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Ships in Composite Materials

2nd Semester Project Work

Assignment 2

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Introduction

The objective of this project is to design the structures of a yatch made of composite material, taking into account the minimum load requirements defined load requirements defined by the classification society Bureau Veritas (BV). The results were obtained using the BV software ComposeIT.

The components, which include stiffeners and plates, are identified by their placement, which might be on the bottom, the side, or even on deck.

1. Vessel's Main Characteristics

The very first step in this testing process will be to review the vessel's characteristics and perform some initial calculations. For our vessel we obtain from the project specifications:

Length	26 m
Length water line	24 m
Breath water line	6 m
Draft	2 m
Depth	3 m
Navigation Area	1
Cb	0.5
Service Speed	20 knots

Figure 1 - Ship main characteristics

In addition, at frame 8, it is described as a transverse frame with a 0.9 m span between them and the main section.

Furthermore, Vetrotex 1250 and 860 are woven rovings with 1250 g/m2 and 860 g/m2 weights and 50 percent balanced directions. Taking into account ordinary polyester resin and E-glass fiber.

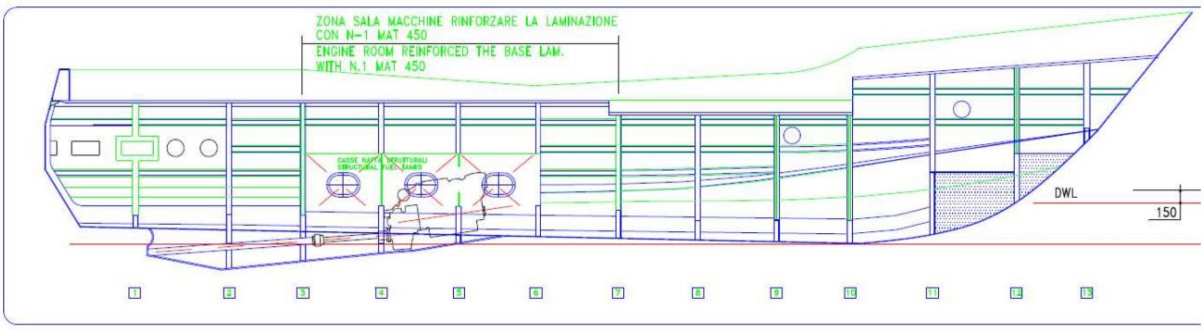


Figure 2 - Ship technical drawings

2. Design Loads

External wave loads and external dynamic loads must be verified on the bottom and side shell structures.

To compute the local loads on the bottom and side shells, the NR500 Pt B, Ch4, Sec 3 of the Bureau Veritas standards for yachts were used. The exterior stresses were only examined; the interior loads induced by floods are outside the scope of this research.

Wave loads are the loads caused by the pressure of the wave and the motion of the vessel. Dynamic loads are created by slamming forces and side impacts and have a duration shorter than the wave period.

Two notions will be employed in the computations: bottom area and side shell area. The bottom area of the hull is the region under the waterline. The space above the waterline is known as the side shell area.

Below we can observe the representation of the midship section for frame number 8, regarding the corresponding geometry and information of the section, which will be useful for the calculation of wave loads and dynamic loads.

The analytical implementation will be carried out using the Excel spreadsheet and its functionality will be discussed in accordance with BV rules and in the context of the assumptions made.

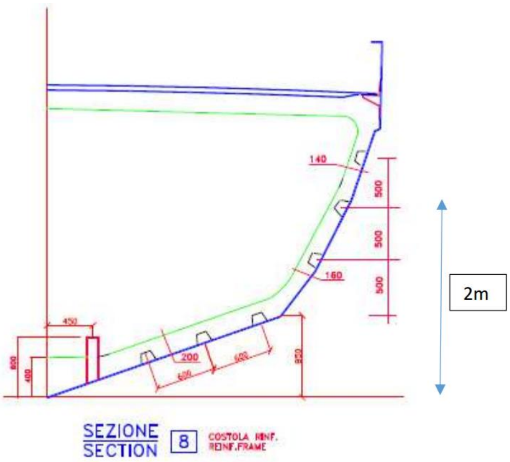


Figure 3 - Section 8 of the ship

The problem indicates that the objects under consideration are the hull bottom and bottom stiffeners; thus, the relevant local loads computed are the wave loads and the dynamic load, bottom slamming. Keep in mind that the bottom area is the part of the hull below the waterline [S3 - 1.2.3]. In the following figure, the bottom area is coloured and the dimensions are shown:

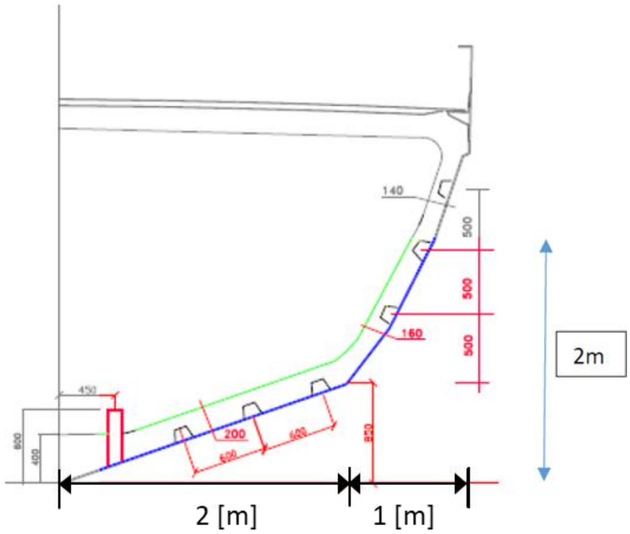


Figure 4 - Main section dimensions

It should be noted that some assumptions were made, specifically for the hull bottom laminate section 4 and stiffener 4 depicted in figure 3. The fold in section 4 is assumed to be in the same position as stiffener 4.

With the previously mentioned considerations, the relevant local loads can be estimated using the BV rules.

2.1. Wave Loads

The wave loads, Ps, are the hull loads caused by wave pressure and ship movements and are computed using the wave parameter Cw.

These wave loads must be computed for the scantling of the bottom and side shells of all types of boats.

The wave loads in kN/m2 in the various sections of the hull defined in figure are to be determined using the following formula:

$$P_s = 9.807.n.\left[T + \left(\frac{C_W}{X_i} + h_2\right) - z\right]\ [kN/m^2]$$

Where n is the coefficient given in Ch4, Sec 1, [4], depending on the navigation notation. T is the total draught in metres. The wave load coefficient is denoted by Xi. Cw is the wave height to be computed, h2 is the distance in metres to be estimated based on the region under consideration, and z is the height of the calculation point.

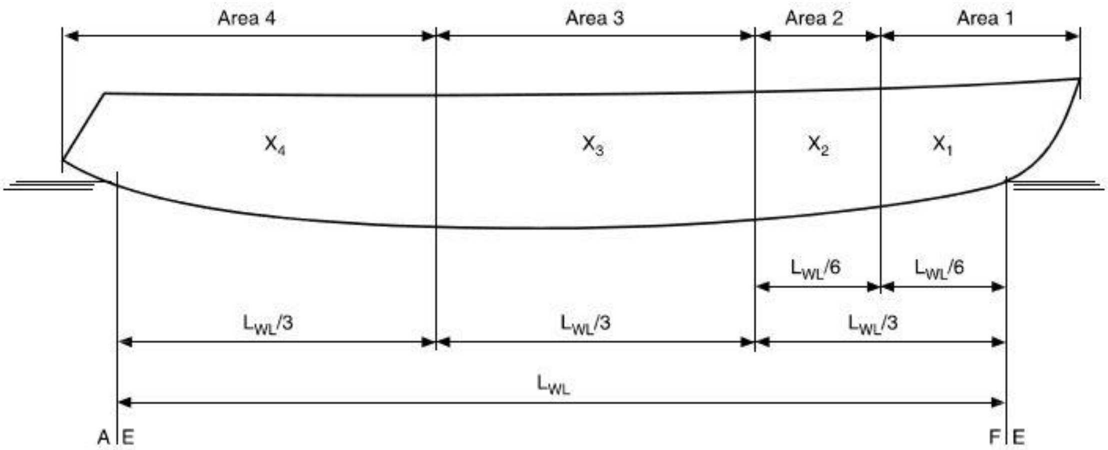
The total draught is 2 metres. According to the guidelines, the h2 distance between the bottom and the exterior side shell must be zero.

The following figure was used in the selection of the region. Area 3 was chosen because the main section is 2/3 Lwl from the aft perpendicular.

For a Lwl of 24 metres, the wave height was computed using the following formula:

$$C_W = 10\,log(L_{WL}) - 10 = 3.98$$

The choice was made on the basis of the conditions set by the register by means of the following representation:



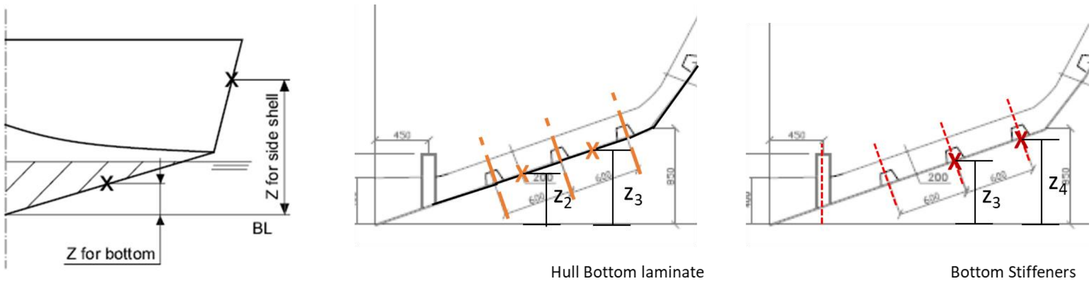


Figure 5 – Structural elements and dimensions drawings

The wave load coefficient is 2.2, and the navigation coefficient n is assumed to be 1, as calculated from the tables below for a monohull motor yacht:

Type of yachts	Area 4 X_4	Area 3 X_3	Area 2 X_2	Area 1 X_1
Monohull motor yacht	2,8	2,2	1,9	1,7
Monohull sailing yacht	2,2	1,9	1,7	1,4
Multihull motor yacht	2,8	2,2	1,9	1,4
Multihull sailing yacht	2,5	2,2	1,7	1,2

Navigation notation	Navigation coefficient n
• Unrestricted navigation or navigation limited to 60 nautical miles • Design category A and B (EC Directive)	1,00
• Coastal area • Design category C (EC Directive)	0,80
• Sheltered area • Design category D (EC Directive)	0,65
Note 1: The categories A, B, C and D are defined by the EC Directive 9425 as amended 2003/44.	

Figure 6 - Monohul motor yacht coefficients table

Following the BV register's requirements, the wave load values must adhere to a minimum value, Pdmin.

Where the navigation coefficient is the same as in the preceding example. Because the coefficient φ1 is a reduction coefficient that is only relevant to deck plates, it is treated as 1. Because there is no partial protection in any of the plates, the reduction coefficient φ3 is also equal to 1. Because of the LWL is ≤ 50 m, the coefficient φ2 is equal to 0.42.

