MASTER THESIS

Structure design of a sailing yacht by rules and direct method

"Advanced Master in Naval Architecture" conferred by University of Liege
"Master of Sciences in Applied Mechanics, specialization in Hydrodynamics,
Energetics and Propulsion" conferred by Ecole Centrale de Nantes
developed at University of Genoa in framework of the
"EMSHIP"
Erasmus Mondus Master Course
in "Integrated Advanced Ship Design"

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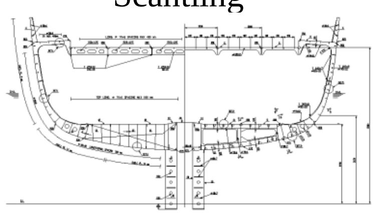
Student: Ivan Klarić

La Spezia, February 2012

Contest

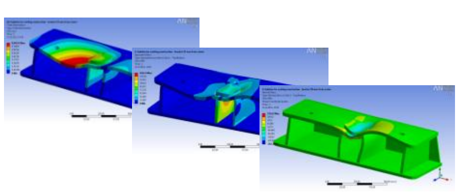
Scantling



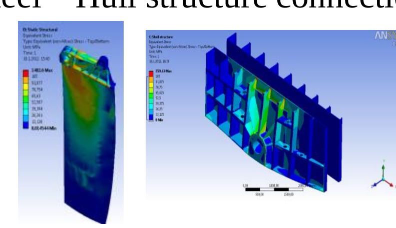
Aluminum

Types of aluminum and the alloys
Chemical properties
Mechanical properties
Advantages
Disadvantages

Main mast base foundation



Keel – Hull structure connection



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L_{OA} = 58.6 m D = 3.85 m v = 15.5 kn
B = 11.4 m T = 2.15 m Δ = 540 t

American Bureau of Shipping (ABS) rules

Guide for Building and Classing Offshore Racing Yachts, 1994

Chapter 7: Thickness of the shell

$$t = sc\sqrt{\frac{pk}{\sigma_a}}$$

Chapter 8: Section modulus

$$SM = \frac{Chsl^2}{\sigma_a} + SM_k$$

Deck structure (t = 5 mm)						
Direction	Type	Profile	Web [mm]	Flange [mm]	$SM_{required}$	$SM_{profile}$
Longitudinal	Primary	T	250 x 8	100 x 12	104,28	133,82
Longitudinal	Secondary	FB	70 x 6		4,00	4,90
Transverse	Main frame	T	250 x 8	60 x 8	96,14	112,43
Transverse	Frame	FB	120 x 12		24,03	28,80
Side structure (t = 8 mm)						
Direction	Type	Profile	Web [mm]	Flange [mm]	$SM_{required}$	$SM_{profile}$
Longitudinal	Primary	T	160 x 7	80 x 12	60,07	65,46
Longitudinal	Secondary	FB	90 x 8		10,30	10,80
Transverse	Main frame	T	160 x 9	90 x 12	41,26	52,00
Bottom (t = 14 mm) and inner bottom (t = 12 mm)						
Direction	Place	Profile	Longitudinals	Stiffeners	$SM_{required}$	$SM_{profile}$
Longitudinal	Bottom	FB	120 x 12		22,60	28,80
Longitudinal	Iner bottom	FB	70 x 6		10,31	11,67
Longitudinal	Bottom bulkhead	FB		70 x 6	10,31	11,67

Scantling

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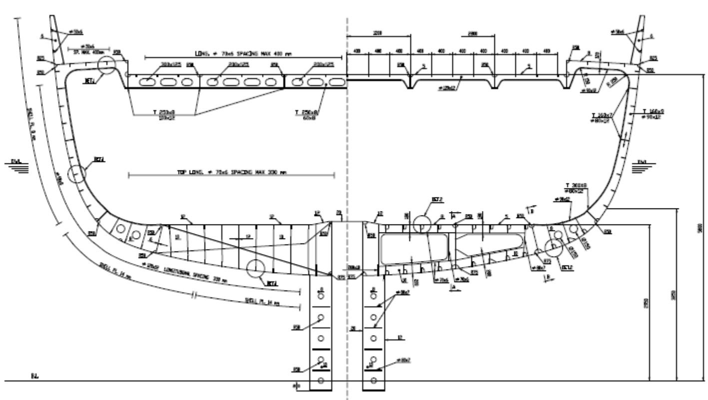

