A DESIGN AND OPTIMIZATION ANALYSIS ON METAL STRUCTURES

Lecturer PhD. eng. Florin CIOFU, Engineering Faculty, ”Lucian Blaga” University of Sibiu, cristian.ciofu@ulbsibiu.ro

ABSTRACT: *The design activity using the CATIA program often encounters situations in which parts families must be created. They usually have the same constructive shape, but differ in size. Also, in the design of the assemblies it is useful to create dimensional links between two or more components, so that the modification of one of them leads automatically to the modification of the other. This mode of design involves advanced knowledge of modeling, programming and management of parameters and relationships, being called parameterized assisted design.*

KEY WORDS: optimisation, variable, stress, translational, structure

1. INTRODUCTION

CATIA (Computer Aided Three dimensional Interactive Applications) is a product of the company Dassault Systemes representing one of the most advanced integrated platform type: CAD/CAM/CAE based assembly modeling on the latest technologies in the field of software industry [3].

CATIA V5 is available as from the year 1999. At the current time CATIAV5 contains more than 140 robust applications covering the following areas of electronic engineering:

- explicit hybrid parametric modeling;
- surface modeling, sheet metal;
- assembly modeling, design optimization;
- generating drawing drawings;
- design of molds and shapes;
- reverse engineering, rapid prototyping;
- analysis using finite element method;
- kinematic analysis using the virtual prototype;
- simulation of manufacturing processes;
- design of electrical parts, pipelines, heating, ventilation and air conditioning;
- translators for converting entities into / from other design environments.

Using the finite element method can solve some types of problems such as:

-Problems independent of time [4]:
    -analysis of the tensions and registering strains;
    - static analysis of structures;
    - inter-surface contact analysis;
    - temperature stress analysis;
- Problems of spreading or transition:
    -problems of fracture mechanics and fissures under dynamic loads, fatigue behavior, J-integral, cracks, crack growth;
    - the response of structures to aperiodic tasks;
- Own value problems:
    - natural frequencies and own modes of structures;

2. THEORETICAL ASPECTS

Cost, labor economy, application of new, simplified methods, use of innovative materials and environmentally friendly technologies, outstanding shapes and design; all these are fundamental features of structural optimization. New trends and research in this field have been driven in recent decades by the application of knowledge and observations obtained from the study of natural processes, organisms, structures and materials, from subatomic particles to the behavior of insects and animals, anatomy, relationships ecological of natural habitats, and then the application of this knowledge to the design of structures and the built environment [1].

The results are extracted from the careful and systematic analysis of the ways in which nature designed structures. On this basis we can develop criteria and strategies to evolve constructions in a similar way, efficiently and sustainably, finding new resources, and responding to the dynamic environment in which structures are placed. A lightweight structure requires less construction material and thus manages to ensure maximum, rational use of resources. Using optimal geometries for structures ensures their superior strength and at the same time reduces consumption and losses. In nature we find countless examples of optimization.

The honeycomb structure is an example of efficient compact arrangement. In the case of metals and alloys, atoms take the positions that require the minimum possible energy consumption by forming unit cells that define the crystal structure of the material. For pillars, optimization is not a new trend. Optimization techniques are currently used in most industrial fields, such as: aeronautical industry, automobile industry, electrical industry, chemical industry, etc. Some examples of diversified industrial applications of optimization technology are listed below [1]:

- weight, vibration, noise and optimizing fuel consumption in cars, reducing manufacturing costs and improving quality;
- design of aircraft and aerospace structures of minimum weight;
- design of structures, such as bridges, towers, dams for a minimum cost;
- optimal design of various mechanical components such as fasteners, cams, machine tools, etc ;
- optimal design of electrical networks;
- optimization of production, planning, and control, etc.

When topological optimization is performed without taking into account manufacturing restrictions, very attractive structures are often produced, but they cannot be achieved too easily. It should be noted that topological optimization rarely produces the final design, even if manufacturing restrictions are used. This is because topological optimization does not normally include stress constraints. However, it helps to identify the ways of unloading the applied forces and provides a very good starting point for shape optimization and dimensional optimization.

In the process of designing structures, in various engineering fields, designers choose the best decision-making option, at every step, related to structural and non-structural aspects, such as rigidity, strength, serviceability, aesthetic properties. In other words, they make decisions to achieve the best design, so that the structural design process can be seen as optimal design even if it does not explicitly seek to find an optimal. Structural optimization is seen as the application of optimization methods in structural design.

The typical structural optimization problem is formulated as minimizing an objective function (cost functions), usually representing the weight of the structure or its volume [1].

3. CASE STUDY

3.1. Constructive typology

For the study, a structural element of the type supporting element of a beam, embedded at the ends in the middle on which a force acts, was considered. The shape of this support element is hyperboloid, with a length of 1000 mm, a base diameter of 100 mm and a minimum diameter of 50 mm. In order to optimize the constructive form, four variants were considered: solid structure, fiber structure, longitudinal reticular structure and box structure (fig.1).

