Ship Structure Optimization Using CAD/FEM Integration

Amirouche Amrane, JD Caprace, Philippe Rigo
ANAST, University of Liege, Belgium

ABSTRACT

In ship structural design, scantling optimization using mathematical algorithms is not yet largely implemented in industry. Optimization with mathematical algorithms can be very helpful to find the best solution (minimum weight, minimum cost, maximum inertia,…). Typically, finite element analysis (FEA) tools are used in ship structural assessment. But, to build a FEM model from a CAD one is not easy. It needs a big amount of manual work. In the present work, an innovative optimization workflow was developed. The following steps are carried automatically without any manual intervention. First, from the 3D CAD model, an idealized CAD model is created by the idealization module to take into account the FEM needs. Then, the idealized CAD model is transferred to the FEM tool. After that, the FEM model is meshed and loaded. After FEM solving, the results (stress, displacement, volume etc.) are transferred to the optimizer. The optimizer evaluates the values of the objective function and the constraints previously defined and modify the design variables (plate thickness and the stiffener scantling) to create a new structural model. After several iterations, the optimum solution is evaluated.

KEY WORDS

Ship Structures, BESST, Optimization, CAD, FEM, AVEVA Marine, ANSYS, ModeFrontier

INTRODUCTION

The optimization process developed on the present work is presented on the following steps (Figure 1). The 3D CAD model is transferred from the CAD software to the idealization module. The idealization module will generate a simplified geometry which belongs to the FEM needs and then the idealized CAD model is transferred to the FEM tool to create a meshed and loaded structural model. After solving, the results (stress, displacement, volume etc.) are transferred to the optimizer.

The optimizer evaluates the values of the objective function and the constraints previously defined and modify the design variables (plate thickness and the stiffener scantling) to create a new structural model. After FEM solving, the results (stress, displacement, volume etc) are transferred again to the optimizer.

AVEVA Marine is used as CAD software. The idealizer was developed by AVEVA (Bohm 2010), (Doig 2009, 2010). ANSYS is used as FEM software and ModeFrontier software is the optimization platform.

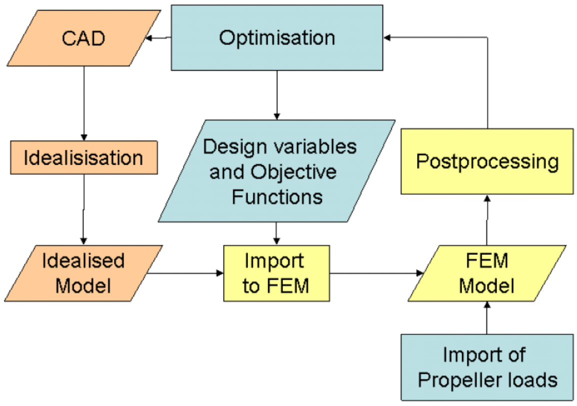

Figure 1: Optimization workflow (Bohm 2010)

FIRST APPLICATION: double bottom structure

The scantling optimization of a typical ship double bottom structure is achieved (Figure 2). Structural and geometrical requirements are imposed. The double bottom structure is considered clamped on one edge and moment of 100000 kNm is applied on the opposite edge. A constant pressure of 0.01 N/mm^2 acts on the underside of the bottom shell (i.e. the pressure acts in the +z direction). A constant pressure of 0.005 N/mm^2 acts on the side shell (Figure 3). The dimensions of the structure are presented on Table 1.