This value is found for area 3 using the following formula:

$$P1_{23_{dmin}} = 19.6 \text{ n } \varphi 1 \ \varphi 2 \ \varphi 3 \ \geq \ 7 \ kN/m^2$$

φ1	[-]	1,00
φ2	[-]	0,42
φ3	[-]	1,00
Pdmin	[kN/m²]	8,23

Table 1 - Minimum Sea Pressure

As a result, the wave loads values for the hull laminates, with the bottom angle θ= 0.40 [rad], are given in the table below as a function of the height z:

		z [m]	Ps [kN/m²]
Hull Laminate	1	0,29	38,74
	2	0,50	36,66
	3	0,73	34,36
	4	1,10	30,76
	5	1,60	25,86

Table 2 - Wave Loads Hull laminate

And for the stiffeners the following results:

		z [m]	Ps [kN/m²]
Stiffeners	1	0,19	39,67
	2	0,38	37,81
	3	0,62	35,51
	4	0,85	33,21
	5	1,35	28,31
	6	1,85	23,40

Table 3 - Wave Loads Stiffeners

2.2. Dynamic Loads

The dynamic loads, P_{sl} and P_{smin}, are loads with a considerably shorter duration than the period of wave loads and are made up of:

• bottom slamming pressures (P_{sl}): should be computed for the scantling of the bottom of fast motor boats and monohull sailing yachts.

• side shell impacts and under cross deck impacts for catamaran (P_{smin}): should be computed for the scantling of all types of yacht's side shells and the scantling of the catamaran's cross deck.

The bottom slamming pressure is calculated with the formula:

$$p_{sl} = 70.\frac{\Delta}{S_r}.K_1.K_2.K_3.a_{CG}$$

And the displacement is calculated by the following equation:

$$\rho = \frac{\Delta}{\nabla} \Leftrightarrow \Delta = \rho.\nabla \Leftrightarrow \Delta = \rho.C_B.L_{WL}.B_{WL}.Draft = 147.6\ [ton]$$

The reference area is calculated using the following expression, where T is the full load draught:

$$S_r = 0.7.\frac{\Delta}{T} = 50{,}40[m^2]$$

Ultimately, the total vertical acceleration will be the specified design vertical acceleration:

$$a_{CG} = foc.Soc.\frac{V}{\sqrt{L_{WL}}}$$

Where foc and Soc are 0.666 and 0.3, respectively. The vessel was considered a cruise sailing yacht for the foc value, and the sea conditions considered for the soc value were the worst-case scenario, open sea. The values for foc and soc are obtained from the tables listed below.

Type of design **(1)**	Cruise motor yacht	Sport motor yacht	Offshore racing motor yacht **(2)**	Motor yacht with specific equipment
foc	0,666	1,000	1,333	1,666

(1) The type of design is to be defined by the yacht designer, based on the following type classification:
- Cruise Motor yacht:
  At maximum speed in service, the hull is mainly intended to be sustained by a combination of buoyancy and planning effect
- Sport Motor yacht:
  At maximum speed in service, the hull may be submitted during short moments to only planning effect
- Offshore racing Motor yacht:
  At maximum speed in service, the hull is consistently submitted to planning effect
- Motor yacht with specific equipment:
  The yacht is submitted to the same effect as Offshore racing Motor yacht and is fitted with safety arrangement (for example safety belts).

(2) This value is given for information only, racing yachts not being covered by the present Rules (see Pt A, Ch 1, Sec 1, [1.1.5]).

Sea conditions **(1)**	Open sea **(2)**	Restricted open sea **(3)**	Moderate environment **(4)**	Smooth sea **(5)**
Soc	C_F **(6)**	0,3	0,23	0,14

(1) The sea conditions are defined with reference to significant wave heights H_s which are exceeded for an average of not more than 10 percent of the year:
- Open-sea service: $H_s \geq 4{,}0$ m
- Restricted open-sea service: $2{,}5 \text{ m} \leq H_s < 4{,}0$ m
- Moderate environment service: $0{,}5 \text{ m} < H_s < 2{,}5$ m
- Smooth sea service: $H_s \leq 0{,}5$ m.

(2) Category A in case of EC Directive, **unrestricted navigation** or **navigation limited to 60 nautical miles** for Classification.

(3) Category B in case of EC Directive.

(4) Category C in case of EC Directive, **coastal area** for Classification.

(5) Category D in case of EC Directive, **sheltered area** for Classification.

(6) $C_F = 0,2 + \frac{0,6}{V/\sqrt{L_W}} \geq 0,32$

Figure 7 - foc and soc tables from CS rules

The dynamic load coefficients are as follows: $K_1 = 1$ because the section is between 0.5 and 0.8 of the ship's length.

K_2 is equal to 0.54. Because we lack all of the information needed to calculate this value, we will assume a value that is slightly higher than the minimum required.

And K_3 is given by $K_3 = \frac{50-\alpha_d}{50-\alpha_{dCG}}$

Where according to the figure below, the values of α_d and α_{dCG} will be equal because the section we are studying is where the longitudinal center of gravity is located.

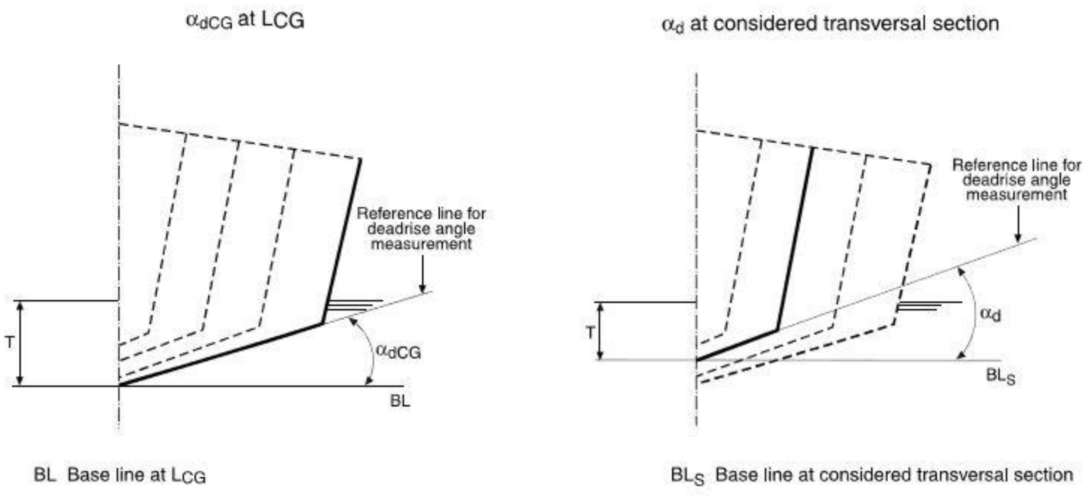


Figure 8 - Reference line for deadrise angle measurements

So, the dynamic load value for the bottom slamming is given in the table below:

K1	[-]	1,00
K2	[-]	0,54
K2 min	[-]	0,35
K3	[-]	1,00
Sr	[m^2]	50,40
α cg	[g]	0,62
Sa	[m^2]	0,54
u	[-]	1,07
Psl	[kN/m^2]	66,59

Figure 9 - Dynamic load values for bottom slamming table

3. BV Rules Verification

This chapter proposes that the given laminate be verified using the BV rules NR546. The rules are verified in this section with the help of the Bureau Veritas software COMPOSEIT. This software enables the yachting industry to perform detailed strength analyses on composite panels and stiffeners.

The software analyses the strength of the composite panels and stiffeners. The software's methodology is presented below. It begins with the definition of the individual layers, laminates, plates, and stiffeners. The load applied to those elements is then specified. The final step is to determine whether the rules' criteria have been met.

For this problem, the following assumptions were considered:

- Main frame #8.
- Transverse reinforced frames with 0.9 [m] span.
- Vetrotex 1250 and 860 as woven roving with 1250 [g/m^2] and 860 [g/m^2] respectively and 50% balanced directions.
- Standard polyester resin and E-glass fibre.

3.1. Composite IT Iteration

We began by defining the individual layers to be used using the information available on the assignment. We knew that two woven roving fabrics from VETROETEX were used. We were aware of their weight per square metre and balanced directions. The type of fibre and resin used, namely E glass and standard polyester, were also specified. Only one parameter was missing: the percentage of fibre. As a result, we had no choice but to assume it. We did it by selecting a percentage of fibre that resulted in a final thickness equal to the values listed in the table below. And we have slightly modified the mass fractions on m^2 in order to allow the required thickness in the laminate table to be correctly achieved.

SCHEDA DI LAMINAZIONE CARENA – HULL LAMINATION SCHEDULE												
ZONA		TIPO DI RINFORZO	RAPPORTO DI IMPREGNAZ. R/V	PERCENT. RINFORZO SU LAMINATO %	SPESSORE UNITARIO LAMINATO mm	SPESSORE TOTALE LAMINATO mm		PESO TOTALE RINFORZO gr/mt2		PESO UNITARIO LAMINATO gr/mt2	PESO TOTALE LAMINATO gr/mt2	
						FIANCO	FONDO	FIANCO	FONDO			
		GEAL COAT										
	1	MAT 300	2.5:1	28	0.74	0.74	0.74	300	300	1050	1050	1050
	2	MAT 450	2.0:1	33	0.92	1.66	1.66	750	750	1350	2400	2400
	3	MAT 450	2.0:1	33	0.92	2.58	2.58	1200	1200	1350	3750	3750
	4	MAT 450	2.0:1	33	0.92	3.50	3.50	1650	1650	2620	5100	5100
	5	VETROTEX 1250	1.1:1	47	1.64	5.14	5.14	2900	2900	2620	7720	7720
	6	VETROTEX 1250	1.1:1	47	1.64	6.78	6.78	4150	4150	2620	10340	10340
	7	VETROTEX 1250	1.1:1	47	1.64	8.42	8.42	5400	5400	2620	10600	10600
	8	VETROTEX 1250	1.1:1	47	1.64	10.06	10.06	6650	6650	2620	13220	13220
	9	VETROTEX 1250	1.1:1	47	1.64	11.70	11.70	7900	7900	2620	15840	15840
	10	VETROTEX 1250	1.1:1	47	1.64		13.34		9150	2620		18460
	11	VETROTEX 1250	1.1:1	47	1.64		14.98		10400	2620		21080
	12	VETROTEX 1250	1.1:1	47	1.64		16.62		11650			23700
ZONE		REINFORCEMENT TYPE	RESIN REINFORC. RATIO	REINFORC. CONTAINT. %	NOMINAL THICKNESS mm	SIDE	BOTTOM	SIDE	BOTTOM	NOMINAL LAMINATION WEIGHT gr/mt2		
						TOTAL LAMINATION THICKNESS mm		TOTAL REINFORCEMENT WEIGHT gr/mt2			TOTAL LAMINATION WEIGHT gr/mt2	

Figure 10 - Hull lamination schedule table

The software requires a number of inputs. First, the necessary layer characteristics were added to the software's individual layers section. ud (unidirectional), vetrotex 1250 and vetrotex 860 (woven roving), mat 450 and mat 300 were the layers defined (Mat). The necessary inputs for the individual layers, are shown in the figure below.

