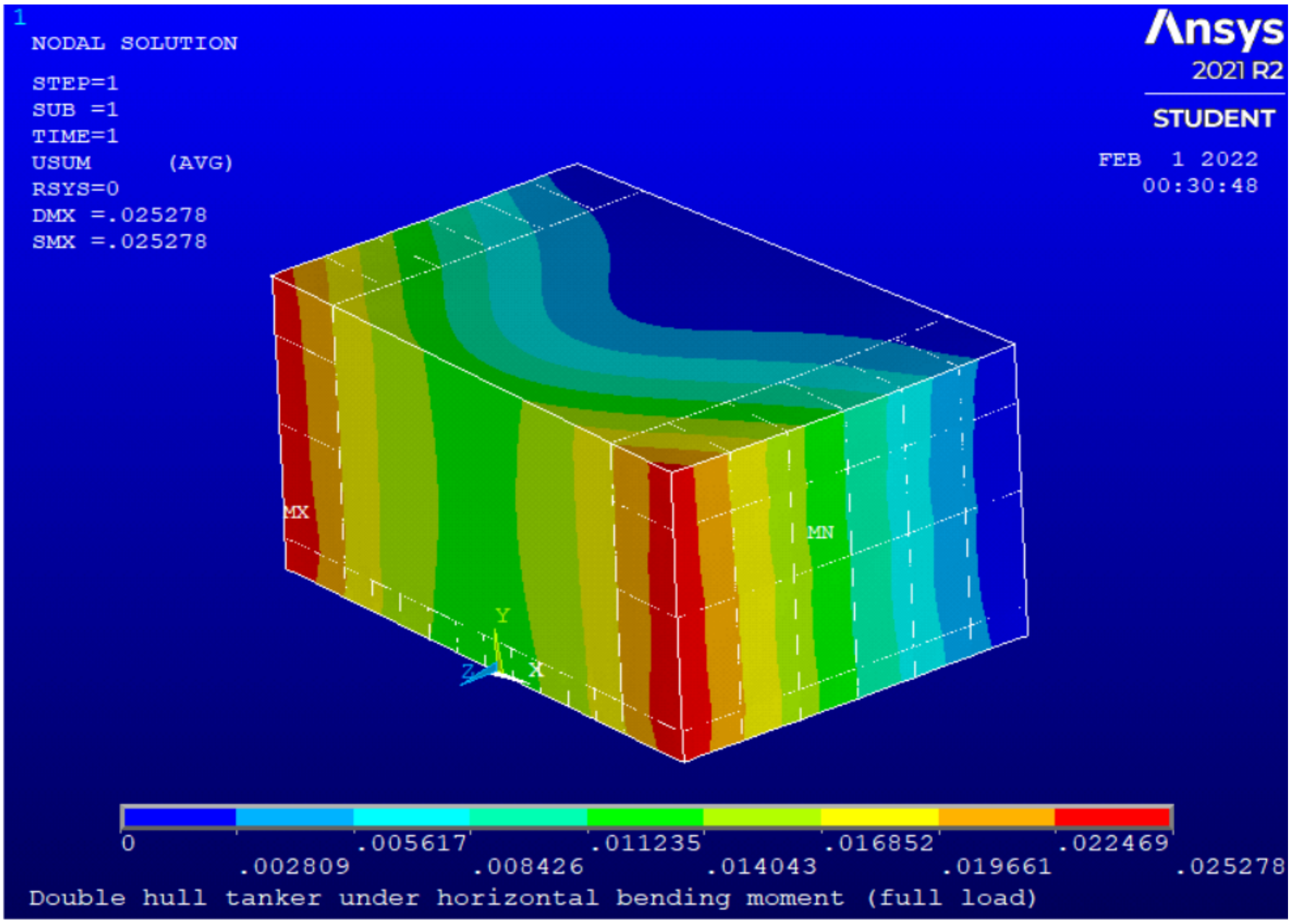
The result:

	Sagging	Hogging	
Ms	-4043958,62	4439870,66	[kN*m]
Mw	-6843622,29	11820802,1	[kN*m]
Mt	-10887580,9	16260672,8	[kN*m]
σ_{deck}	-175000,002	261363,64	[kN/m^2]
	-175,00	261,36	[Mpa]

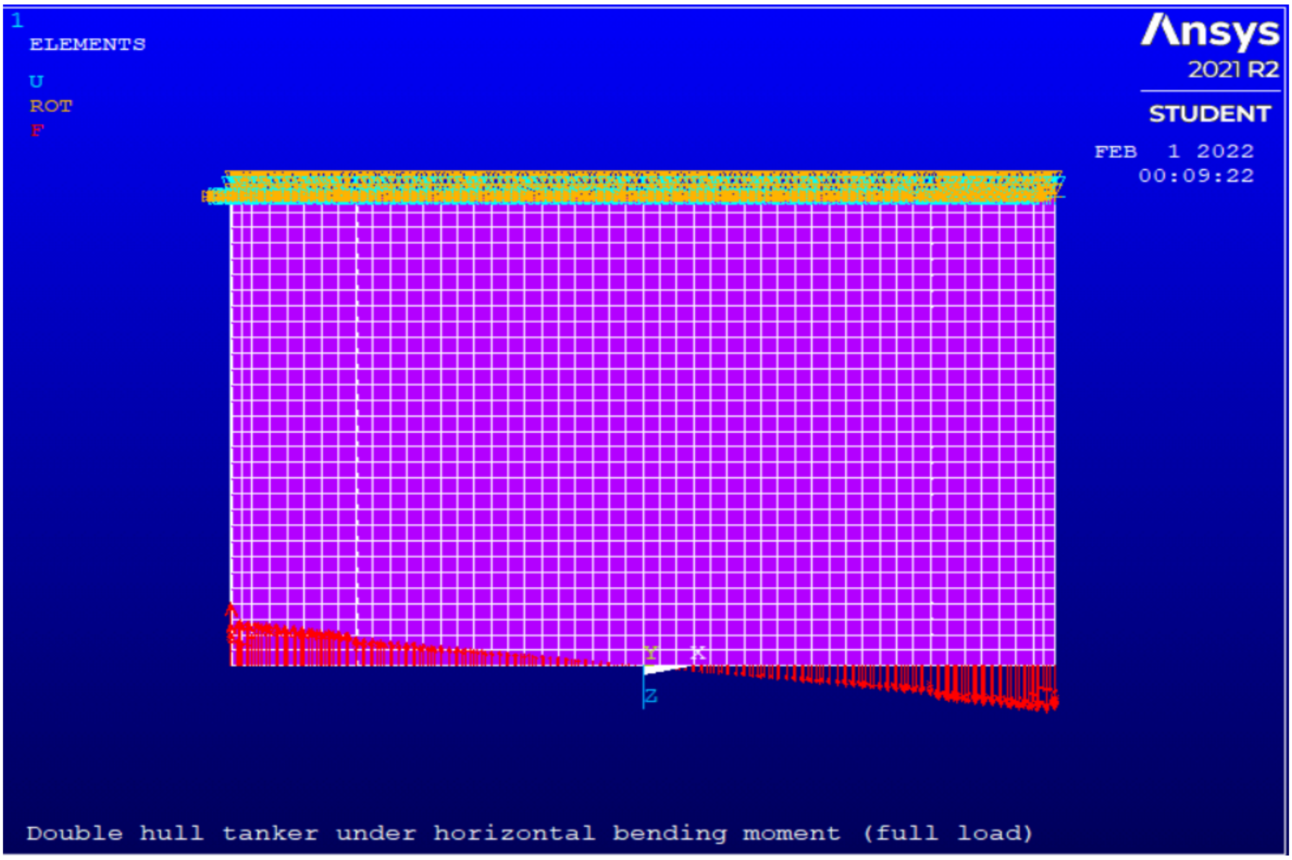
The horizontal bending moment has indeed been applied in the same way as the vertical bending moment, but it only changes for Y i-Y G in the X i transversal position of the i-node since the direction of the moment has changed.

Results:

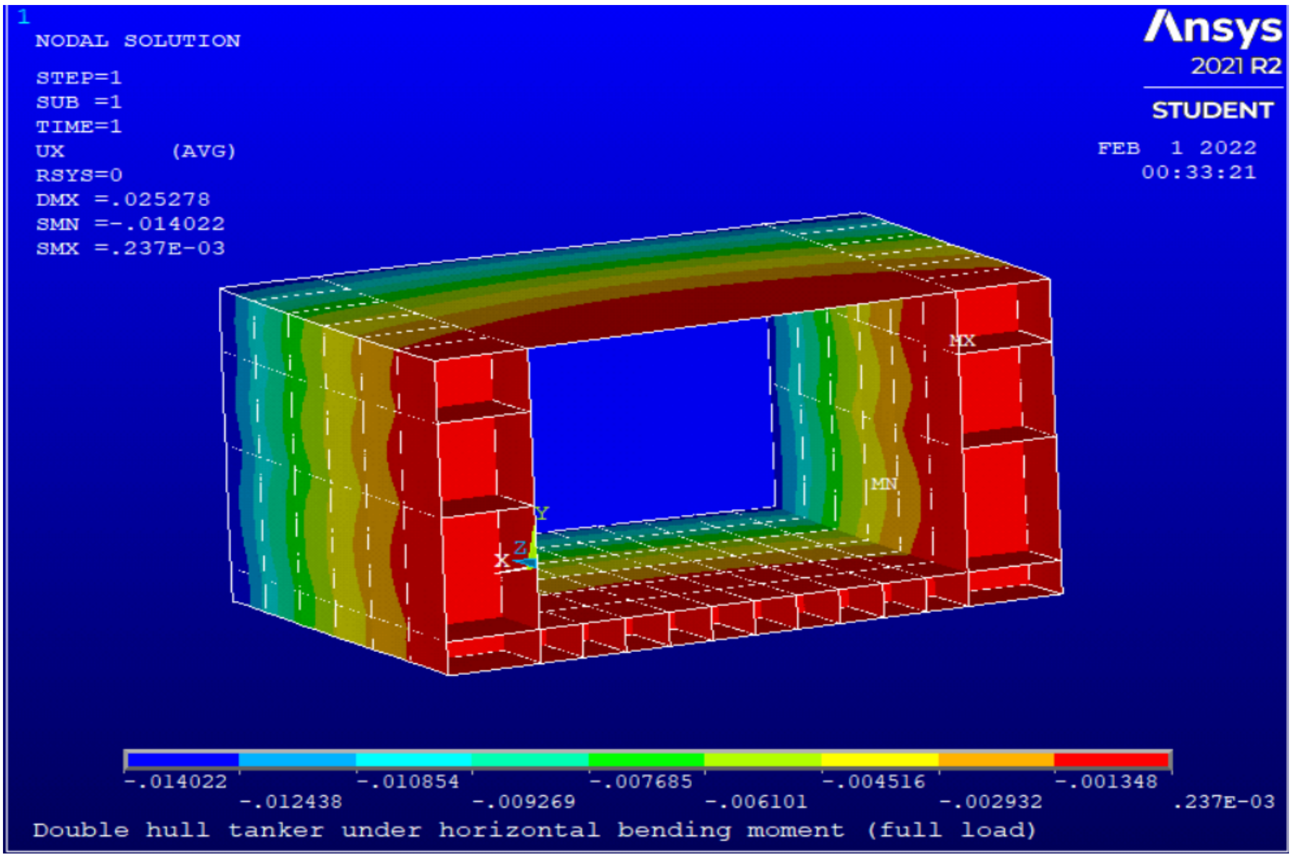
Total displacement



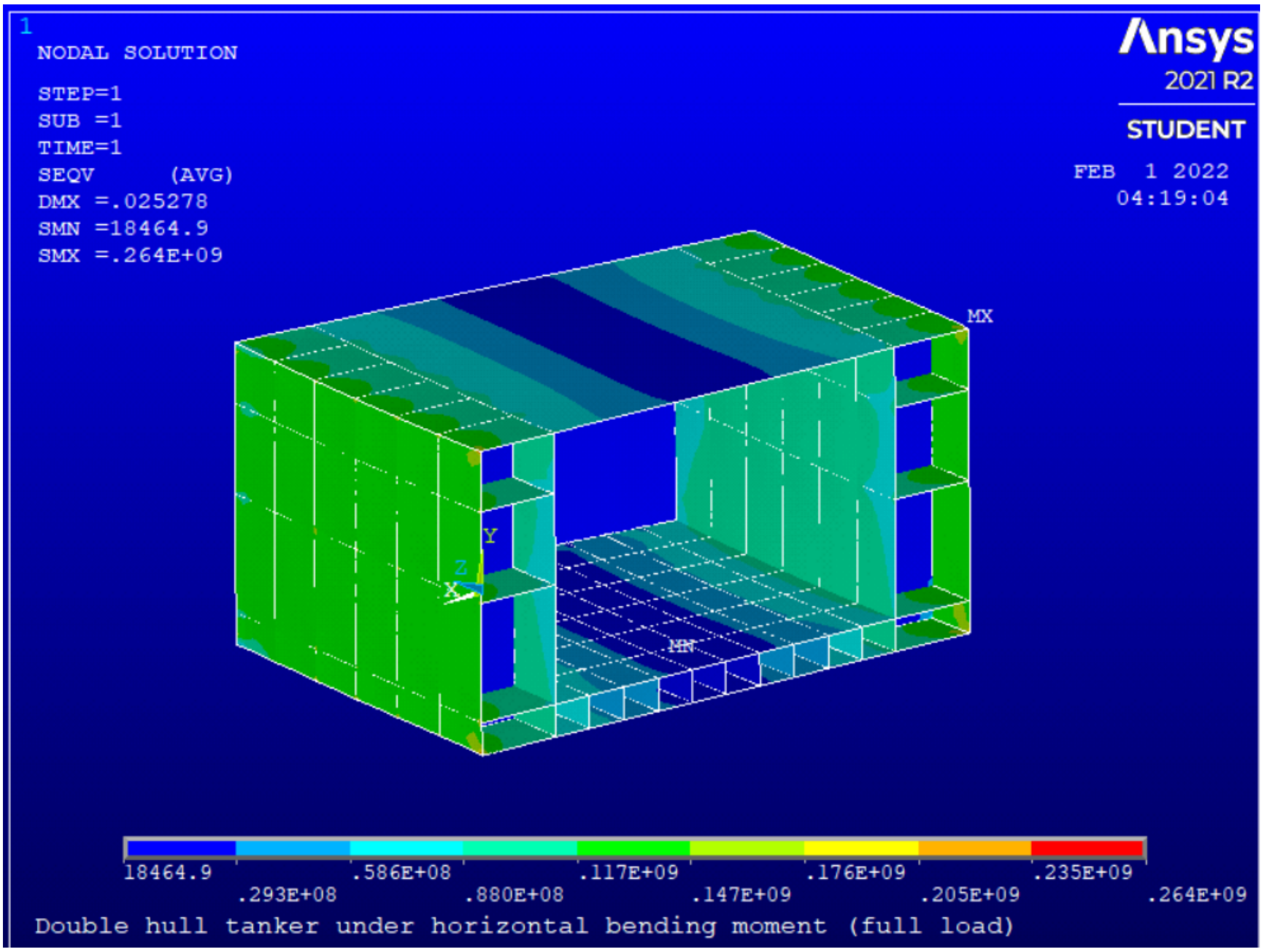
Main Mesh of representation for the horizontal bending moment