Aluminium

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History of aluminum boats:

1892 – power boat *Mignon* – Switzerland
1894 – 58 m torpedo boat *Falcon* - Scotland
1894 – several 5.48 m boats built in USA for polar expeditions
1895 – aluminium boat *Defender* – won The America's Cup

Aluminium boats in that time had several problems with corrosion

Table Families of aluminum alloys:

Alloy element	Series
None	1000
Copper	2000
Manganese	3000
Magnesium	5000
Magnesium and silicon	6000
Zinc and magnesium	7000

Marine application:
Alloy 5083 it was registered in 1954 by the Aluminum Association
Properties of 5083 alloy:
-Corrosion resistance
- High strength
- Good mouldability
- Excellent for welding

Aluminum

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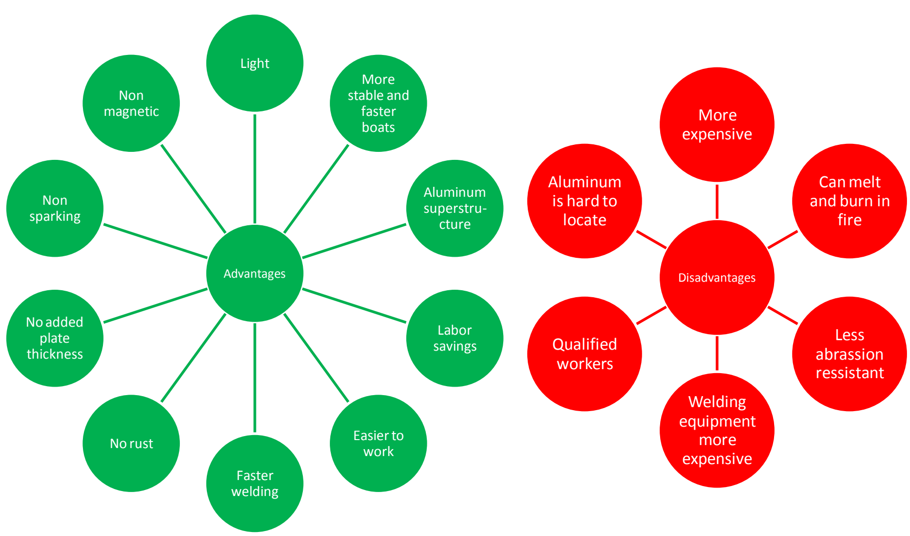

Finite element method analysis

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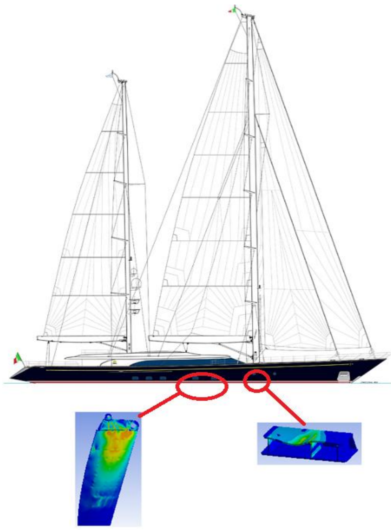

Software:
Modeling – SolidWorks 2010
Analysis – Ansys Workbench v13.

Models:
Main mast base foundation
Keel – Hull structure connection

Goal:
Verification of the existing structure for the new loads coming from the new mast
Become familiar with the software features
Verification of the structure according to the ABS rules