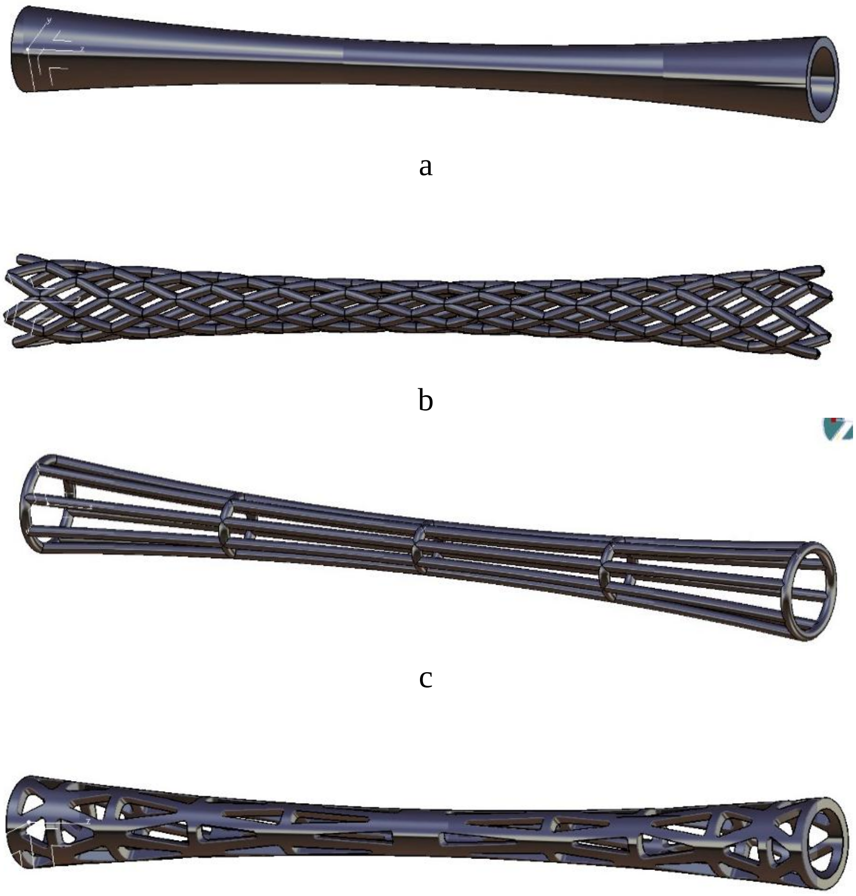


Fig.1. Constructive variants of the connecting element: a- solid structure; b - fiber structure; c - longitudinal reticular structure; d - box structure.

The material chosen for making the connecting element is aluminum, whose physical-mechanical characteristics are presented in table 1.

Table 1. Physico-mechanical characteristics of aluminum

Melting temperature	658,7 ^{o}C
Density	2,7 g/cm^3
Flow limit	12 kgf/mm^2
Allowable deformation	75 – 90%
Hardness	30 – 35 HB
Tensile strength	15 kgf/mm^2

3.2. FEM analysis

In order to simulate real working conditions of the connecting element, the CATIA Generative Structural Analysis module was used. The connecting element was considered to be embedded on both ends by acting with a force on its middle (fig.2). Initially the pressing force was charged to the value of 100 N after which it increased to 200 N.