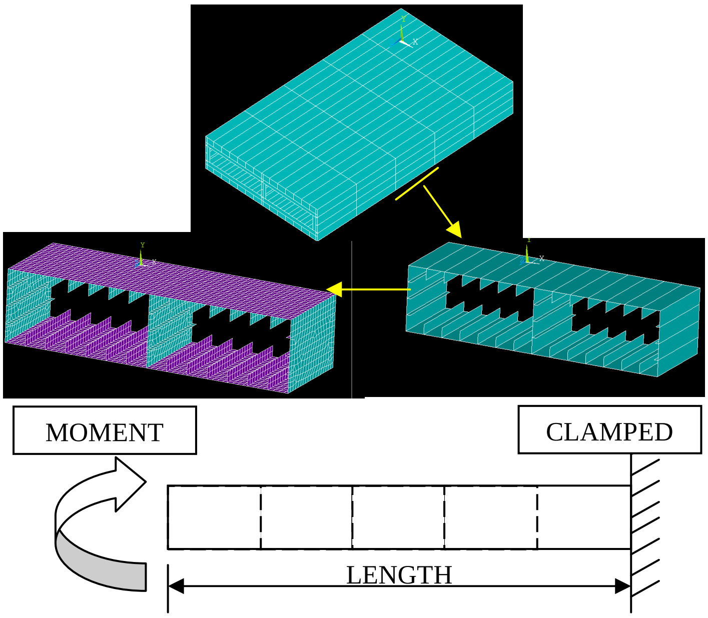

Figure 2: double bottom structure

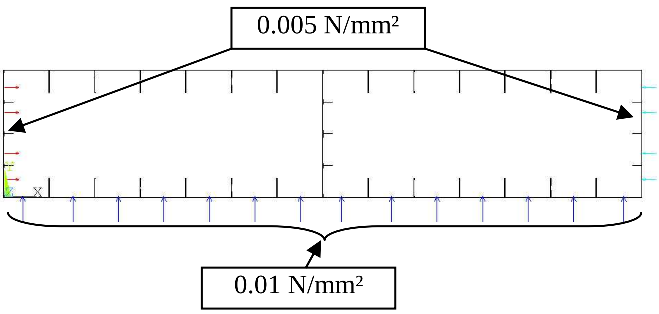

Figure 3: Pressures

Variable (mm)	symbol	value
BREADTH	BREADTH	10180
HEIGHT	HEIGHT	20210000
LENGTH	LENGTH	17800
Young's modulus (MPa)	Young's modulus	210 000
Poisson ratio	Poisson ratio	0.33
Frame spacing	FR_SPACING	3560
Web height of bottom stiffeners	HW_B	430
Web height of double bottom stiffeners	HW_DB	430
Web height of side stiffeners	HW_S	160
Web height of bottom frames	HW_FR_B	600
Web height of double bottom frames	HW_FR_DB	600
Web height of side frames	HW_FR_S	400
Number of frames	N_SEC	5
number of bottom stiffeners	N_Stif_B	6
number of double bottom stiffeners	N_Stif_DB	6
number of side stiffeners	N_Stif_S	3
Web thickness of bottom stiffeners	TW_B	17
Web thickness of double bottom stiffeners	TW_DB	17
Web thickness of side stiffeners	TW_S	9
bottom plate thickness	Th_B	15
Double bottom plate thickness	Th_DB	16
side plate thickness	Th_S	13
Web thickness of bottom frames	Th_FR_B	20
Web thickness of double bottom frames	Th_FR_DB	20
Web thickness of side frames	Th_FR_S	20

Table 1: Dimensions of the double bottom structure

The design variables and their limits are presented on Table 2. The minimum weight (volume) optimization is done. Maximum Von Mises stress is constrained to 235MPa.

Some geometrical constraints are imposed:

- Web thickness of frames less than the double of the plate thickness
- Web thickness of stiffeners less than the double of the plate thickness
- the plate thickness less than the double of web thickness of stiffeners
- Web height of the frames greater than the web height of stiffeners

Additionally, equality constraint applied to impose the same number of stiffeners on the bottom and double bottom areas.

The optimization workflow developed built with ModeFrontier software is presented in Figure 4. The design variables are defined on the top. The optimization is done by using the SIMPLEX algorithm, Murty (1983). ModeFrontier offers the possibility to use discrete variables and also to use values from catalogue. The stiffeners are bulb profiles. They are defined by an index witch correspond to the dimensions from the catalogue.

Designs variables			
Variable (mm)	symbol	Min	Max
Web height of bottom stiffeners	HW_B	160.0	430.0
Web height of double bottom stiffeners	HW_DB	200.0	430.0
Web height of side stiffeners	HW_S	140.0	400.0
Web height of bottom frames	HW_FR_B	320.0	960.0
Web height of double bottom frames	HW_FR_DB	320.0	1000.0
Web height of side frames	HW_FR_S	180.0	940.0
Number of frames	N_SEC	4.0	6.0
number of bottom stiffeners	N_Stif_B	5.0	7.0
number of double bottom stiffeners	N_Stif_DB	5.0	7.0
number of sisde stiffeners	N_Stif_S	1.0	3.0
Web thickness of bottom stiffeners	TW_B	9.0	17.0
Web thickness of double bottom stiffeners	TW_DB	8.5	20.0
Web thickness of side stiffeners	TW_S	7.0	16.0
bottom plate thickness	Th_B	8.0	29.0
Double bottom plate thickness	Th_DB	9.0	23.0
side plate thickness	Th_S	7.0	27.0
Web thickness of bottom frames	Th_FR_B	10.0	27.0
Web thickness of double bottom frames	Th_FR_DB	6.0	28.0
Web thickness of side frames	Th_FR_S	7.0	30.0