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Main mast base foundation

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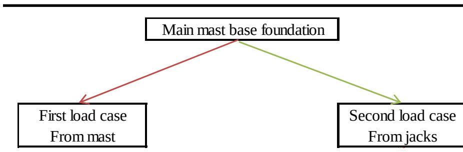
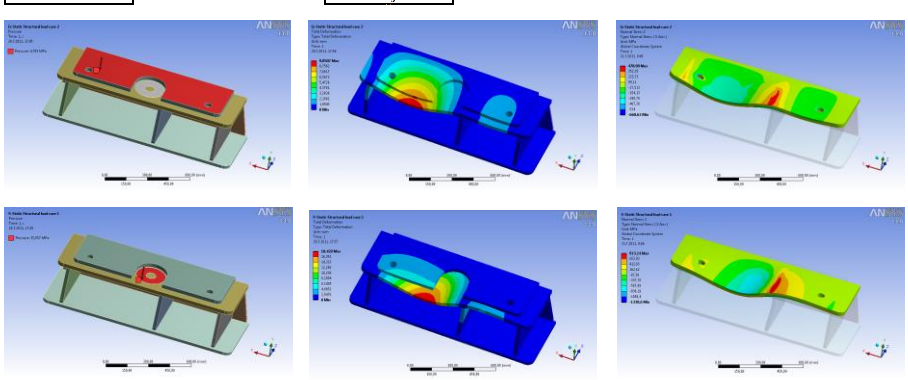


Comparison:	First load case	Second load case
Total deformation	9.85 mm	18.42 mm
Normal stress	479 MPa	913 MPa



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Main mast base foundation

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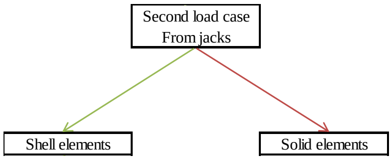
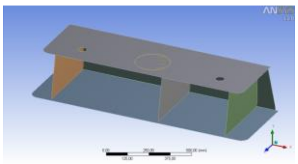
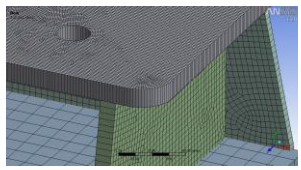
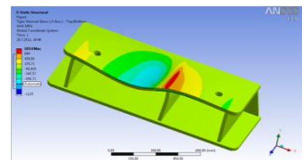
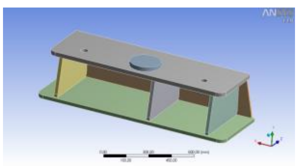
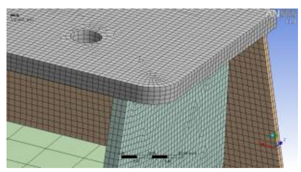
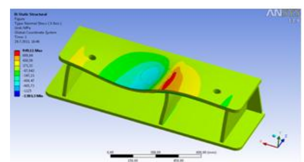


Comparison:0	Solid element	Shell element
Total deformation	19.45 mm	20.07 mm
Von-Mises	1812 MPa	1610 MPa
Normal stress (tension)	949 MPa	1034 MPa
Normal stress (compression)	1384 MPa	1125 MPa
Shear stress	368 MPa	253 MPa

Main mast base foundation

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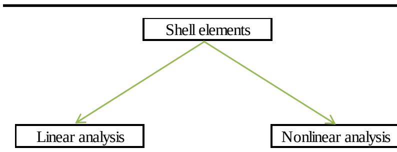
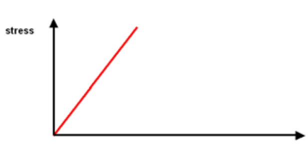
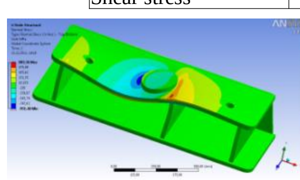
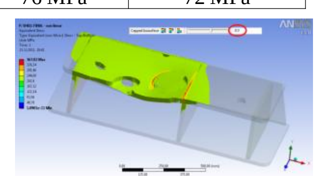
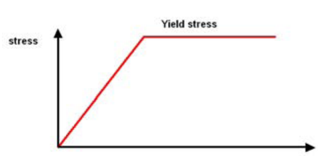
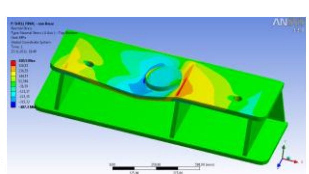
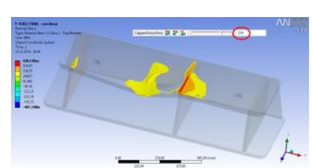


Comparison:	Linear analysis	Nonlinear analysis
Total deformation	16.86 mm	50.43 mm
Von-Mises stress	1022 MPa	368 MPa
Normal stress	883 MPa	420 MPa
Shear stress	76 MPa	72 MPa