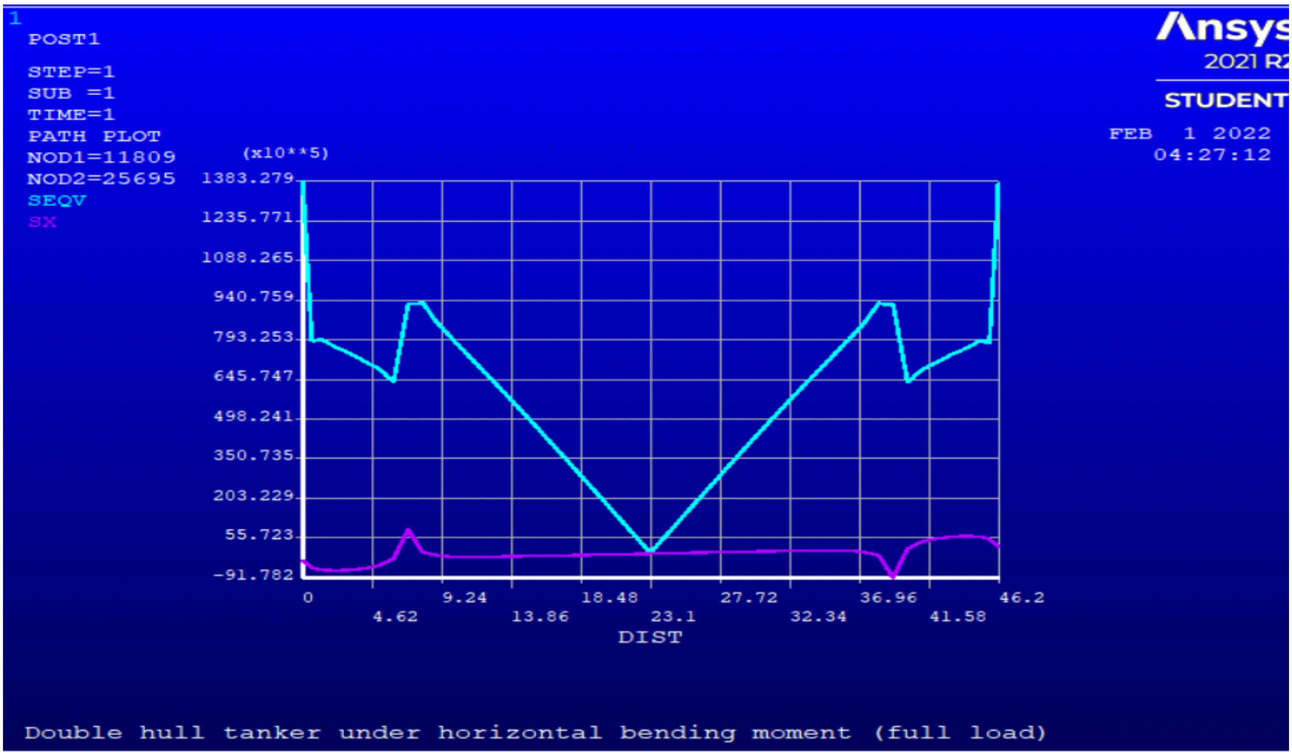
Displacement with X direction



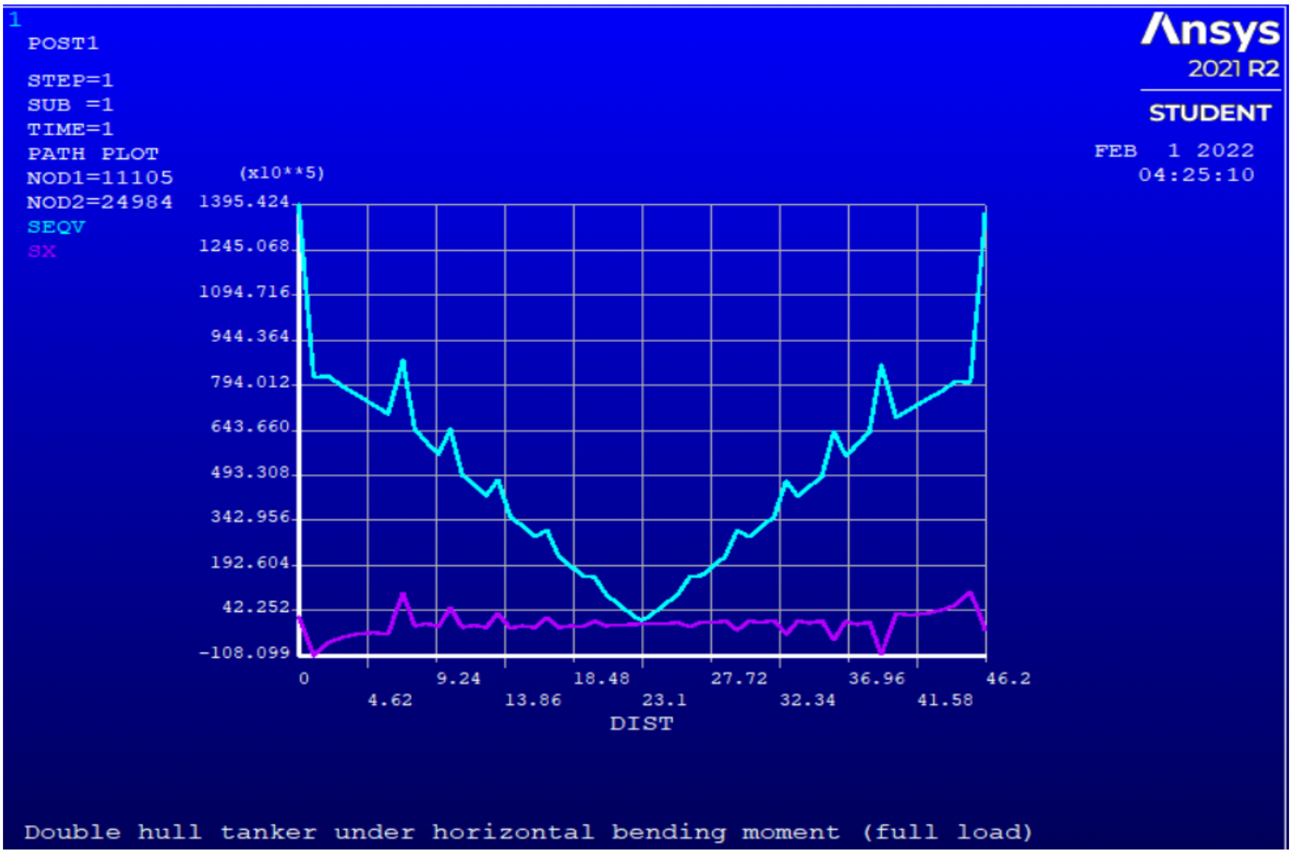
Von Mises stresses



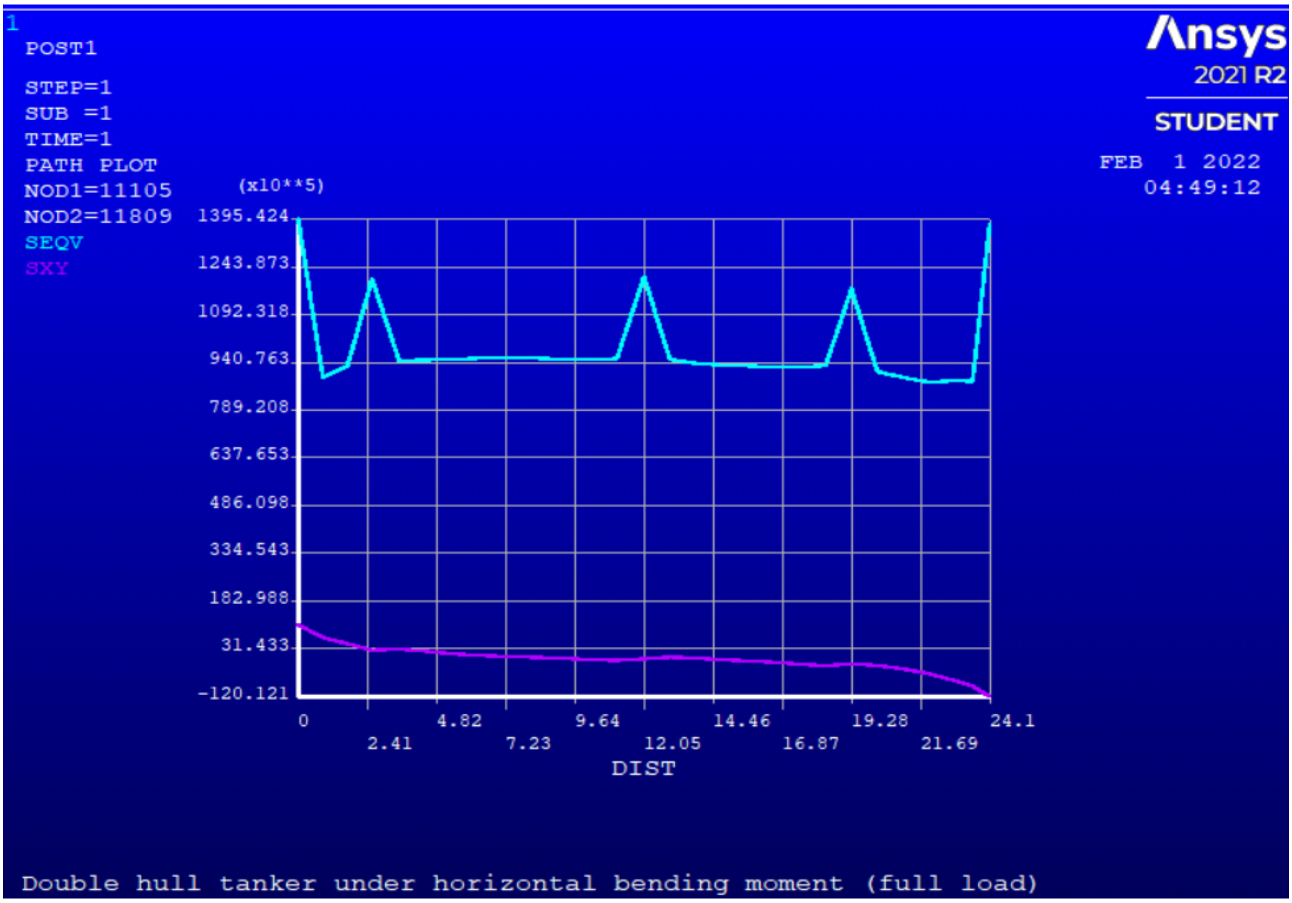
Bottom representation



Deck representation



Portside representation



9. Vertical shear force

The quantity of vertical shear force has been calculated as the total of shear force in still water and induced waves, which have been determined using the following formulas:

- Still water

$$Q_{SO} = 5M_{SO}/L \quad \text{[kN]},$$

in hogging (because it is the worst condition)

$$Q_S = k_{sq}Q_{SO} \quad \text{[kN]},$$

For our case $K_{sq} = 1$

- Wave induced

$$Q_W = 0.3\beta k_{wq}C_w LB(C_b + 0.7) \quad \text{[kNm]}$$

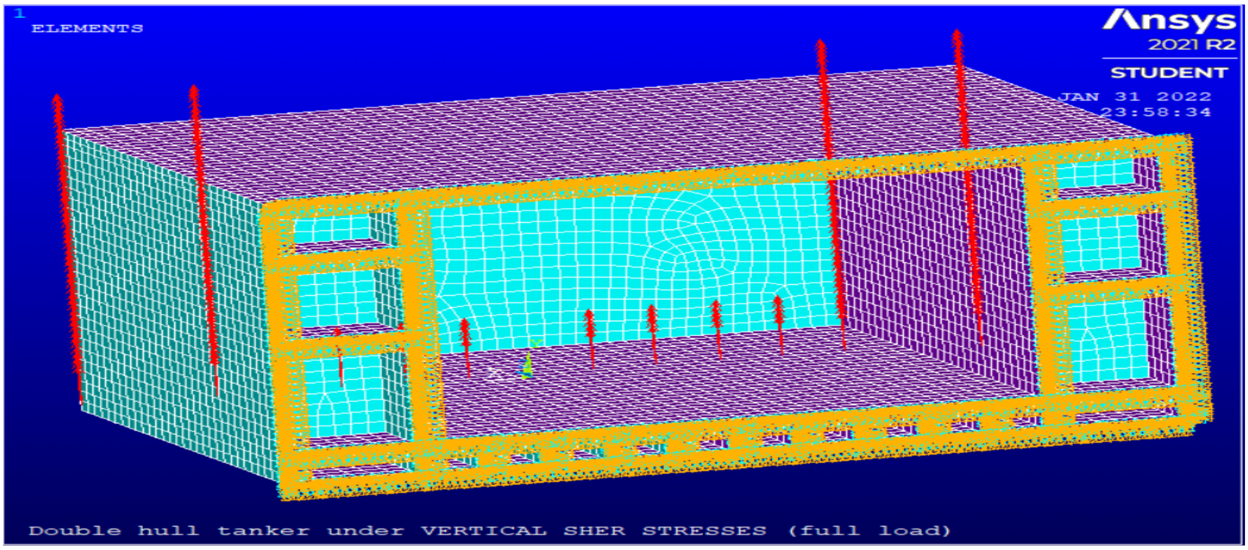
For our case $K_{wq} = 1$ and $\beta = 1$