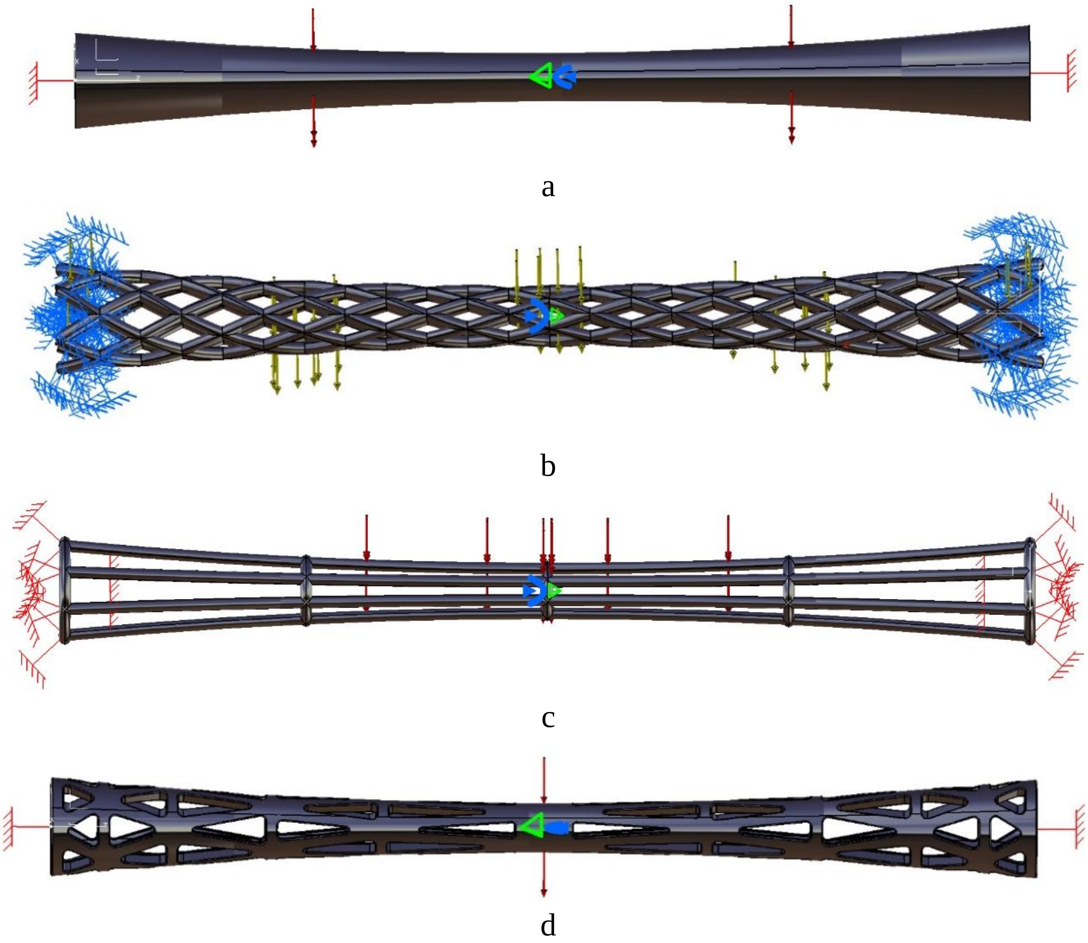
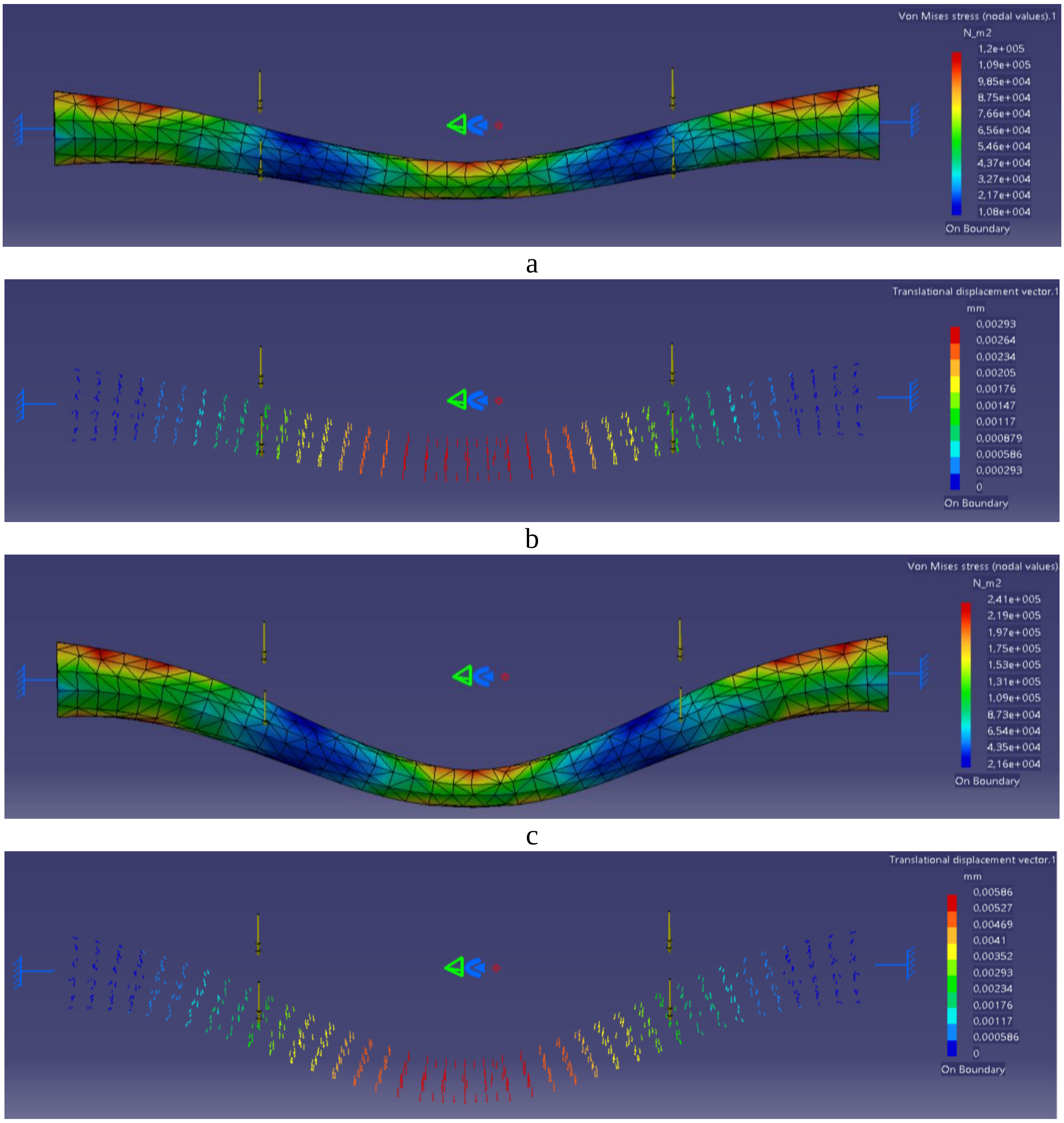