Main mast base foundation

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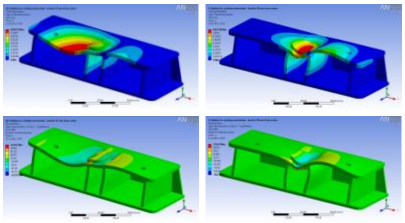
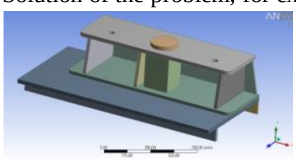
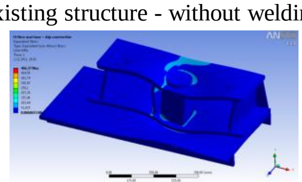
Solution of the problem, for existing structure - welding

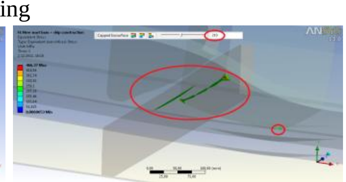


Position of the bracket	Deformation	Von-Mises	Normal stress
In the middle	1,401 mm	218 MPa	139 MPa
15 mm	0,842 mm	182 MPa	122 MPa
20 mm	0,725 mm	169 MPa	142 MPa
25 mm	0,627 mm	160 MPa	160 MPa
30 mm	0,550 mm	169 MPa	177 MPa
50 mm	0,677 mm	233 MPa	235 MPa

Solution of the problem, for existing structure - without welding







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Main mast base foundation

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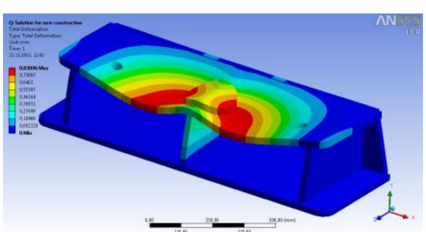
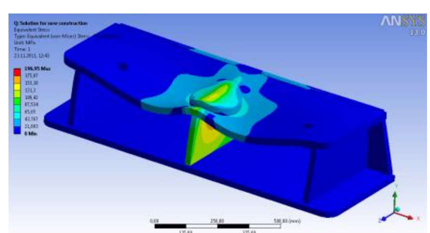
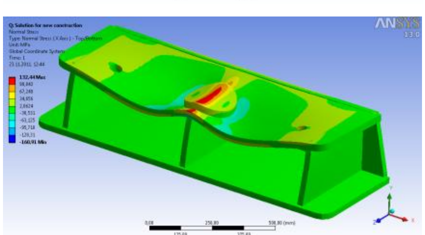
Solution for the new construction







Total deformation	0.831 mm
Von-Mises stress	197 MPa
Normal stress	132 MPa
Shear stress	8 MPa

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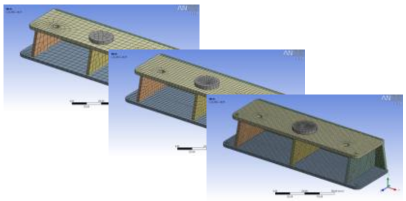
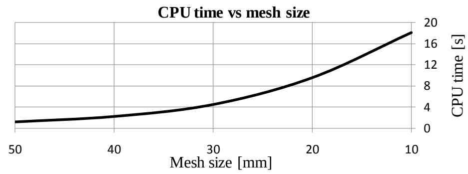
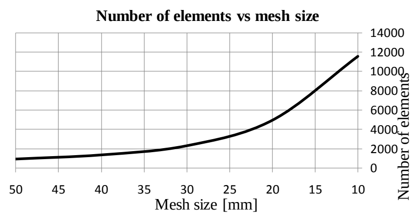
Main mast base foundation

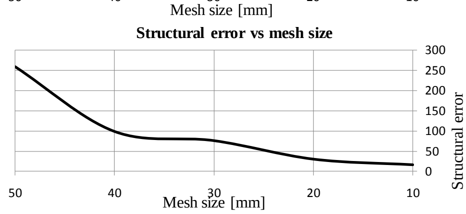
Influence of the mesh on the results



Mesh [mm]	50	40	30	20	10
Von-Mises [MPa]	170,56	175,06	171,76	173,52	194,38
Normal stress [Mpa]	91,76	82,02	117,63	133,36	123,42
Shear stress [Mpa]	3,58	4,56	5,02	6,28	6,93
Total deformation [mm]	0,804	0,762	0,811	0,83	0,816
Error	259	99,21	76,52	30,84	16,97
Number of elements	956	1383	2328	4958	11560
CPU time [s]	1,2	2,23	4,49	9,56	18,08