Table 2: Design variables

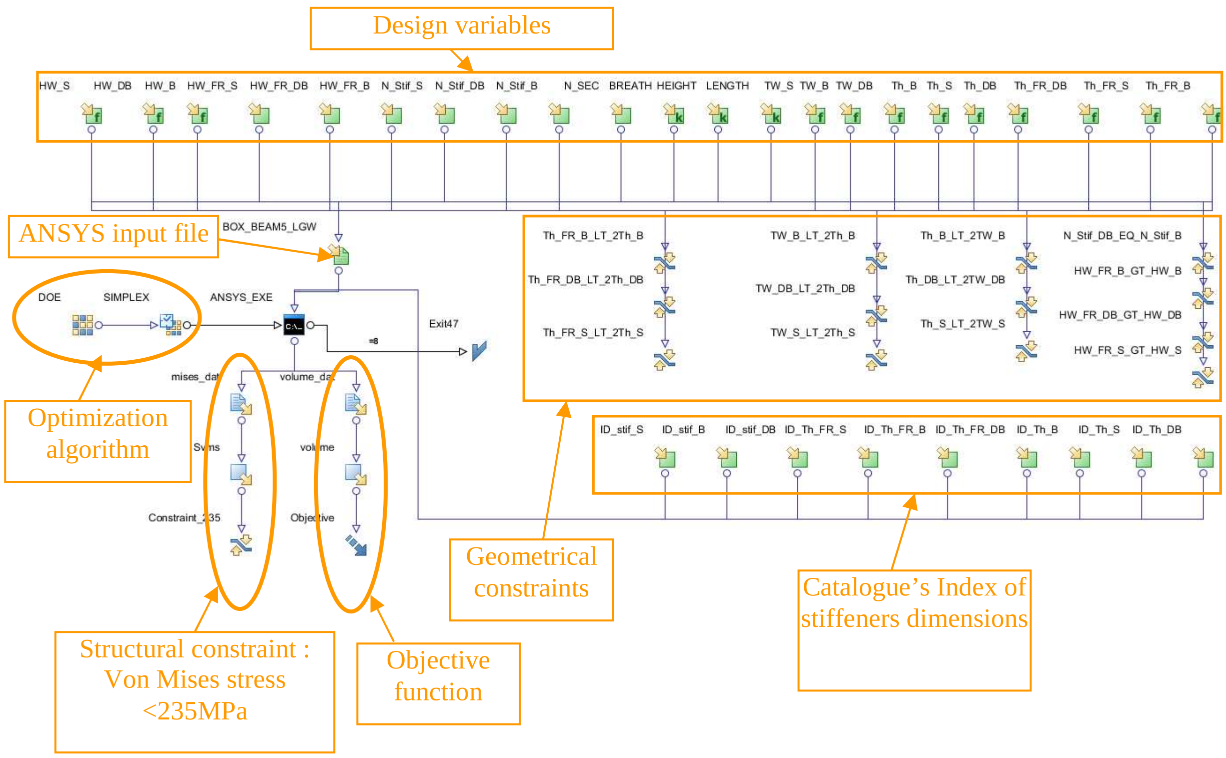

Figure 4: Optimization workflow

The optimization results are presented in Figure **5** and Figure **6**. We can see the variation of the objective function, maximum Von Mises stress, the number of frames, number of stiffeners and plate's thickness at all the areas.

The optimum is reached on the 28th iteration. The minimum value of the volume is 3.99E+09 mm³. The Von Mises stress at this iteration is 221.68 MPa (less than the limit 235MPa). All the results after optimization are presented on the Table 3.In Figure 7 and Figure 8 are plotted some comparisons between the initial design and the optimized one.