Fig.2. Clamp mode and distributed force

Once the restrictions and loading have been established, the actual step of the calculation (analysis) follows. Clicking the Compute icon on the toolbar selects All, the first effect of the action is to update the Static Case Solution element. After the calculation is complete, the user has the Image bar tools available to view the results. The specifications tree is completed according to the inserted images. In fig.3, the image (using the Von Mises Stress, Deformation, Principal Stress and Precision) is displayed, corresponding to the calculation of the model and load considered, with the statement that the deformations are presented slightly overstated to ease the stage of determining the conclusions of the analysis [2, 5].

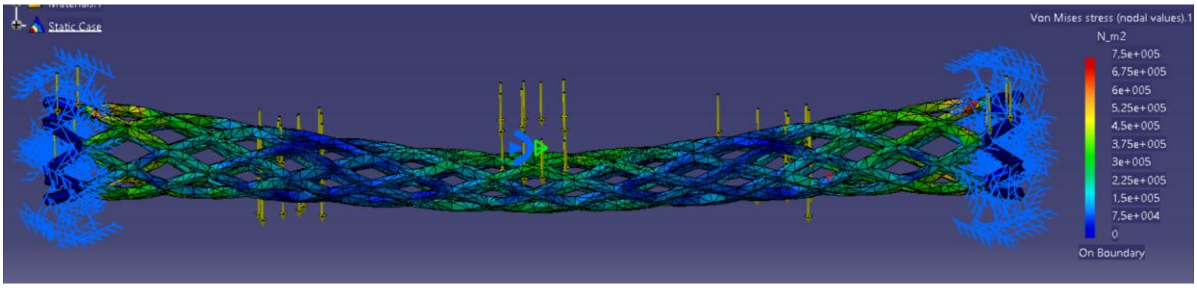