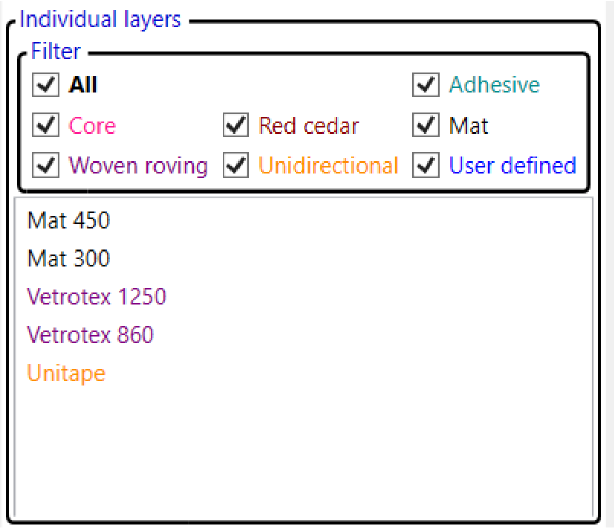


Figure 11 - Individual layer

The inputs for laminates are the lamination schedule provided in the assignment. Due to the fibre percentages of the layers under consideration, the fabrication process for the bottom laminate was defined as Hand Lay-Up. The Fabrication process for the web and flange laminates, on the other hand, was defined as Infusion, despite the fact that the percentages of fibre in the layers under consideration suggested Hand Lay-Up. This was done to ensure that the class requirements were met. Furthermore, the relationship between fabrication process and fibre percentage is not a hard and fast rule and varies from shipyard to shipyard.

The following figure depicts the hull lamination schedule used in the bottom plates:

Layer	**Type**	**Label**	**Angle**	**Thickness[mm]**
1	Mat	Mat 300		0.74
2	Mat	Mat 450		0.92
3	Mat	Mat 450		0.92
4	Mat	Mat 450		0.92
5	Woven Roving	Vetrotex 1250	0.00	1.64
6	Woven Roving	Vetrotex 1250	90.00	1.64

Layer	Type	Label	Angle	Thickness[mm]
7	Woven Roving	Vetrotex 1250	0.00	1.64
8	Woven Roving	Vetrotex 1250	0.00	1.64
9	Woven Roving	Vetrotex 1250	0.00	1.64
10	Woven Roving	Vetrotex 1250	0.00	1.64
11	Woven Roving	Vetrotex 1250	0.00	1.64
12	Woven Roving	Vetrotex 1250	0.00	1.64

Figure 12 - Hull lamination schedule for bottom plates

For the web, the lamination is the following:

Layer	Type	Label	Angle	Thickness[mm]
1	Mat	Mat 450		0.92
2	Woven Roving	Vetrotex 860	0.00	1.20
3	Woven Roving	Vetrotex 860	90.00	1.20
4	Woven Roving	Vetrotex 860	90.00	1.20

Figure 13 - Web lamination schedule

And for the the longitudinal flange:

Layer	Type	Label	Angle	Thickness[mm]
1	Mat	Mat 450		0.92
2	Woven Roving	Vetrotex 860	0.00	1.20
3	Woven Roving	Vetrotex 860	90.00	1.20
4	Unidirectional	Unitape	0.00	0.90
5	Unidirectional	Unitape	0.00	0.90
6	Unidirectional	Unitape	0.00	0.90

Layer	Type	Label	Angle	Thickness[mm]
7	Unidirectional	Unitape	0.00	0.90
8	Woven Roving	Vetrotex 860	90.00	1.20
9	Woven Roving	Vetrotex 860	0.00	1.20

Figure 14 - Longitudinal flange lamination schedule

It should be noted that the laminate Schedule for Stiffener 1 Flange has 10 UD layers rather than 4. (this can be verified in COMPOSEIT).

The dimensions and loads applied are included in the plates and stiffeners inputs. It should be noted that the previous section's estimated local loads include the hydrostatic load (Ps) and the bottom slamming load (Psl). The example in the figure below shows the input for bottom plate 2, but the process is the same for all the other plates.

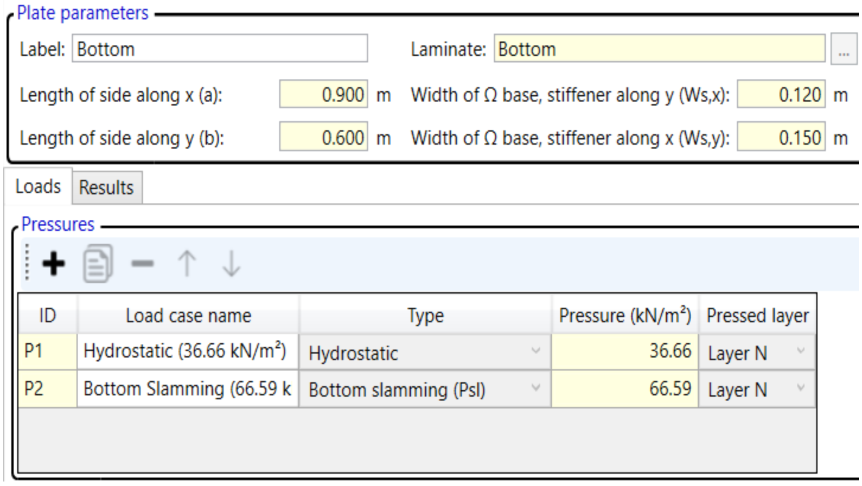


Figure 15 - Plate parameters

Note that the dimensions of plates and stiffeners were estimated with the data given by the professor in the assignment.

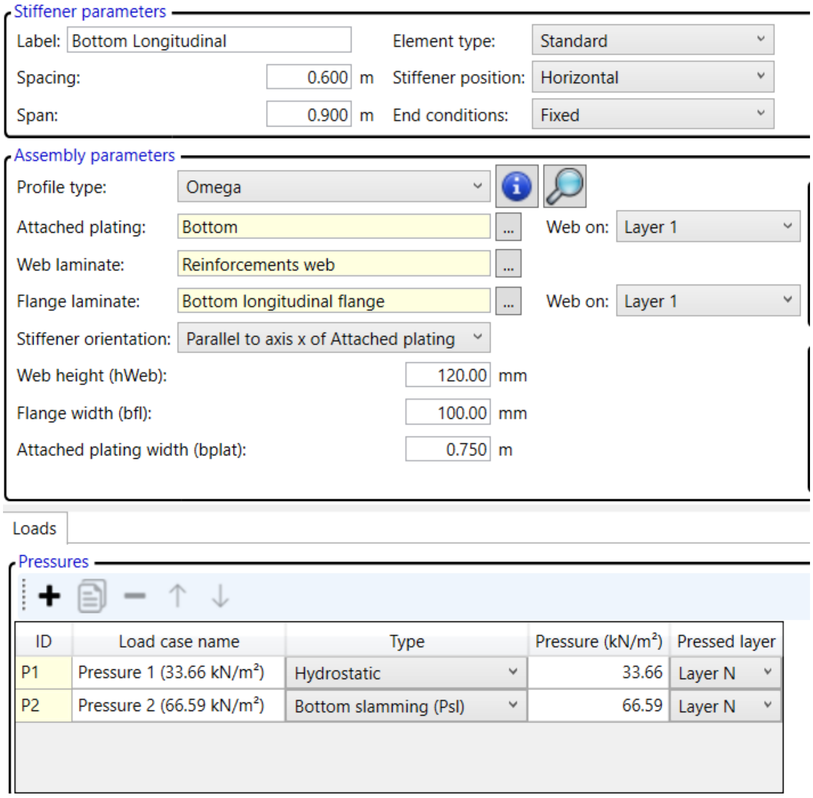


Figure 16 - Stiffener parameters

4. Results

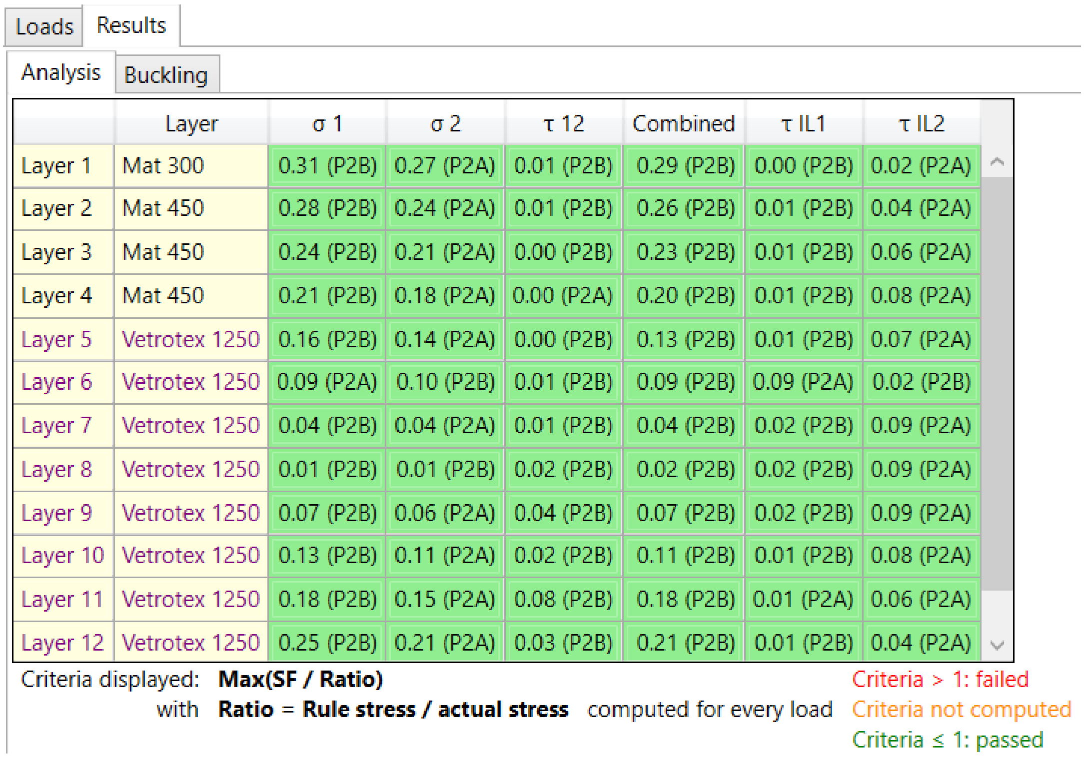
The final step was to inspect the laminates for compliance with the rule's criteria. We already knew the distance between transverse stiffeners is 0.9 [m]. As a result, we assumed that the bottom and side plates were 1.1 [m] long and 0.6 [m] wide.

The software's results panel can determine whether or not the criteria are met. Where the axial and shear stresses are computed for each layer and a colour is assigned to the value. If the value is green, it complies with the rules; if it is red, it does not.

As a result, the two tables that follow show that both of the laminates proposed in the assignment comply with the class rules.