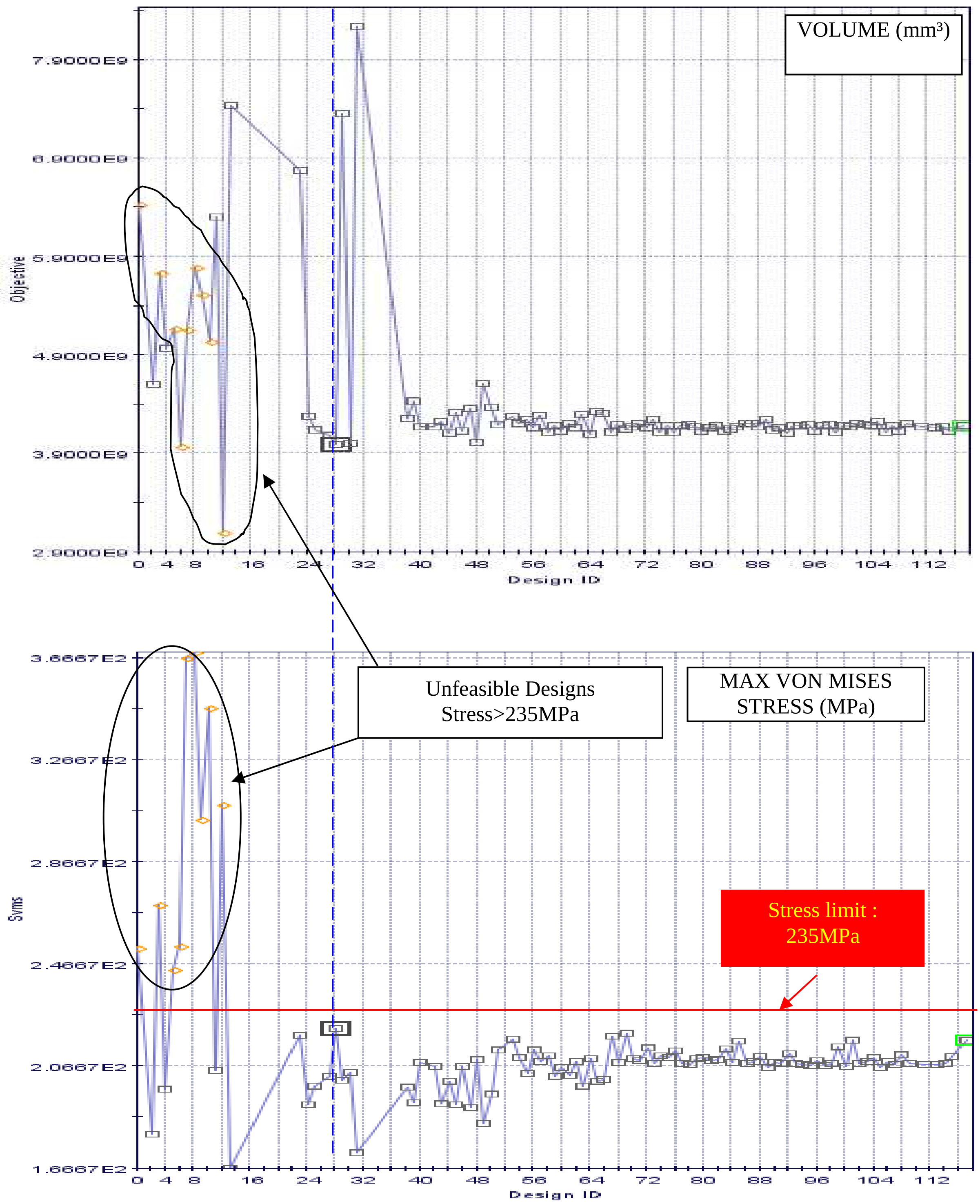

Figure 5: Optimization results: objective function and constraint

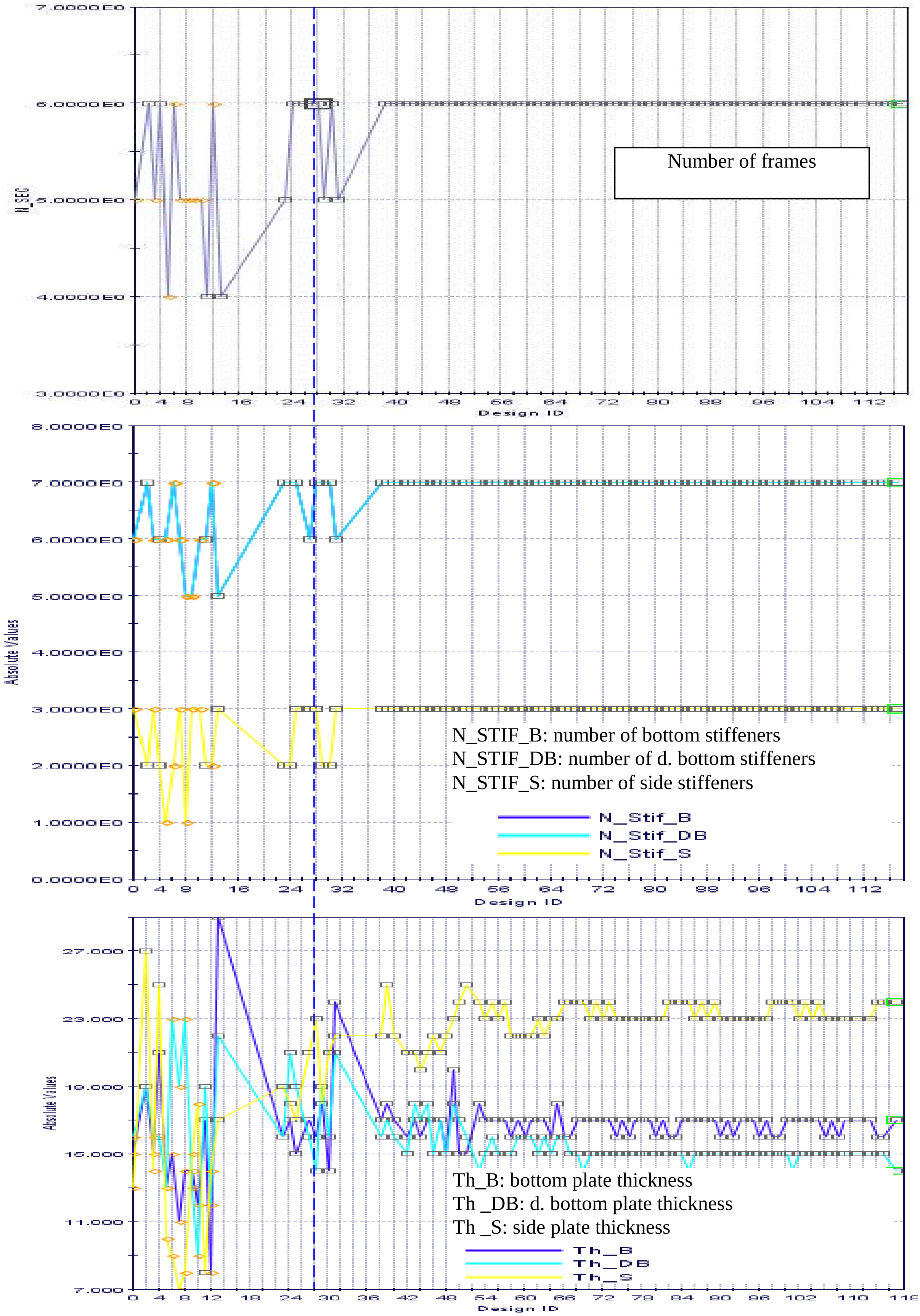

Figure 6: Optimization results: plate thicknesses and number of frames and stiffeners

Optimization results			
	initial	optimum	%
volume	6.43E+09	3.99E+09	38%
Maximum Von Mises stress	253.24	221.68	12%
Designs variables (mm)			
Web height of bottom stiffeners	370	260	-30%
Web height of double bottom stiffeners	430	260	-40%
Web height of side stiffeners	160	370	131%
Web height of bottom frames	600	480	-20%
Web height of double bottom frames	600	820	37%
Web height of side frames	400	800	100%
Number of frames	5	6	20%
number of bottom stiffeners	6	7	17%
number of double bottom stiffeners	6	7	17%
number of sisde stiffeners	3	3	0%
Web thickness of bottom stiffeners	15	10	-33%
Web thickness of double bottom stiffeners	17	11	-35%
Web thickness of side stiffeners	9	14	56%
bottom plate thickness	15	16	7%
Double bottom plate thickness	16	14	-13%
side plate thickness	13	23	77%
Web thickness of bottom frames	20	15	-25%
Web thickness of double bottom frames	20	11	-45%
Web thickness of side frames	20	19	-5%