a

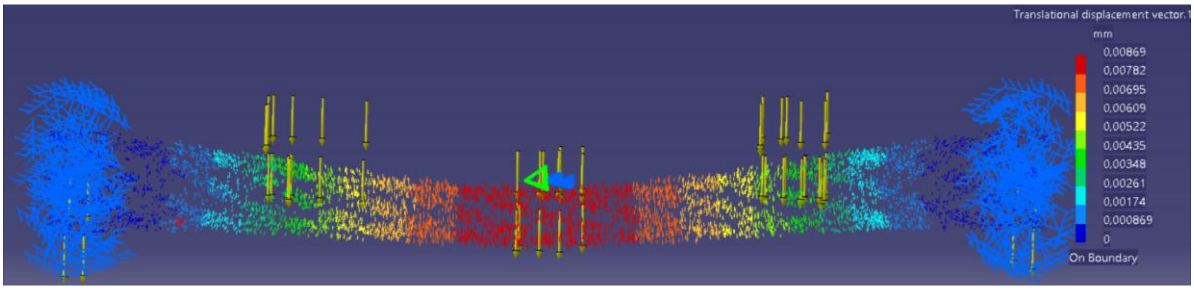
b

c

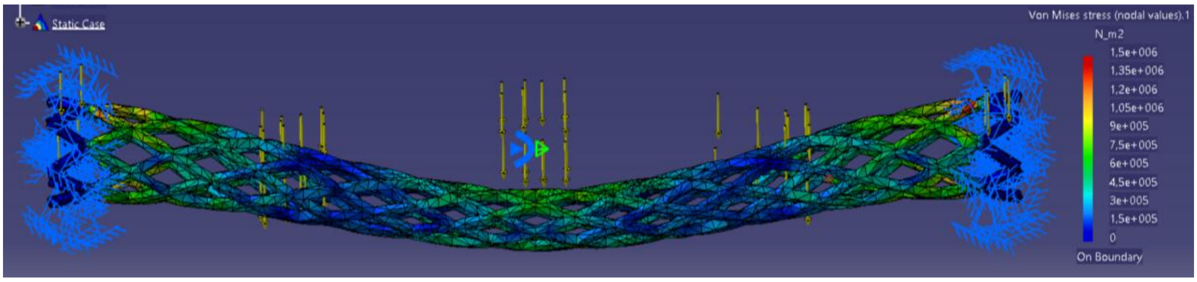
d


Static Case
Von Mises stress (nodal values).1
N_m2
7,5e+005
6,75e+005
6e+005
5,25e+005
4,5e+005
3,75e+005
3e+005
2,25e+005
1,5e+005
7,5e+004
0
On Boundary

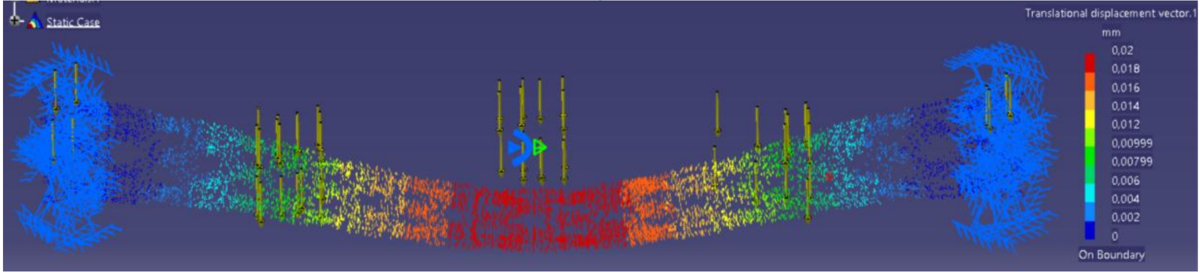
e


Translational displacement vector.1
mm
0,00869
0,00782
0,00695
0,00609
0,00522
0,00435
0,00348
0,00261
0,00174
0,000869
0
On Boundary

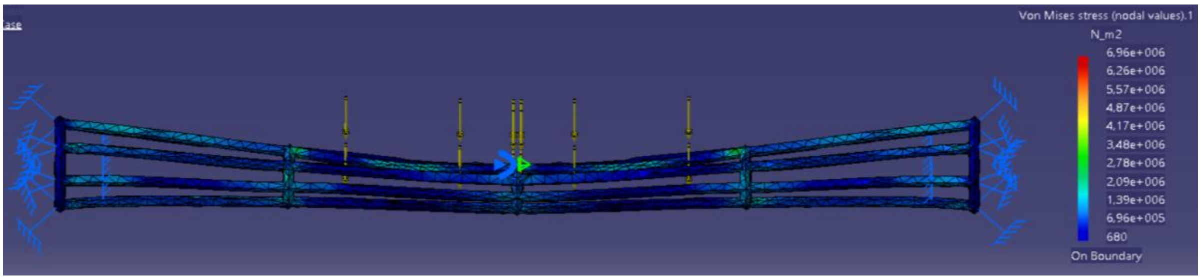
f


Static Case
Von Mises stress (nodal values).1
N_m2
1,5e+006
1,35e+006
1,2e+006
1,05e+006
9e+005
7,5e+005
6e+005
4,5e+005
3e+005
1,5e+005
0
On Boundary

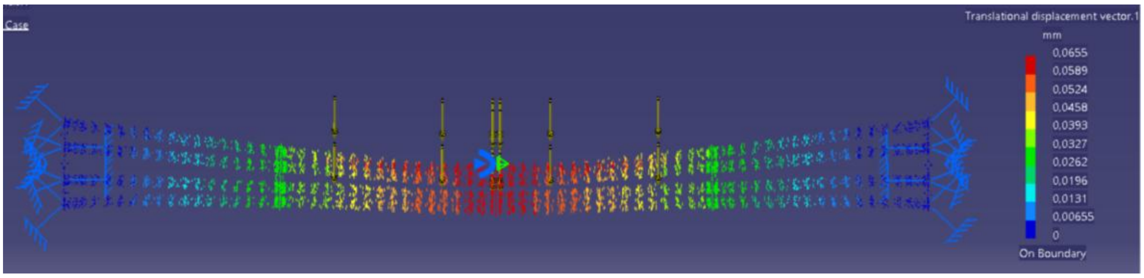
g


Static Case
Translational displacement vector.1
mm
0,02
0,018
0,016
0,014
0,012
0,00999
0,00799
0,006
0,004
0,002
0
On Boundary