Bottom Lamination:

By running the COMPOSEIT software with all of the previous inputs it is obtained the results exhibited in the figure below for bottom plate 1, note that it is only presented the result for plate 1 since it is associated with the highest hydrostatic load



	Layer	σ 1	σ 2	τ 12	Combined	τ IL1	τ IL2
Layer 1	Mat 300	0.31 (P2B)	0.27 (P2A)	0.01 (P2B)	0.29 (P2B)	0.00 (P2B)	0.02 (P2A)
Layer 2	Mat 450	0.28 (P2B)	0.24 (P2A)	0.01 (P2B)	0.26 (P2B)	0.01 (P2B)	0.04 (P2A)
Layer 3	Mat 450	0.24 (P2B)	0.21 (P2A)	0.00 (P2B)	0.23 (P2B)	0.01 (P2B)	0.06 (P2A)
Layer 4	Mat 450	0.21 (P2B)	0.18 (P2A)	0.00 (P2A)	0.20 (P2B)	0.01 (P2B)	0.08 (P2A)
Layer 5	Vetrotex 1250	0.16 (P2B)	0.14 (P2A)	0.00 (P2B)	0.13 (P2B)	0.01 (P2B)	0.07 (P2A)
Layer 6	Vetrotex 1250	0.09 (P2A)	0.10 (P2B)	0.01 (P2B)	0.09 (P2B)	0.09 (P2A)	0.02 (P2B)
Layer 7	Vetrotex 1250	0.04 (P2B)	0.04 (P2A)	0.01 (P2B)	0.04 (P2B)	0.02 (P2B)	0.09 (P2A)
Layer 8	Vetrotex 1250	0.01 (P2B)	0.01 (P2B)	0.02 (P2B)	0.02 (P2B)	0.02 (P2B)	0.09 (P2A)
Layer 9	Vetrotex 1250	0.07 (P2B)	0.06 (P2A)	0.04 (P2B)	0.07 (P2B)	0.02 (P2B)	0.09 (P2A)
Layer 10	Vetrotex 1250	0.13 (P2B)	0.11 (P2A)	0.02 (P2B)	0.11 (P2B)	0.01 (P2B)	0.08 (P2A)
Layer 11	Vetrotex 1250	0.18 (P2B)	0.15 (P2A)	0.08 (P2B)	0.18 (P2B)	0.01 (P2A)	0.06 (P2A)
Layer 12	Vetrotex 1250	0.25 (P2B)	0.21 (P2A)	0.03 (P2B)	0.21 (P2B)	0.01 (P2B)	0.04 (P2A)

Figure 17 - Bottom plate #1

It is worth noting that the results obtained for all of the defined bottom plates are very similar, as these results can be confirmed in the COMPOSEIT file for the first question delivered with the report.

The hull bottom laminate complies with the rules in study, based on the figure and the rest of the COMPOSEIT results for the plates.

The mechanical properties of the hull bottom laminate are shown in the figure below:

Laminate results

Display:	Global results				
Thickness:	16.64	mm	Weight:	26.104	kg/m²
Fiber weight:	11.505	kg/m²	Resin weight:	14.599	kg/m²
Ex:	12783	MPa	Vx:	8.801	mm
Ey:	13310	MPa	Vy:	8.917	mm
Gxy:	2427	MPa	[EI]x:	4.517E+6	N.mm²/mm
vx:	0.146		[EI]y:	4.708E+6	N.mm²/mm
vy:	0.153		Density:	1.569	g/cm³

Show rigidity matrixes...

Table 5 - Bottom laminate results

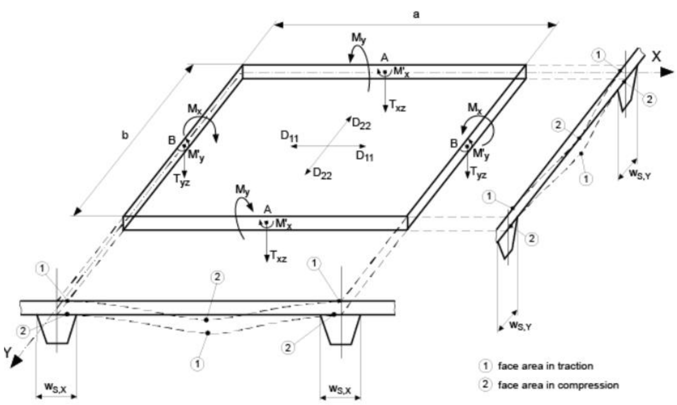


Figure 18 - Laminate properties

Stiffeners Lamination:

The stiffeners were treated the same way. However, the same cells turned orange this time. Specifically, the cells that correspond to TauIL1 and TauIL2 These stress levels correspond to the interlaminar breaking stresses in directions 1 and 2. So we believe one of two things can happen. Or, as indicated by the text "N/A" on orange cells, these stresses are not computed to the stiffeners. Or we made a typo in the stiffener input and definition.

We continued with the project without further investigation because we couldn't determine which of the options was correct.

Another thing to note is that we divided the stiffeners into three sections. The bottom longitudinals were divided first, followed by the transverse stiffeners. The bottom transverse reinforcements and the side shell transverse reinforcements This was done so that we could apply hydrostatic and slamming loads to the bottom transverse stiffeners, as well as hydrostatic and side impact loads to the side stiffeners.

The results of the analysis of the three stiffeners are shown below:

Load case results

Load type: Hydrostatic

Attached plating | Web | Flange | Comments

Laminate: Bottom **Results computed at stiffener ends**

Mx: 1.030 kN.m Tyz: 6.06 kN Nx: 0.00 kN ε0x: -0.0052 %

Layers

		σ 1				σ 2				τ 12				Comb	
	Layer	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	**Ratio**	SF
Layer 1	Mat 300	-0.46	-98.2	**>20**	2.76	-0.14	-98.2	**>20**	2.76	0.00	48.7	**>20**	3.04	**>20**	2.90
Layer 2	Mat 450	-0.51	-111.	**>20**	2.76	-0.15	-111.	**>20**	2.76	0.00	55.0	**>20**	3.04	**>20**	2.90
Layer 3	Mat 450	-0.51	-111.	**>20**	2.76	-0.15	-111.	**>20**	2.76	0.00	55.0	**>20**	3.04	**>20**	2.90
Layer 4	Mat 450	-0.51	-111.	**>20**	2.76	-0.15	-111.	**>20**	2.76	0.00	55.0	**>20**	3.04	**>20**	2.90
Layer 5	Vetrotex 1250	-0.75	-204.	**>20**	3.31	-0.09	-221.	**>20**	3.31	0.00	25.2	**>20**	2.48	**>20**	2.90
Layer 6	Vetrotex 1250	-0.09	-204.	**>20**	3.31	-0.81	-221.	**>20**	3.31	0.00	25.2	**>20**	2.48	**>20**	2.90
Layer 7	Vetrotex 1250	-0.75	-204.	**>20**	3.31	-0.09	-221.	**>20**	3.31	0.00	25.2	**>20**	2.48	**>20**	2.90
Layer 8	Vetrotex 1250	-0.74	-204.	**>20**	3.31	-0.10	-221.	**>20**	3.31	0.03	25.2	**>20**	2.48	**>20**	2.90
Layer 9	Vetrotex 1250	-0.74	-204.	**>20**	3.31	-0.10	-221.	**>20**	3.31	0.03	25.2	**>20**	2.48	**>20**	2.90
Layer 10	Vetrotex 1250	-0.75	-204.	**>20**	3.31	-0.09	-221.	**>20**	3.31	0.00	25.2	**>20**	2.48	**>20**	2.90
Layer 11	Vetrotex 1250	-0.74	-204.	**>20**	3.31	-0.10	-221.	**>20**	3.31	0.03	25.2	**>20**	2.48	**>20**	2.90
Layer 12	Vetrotex 1250	-0.75	-204.	**>20**	3.31	-0.09	-221.	**>20**	3.31	0.00	25.2	**>20**	2.48	**>20**	2.90

Figure 19 - Stiffener analysis results

Load case results

Load type: Hydrostatic

Attached plating | Web | Flange | Comments

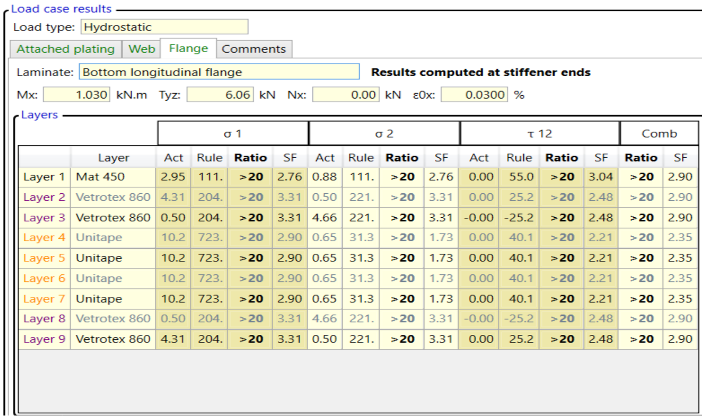
Laminate: Reinforcements web **Results computed at stiffener ends**

Mx: 1.030 kN.m Tyz: 6.06 kN Nx: 0.00 kN γ0xy: 0.1939 %

Layers

		σ 1				σ 2				τ 12				Comb	
	Layer	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	**Ratio**	SF
Layer 1	Mat 450	0.00	111.	**>20**	2.76	0.00	111.	**>20**	2.76	6.67	55.0	**8.25**	3.04	**8.25**	2.90
Layer 2	Vetrotex 860	0.00	204.	**>20**	3.31	0.00	221.	**>20**	3.31	4.08	25.2	**6.19**	2.48	**6.19**	2.90
Layer 3	Vetrotex 860	0.00	204.	**>20**	3.31	-0.00	-221.	**>20**	3.31	-4.08	-25.2	**6.19**	2.48	**6.19**	2.90
Layer 4	Vetrotex 860	0.00	204.	**>20**	3.31	-0.00	-221.	**>20**	3.31	-4.08	-25.2	**6.19**	2.48	**6.19**	2.90
Layer 5	Vetrotex 860	0.00	204.	**>20**	3.31	0.00	221.	**>20**	3.31	4.08	25.2	**6.19**	2.48	**6.19**	2.90
Layer 6	Vetrotex 860	0.00	204.	**>20**	3.31	0.00	221.	**>20**	3.31	4.08	25.2	**6.19**	2.48	**6.19**	2.90
Layer 7	Vetrotex 860	0.00	204.	**>20**	3.31	-0.00	-221.	**>20**	3.31	-4.08	-25.2	**6.19**	2.48	**6.19**	2.90
Layer 8	Vetrotex 860	0.00	204.	**>20**	3.31	-0.00	-221.	**>20**	3.31	-4.08	-25.2	**6.19**	2.48	**6.19**	2.90
Layer 9	Vetrotex 860	0.00	204.	**>20**	3.31	0.00	221.	**>20**	3.31	4.08	25.2	**6.19**	2.48	**6.19**	2.90
Layer 10	Mat 450	0.00	111.	**>20**	2.76	0.00	111.	**>20**	2.76	6.67	55.0	**8.25**	3.04	**8.25**	2.90