Table 3: Optimization results

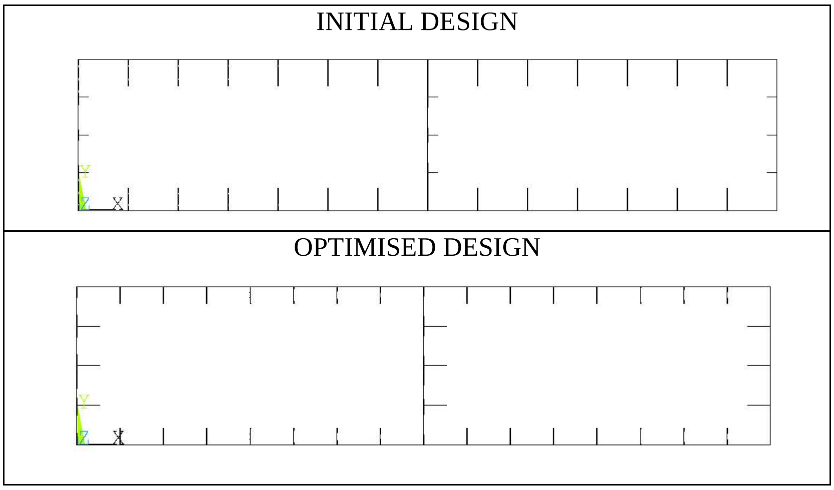

Figure 7: Initial and optimized cross section

INITIAL DESIGN	OPTIMISED DESIGN

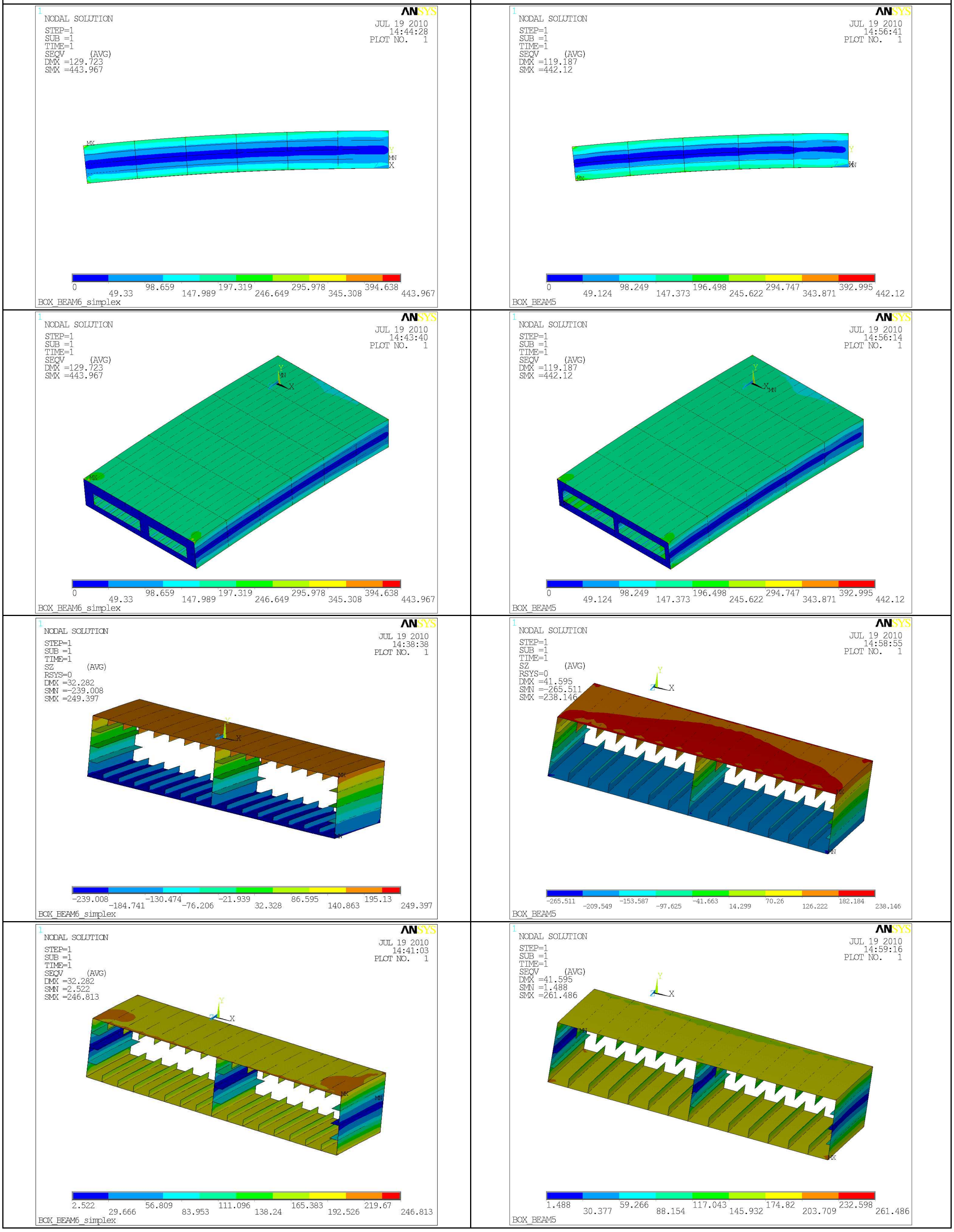

Figure 8: Initial and optimized ANSYS models

SECOND APPLICATION: DECK STRUCTURE

The model studied is a deck structure shown in Figure 9. The structure is constituted by deck Plate, longitudinal girders, transversal frames, longitudinal stiffeners and two longitudinal walls connected to the deck structure. The boundary conditions are presented on Figure 9.
The initial scantling is defined on Table 4.

The Young's modulus E =2.060x10^5 MPa and the Poisson ratio is 0.33.

Element	symbol	Value (mm)
Longitudinal girders: flange width	GR_BF	300
Longitudinal girders: web height	GR_HW	600
Longitudinal girders: flange thickness	GR_TF	10
Longitudinal girders: web thickness	GR_TW	5
Transversal frames: flange width	db_BF	180
Transversal frames: web height	db_HW	300
Transversal frames: flange thickness	db_TF	10
Transversal frames: web thickness	db_TW	5
Deck thickness	Deck_thickness	10
Longitudinal wall thickness	Thick_lw060002	10
Deck stiffener	deck_profile	Hp160x9
Longitudinal wall stiffener	STI_lw060002	Hp180x8

