An Optimisation Methodology for Ship Structural Design using CAD/FEM Integration

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Abstract

In ship structural design, scantling optimisation using mathematical algorithms is not yet largely implemented in industry. Optimisation with mathematical algorithms can be very helpful to find the best solution (minimum weight, minimum cost, maximum inertia,etc.). 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 optimisation 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 optimiser. The optimiser 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.

1. Introduction

The optimisation process developed on the present work is presented on the following steps, Fig.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 optimiser.

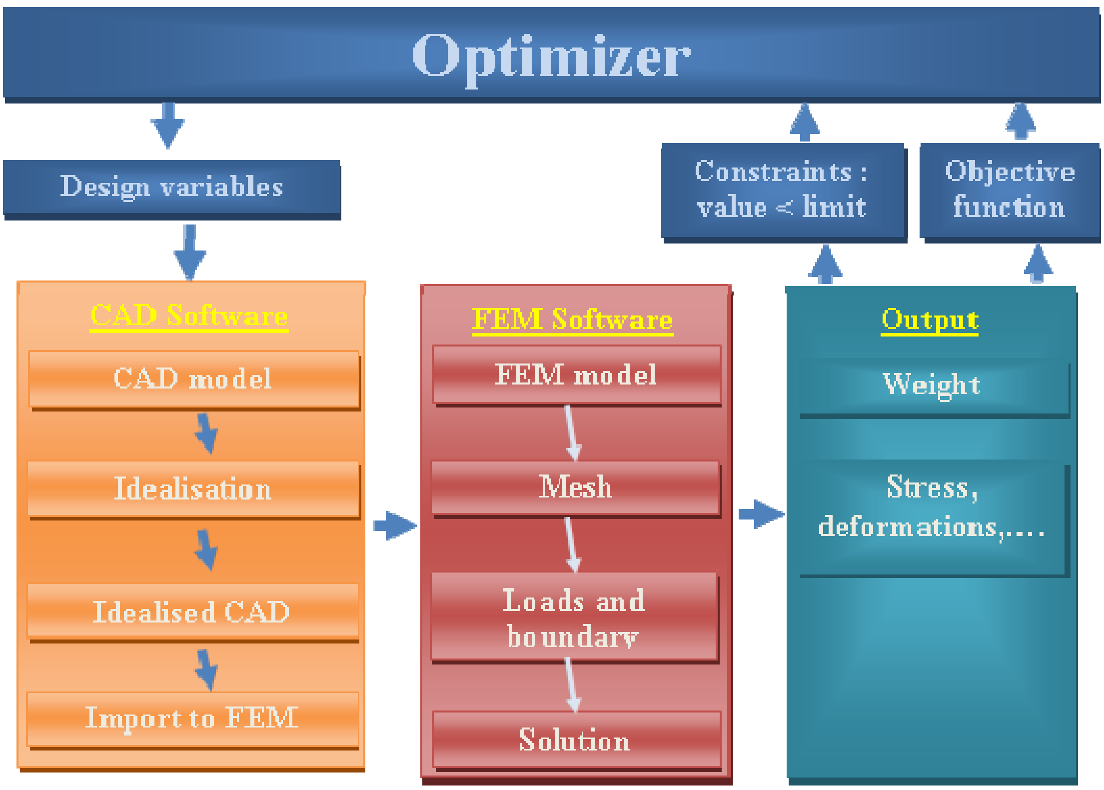

Fig. 1: Optimisation workflow

The optimiser 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 optimiser.

AVEVA Marine, *Bohm (2010), Doig et al. (2009), Doig and Bohm (2010)*, and FORAN are used as CAD software. An idealized geometry is created and transferred to ANSYS (FEA tool) to build the FEM model. For the optimisation process, modeFRONTIER is used. This platform has a full library of algorithms for both single and multi-objective optimisation and allows easy coupling to ANSYS. As a case study, the scantling optimisation is performed for a typical deck structure for local optimisation. Structural and geometrical requirements are imposed.

2. Description of the case study: Deck structure

The model studied is a deck structure shown in Fig.2. 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 in Fig.2. A lateral pressure of 0.2 MPa is applied on the deck. The initial scantlings are defined in Table I. The Young's modulus E = 2.060·10^5 MPa and the Poisson ratio is 0.33.