Figure 20 - Stiffener analysis results



Load case results

Load type: Hydrostatic

Attached plating | Web | Flange | Comments

Laminate: Bottom longitudinal flange **Results computed at stiffener ends**

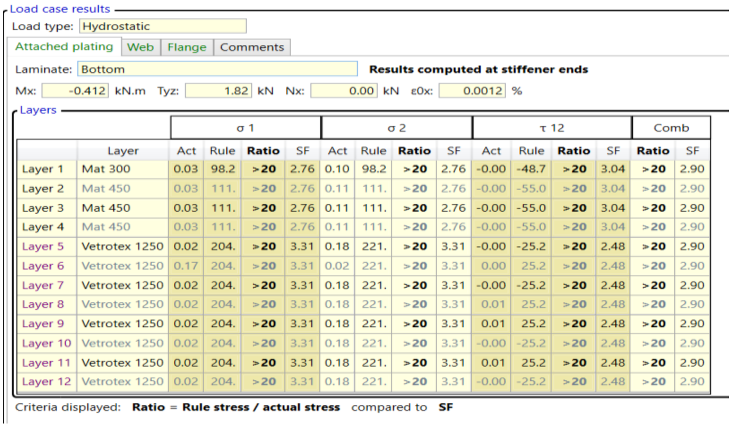
Mx: 1.030 kN.m Tyz: 6.06 kN Nx: 0.00 kN ε0x: 0.0300 %

Layers

		σ 1				σ 2				τ 12				Comb	
	Layer	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	**Ratio**	SF
Layer 1	Mat 450	2.95	111.	**>20**	2.76	0.88	111.	**>20**	2.76	0.00	55.0	**>20**	3.04	**>20**	2.90
Layer 2	Vetrotex 860	4.31	204.	**>20**	3.31	0.50	221.	**>20**	3.31	0.00	25.2	**>20**	2.48	**>20**	2.90
Layer 3	Vetrotex 860	0.50	204.	**>20**	3.31	4.66	221.	**>20**	3.31	-0.00	-25.2	**>20**	2.48	**>20**	2.90
Layer 4	Unitape	10.2	723.	**>20**	2.90	0.65	31.3	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 5	Unitape	10.2	723.	**>20**	2.90	0.65	31.3	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 6	Unitape	10.2	723.	**>20**	2.90	0.65	31.3	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 7	Unitape	10.2	723.	**>20**	2.90	0.65	31.3	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 8	Vetrotex 860	0.50	204.	**>20**	3.31	4.66	221.	**>20**	3.31	-0.00	-25.2	**>20**	2.48	**>20**	2.90
Layer 9	Vetrotex 860	4.31	204.	**>20**	3.31	0.50	221.	**>20**	3.31	0.00	25.2	**>20**	2.48	**>20**	2.90

Figure 21 - Stiffener analysis results

The remaining omega stiffener results were also in accordance with the class rules (even though with smaller safety factors). Stiffener 2 (the most significant of the remaining stiffeners) results are shown below.



Load case results

Load type: Hydrostatic

Attached plating | Web | Flange | Comments

Laminate: Bottom **Results computed at stiffener ends**

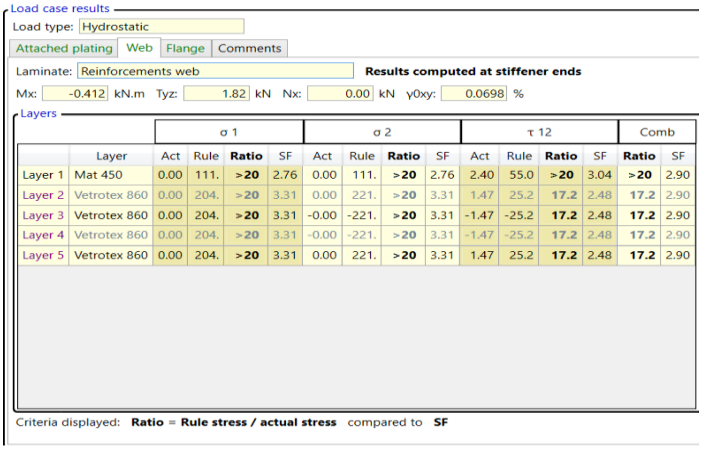
Mx: -0.412 kN.m Tyz: 1.82 kN Nx: 0.00 kN ε0x: 0.0012 %

Layers

		σ 1				σ 2				τ 12				Comb	
	Layer	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	**Ratio**	SF
Layer 1	Mat 300	0.03	98.2	**>20**	2.76	0.10	98.2	**>20**	2.76	-0.00	-48.7	**>20**	3.04	**>20**	2.90
Layer 2	Mat 450	0.03	111.	**>20**	2.76	0.11	111.	**>20**	2.76	-0.00	-55.0	**>20**	3.04	**>20**	2.90
Layer 3	Mat 450	0.03	111.	**>20**	2.76	0.11	111.	**>20**	2.76	-0.00	-55.0	**>20**	3.04	**>20**	2.90
Layer 4	Mat 450	0.03	111.	**>20**	2.76	0.11	111.	**>20**	2.76	-0.00	-55.0	**>20**	3.04	**>20**	2.90
Layer 5	Vetrotex 1250	0.02	204.	**>20**	3.31	0.18	221.	**>20**	3.31	-0.00	-25.2	**>20**	2.48	**>20**	2.90
Layer 6	Vetrotex 1250	0.17	204.	**>20**	3.31	0.02	221.	**>20**	3.31	0.00	25.2	**>20**	2.48	**>20**	2.90
Layer 7	Vetrotex 1250	0.02	204.	**>20**	3.31	0.18	221.	**>20**	3.31	-0.00	-25.2	**>20**	2.48	**>20**	2.90
Layer 8	Vetrotex 1250	0.02	204.	**>20**	3.31	0.18	221.	**>20**	3.31	0.01	25.2	**>20**	2.48	**>20**	2.90
Layer 9	Vetrotex 1250	0.02	204.	**>20**	3.31	0.18	221.	**>20**	3.31	0.01	25.2	**>20**	2.48	**>20**	2.90
Layer 10	Vetrotex 1250	0.02	204.	**>20**	3.31	0.18	221.	**>20**	3.31	-0.00	-25.2	**>20**	2.48	**>20**	2.90
Layer 11	Vetrotex 1250	0.02	204.	**>20**	3.31	0.18	221.	**>20**	3.31	0.01	25.2	**>20**	2.48	**>20**	2.90
Layer 12	Vetrotex 1250	0.02	204.	**>20**	3.31	0.18	221.	**>20**	3.31	-0.00	-25.2	**>20**	2.48	**>20**	2.90

Criteria displayed: **Ratio = Rule stress / actual stress** compared to **SF**

Figure 2221 - Stiffener analysis results



Load case results

Load type: Hydrostatic

Attached plating | Web | Flange | Comments

Laminate: Reinforcements web **Results computed at stiffener ends**

Mx: -0.412 kN.m Tyz: 1.82 kN Nx: 0.00 kN γ0xy: 0.0698 %

Layers

		σ 1				σ 2				τ 12				Comb	
	Layer	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	**Ratio**	SF
Layer 1	Mat 450	0.00	111.	**>20**	2.76	0.00	111.	**>20**	2.76	2.40	55.0	**>20**	3.04	**>20**	2.90
Layer 2	Vetrotex 860	0.00	204.	**>20**	3.31	0.00	221.	**>20**	3.31	1.47	25.2	**17.2**	2.48	**17.2**	2.90
Layer 3	Vetrotex 860	0.00	204.	**>20**	3.31	-0.00	-221.	**>20**	3.31	-1.47	-25.2	**17.2**	2.48	**17.2**	2.90
Layer 4	Vetrotex 860	0.00	204.	**>20**	3.31	-0.00	-221.	**>20**	3.31	-1.47	-25.2	**17.2**	2.48	**17.2**	2.90
Layer 5	Vetrotex 860	0.00	204.	**>20**	3.31	0.00	221.	**>20**	3.31	1.47	25.2	**17.2**	2.48	**17.2**	2.90

Criteria displayed: **Ratio = Rule stress / actual stress** compared to **SF**

Figure 23 - Stiffener analysis results

Load case results

Load type: Hydrostatic

Attached plating | Web | Flange | Comments

Laminate: Transverse reinforcement flange **Results computed at stiffener ends**

Mx: -0.412 kN.m Tyz: 1.82 kN Nx: 0.00 kN ε0x: -0.0031 %

Layers

		σ 1				σ 2				τ 12				Comb	
	Layer	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	Act	Rule	**Ratio**	SF	**Ratio**	SF
Layer 1	Mat 450	-0.31	-111.	**>20**	2.76	-0.09	-111.	**>20**	2.76	0.00	55.0	**>20**	3.04	**>20**	2.90
Layer 2	Vetrotex 860	-0.45	-204.	**>20**	3.31	-0.05	-221.	**>20**	3.31	0.00	25.2	**>20**	2.48	**>20**	2.90
Layer 3	Vetrotex 860	-0.05	-204.	**>20**	3.31	-0.49	-221.	**>20**	3.31	0.00	25.2	**>20**	2.48	**>20**	2.90
Layer 4	Unitape	-1.07	-482.	**>20**	2.90	-0.07	-91.6	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 5	Unitape	-1.07	-482.	**>20**	2.90	-0.07	-91.6	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 6	Unitape	-1.07	-482.	**>20**	2.90	-0.07	-91.6	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 7	Unitape	-1.07	-482.	**>20**	2.90	-0.07	-91.6	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 8	Unitape	-1.07	-482.	**>20**	2.90	-0.07	-91.6	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 9	Unitape	-1.07	-482.	**>20**	2.90	-0.07	-91.6	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 10	Unitape	-1.07	-482.	**>20**	2.90	-0.07	-91.6	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 11	Unitape	-1.07	-482.	**>20**	2.90	-0.07	-91.6	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35
Layer 12	Unitape	-1.07	-482.	**>20**	2.90	-0.07	-91.6	**>20**	1.73	0.00	40.1	**>20**	2.21	**>20**	2.35

Criteria displayed: **Ratio = Rule stress / actual stress** compared to **SF**

Figure 22 - Stiffener analysis results

As a result of the findings, it is concluded that all stiffeners meet the criteria.

The stiffeners laminate mechanical properties results are shown in the tables below:

Laminate results

Display: Global results

Thickness:	9.33	mm	Weight:	15.481	kg/m²
Fiber weight:	8.044	kg/m²	Resin weight:	7.437	kg/m²
Ex:	21208	MPa	Vx:	4.933	mm
Ey:	11361	MPa	Vy:	4.761	mm
Gxy:	2491	MPa	[EI]x:	9.723E+5	N.mm²/mm
vx:	0.172		[EI]y:	8.817E+5	N.mm²/mm
vy:	0.091		Density:	1.660	g/cm³

Show rigidity matrixes...

Figure 23 - Stiffener element: Bottom longitudinal flange

Laminate results

Display: Global results

Thickness:	5.71	mm	Weight:	9.005	kg/m²
Fiber weight:	4.044	kg/m²	Resin weight:	4.961	kg/m²
Ex:	13713	MPa	Vx:	3.017	mm
Ey:	13717	MPa	Vy:	3.017	mm
Gxy:	2281	MPa	[EI]x:	1.929E+5	N.mm²/mm
vx:	0.133		[EI]y:	2.005E+5	N.mm²/mm
vy:	0.133		Density:	1.578	g/cm³

Show rigidity matrixes...