Table 4: Initial geometry

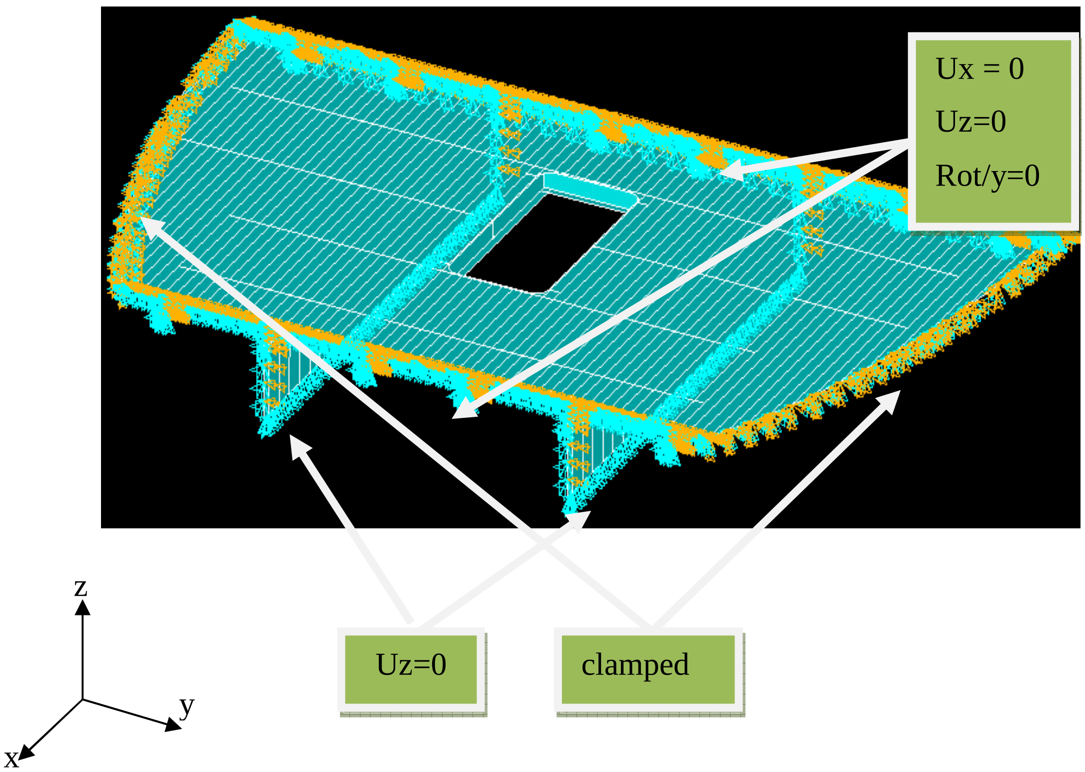

Figure 9: Deck structure (boundary conditions)

The meshed structure is showed on Figure 10 . Plate, girders and frames are modelled with shell elements. The longitudinal stiffeners are modelled with beam elements.

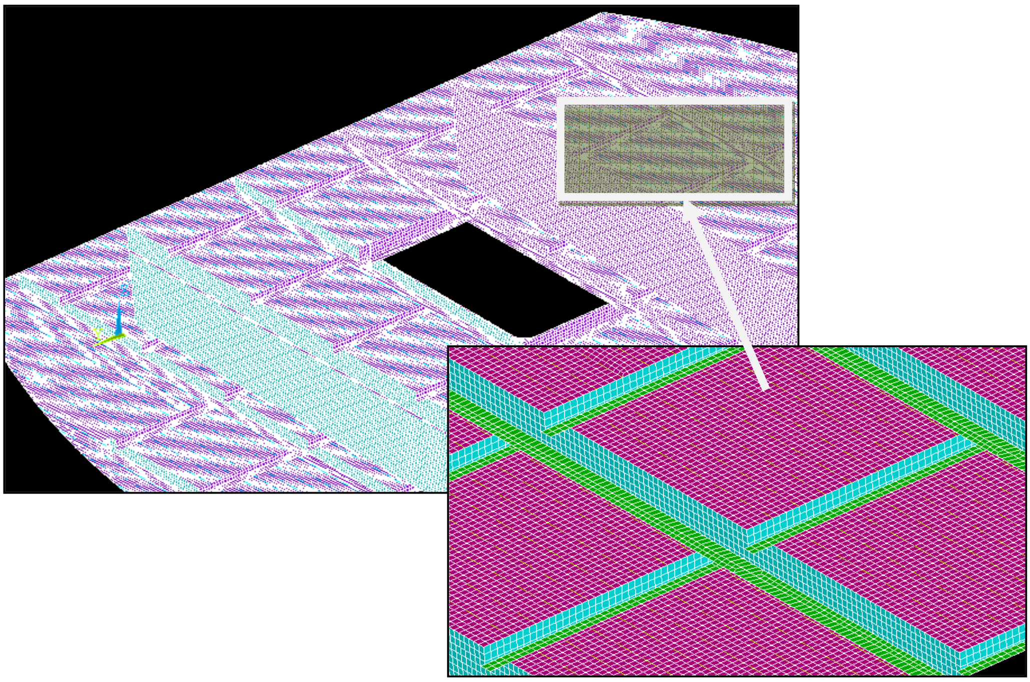

Figure 10: mesh

The following, the design variables are considered:

- Plate thickness
- Longitudinal girders : web height and thickness, flange breath and thickness
- Transversal frames : web height and thickness, flange breath and thickness
- Longitudinal stiffeners profile

The maximum and minimum dimensions allowed are presented on Table 5. The values of plate thicknesses and stiffeners profiles are taken from catalogues.

	Min (mm)	Max (mm)
Longitudinal girders: flange width	50	700
Longitudinal girders: web height	200	1000
Longitudinal girders: flange thickness	5	40
Longitudinal girders: web thickness	5	40
Transversal frames: flange width	60	180
Transversal frames: web height	200	1000
Transversal frames: flange thickness	5	40
Transversal frames: web thickness	5	40
Deck thickness	5	40
Longitudinal wall thickness	5	40
Deck stiffener	Hp60x4	Hp430x17
Longitudinal wall stiffener	Hp60x4	Hp430x17

Table 5: design variables limits

The volume of the structure is defined as the objective function to minimize. As a constraint, the maximum stress is imposed to be less than 235 MPa.

The optimization workflow is shown in Figure 11.