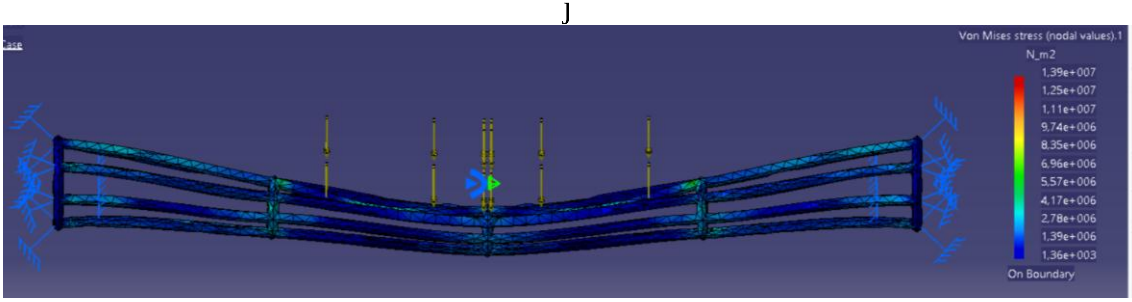
h


Von Mises stress (nodal values).1
N_m2
6,96e+006
6,26e+006
5,57e+006
4,87e+006
4,17e+006
3,48e+006
2,78e+006
2,09e+006
1,39e+006
6,96e+005
680
On Boundary

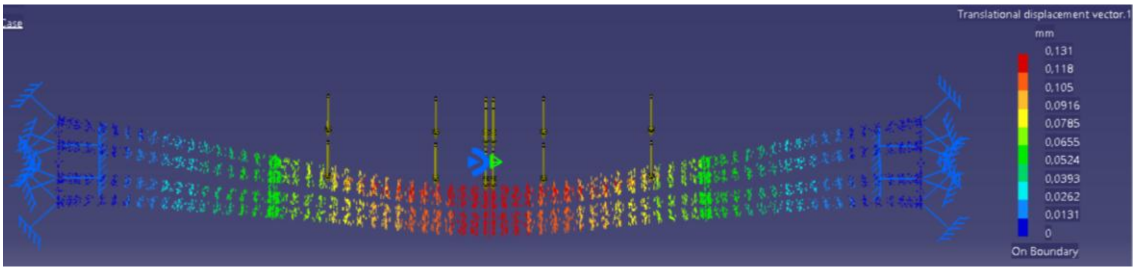
i


Case
Translational displacement vector.1
mm
0,0655
0,0589
0,0524
0,0458
0,0393
0,0327
0,0262
0,0196
0,0131
0,00655
0
On Boundary

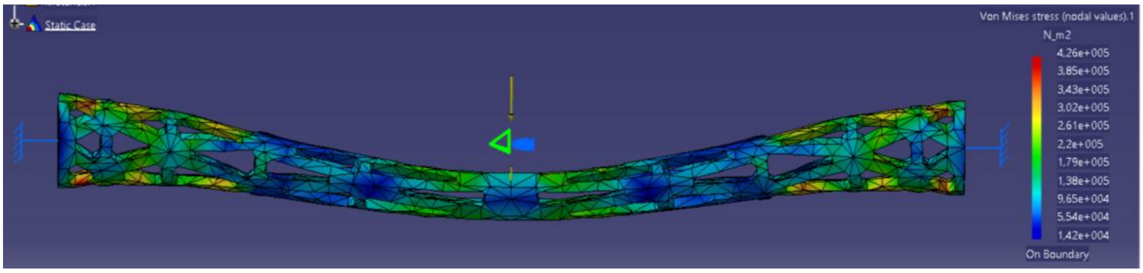
j


Case
Von Mises stress (nodal values).1
N_m2
1,39e+007
1,25e+007
1,11e+007
9,74e+006
8,35e+006
6,96e+006
5,57e+006
4,17e+006
2,78e+006
1,39e+006
1,36e+003
On Boundary

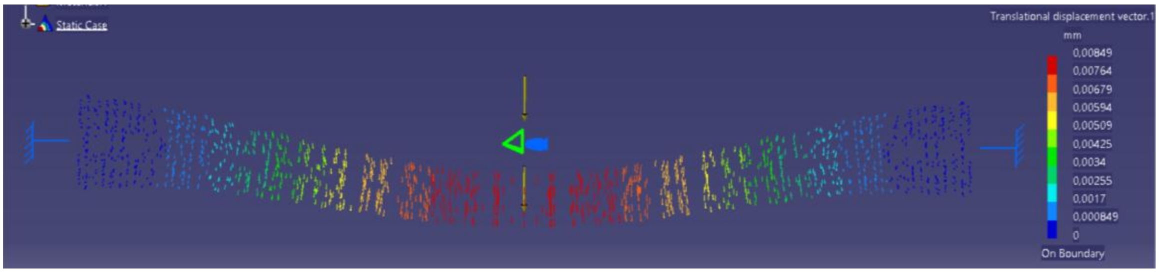
k


Case
Translational displacement vector.1
mm
0,131
0,118
0,105
0,0916
0,0785
0,0655
0,0524
0,0393
0,0262
0,0131
0
On Boundary