Figure 24 - Stiffener element: Web

Laminate results

Display: Global results

Thickness:	14.76	mm	Weight:	25.195	kg/m²
Fiber weight:	14.044	kg/m²	Resin weight:	11.151	kg/m²
Ex:	25755	MPa	Vx:	7.681	mm
Ey:	9913	MPa	Vy:	7.422	mm
Gxy:	2603	MPa	[EI]x:	4.854E+6	N.mm²/mm
vx:	0.203		[EI]y:	3.263E+6	N.mm²/mm
vy:	0.078		Density:	1.707	g/cm³

Show rigidity matrixes...

Figure 25 - Stiffener element: Transversal flange

5. Laminate Reduction

The challenge of finding a reduced laminate that meets class standards for both the hull and the stiffeners proved to be rather challenging. Individual layers were gradually removed from the original hull/stiffener laminates, and these new constructions were tested to see if they could bear the stipulated Hydrostatic and Bottom Slamming Loads.

Overall, the order of the individual layers was preserved, with just a reduction in the number of repeated individual layers (to reduce the overall laminate thickness). This was done to avoid drastically altering the existing Production Process (which is important considering the Shipyard workers acquaintance with the Production process leads to better final results).

Furthermore, the fabrication methods for the bottom and stiffener laminates were retained.

Hull Laminate:

The class-compliant reduced hull laminate has one MAT 300 layer, two MAT 450 layers (the previous hull laminate had one MAT 300 layer and three MAT 450 levels), and six Vetrotex 1250 layers (while the original hull laminate had 8 Vetrotex 1250 layers).

Despite the fact that this is the bare minimum hull laminate that meets class standards, it should be noted that the resulting stresses for the hull bottom under the proposed Design Loads result in safety factors that are substantially closer to the class-defined limit safety factor.

Individual Bottom Plate Results are only shown for the two plates situated on the deepest areas of the hull since they are associated with the biggest Hydrostatic Loads, and if those plates comply with class criteria, Plates associated with minor Loads will undoubtedly comply as well (this is verified in ComposeIT).

Layer	Type	Label	Angle	Thickness [mm]
1	Mat	Mat 300	0.00	0.74
2	Mat	Mat 450	0.00	0.92
3	Mat	Mat 450	0.00	0.92
4	Woven Roving	Vetrotex 1250	0.00	1.64
5	Woven Roving	Vetrotex 1250	0.00	1.64
6	Woven Roving	Vetrotex 1250	0.00	1.64
7	Woven Roving	Vetrotex 1250	0.00	1.64
8	Woven Roving	Vetrotex 1250	0.00	1.64
9	Woven Roving	Vetrotex 1250	0.00	1.64

Figure 26 - Hull lamination schedule

Laminate results

Display: Global results

Thickness:	12.44	mm	Weight:	19.503	kg/m²
Fiber weight:	8.591	kg/m²	Resin weight:	10.912	kg/m²
Ex:	12880	MPa	Vx:	6.659	mm
Ey:	13687	MPa	Vy:	6.714	mm
Gxy:	2312	MPa	[EI]x:	1.894E+6	N.mm²/mm
vx:	0.134		[EI]y:	1.99E+6	N.mm²/mm
vy:	0.143		Density:	1.568	g/cm³

Show rigidity matrixes...

Figure 27 - Laminate global results

Layer		σ 1	σ 2	τ 12	Combined	τ IL1	τ IL2
Layer 1	Mat 300	0.59 (P2B)	0.51 (P2A)	0.00 (P1A)	0.56 (P2B)	0.01 (P2B)	0.04 (P2A)
Layer 2	Mat 450	0.51 (P2B)	0.44 (P2A)	0.00 (P1A)	0.49 (P2B)	0.01 (P2B)	0.08 (P2A)
Layer 3	Mat 450	0.42 (P2B)	0.37 (P2A)	0.00 (P1A)	0.40 (P2B)	0.02 (P2B)	0.11 (P2A)
Layer 4	Vetrotex 1250	0.29 (P2B)	0.25 (P2A)	0.00 (P1A)	0.25 (P2B)	0.02 (P2B)	0.11 (P2A)
Layer 5	Vetrotex 1250	0.14 (P2B)	0.13 (P2A)	0.00 (P1A)	0.13 (P2B)	0.02 (P2B)	0.13 (P2A)
Layer 6	Vetrotex 1250	0.01 (P2A)	0.01 (P2B)	0.00 (P1A)	0.01 (P2B)	0.02 (P2B)	0.13 (P2A)
Layer 7	Vetrotex 1250	0.16 (P2B)	0.13 (P2A)	0.00 (P1A)	0.13 (P2B)	0.02 (P2B)	0.13 (P2A)
Layer 8	Vetrotex 1250	0.31 (P2B)	0.26 (P2A)	0.00 (P1A)	0.25 (P2B)	0.02 (P2B)	0.11 (P2A)
Layer 9	Vetrotex 1250	0.46 (P2B)	0.39 (P2A)	0.00 (P1A)	0.38 (P2B)	0.01 (P2B)	0.06 (P2A)

Criteria displayed: **Max(SF / Ratio)**
with **Ratio** = **Rule stress / actual stress** computed for every load

Criteria > 1: failed
Criteria not computed
Criteria ≤ 1: passed

Figure 28 - Bottom plate 1 results

Layer		σ 1	σ 2	τ 12	Combined	τ IL1	τ IL2
Layer 1	Mat 300	0.91 (P2B)	0.51 (P2A)	0.00 (P1A)	0.86 (P2B)	0.00 (P2B)	0.04 (P2A)
Layer 2	Mat 450	0.79 (P2B)	0.44 (P2A)	0.00 (P1A)	0.75 (P2B)	0.01 (P2B)	0.08 (P2A)
Layer 3	Mat 450	0.65 (P2B)	0.37 (P2A)	0.00 (P1A)	0.62 (P2B)	0.01 (P2B)	0.12 (P2A)
Layer 4	Vetrotex 1250	0.45 (P2B)	0.25 (P2A)	0.00 (P1A)	0.39 (P2B)	0.01 (P2B)	0.12 (P2A)
Layer 5	Vetrotex 1250	0.22 (P2B)	0.13 (P2A)	0.00 (P1A)	0.19 (P2B)	0.02 (P2B)	0.14 (P2A)
Layer 6	Vetrotex 1250	0.01 (P2B)	0.02 (P2B)	0.00 (P1A)	0.01 (P2B)	0.02 (P2B)	0.14 (P2A)
Layer 7	Vetrotex 1250	0.24 (P2B)	0.13 (P2A)	0.00 (P1A)	0.20 (P2B)	0.02 (P2B)	0.14 (P2A)
Layer 8	Vetrotex 1250	0.47 (P2B)	0.26 (P2A)	0.00 (P1A)	0.39 (P2B)	0.01 (P2B)	0.11 (P2A)
Layer 9	Vetrotex 1250	0.70 (P2B)	0.39 (P2A)	0.00 (P1A)	0.58 (P2B)	0.01 (P2B)	0.07 (P2A)

Criteria displayed: **Max(SF / Ratio)**
with **Ratio** = **Rule stress / actual stress** computed for every load

Criteria > 1: failed
Criteria not computed
Criteria ≤ 1: passed

Figure 29 - Bottom plate 2 results

Stiffeners Laminate:

The lamination for Stiffener 1 will be different from the rest of the Stiffeners due to the variance in geometry. The laminate for Stiffener 1 web is one layer of MAT 450 and one layer of Vetrotex 1250 (the original stiffener web laminate was one layer of MAT 450 and three layers of Vetrotex 850), and the laminate for Stiffener 1's flange is the same as the web but with one Unidirectional Layer (while the original had 10 Unidirectional Layers).

	Layer	Angle	Thickness [mm]
1	MAT 450	0	0.93
2	Vetrotex 1250	0	1.64

Table 9 - Stiffener 1 Web Lamination Schedule

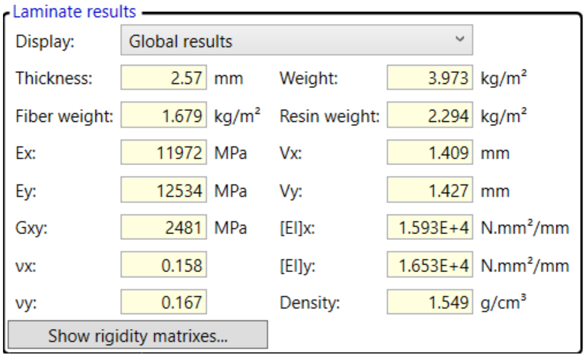


Figure 30 - Laminate global results

	Layer	Angle	Thickness [mm]
1	MAT 450	0	0.93
2	Unidirectional	0	0.90
3	Vetrotex 860	0	1.19

Table 11 - Stiffener 1 Flange Lamination Schedule

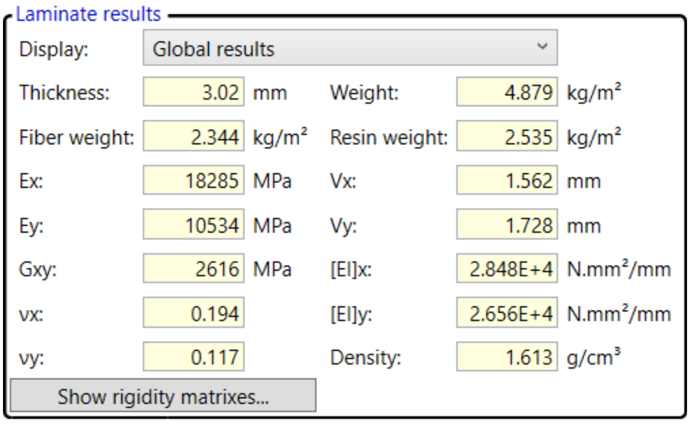


Figure 31 - Laminate global results

Loads | Results

Analysis | Buckling

Attached plating | Web | Flange

	Layer	σ 1	σ 2	τ 12	Combined
Layer 1	Mat 300	0.00 (P2)	0.01 (P2)	0.00 (P2)	0.01 (P2)
Layer 2	Mat 450	0.00 (P2)	0.01 (P2)	0.00 (P2)	0.01 (P2)
Layer 3	Mat 450	0.00 (P2)	0.01 (P2)	0.00 (P2)	0.01 (P2)
Layer 4	Mat 450	0.00 (P2)	0.01 (P2)	0.00 (P2)	0.01 (P2)
Layer 5	Vetrotex 1250	0.00 (P2)	0.01 (P2)	0.00 (P2)	0.01 (P2)
Layer 6	Vetrotex 1250	0.01 (P2)	0.00 (P2)	0.00 (P2)	0.01 (P2)
Layer 7	Vetrotex 1250	0.00 (P2)	0.01 (P2)	0.00 (P2)	0.01 (P2)
Layer 8	Vetrotex 1250	0.00 (P2)	0.01 (P2)	0.00 (P2)	0.01 (P2)
Layer 9	Vetrotex 1250	0.00 (P2)	0.01 (P2)	0.00 (P2)	0.01 (P2)

Criteria displayed: **Max(SF / Ratio)**
with **Ratio = Rule stress / actual stress** computed for every load