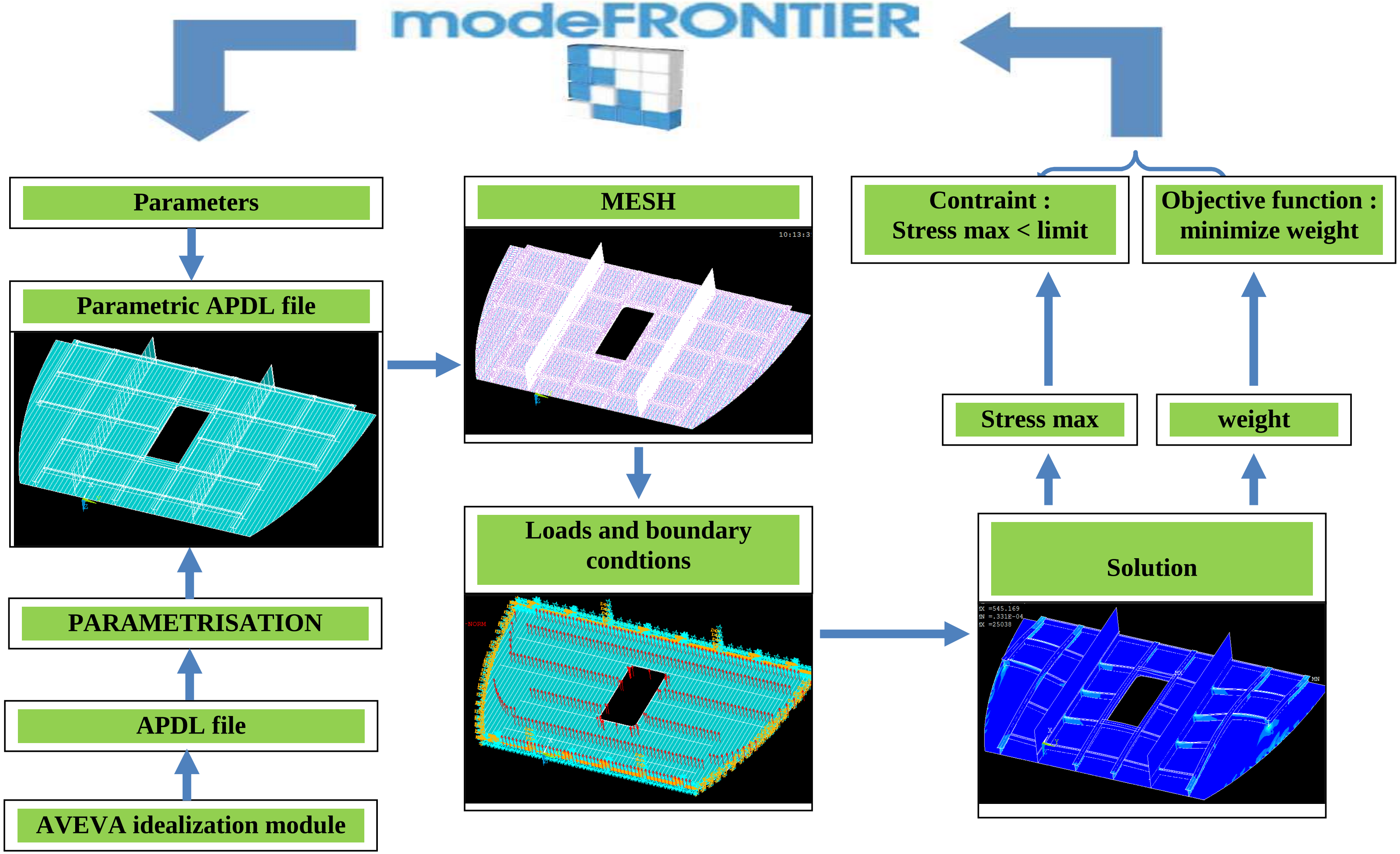

Figure 11: Optimization process

The optimization results are presented in Figure 12 and Figure 13 . We can see the variation of the objective function and maximum Von Mises stress. The optimum is reached on the 278th iteration. The minimum value of the weight is 95.5x10³ kg. The Von Mises stress at this iteration is 225.4 MPa.

For a comparison, additional to the initial design, the results of two other iterations are plotted. On the iteration 266, we have the minimum value of the weight 946 kN. This value is lower than optimum solution but the stress here is bigger than the limit (244.3MPa). The principal difference between these two designs is the longitudinal girders web height. So, this solution is not feasible.

Another iteration is plotted (iteration 10). It represents the case of maximum weight. On Table 6, we can see the values of the design variables on the iterations 10, 266 an 278.

Iteration	Initial geometry	10	266	278
Longitudinal girders: flange width	300	450	600	600
Longitudinal girders: web height	600	1000	550	650
Longitudinal girders: flange thickness	10	6	7	6
Longitudinal girders: web thickness	5	22	8	8
Transversal frames: flange width	180	120	100	100
Transversal frames: web height	300	750	250	250
Transversal frames: flange thickness	10	40	15	11
Transversal frames: web thickness	5	27	5	5
Deck thickness	10	30	6	6
Longitudinal wall thickness	10	26	6	7
Deck stiffener	Hp160x9	hp370x14	hp220x9	hp220x9
Longitudinal wall stiffener	Hp180x8	hp220x9	hp400x14	hp400x14
Total weight (kN)	**1106**	**2851**	**946**	**955**
Maximum stress (MPa)	**341.1**	**59.7**	**244.3**	**225.4**