Table I: Initial geometry

Element	[mm]	Element	[mm]
Longitudinal girders: flange width	300	Transversal frames: flange thickness	10
Longitudinal girders: web height	600	Transversal frames: web thickness	5
Longitudinal girders: flange thickness	10	Deck thickness	10
Longitudinal girders: web thickness	5	Longitudinal wall thickness	10
Transversal frames: flange width	180	Deck stiffener	Hp160x9
Transversal frames: web height	300	Longitudinal wall stiffener	Hp180x8

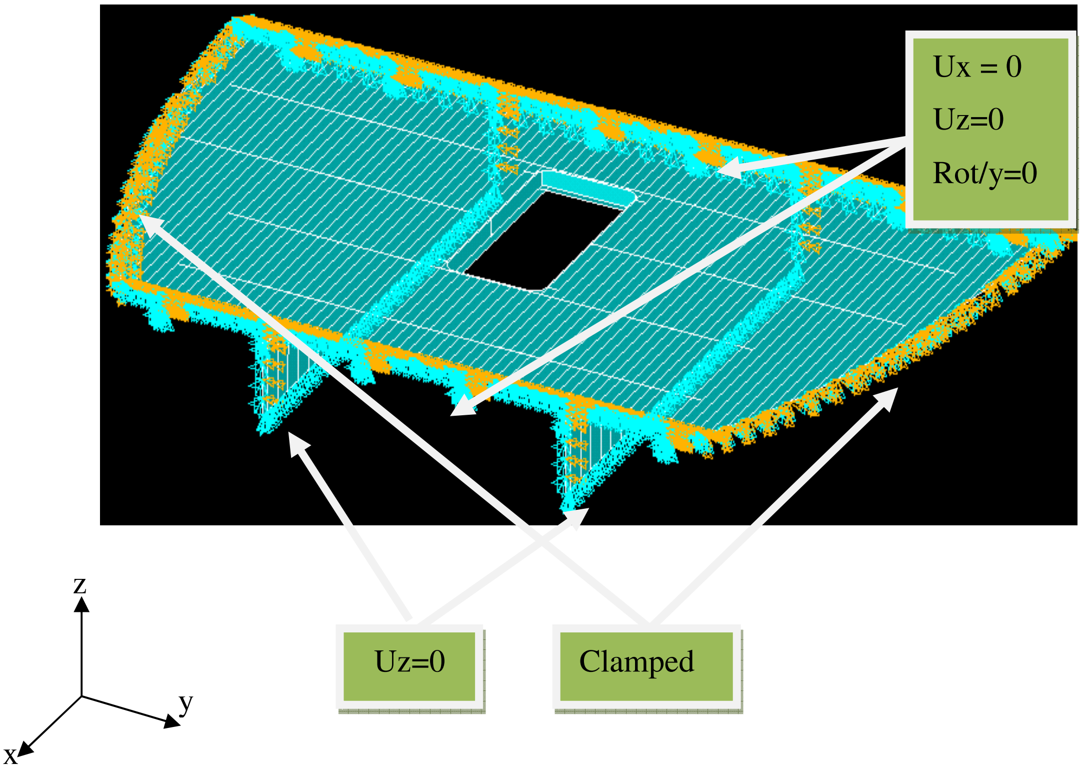

Fig. 1: Deck structure (boundary conditions)

Fig.3 shows the meshed structure. Plate, girders and frames are modelled with shell elements. The longitudinal stiffeners are modelled with beam elements.