Criteria > 1: failed
Criteria not computed
Criteria ≤ 1: passed

Figure 32- Results for Stiffener 1 – Attached Plating

Loads | Results

Analysis | Buckling

Attached plating | Web | Flange

	Layer	σ 1	σ 2	τ 12	Combined
Layer 1	Mat 450	0.00 (P1)	0.00 (P1)	0.71 (P2)	0.68 (P2)
Layer 2	Vetrotex 1250	0.00 (P1)	0.00 (P1)	0.78 (P2)	0.91 (P2)
Layer 3	Vetrotex 1250	0.00 (P1)	0.00 (P1)	0.78 (P2)	0.91 (P2)
Layer 4	Mat 450	0.00 (P1)	0.00 (P1)	0.71 (P2)	0.68 (P2)

Criteria displayed: **Max(SF / Ratio)**
with **Ratio = Rule stress / actual stress** computed for every load

Criteria > 1: failed
Criteria not computed
Criteria ≤ 1: passed

Figure 33 - Results for Stiffener 1 – Web

Loads | Results

Analysis | Buckling

Attached plating | Web | Flange

	Layer	σ 1	σ 2	τ 12	Combined
Layer 1	Mat 450	0.15 (P2)	0.05 (P2)	0.00 (P1)	0.14 (P2)
Layer 2	Unitape	0.13 (P2)	0.03 (P2)	0.00 (P1)	0.09 (P2)
Layer 3	Vetrotex 860	0.15 (P2)	0.02 (P2)	0.00 (P1)	0.12 (P2)

Criteria displayed: **Max(SF / Ratio)**
with **Ratio = Rule stress / actual stress** computed for every load

Criteria > 1: failed
Criteria not computed
Criteria ≤ 1: passed

Figure 34 - Results for Stiffener 1 – Flange

And for rest of the stiffeners, the laminate for the web is the same as the official version because no thickness reduction was possible while meeting class requirements, and the laminate for the flange is the original flange laminate but with all of the Unidirectional Layers removed – so the Flange Laminate is equal to the original Web Laminate.

Layer	Type	Label	Angle	Thickness[mm]
1	Mat	Mat 450		0.92
2	Woven Roving	Vetrotex 860	0.00	1.20
3	Woven Roving	Vetrotex 860	90.00	1.20
4	Woven Roving	Vetrotex 860	90.00	1.20

Table 13 - Stiffeners 2, 3, 4, 5 and 6 Web and Flange Lamination Schedule

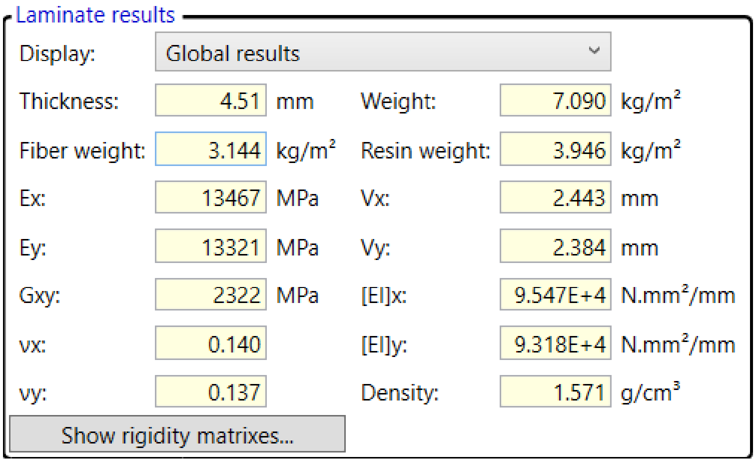
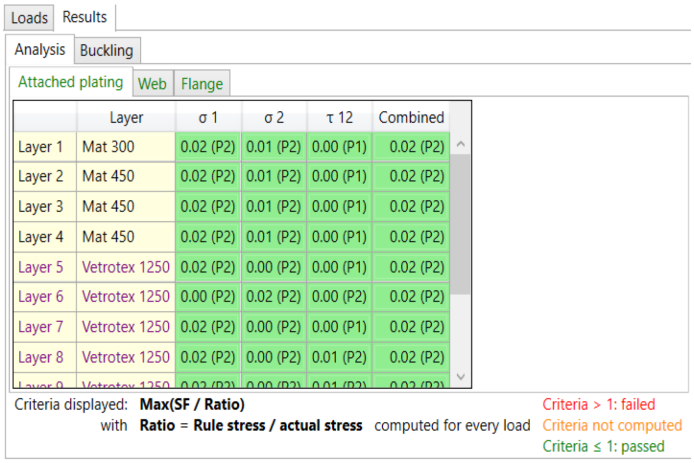


Figure 35 - Laminate global results

Individual stiffener results are only shown for stiffener 2 since it is located in the deepest region of the hull (related with the largest Hydrostatic Loads), and if this stiffener complies with class criteria, then other stiffeners associated with lower Loads will surely comply as well (this is verified in ComposeIT).

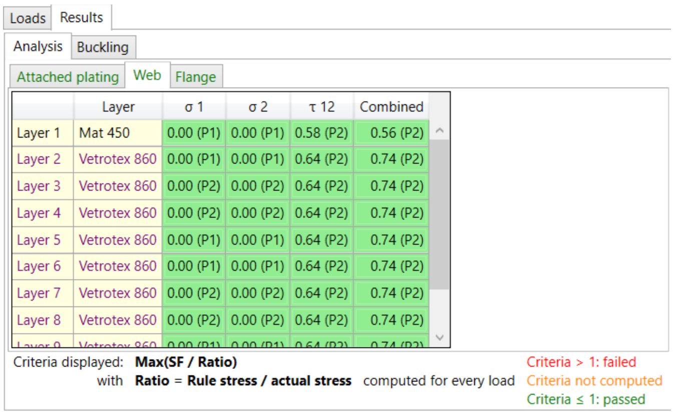


Loads | Results
Analysis | Buckling
Attached plating | Web | Flange

	Layer	σ 1	σ 2	τ 12	Combined
Layer 1	Mat 300	0.02 (P2)	0.01 (P2)	0.00 (P1)	0.02 (P2)
Layer 2	Mat 450	0.02 (P2)	0.01 (P2)	0.00 (P1)	0.02 (P2)
Layer 3	Mat 450	0.02 (P2)	0.01 (P2)	0.00 (P1)	0.02 (P2)
Layer 4	Mat 450	0.02 (P2)	0.01 (P2)	0.00 (P1)	0.02 (P2)
Layer 5	Vetrotex 1250	0.02 (P2)	0.00 (P2)	0.00 (P1)	0.02 (P2)
Layer 6	Vetrotex 1250	0.00 (P2)	0.02 (P2)	0.00 (P2)	0.02 (P2)
Layer 7	Vetrotex 1250	0.02 (P2)	0.00 (P2)	0.00 (P1)	0.02 (P2)
Layer 8	Vetrotex 1250	0.02 (P2)	0.00 (P2)	0.01 (P2)	0.02 (P2)

Criteria displayed: **Max(SF / Ratio)**
with **Ratio = Rule stress / actual stress** computed for every load
Criteria > 1: failed
Criteria not computed
Criteria ≤ 1: passed

Figure 36 - Results for Stiffener 2 – Attached Plating

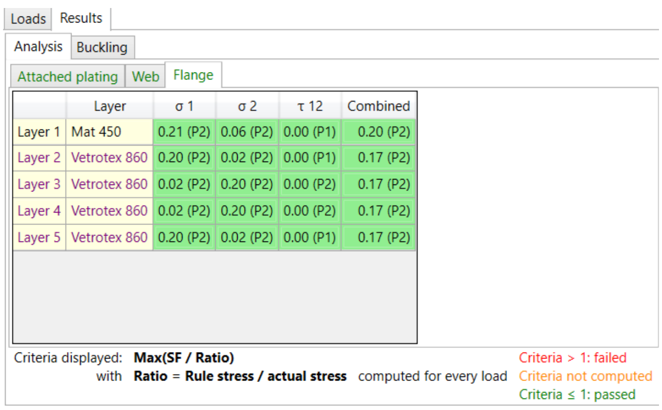


Loads | Results
Analysis | Buckling
Attached plating | Web | Flange

	Layer	σ 1	σ 2	τ 12	Combined
Layer 1	Mat 450	0.00 (P1)	0.00 (P1)	0.58 (P2)	0.56 (P2)
Layer 2	Vetrotex 860	0.00 (P1)	0.00 (P1)	0.64 (P2)	0.74 (P2)
Layer 3	Vetrotex 860	0.00 (P2)	0.00 (P2)	0.64 (P2)	0.74 (P2)
Layer 4	Vetrotex 860	0.00 (P2)	0.00 (P2)	0.64 (P2)	0.74 (P2)
Layer 5	Vetrotex 860	0.00 (P1)	0.00 (P1)	0.64 (P2)	0.74 (P2)
Layer 6	Vetrotex 860	0.00 (P1)	0.00 (P1)	0.64 (P2)	0.74 (P2)
Layer 7	Vetrotex 860	0.00 (P2)	0.00 (P2)	0.64 (P2)	0.74 (P2)
Layer 8	Vetrotex 860	0.00 (P2)	0.00 (P2)	0.64 (P2)	0.74 (P2)

Criteria displayed: **Max(SF / Ratio)**
with **Ratio = Rule stress / actual stress** computed for every load
Criteria > 1: failed
Criteria not computed
Criteria ≤ 1: passed

Figure 37 - Results for Stiffener 2 – Web



Loads | Results
Analysis | Buckling
Attached plating | Web | Flange

	Layer	σ 1	σ 2	τ 12	Combined
Layer 1	Mat 450	0.21 (P2)	0.06 (P2)	0.00 (P1)	0.20 (P2)
Layer 2	Vetrotex 860	0.20 (P2)	0.02 (P2)	0.00 (P1)	0.17 (P2)
Layer 3	Vetrotex 860	0.02 (P2)	0.20 (P2)	0.00 (P2)	0.17 (P2)
Layer 4	Vetrotex 860	0.02 (P2)	0.20 (P2)	0.00 (P2)	0.17 (P2)
Layer 5	Vetrotex 860	0.20 (P2)	0.02 (P2)	0.00 (P1)	0.17 (P2)

Criteria displayed: **Max(SF / Ratio)**
with **Ratio = Rule stress / actual stress** computed for every load
Criteria > 1: failed
Criteria not computed
Criteria ≤ 1: passed

Figure 38 - Results for Stiffener 2 – Flange

6. Exercise 3: Deck Laminate

For the last part of our project we'll be proposing a deck laminate that complies with the class rules, assessing the class critical design load and at a worst case scenario.

To do so, we'll start by following the BV rules (namely Section 4, Chapter 4: "Local Loads on Decks, Superstructures, Watertight Bulkheads and Tanks" of BV 4760.5.NR500) from which we'll define the local loads on our deck.