Results:

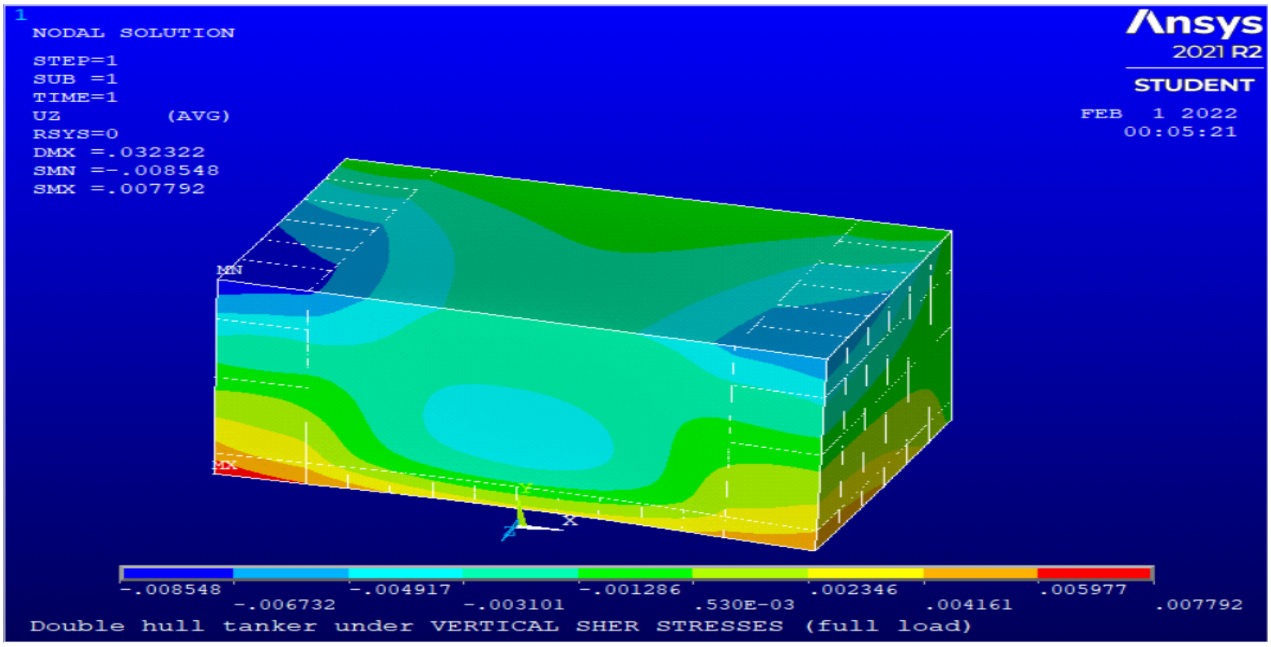
Atot	3,28596	[m^2]
xg	0	[m]
Itot	1320,33	[m^4]
Msh	4439871	[kN*m]
Qso	77565,9	[kN]
Ksq	1	
Qs	77565,9	[kN]
Kwq	1	
β	1	
Qw	62869,4	[kN]
Qtot	140435	[kN]

The shear force is distributed in the Y direction across the nodes of the vertical components of the section in reference to A i. Results:

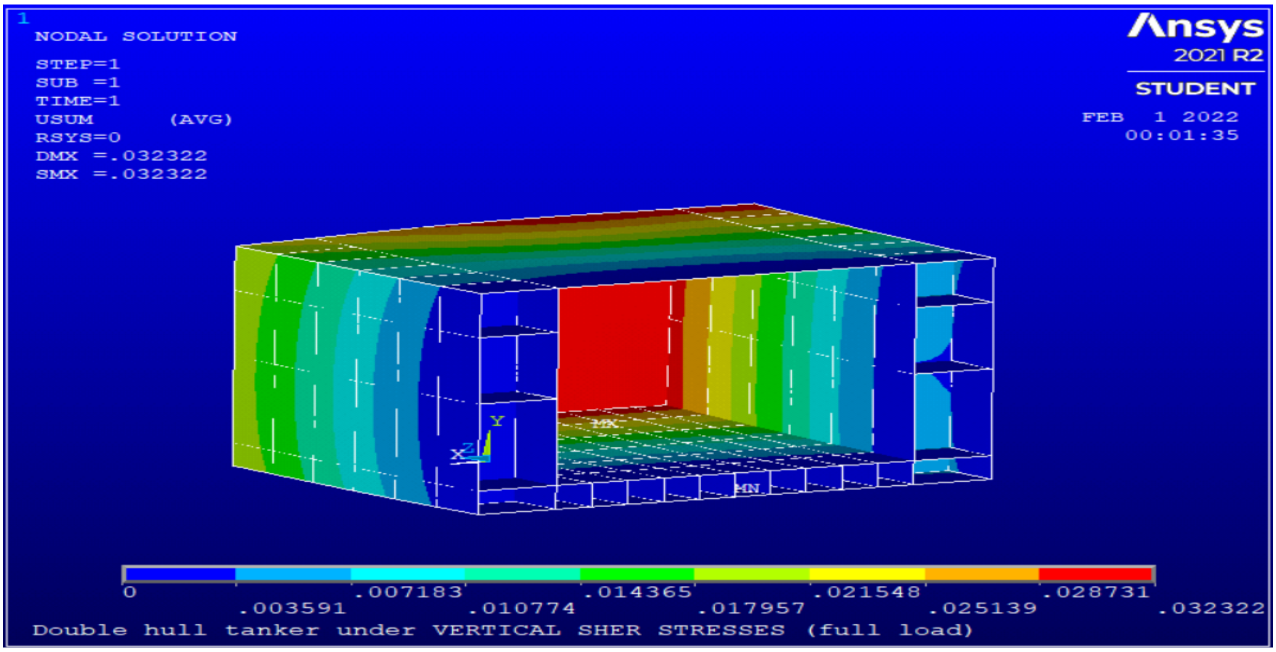
General mash of vertical shearing representation



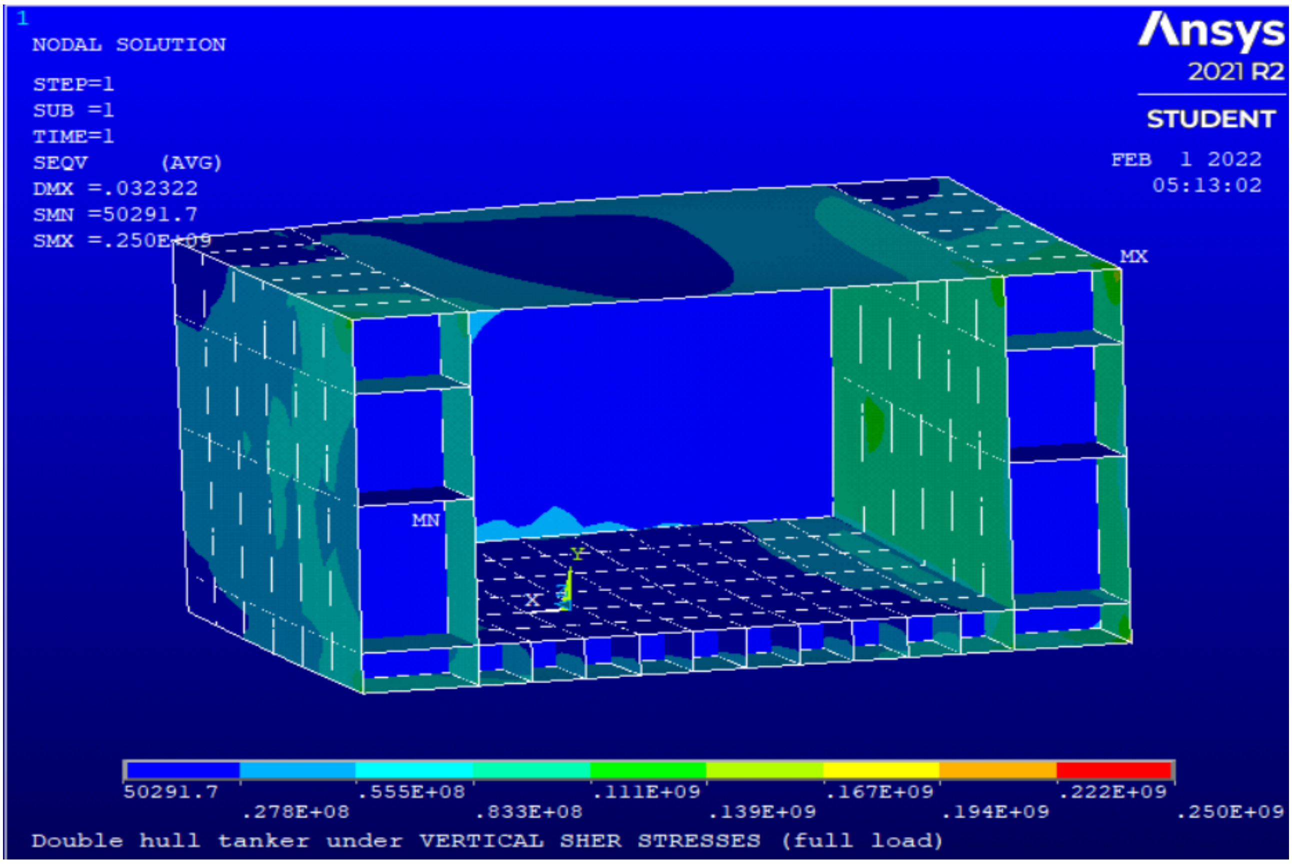
Displacement reresentation in direction Z