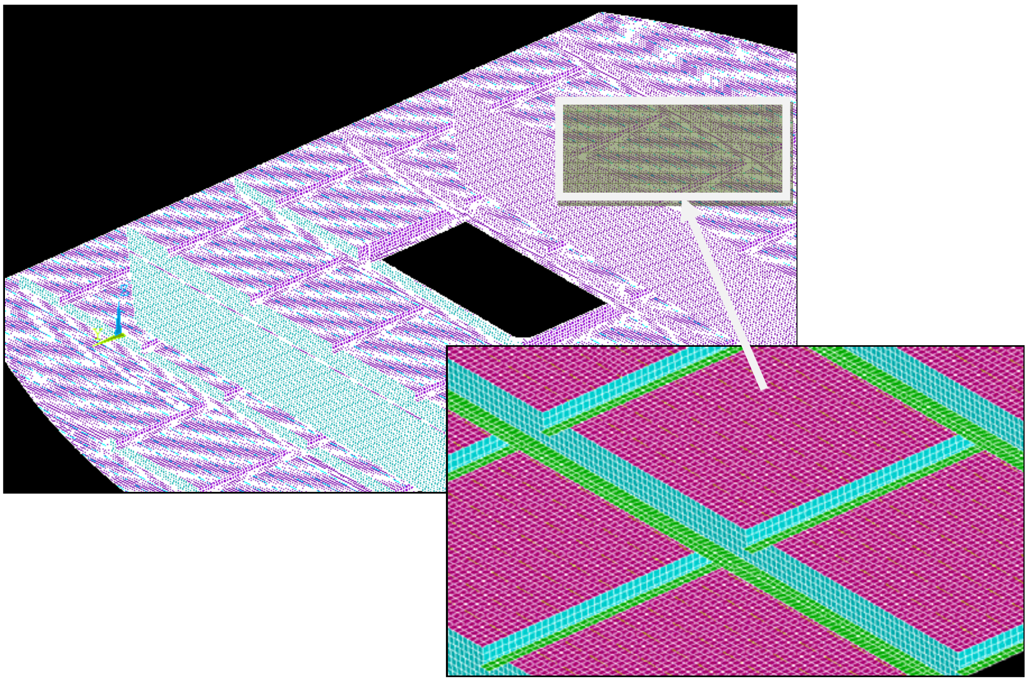

Fig. 2: Mesh

The following 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: web height and thickness, flange breath and thickness
- Number of stiffeners between girders

Maximum and minimum dimensions allowed are presented in Table II. The values of plate thicknesses and stiffeners profiles are taken from catalogues.

Table II: Design variable limits

	Min (mm)	Max (mm)
Longitudinal girders: flange width	50	500
Longitudinal girders: web height	200	1000
Longitudinal girders: flange thickness	5	40
Longitudinal girders: web thickness	5	40
Transversal frames: flange width	50	500
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
Number Deck stiffener between girders	5	15
Deck stiffener	Hp60x4	Hp430x17
Longitudinal wall stiffener	Hp60x4	Hp430x17

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. 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

Optimisation results are presented in Figs. 4 and 5. We can see the variation of the objective function and maximum Von Mises stress. The optimum is reached on the 210th iteration. The minimum value of the weight is 83661.9 kg. The Von Mises stress at this iteration is 220.4 MPa.