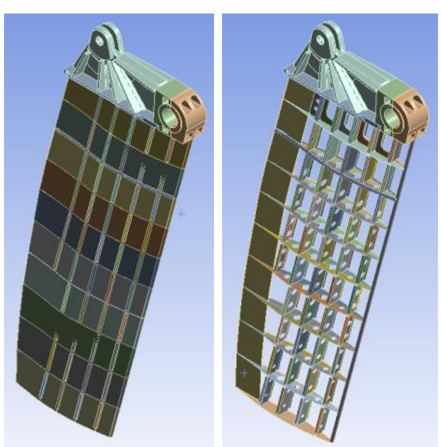


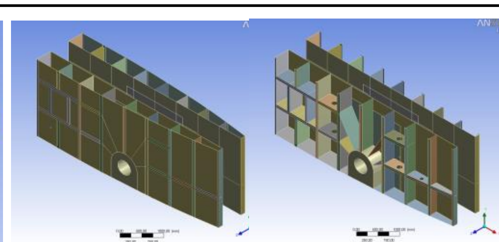




Structural error: $E_S = \frac{\| f_{exact} - f_{numeric} \|}{\| f_{exact} \|}$

Keel – Hull structure connection



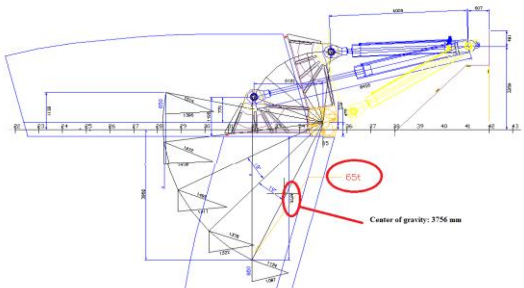


According to ABS rules:
Assumed load : weight of the keel below the section of the keel under consideration acting at its centre of gravity

Allowable stress: $0.5\sigma_y$ - primary stress

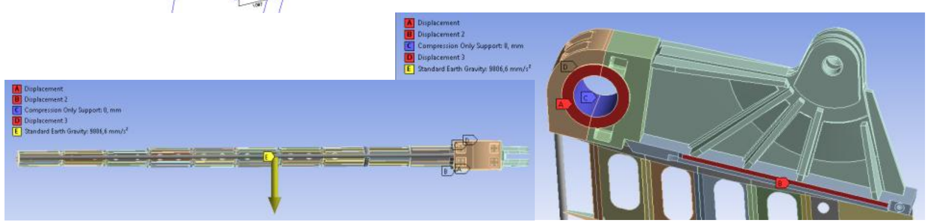
Keel – Hull structure connection

Loads and boundary conditions:



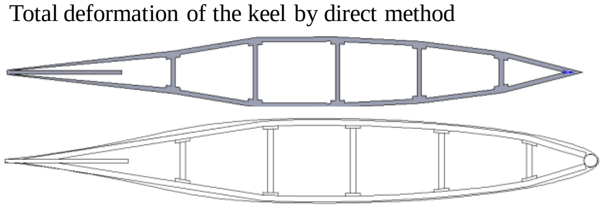
Load: 65 tons in the centre of gravity – data obtained by Perini Navi

Boundary conditions:
- Pin – simulation with compression only support
- Displacement supports A – B in z direction and D in y direction



Keel – Hull structure connection

Total deformation of the keel by direct method



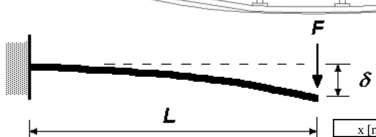
I=3220628979 mm^4

A=204731 mm^2

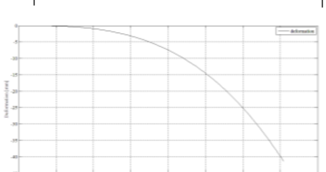
E=71000 N/mm^2

$$\delta = \frac{FL^3}{3EI}$$

$$\delta = 41.38\ mm$$



$$\sigma = \frac{M \cdot z}{I} \qquad M = F \cdot x$$



x [m]0	3544	3344	3144	2944	2744	2544
M [Nmm]	2259831600	2132301600	2004771600	1877241600	1749711600	1622181600
σ [N/mm²]	136,83	129,10	121,38	113,66	105,94	98,22