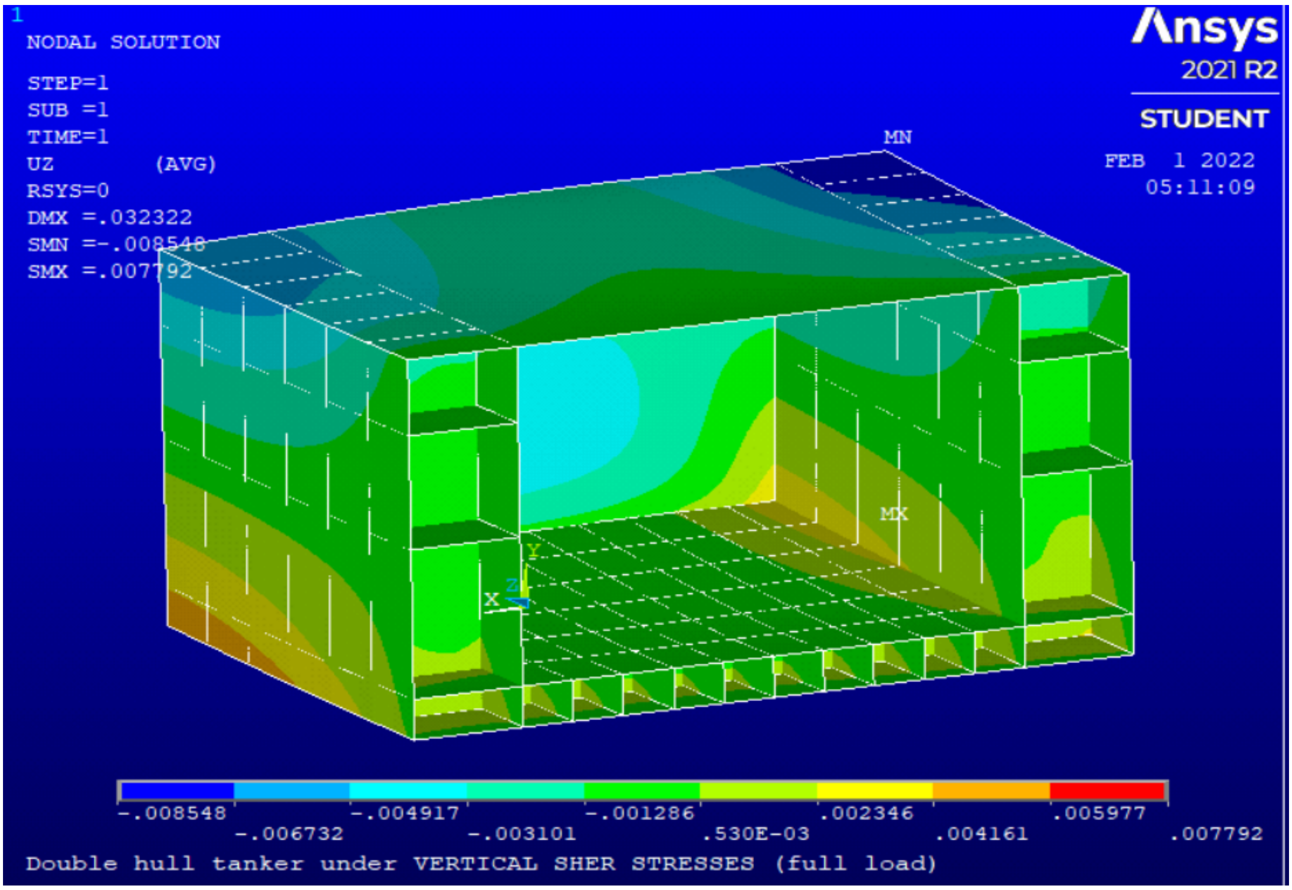
Total displacement representation



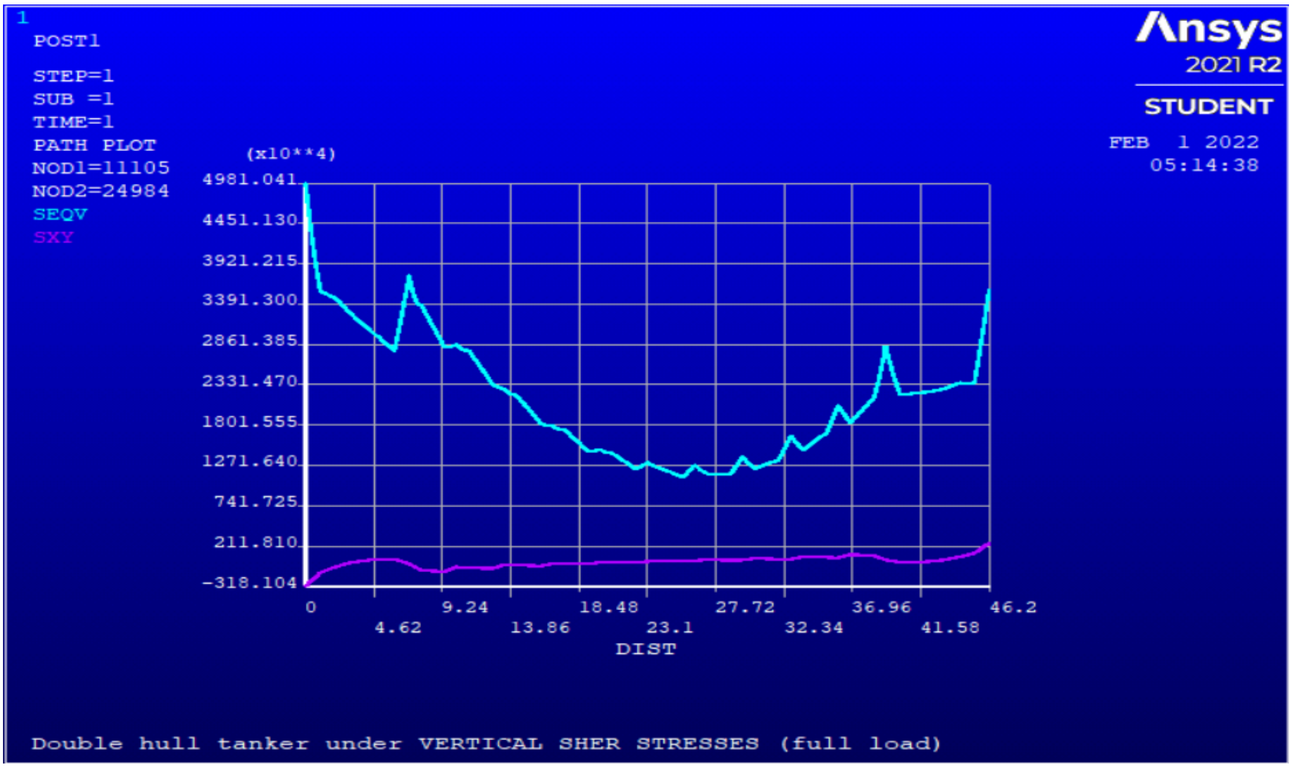
Von Mises stresses



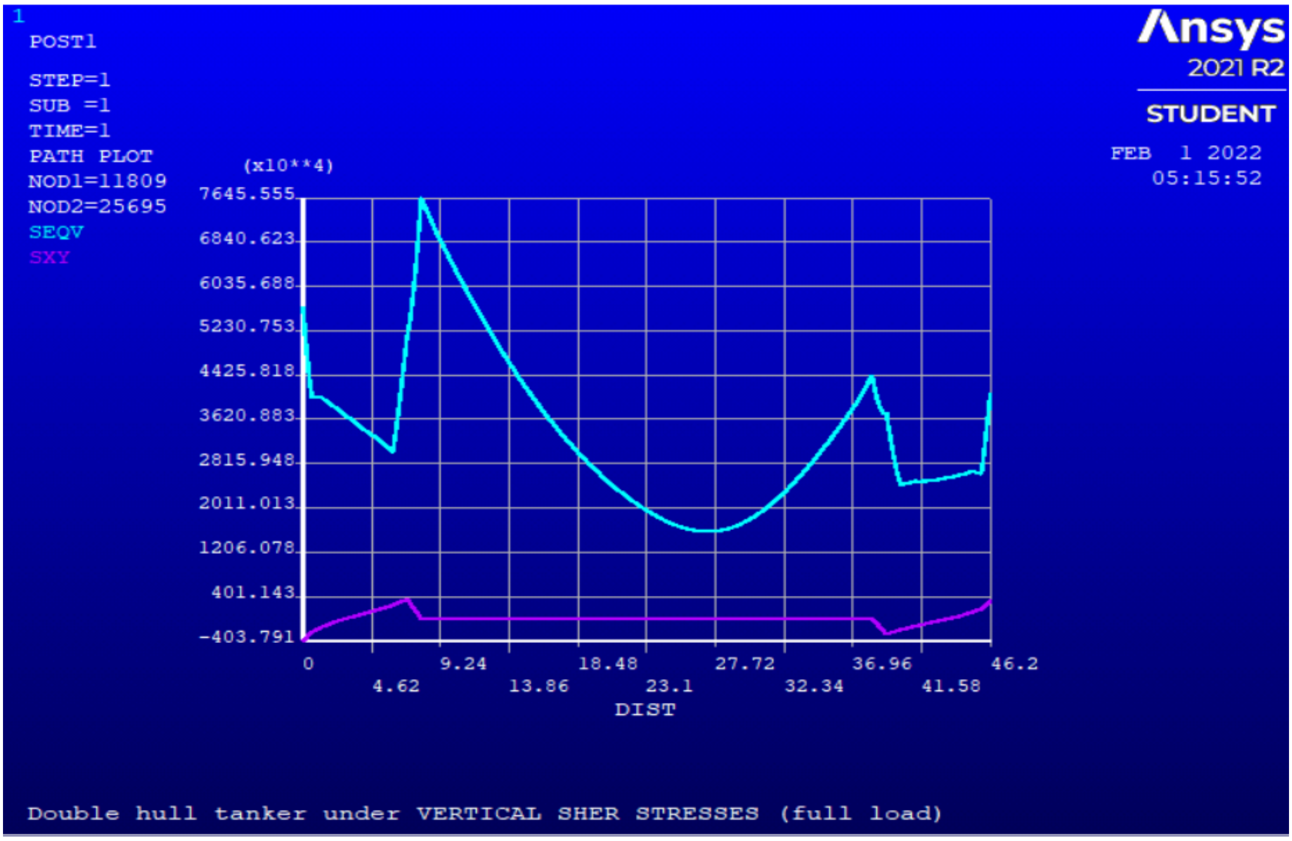
Path representation



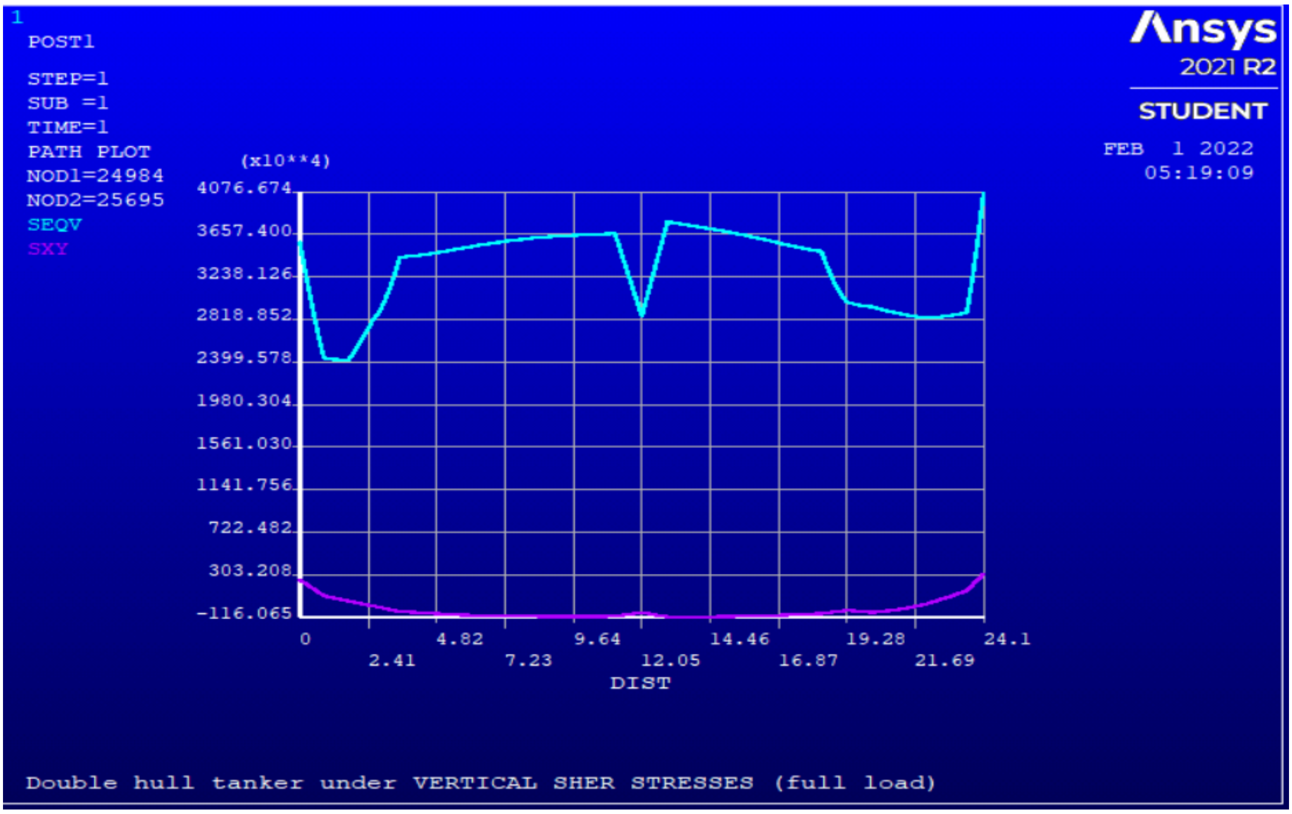
Botttom representation



Deck representation



Portside representation



10. Horizontal shear force

The value of horizontal shear force is induced of waves and it has been estimated with the next formula: $Q_h = 0.6(Q_s + Q_w)\sin(\frac{360x}{L})$ [kN]

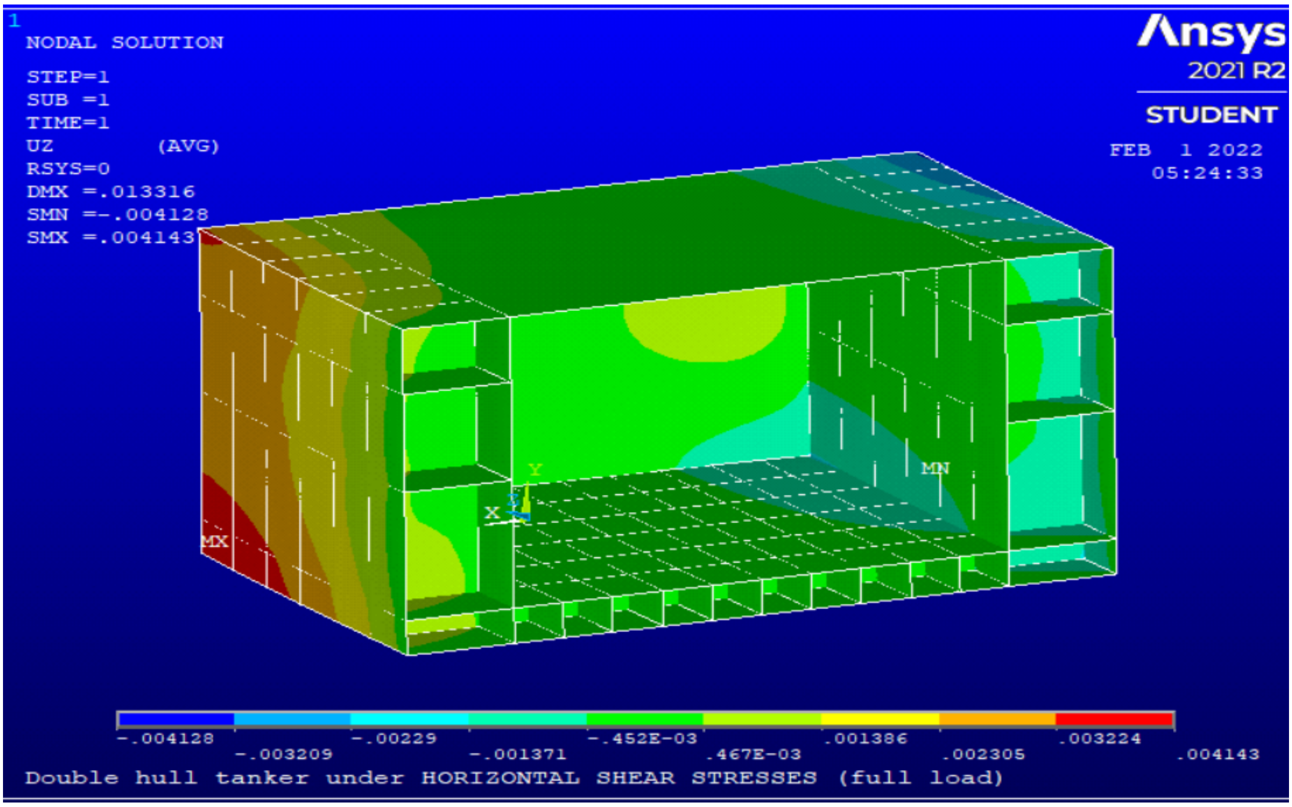
The results:

Atot	3,43215	[m^2]
xg	0	[m]
Itot	1320,329	[m^4]
Msh	4439871	[kN*m]
Qso	77565,87	[kN]
Ksq	1	
Qs	77565,87	[kN]
Kwq	1	
β	1	
Qw	62869,36	[kN]
Qtot	140435,2	[kN]
Qh	-67506	[kN]

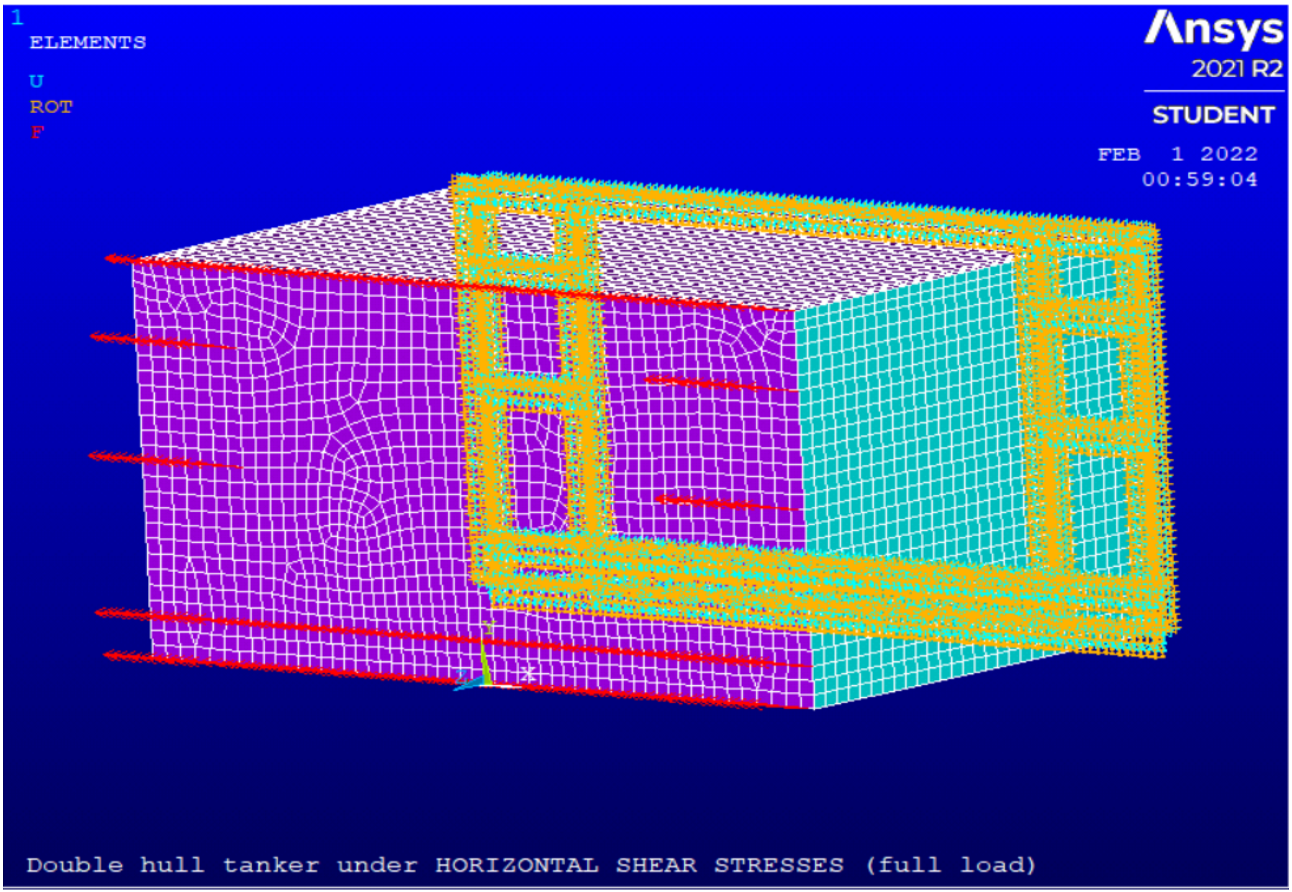
The shear force is divided between nodes of horizontal components of section in relation with A_i and in X direction.

Results:

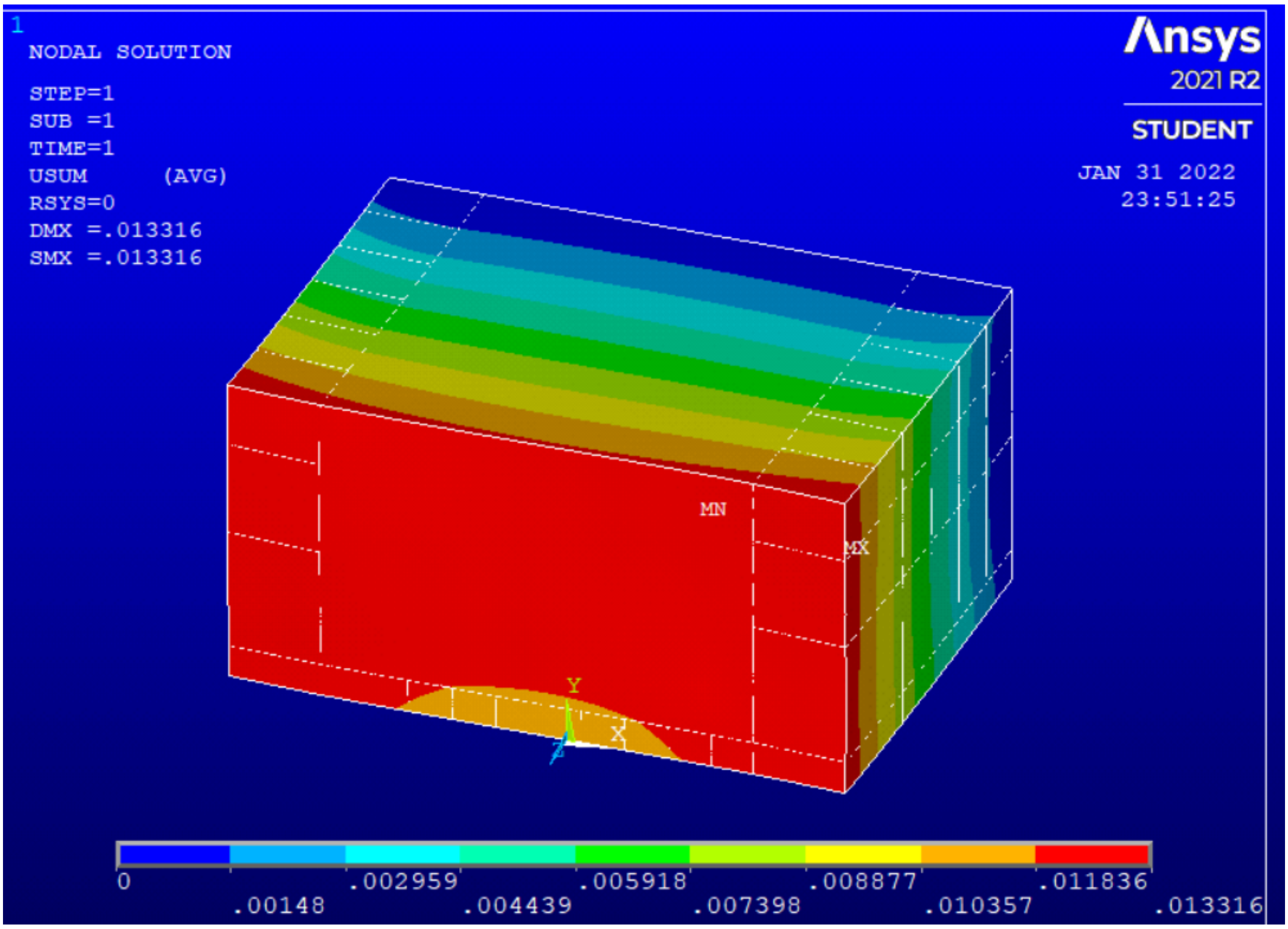
Path representation



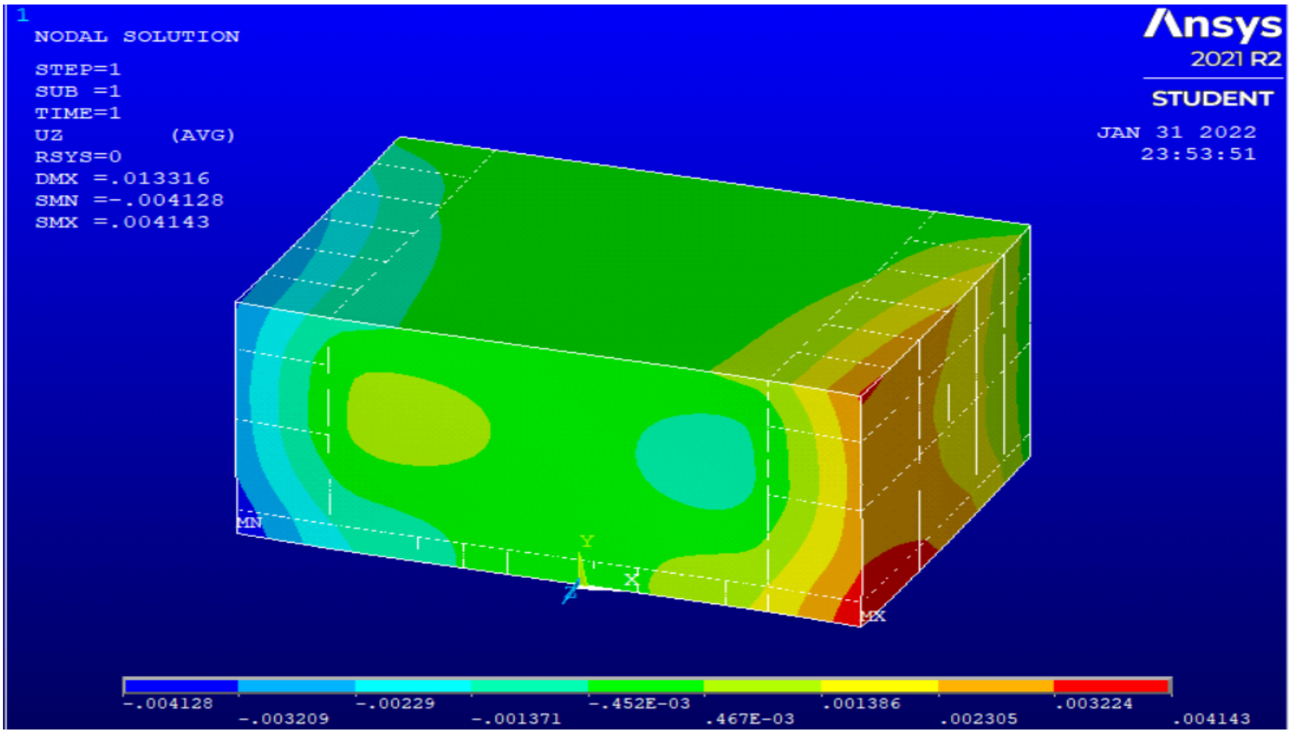
General mesh of representation



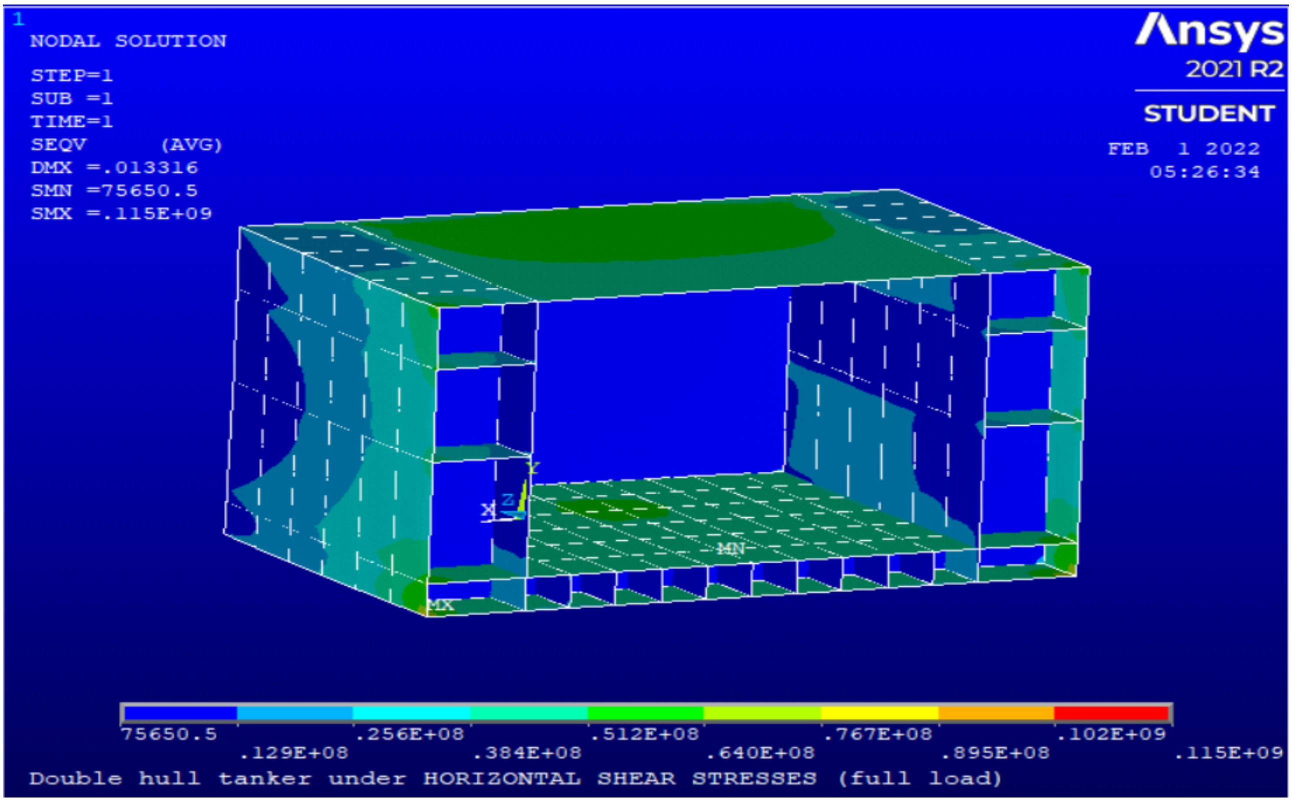
Total displacement representation



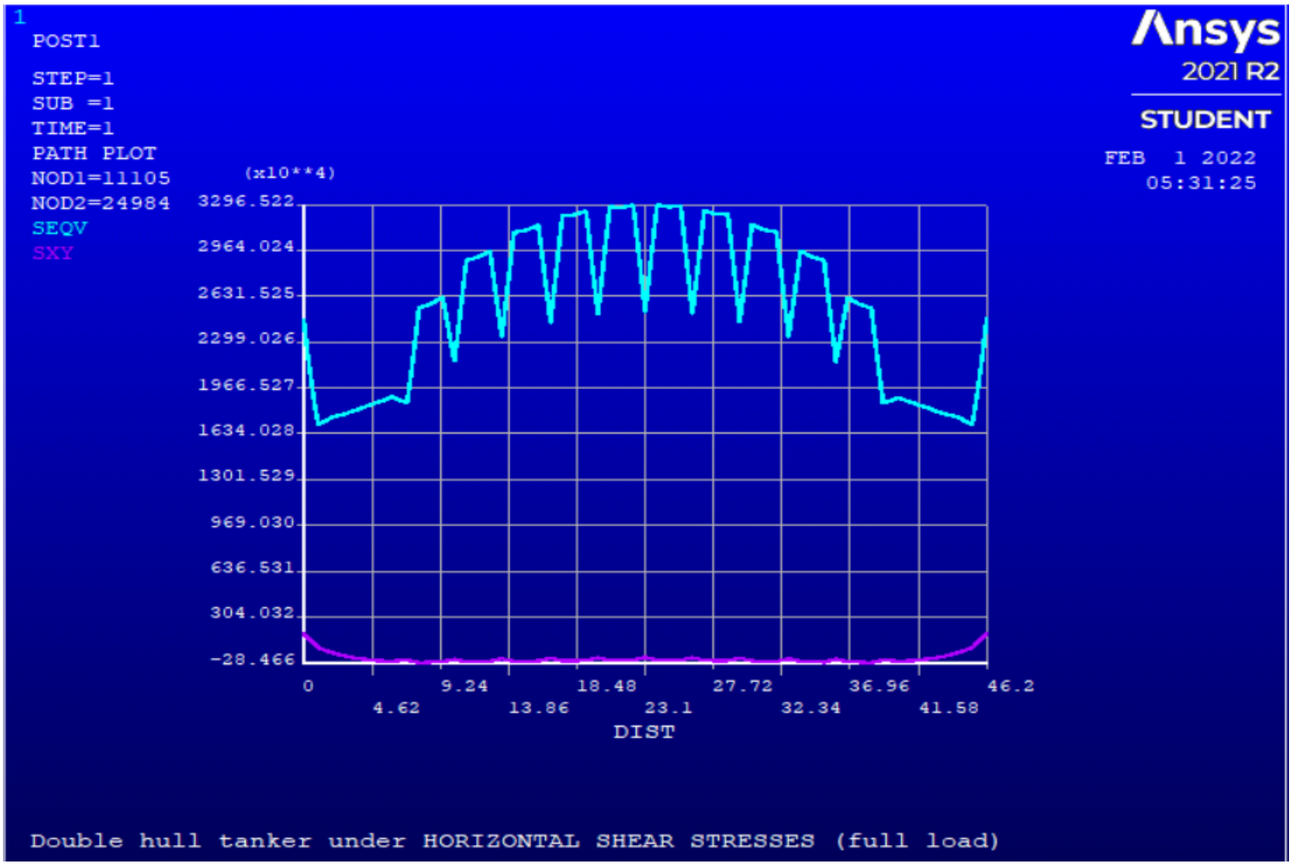
Displecement Z direction



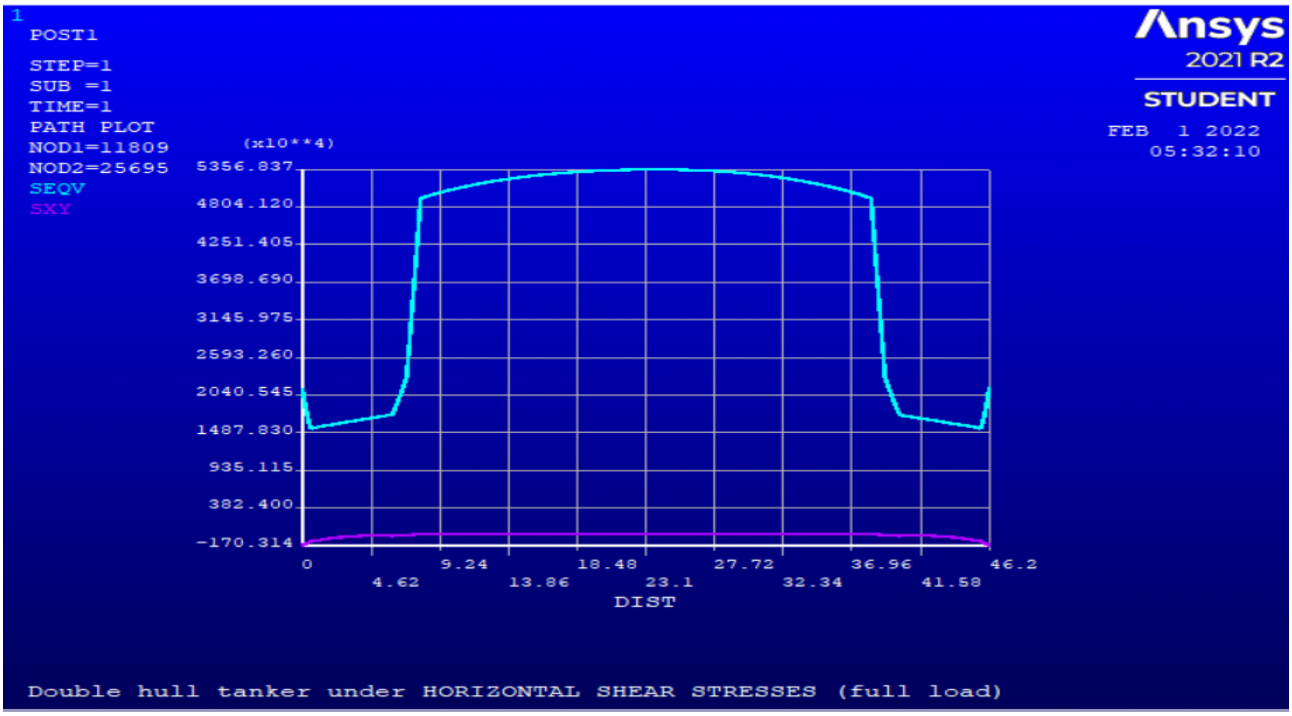
Von Mises stresses representation



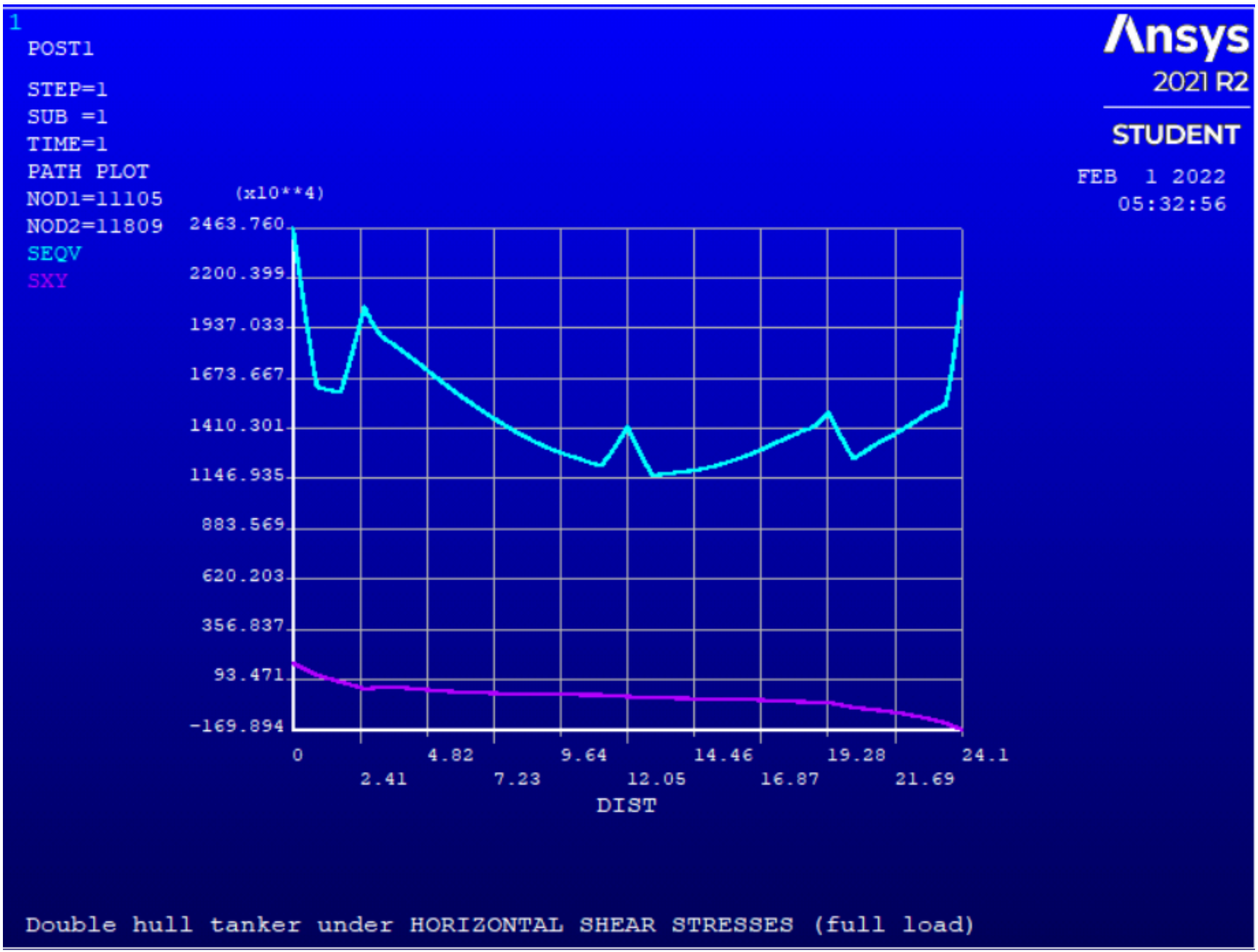
Bottom represntation



Deck representation



Portside representation



11. Torsion moment

The value of twisting moment has been estimated with the next formula:

$$M_{WT} = K_{T1} L^{5/4} (T + 0.3B) C_b Z_e - K_{T2} L^{4/3} B^2 C_{SWP} \;\; [\mathrm{kNm}]$$

$$K_{T1} = 1.4 \sin(\frac{360x}{L})$$

$$K_{T1} = 0.13(1 - \cos(\frac{360x}{L}))$$

For our case $C_{SWP} = 1$, $x = 0.5L$ and $Z_e = Y_G$

Results:

	Sagging	Hogging	
Ms	-4043958,624	4439870,657	[kN*m]
Mw	-6843622,286	11820802,13	[kN*m]
Mt	-10887580,91	16260672,79	[kN*m]
σ_{deck}	-175000,0023	261363,6398	[kN/m^2]
	-175,00	261,36	[Mpa]

xg	0	[m]
Jytot	2,67E+15	[mm^4]
yg	10	[m]
Jxtot	8,75E+14	[mm^4]
Wdeck [m^3]	62,21	[m^3]
Wbottom [m^3]	87,14	[m^3]
Ahorizontal	3,285	[m^2]
Avertical	1,540144596	[m^2]
ATOT	4,83	[m^2]