Table 6: Optimization results

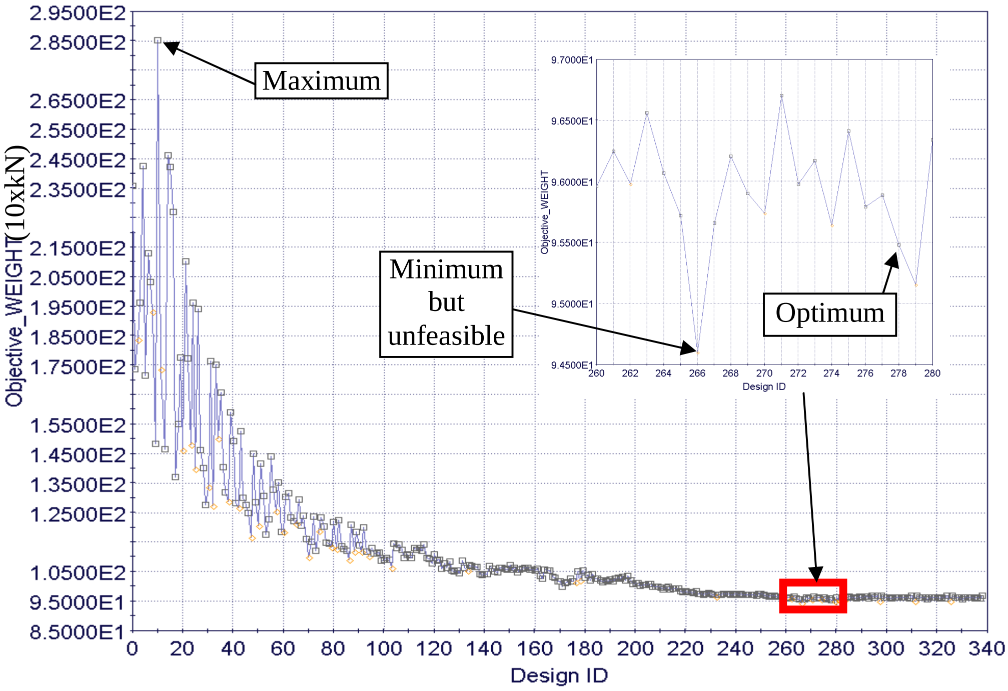

Figure 12: Total weight variation

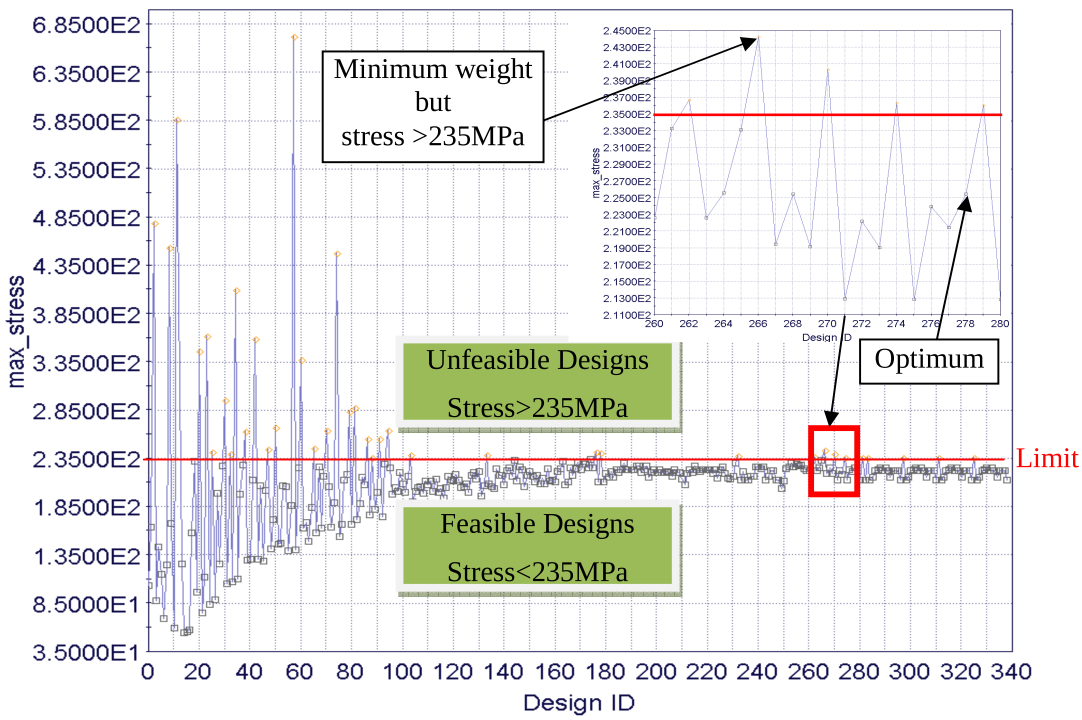

Figure 13: Maximum strength variation

CONCLUSIONS

The present work has been done in the framework of the European BESST Project. The challenge was to develop an innovative structural optimization workflow. So, from a 3D CAD model, FEM model can be created automatically and the FEM results can be used by an optimization algorithm to evaluate an optimum solution. So, a solution is proposed and applied for two examples.

A remaining work is to improve the optimization process by adding more structural constraints (fatigue, buckling, vibration...) and considering other or additional objective functions (minimum cost, maximum inertia,…) to get real feasible optimum solution.

REFERENCES

Bohm M., “Interconnection of Rules based CAD Idealization for Ship Structures to ANSYS”, *ANSYS Conference & 28. CADFEM Users´ Meeting*, Aachen, 2010

Doig R., Bohm M., Stammer J., Hernandez P., Griesch S., Kohn D. and Nilsson, P-O “Reducing Time and Effort for Structural Design and Assessment”, *Proceedings of the International Conference on Computer Applications in Shipbuilding*, p.39-42, Shanghai, China, 2009

Doig R., Bohm M. “Simulation-Based Structural Design of Ships”, *Proceedings of 11th International Symposium on Practical Design of Ships and other Floating Structures*, Rio de Janeiro, Brasil, 2010

Murty, Katta G. “Linear programming”. *New York: John Wiley & Sons, Inc.*, 1983.