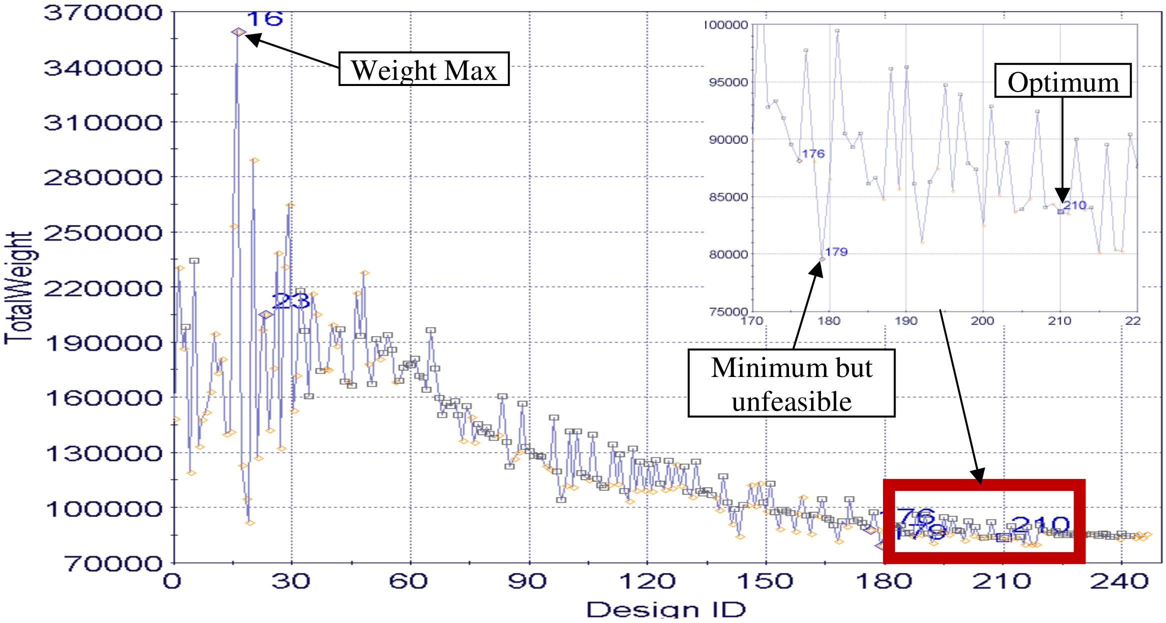

Fig. 3: Total weight variation

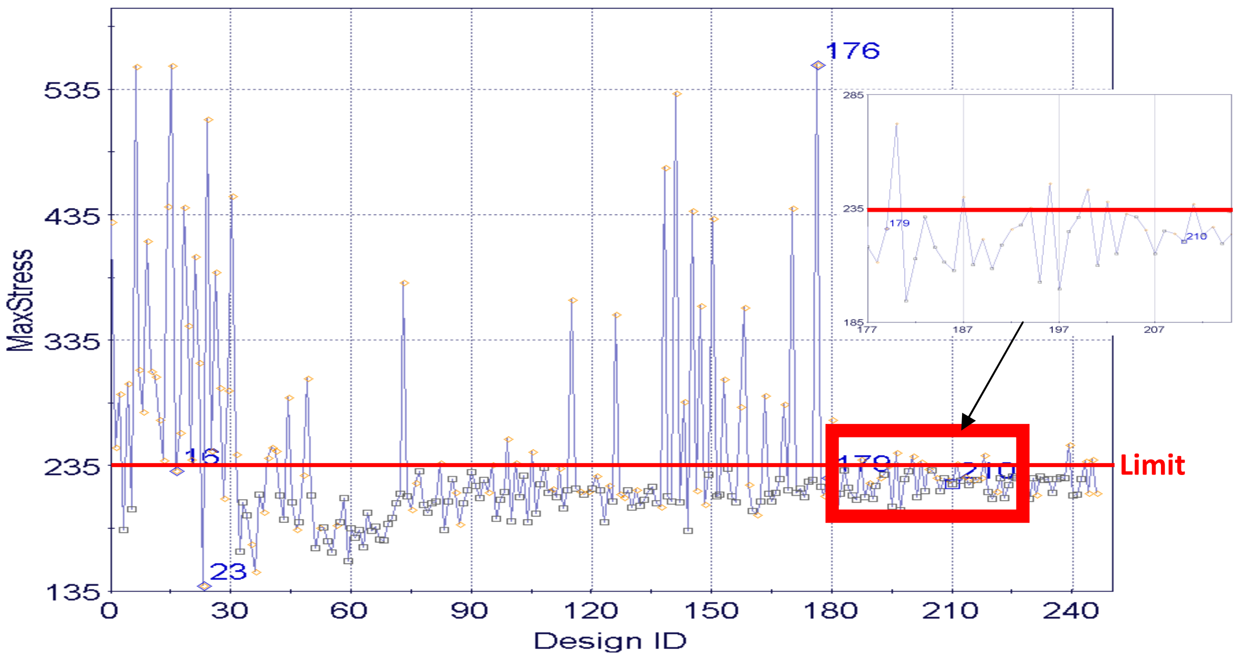

Fig. 4: Maximum stress variation

For a comparison, additional to the initial design, the results of other iterations are plotted. On the iteration 279, we have the minimum value of the weight 79589.2 kg. This value is lower than optimum solution but even if the level of the maximum stress here is lower than the limit (226.2MPa) but one geometrical constraint (Web thickness of stiffeners less than the double of the plate thickness) is not respected, see Fig.6. So, this solution is not feasible.

On iteration 16, the weight becomes maximum. The plate thickness (39 mm), the number (14) and dimensions (hp430x20) of deck longitudinal stiffeners are maximum compared to the other iterations, Figs.7 and 8. Iterations 23 and 179 give the designs with the minimum and maximum level of stress. Table III, in addition to the initial design, gives the values of the design variables on iterations 16, 23, 176, 179 and the optimum 210.