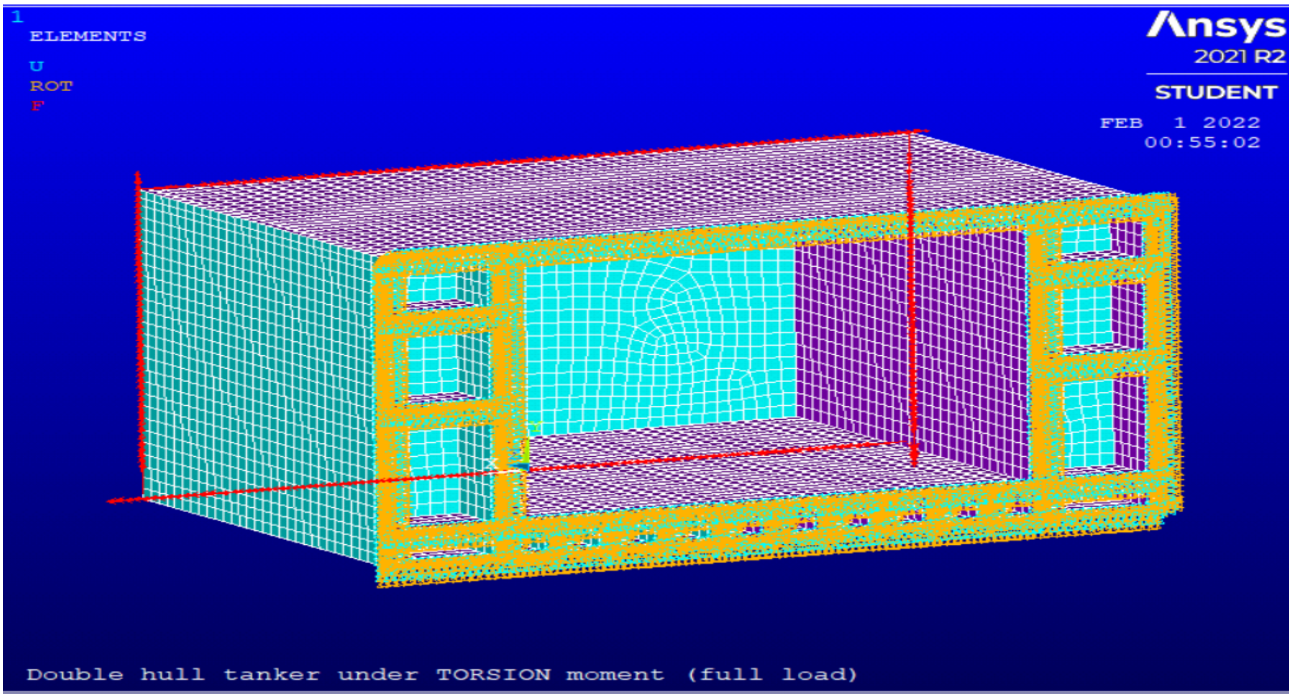
Kt1	-1,12161369	
Kt2	0,207799809	
Cswp	1	
Mwt	-874993,2465	kNm
F2	-18153,38686	kN
F1	-9490,165363	kN

The torsion moment has been applicate like 4 forces distributed on the boundary and these forces must balance the torsion moment, so, the next formulas have been used for that:

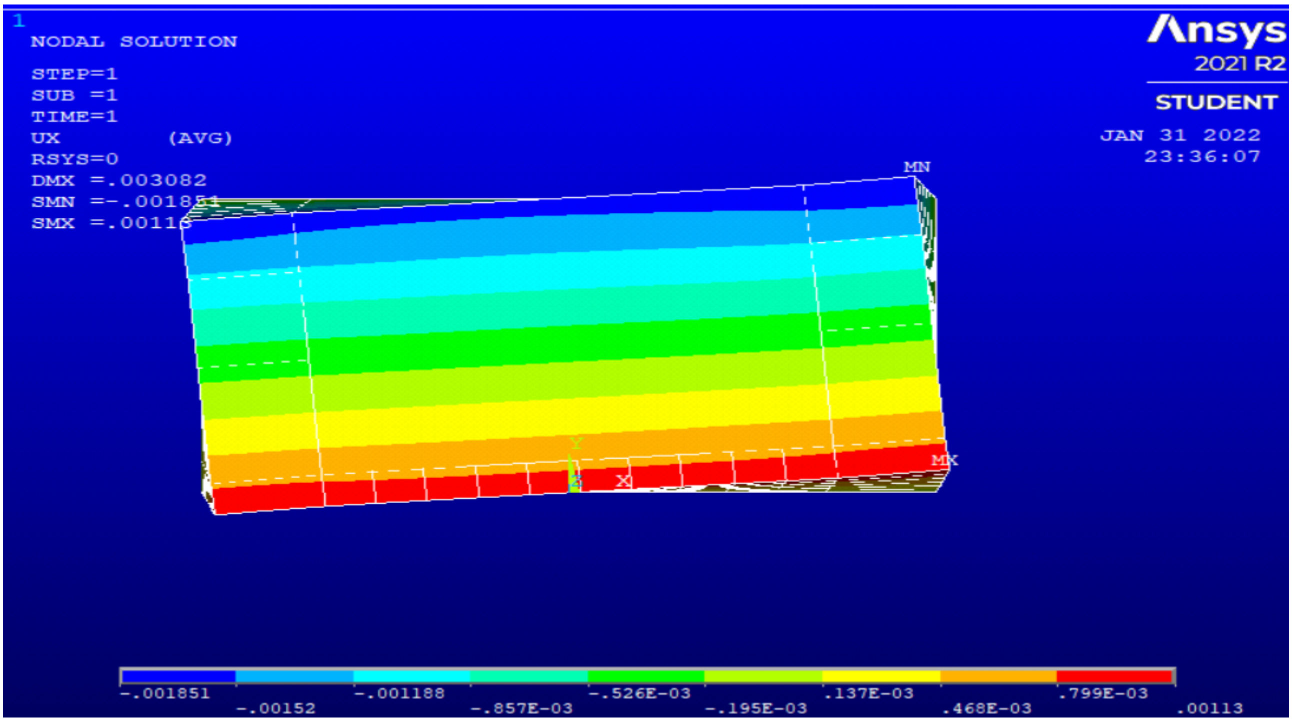
$$F_1 d_1 = F_2 d_2 \qquad\qquad F_1 d_1 + F_2 d_2 = M_T$$

Results:

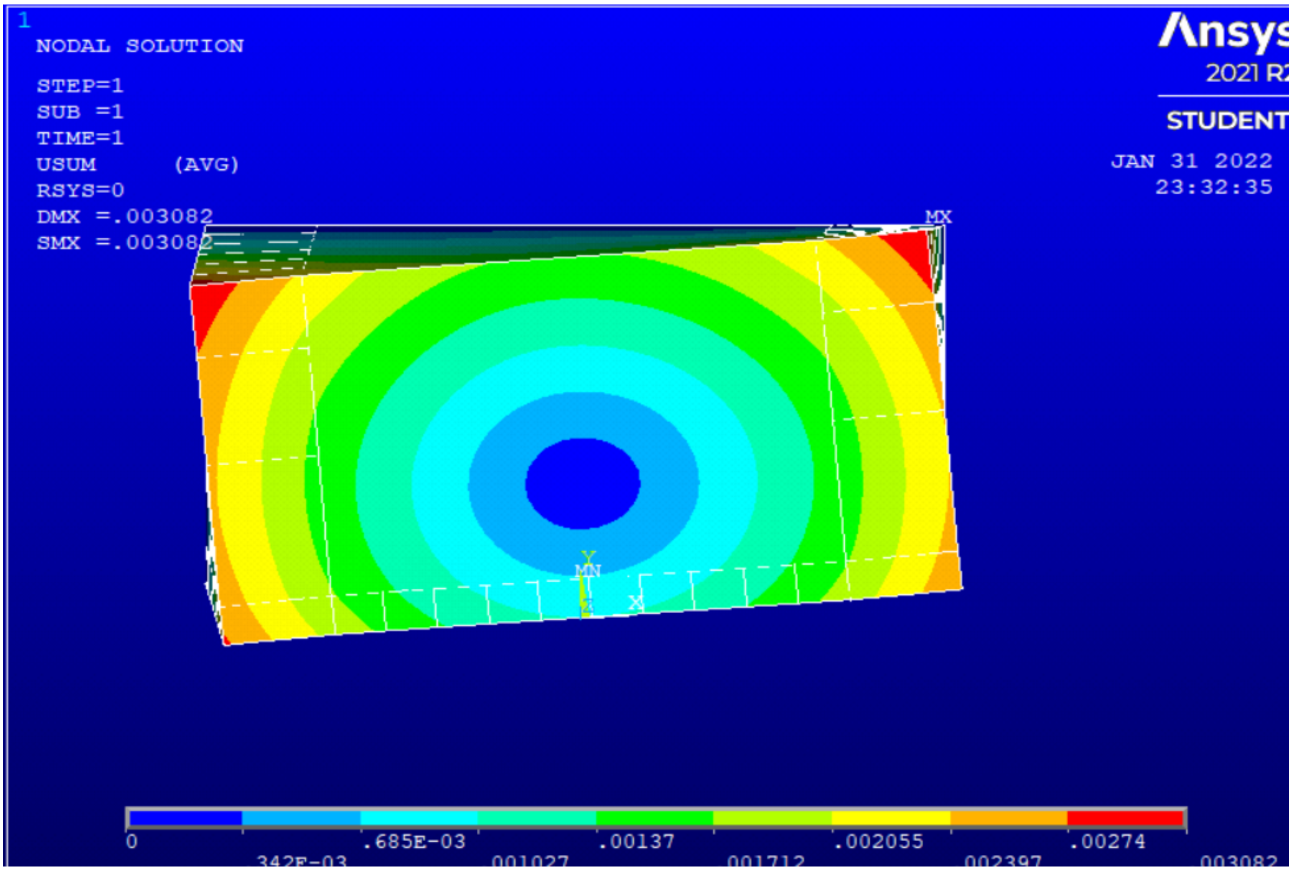
General mesh of torsion moment representation



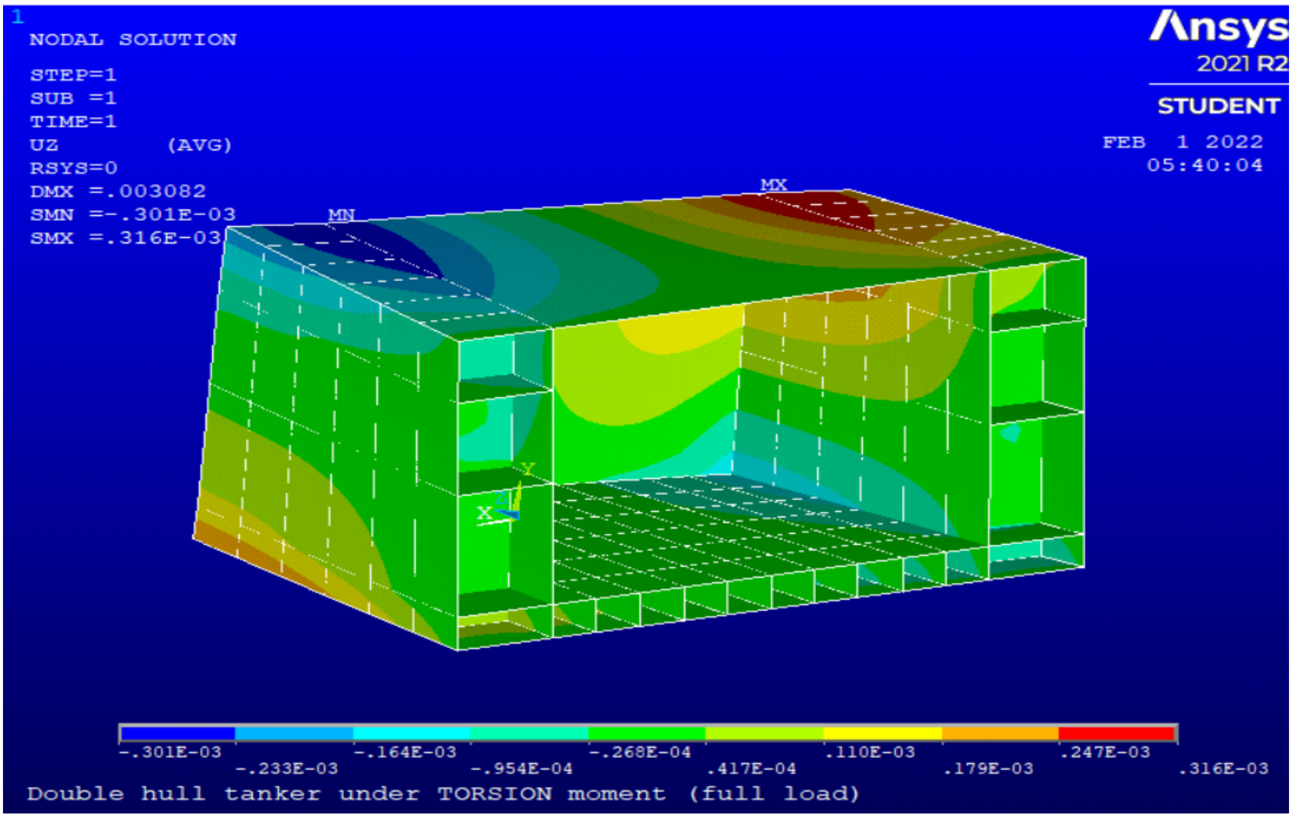
Displacement representation in direction X