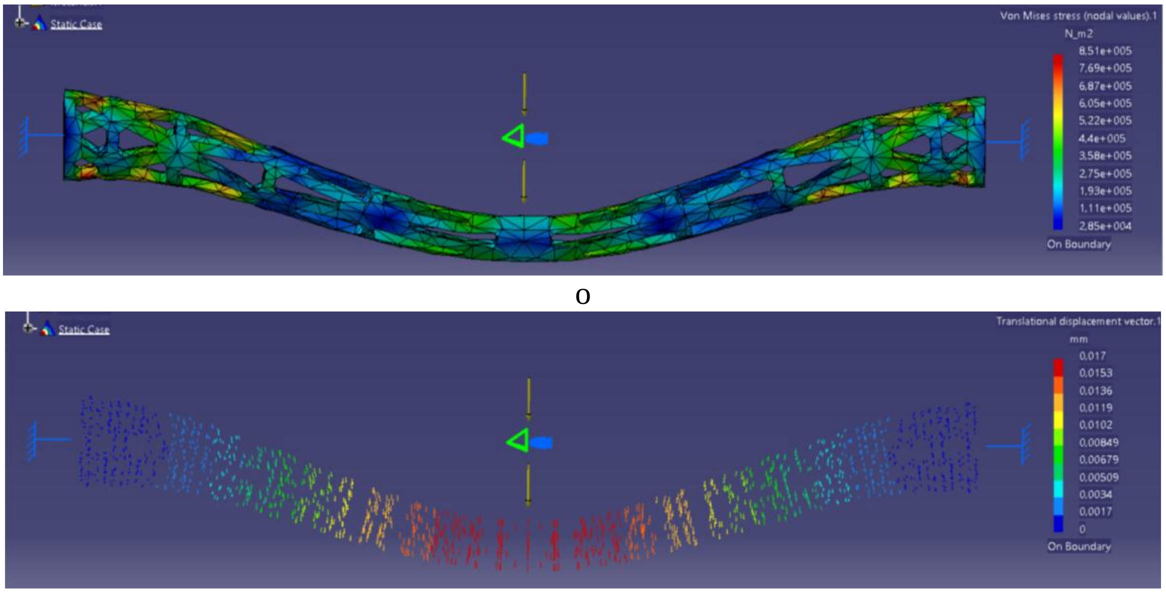
l


Static Case
Von Mises stress (nodal values).1
N_m2
4,26e+005
3,85e+005
3,43e+005
3,02e+005
2,61e+005
2,2e+005
1,79e+005
1,38e+005
9,65e+004
5,54e+004
1,42e+004
On Boundary

m


Static Case
Translational displacement vector.1
mm
0,00849
0,00764
0,00679
0,00594
0,00509
0,00425
0,0034
0,00255
0,0017
0,000849
0
On Boundary

n



o

p

Fig.3. The deformed piece and optimizing the analysis process

3.3. Interpretation of results

In the typical process of optimizing finite dimensional structures, the sectional properties, location of nodes and positioning of structural elements are chosen as variables of the problem. An effective method of optimizing the choice of constructive variant is the analytical method, which uses mathematical theories of calculation and variational methods in the study of the optimal for simple geometric shapes of structural elements, such as beams, bars, plates. This method can be used successfully for single structural components, but it is not possible to use it in complex structures. With this type of method, the optimum is calculated very accurately by solving a system of equations and inequalities that express the optimal conditions.

Table 2 summarizes the most important (variable) data that contribute to the choice of the constructive form of the connecting element.

Table 2. Variables taken into account when choosing the constructive form

Variant	Von Mises stress [N/m^2]		Translational displacement [mm]		Mass [kg]
	F_1 = 100 N	F_2 = 200 N	F_1 = 100 N	F_2 = 200 N	
(a) solid structure	Max. 1,20x10^5 Min. 1,08x10^4	Max. 2,41x10^5 Min. 2,16x10^4	2,93x10^{-3} 0	5,80x10^{-3} 0	2,064
(b) fiber structure	Max. 7,05x10^5 0	Max. 1,06x10^6 0	8,06x10^{-3} 0	20,00x10^{-3} 0	0,764
(c) longitudinal reticular structure	Max. 6,96x10^6 Min. 0,6x10^3	Max. 1,39x10^7 Min. 1,36x10^3	65,50x10^{-3} 0	13,1x10^{-4} 0	0,566
(d) box structure	Max. 4,26x10^5 Min. 1,42x10^4	Max. 8,51x10^5 Min. 2,85x10^4	8,40x10^{-3} 0	17,00x10^{-3} 0	1,140