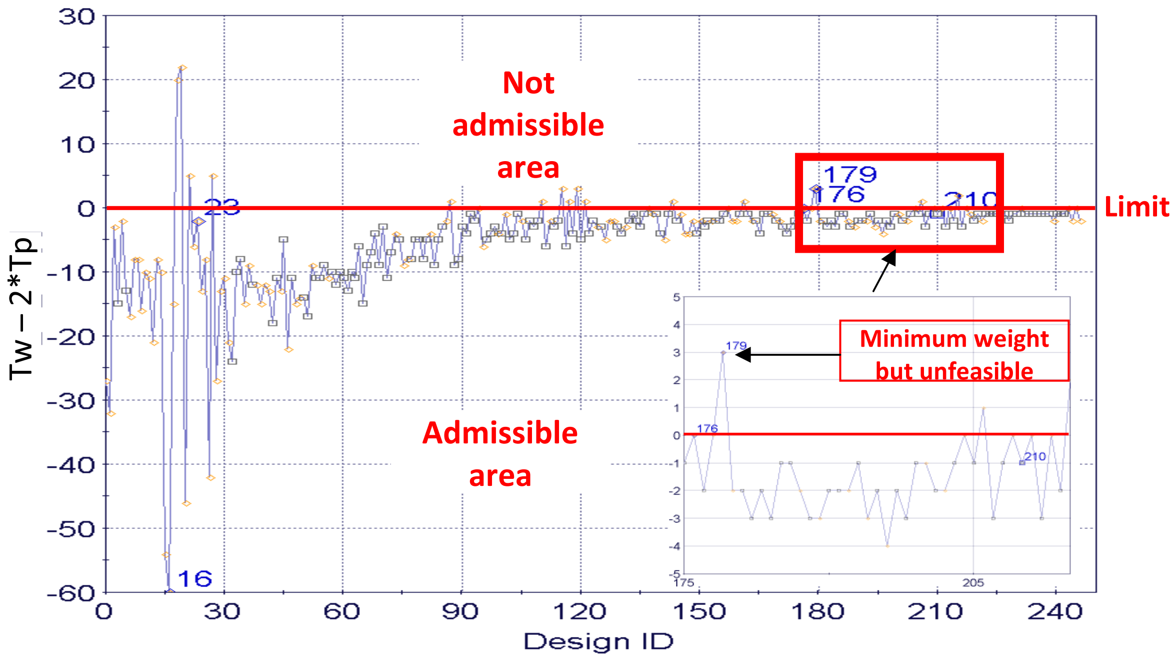

Fig. 5: Web thickness of stiffeners minus the double of the plate thickness

Table III: Optimisation results

	Init. Geom.	16	23	176	179	210
Deck stiffener web height	180.0	430.0	320.0	80.0	80.0	80.0
Deck stiffener web thickness	11.5	20.0	13.0	7.0	6.0	6.0
Deck plate thickness	22.0	39.0	19.0	9.0	7.0	9.0
number of Deck stiffeners between girders	5.0	14.0	9.0	11.0	13.0	11.0
Frame web height	345.0	275.0	305.0	390.0	325.0	335.0
Frame web thickness	17.0	18.0	36.0	18.0	17.0	17.0
Frame flange width	375.0	165.0	275.0	225.0	210.0	225.0
Frame flange thickness	11.0	33.0	27.0	31.0	33.0	30.0
Girder web height	440.0	205.0	760.0	945.0	860.0	855.0
Girder web thickness	34.0	34.0	26.0	11.0	10.0	11.0
Girder flange width	255.0	125.0	445.0	495.0	500.0	480.0
Girder flange thickness	14.0	8.0	25.0	18.0	20.0	19.0
long bulkhead stiffeners web height	280.0	180.0	320.0	200.0	180.0	200.0
long bulkhead stiffeners web thickness	10.5	11.5	11.5	12.0	11.5	11.0
long bulkhead plate thickness	14.0	15.0	27.0	10.0	12.0	8.0
Constraint: TW -2*TP =	-27.0	-60.0	-2.0	0.0	**3.0**	-1.0
Constraint: MaxStress	**430.1**	231.4	140.0	**555.2**	226.2	220.4
TotalWeight	148808.3	359144.5	205599.6	88160.5	79589.2	83661.9