x [m]	2344	2144	1944	1744	1544	1344
M [Nmm]	1494651600	1367121600	1239591600	1112061600	984531600	857001600
σ [N/mm²]	90,50	82,78	75,05	67,33	59,61	51,89

x [m]	1144	944	744	544	344	144
M [Nmm]	729471600	601941600	474411600	346881600	219351600	91821600
σ [N/mm²]	44,17	36,45	28,72	21,00	13,28	5,56

Keel – Hull structure connection

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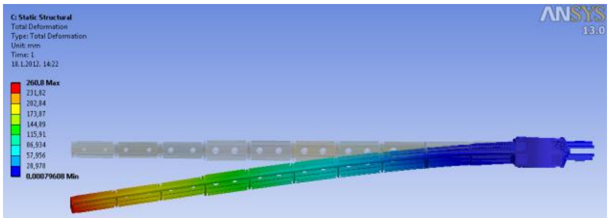
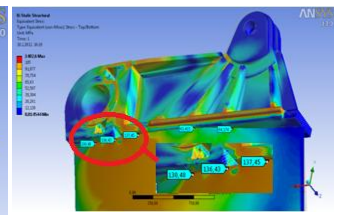
Total deformation obtained by numerical calculation:



Total deformation:
$\delta = 260.8\ mm$
Deformation in the centre of gravity (numerical calculation)
$\delta = 74\ mm$
Deformation (direct method)
$\delta = 41.38\ mm$



Keel – Hull structure connection

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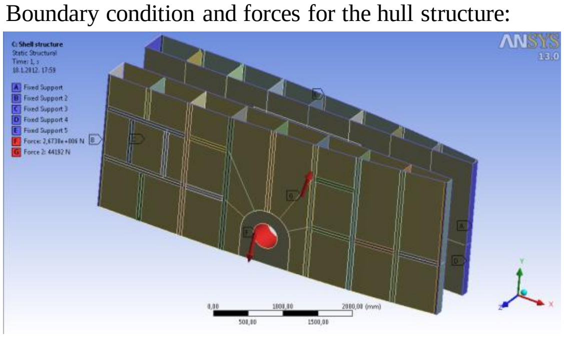
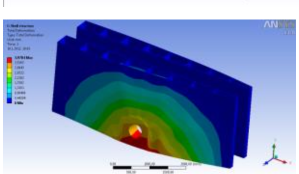
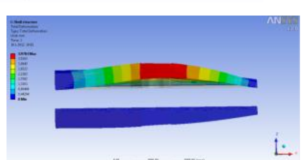
Boundary condition and forces for the hull structure:



Boundary conditions:
- Force – transmitted forces from the keel structure
- Fixed supports A , B, C, D and E – constrain all degrees of freedom





Total deformation is less then 4 milimeters.

Keel – Hull structure connection

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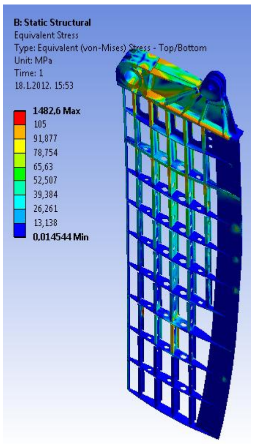
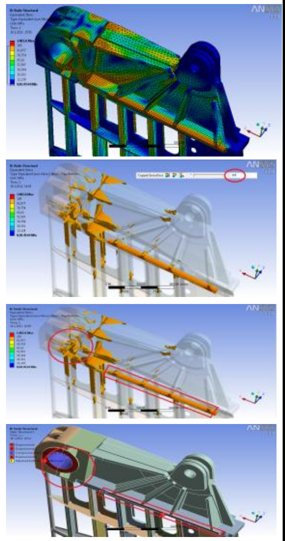
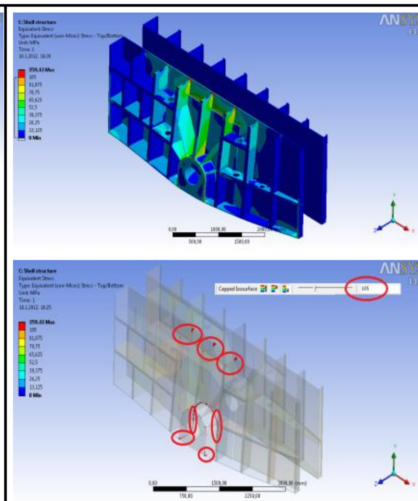
Results – Von-Mises:







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Keel – Hull structure connection

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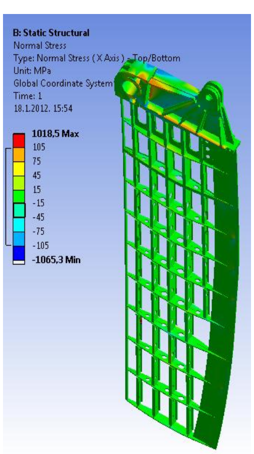
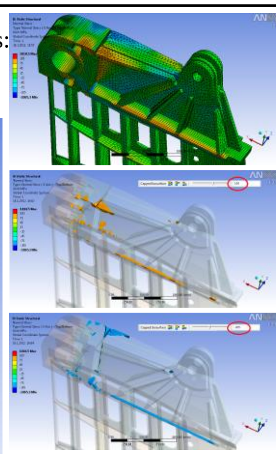
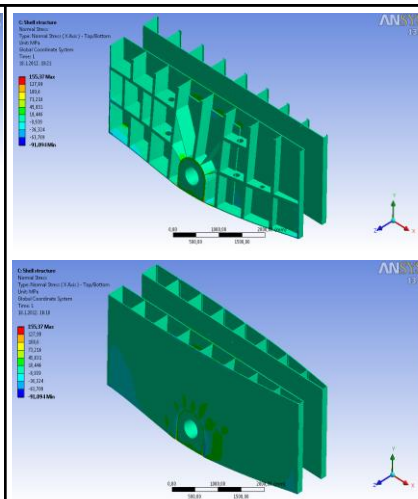
Results – Normal stresses:







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Keel – Hull structure connection

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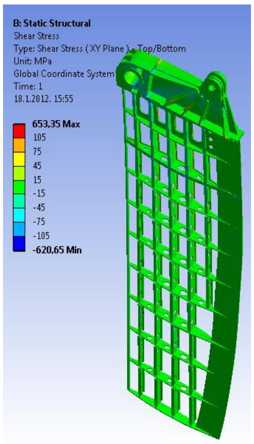
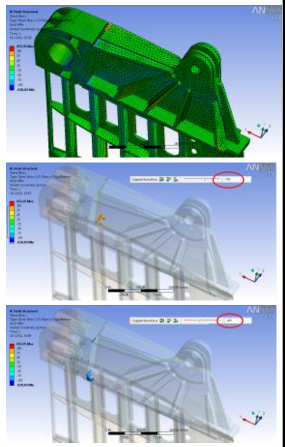
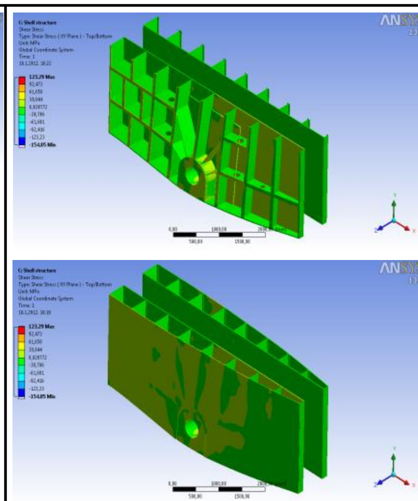
Results – Shear stresses:







Conclusion

PERINI NAVI

Many advantages of the aluminum compared with steel

The most important advantage is corrosion resistance

Finite element method is very powerful tool for solving structural problems

Very easy to operate with ANSYS Workbench

Mesh has the most important influence on the results

Shell elements are better then solid elements

Stresses around boundary condition not to take into a consideration

For result analysis, experience of the engineer is the most important

Engineer should check results using different method

Computer is an instrument for our work and it can't substitute our knowledge and experience

Thank you for your attention