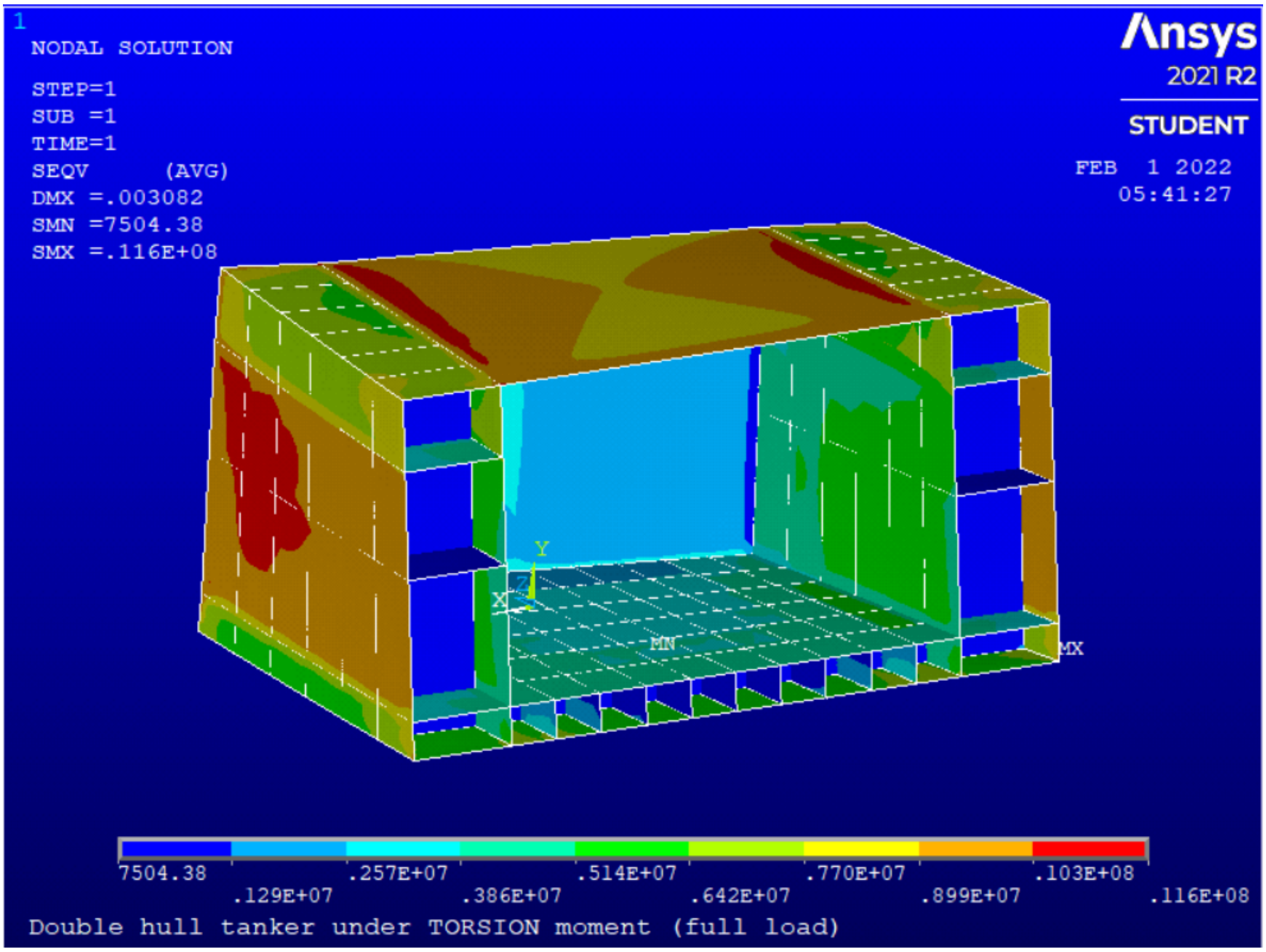
Total displacement representation



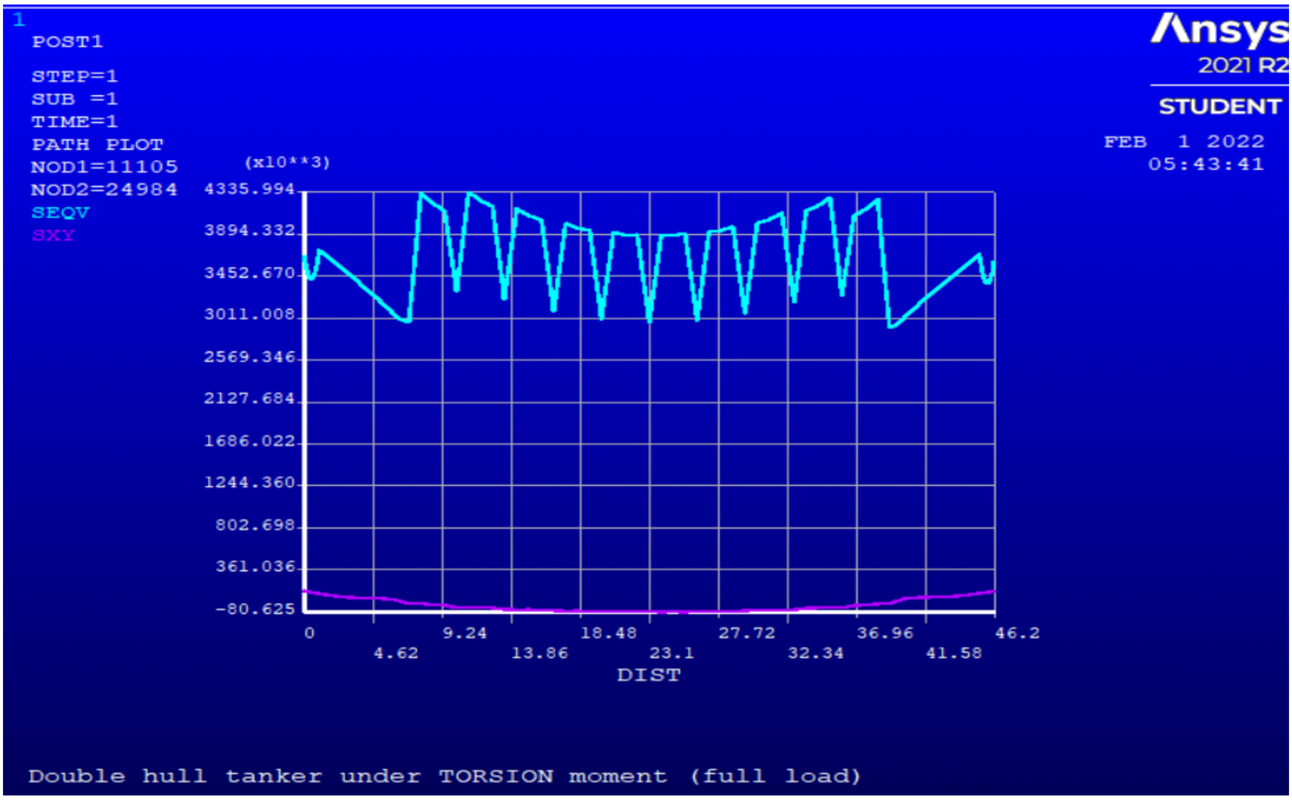
Torsion path representation



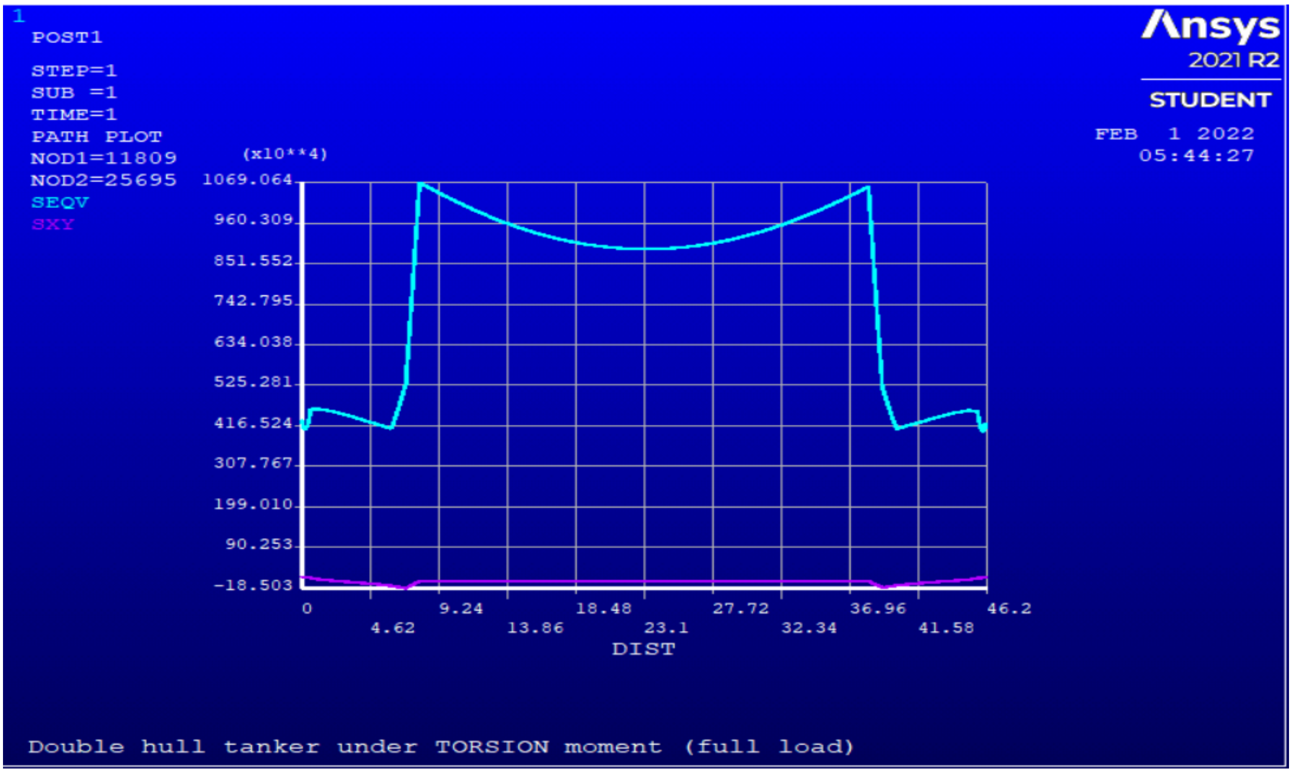
Von Mises stresses representation



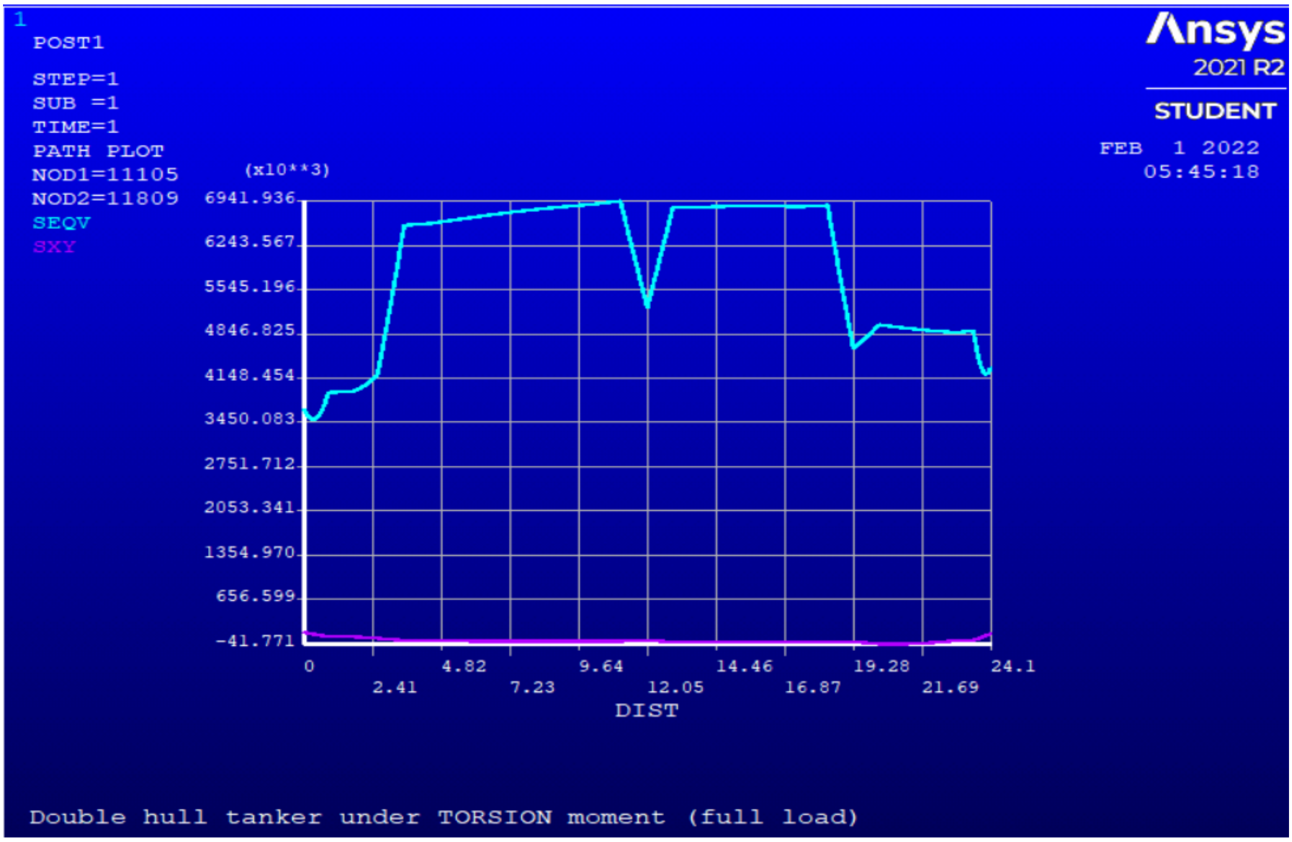
Bottom representation



Deck representation



Portside representation



12. Conclusion

The graphics tell us that the maximum value of stress is on the corner of shear strake when it is subjected of vertical bending moment in hoggin, so the Von Mises stress $\sigma_{VM} = 289\ MPa$ versus the permissible stress that is different for the different steel:

Resistence steel	normal	H32	H36
$\sigma_{yelding}$ [Mpa]	235	315	355
$\sigma_{ammisible}$ [Mpa]	175	236	266

It is feasible to conclude that the findings of this FEM study are unsatisfactory. Indeed, the stresses induced under the most critical loading condition of vertical bending moment exceed the elastic deformation range and approach the fracture point.

Although in this case, not all of the reinforcements that a ship of this type requires in the deck zone were taken into account, the conclusion is: the model needs to be reinforced in the higher part of the structure, as a real Tanker is, which was simplified by increasing the values of the thicknesses for all of the components in this area.

A more accurate defining of the model would fix the not acceptable results obtained.

By examining the displacement vector sum plot, it is feasible to confirm that the displacement values on deck are greater than those on the remainder of the segment. This is corroborated subsequently in the route described in the center of the block, where the longitudinal stresses incurred , with greater values near the deck and lower values on the bottom. This is because the section's horizontal neutral axis is much below the half-draught mark.