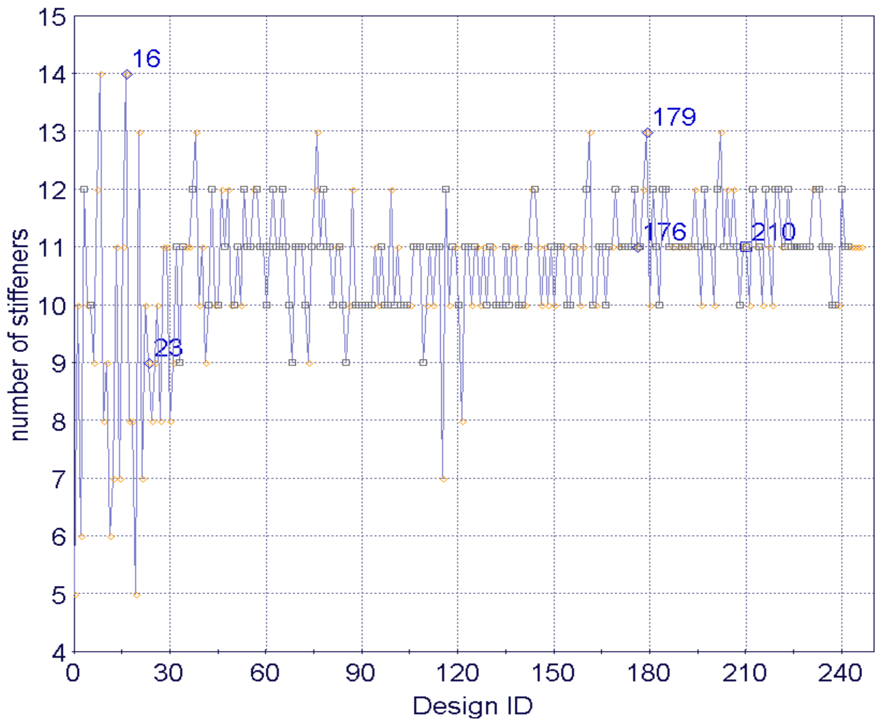

Fig. 6: Number of stiffeners between girders

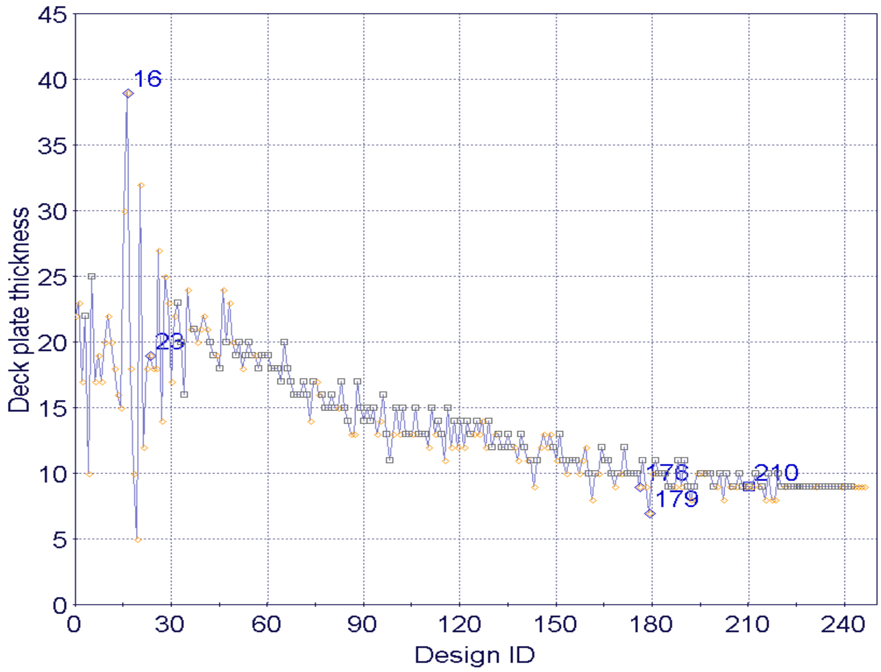

Fig. 7: Deck plate thickness variation

3. Conclusions

In the present work, the challenge was to develop an innovative structural optimisation workflow. From a 3D CAD model, a FEM model can be created automatically and the FEM results can be used by an optimisation algorithm to evaluate an optimum solution. Much effort was spent on performing a correct connection between the different modules included on the developed optimisation workflow. The case study presented is simple. The goal was to test the optimisation workflow. A remaining work is to improve the optimisation process by adding more structural constraints (fatigue, buckling, vibration...) and considering other or additional objective functions (minimum cost, maximum inertia, …) to get a realistic and feasible optimum solution.

Acknowledgements

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