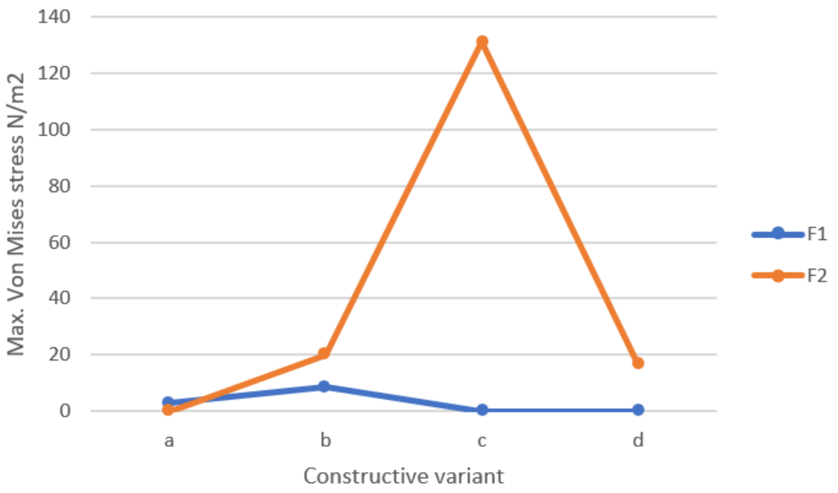


Fig.4. Max. Von Mises stress variatiation

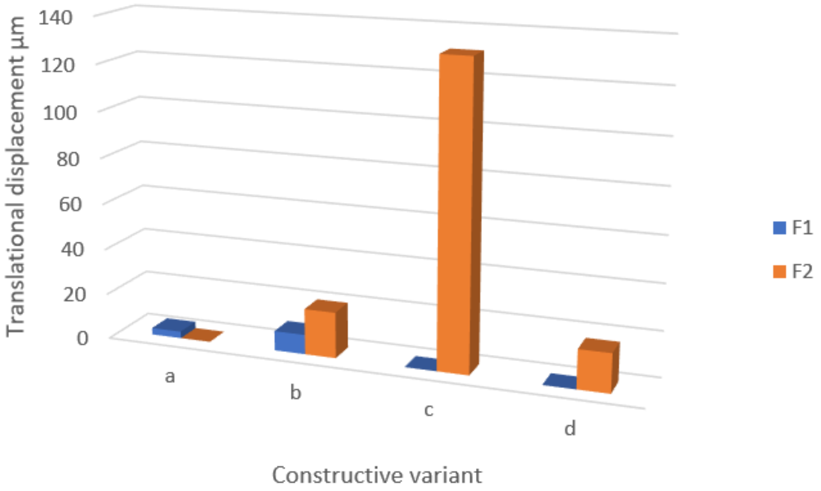


Fig.5. Translational displacement variatiation

4. CONCLUSION

It is observed by analyzing the tested problems that adding more objectives to an optimization problem exponentially increases its complexity. In the case of structural design, a result that is as light and rigid as possible is desired. As these two objectives are conflicting, there must be a compromise. There will be a minimum weight design, a maximum rigidity design and an infinite number of solutions that are a compromise between weight and rigidity.

These solutions cannot be improved from the point of view of one of the criteria without negatively influencing the result of another. Optimization is a challenge for engineers and architects, and although a large number of steps have been taken towards its introduction into current practice, it is not yet adopted by non-specialists. However, access to simple algorithms is extremely useful both in the calculation of classical structures and in the innovation of free-form structures. From a structural point of view, in order to guarantee the necessary level of reliability, specialized expertise is needed in the design and construction of free-form morphologies.

Optimization is recommended in the preliminary design process to find the most suitable solutions in accordance with the expected function of the structure. But the usefulness of the optimization strategy is limited by the inclusion of an advanced analysis in the procedure.

REFERENCES

[1] Balea (Krucke), Ioana D. - *Strategii de optimizare a structurilor metalice bazate pe algoritmi genetici*, Doctoral thesis, 2015

[2] Ciofu, Florin - *Hip implant analysis with CATIA*, Revista Fiability and durability, Nr.2, 2017

[3] Ghionea I.G – *CATIA v5 – aplicaţii în inginerie mecanică*, Editura BREN, Bucureşti 2009;

[4] Ghionea I.G – *Proiectare asistată în CATIA v5* – Elemente teoretice şi aplicaţii, Editura BREN, Bucureşti;

[5] Alin NIOAŢĂ - *FEM structural analysis of a module of end-milling cutter using the CATIA*- FIABILITY & DURABILITY, Nr.1/2019, may, ISSN 1844-640X, pp. 190-195.