From this chapter, we'll obtain the sea pressure at any point in the deck through the following expression – considering that our ship has an exposed deck:

$$P_s = (p_0 - z_D . 9.807) . \varphi_1 . \varphi_3 \ \geq \ P_{dmin}$$

Where:

φ_1 : Reduction coefficient depending of the location of the considered deck with respect to the full load waterline:

- for freeboard deck[(m)], as defined in Ch 2, Sec 3, [2.2.1]: φ_1 = 1,00
- for the first deck just above the freeboard deck[(m)]: φ_1 = 0,75
- for the decks above: φ_1 = 0,50

φ_3 : Reduction coefficient, to be taken equal to 0,7, when the exposed deck is partially protected and not directly exposed to green sea effect

p_0 : Taken equal to the sea bottom pressure P_S in the considered area, in kN/m², calculated according to Ch 4, Sec 3, [2.1.2] with: z = 0

z_D : Vertical distance, in m, between the deck at side at the considered transverse section and:

- the full load waterline for sailing yacht monohull
- the baseline for other type of yacht

P_{dmin} : Minimum sea pressure on deck as defined in [1.1.2].

Meanwhile, the minimum sea pressure P_{dmin}, should be taken as:

- in areas 1 and 2: $P_{dmin} = 19,6\ n\ \varphi_1\ \varphi_2\ \varphi_3 \geq 7$
- in areas 3 and 4: $P_{dmin} = 17,6\ n\ \varphi_1\ \varphi_2\ \varphi_3 \geq 5$
- for exposed decks not accessible to passengers or crew members: P_{dmin} = 3 KN/m²

where:

φ_1, φ_3 : As defined in [1.1.1].

φ_2 : Coefficient taken equal to:

- 0,42 if $L_{WL} < 50$ m
- $L_{WL}/120$ if $L \geq 50$ m

Considering that the deck is level at the ship's depth of 3 meters (z = 3m), we'll divide the deck into 5 different plates to study the local load distribution and obtain the following results for the local deck loads:

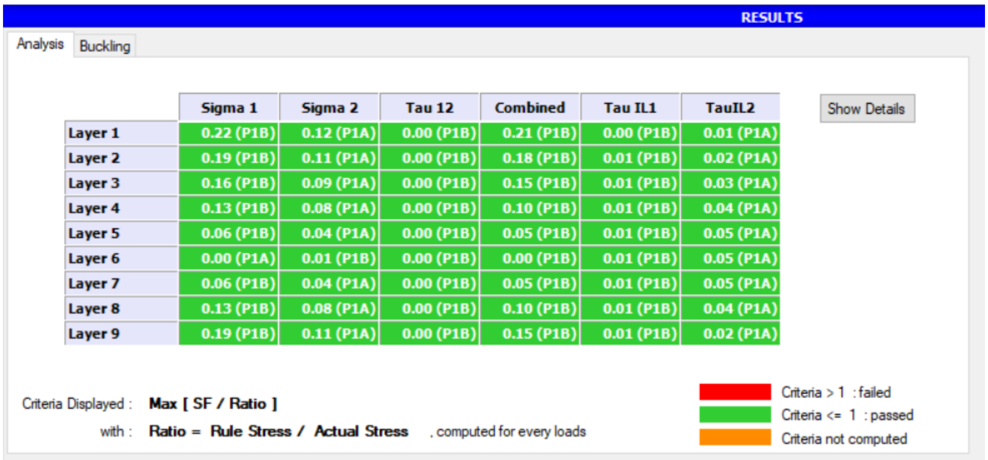
	Zd [m]	φ1	φ3	Ps	Pdmin	p0	Cw
Plate 1	3	1	1	12.12672	8.232	41.54772	3.802112
Plate 2	3	1	1	12.12672	8.232	41.54772	3.802112
Plate 3	3	1	1	12.12672	8.232	41.54772	3.802112
Plate 4	3	1	1	12.12672	8.232	41.54772	3.802112
Plate 5	3	1	1	12.12672	8.232	41.54772	3.802112

Figure 39 - Local load calculations table for the deck plates

For the laminate itself, we'll consider that the deck panel is built as a single laminate in its entirety. The fabrication process will be the same as the one chosen for the hull (hand lay-up) as a cost-effective and simple way of producing our deck.

Additionally, in order to facilitate production and possibly reduce material costs, we'll opt to use the same materials as the ones used for the hull – so these can be ordered in bulk. The laminate layers will also be the same initially, thus ensuring that the yard's production teams are familiar with both the production methods used and the materials that will make up the ship's deck.

By replicating the deck laminate (the reduced iteration) we obtain the following results as per a first ComposeIT iteration:



RESULTS

Analysis | Buckling

	Sigma 1	Sigma 2	Tau 12	Combined	Tau IL1	TauIL2
Layer 1	0.22 (P1B)	0.12 (P1A)	0.00 (P1B)	0.21 (P1B)	0.00 (P1B)	0.01 (P1A)
Layer 2	0.19 (P1B)	0.11 (P1A)	0.00 (P1B)	0.18 (P1B)	0.01 (P1B)	0.02 (P1A)
Layer 3	0.16 (P1B)	0.09 (P1A)	0.00 (P1B)	0.15 (P1B)	0.01 (P1B)	0.03 (P1A)
Layer 4	0.13 (P1B)	0.08 (P1A)	0.00 (P1B)	0.10 (P1B)	0.01 (P1B)	0.04 (P1A)
Layer 5	0.06 (P1B)	0.04 (P1A)	0.00 (P1B)	0.05 (P1B)	0.01 (P1B)	0.05 (P1A)
Layer 6	0.00 (P1A)	0.01 (P1B)	0.00 (P1B)	0.00 (P1B)	0.01 (P1B)	0.05 (P1A)
Layer 7	0.06 (P1B)	0.04 (P1A)	0.00 (P1B)	0.05 (P1B)	0.01 (P1B)	0.05 (P1A)
Layer 8	0.13 (P1B)	0.08 (P1A)	0.00 (P1B)	0.10 (P1B)	0.01 (P1B)	0.04 (P1A)
Layer 9	0.19 (P1B)	0.11 (P1A)	0.00 (P1B)	0.15 (P1B)	0.01 (P1B)	0.02 (P1A)

Show Details

Criteria Displayed : Max [SF / Ratio]
with : Ratio = Rule Stress / Actual Stress , computed for every loads

Criteria > 1 : failed
Criteria <= 1 : passed
Criteria not computed

Figure 40 - ComposeIT analysis results for the first laminate iteration of the deck

As we can see, this would make our deck exceedingly over-dimensioned. With this in mind, we can reduce the layers of our laminate while still ensuring that the final structure complies with CS rules.

To solve this, and obtain an optimum lamination for the deck, we'll make several iterations by reducing our number of layers until an ideal combination that can most closely follow the CS requirements is found. On the final iteration, we obtained the final laminate for the deck as follows:

Layer	Type	Label	Angle	Thickness [mm]
1	Mat	Mat 450	0.00	0.92
2	Mat	Mat 450	0.00	0.92
3	Mat	Mat 450	0.00	0.92
4	Woven Roving	Vetrotex 1250	0.00	1.64
5	Woven Roving	Vetrotex 1250	0.00	1.64

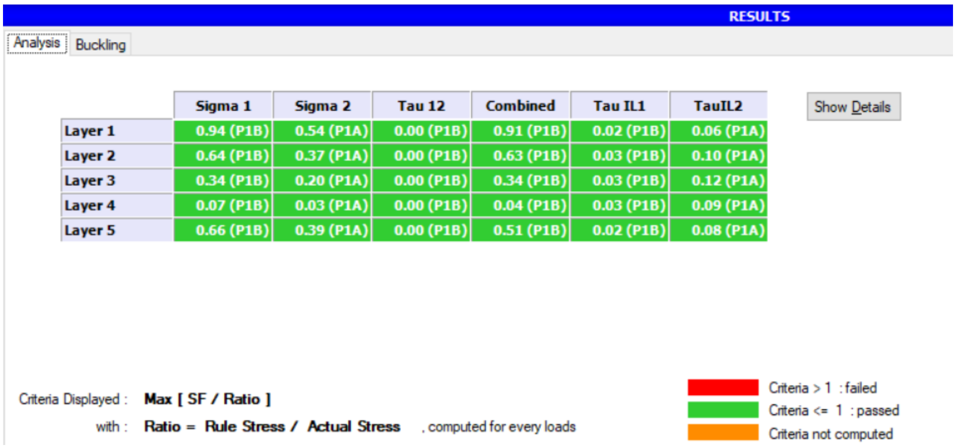
Figure 41 - Deck lamination schedule (final iteration)

With the following laminate results as per ComposeIT:

Thickness [mm]	E_x [MPa]	E_y [MPa]	Gxy [MPa]	Weight [Kg/m^2]	V_x [mm]	V_y [mm]	EI_x [N.mm^2/mm]	EI_y [N.mm^2/mm]
6.04	11 717	11 717	2 621	9.300	3.386	3.386	2.11e+05	2.11e+05

Figure 42 - Laminate global results as per ComposeIT

And the following final analysis results for the iteration:



RESULTS

Analysis Buckling

	Sigma 1	Sigma 2	Tau 12	Combined	Tau IL1	TauIL2
Layer 1	0.94 (P1B)	0.54 (P1A)	0.00 (P1B)	0.91 (P1B)	0.02 (P1B)	0.06 (P1A)
Layer 2	0.64 (P1B)	0.37 (P1A)	0.00 (P1B)	0.63 (P1B)	0.03 (P1B)	0.10 (P1A)
Layer 3	0.34 (P1B)	0.20 (P1A)	0.00 (P1B)	0.34 (P1B)	0.03 (P1B)	0.12 (P1A)
Layer 4	0.07 (P1B)	0.03 (P1A)	0.00 (P1B)	0.04 (P1B)	0.03 (P1B)	0.09 (P1A)
Layer 5	0.66 (P1B)	0.39 (P1A)	0.00 (P1B)	0.51 (P1B)	0.02 (P1B)	0.08 (P1A)

Show Details

Criteria Displayed : **Max [SF / Ratio]**

with : **Ratio = Rule Stress / Actual Stress** , computed for every loads

Criteria > 1 : failed

Criteria <= 1 : passed

Criteria not computed

Figure 43 - ComposeIT analysis results for the final iteration of the deck laminate

The obtained results are the same for all plates, since they're located at the same height (equal to the ship's depth of z = 3 meters). With these results, we can estimate that this deck laminate will be a safe structure, through compliance of all relevant BV rules, while assuming that the deck will now carry any cargo (common for most recreational boats and yachts of this size).

Conclusions

This project provided an opportunity to gain information about the many applications of composite materials in maritime constructions while also meeting Classification Society requirements.

The verification of the vessel's information using commercial software that meets the requirements of the classification registry was successful. The subsequent implementation of lay-up of the slipway and stiffeners according to the minimum requirements imposed by the registry allowed us to understand the system of operation in the design and modelling of the minimum criteria of structural strength and mechanical properties of the components through the variation of layers in terms of materials under verification. After certain rulings and reasoning, we understood how to make the minimum requirements acceptable and received positive feedback from the software regarding our decisions.

The hull laminate reduction permitted the examination of the stresses experienced by the hull structure with the adjustments made to achieve an optimal stage where the hull laminate was as light as feasible while still complying with the requirements.

Finally, the deck laminate design allowed us to make a laminate schedule for a small yacht's deck that both complied with BV rules as well as ensuring that the structure wasn't over dimensioned. Leading to a final laminate which is both safe as per BV rules and as light as possible.

References

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VERITAS, B. (s.d.). "ComposeIT User Guide"

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