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# Topology Optimization of B-pillar with Respect to Mesh Type and Size

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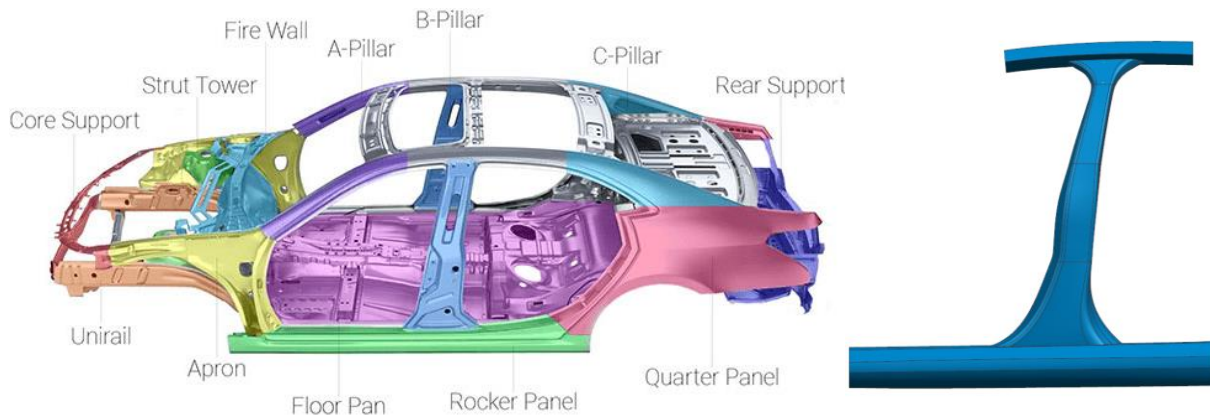
**Abstract.** This paper deals with the influence of different mesh types and element sizes in topology optimization. Meshes from brick elements, tetrahedral elements and combination of both of them were compared in sizes 20, 10 and 7mm. B-Pillar, structural car component, is used here in order to verify the sensitivity of topology optimization due to these changes. Loading case is considering side force 140 kN. Moreover, different solvers implemented in Siemens NX 12 (RAMP, LINEAR, LATTICE and SIMP) were used to analyse how they influence this particular optimization process. It is obvious that highest number of FEM elements is rapidly improving convergence and optimization results but computational time is increasing.

## 1. Introduction

Topology optimization can be considered as a part of a broader theme, called structural optimization. The first works in this area are dated in the 19th century, mainly focusing in truss weight reduction among stress constraints.

The quality of results relies nowadays mostly on the FEM mesh and simulation solver chosen by the user. Optimization highly connected to the increasing demand of industry and evolution of the computer's capacity. Different mesh types and sizes will be compared on a B-Pillar (structural car component- Fig.1) in this paper. Main aim is to verify the sensitivity of topology optimization due to these changes. Moreover, different solvers implemented in Siemens NX 12 will be used to analyse how they influence this particular optimization process. [1,2]





**Figure 1.** Car structure [3] (left) and analysed B-pillar (right)

## 2. Optimization theory

The topology optimization (TO) can be summarized as the searching tool for the optimal distribution of material in a given design domain. It is described by solving of the objective function, while satisfying a series of manufacturing and deformation constraints. This process belongs to a broad kind of optimization called Structural Optimization (SO), that has other types as shape and size optimization. [4]

However, there are advantages between them, and specifically for TO, it is observable that the elastic property of the material, i.e. young modulus, works as a function. It means that its density can vary across the design domain. The other difference, being exclusive for TO, is that material can be removed permanently from the design domain. [5,6]

Objective function  $C(x)$  can be described as (1):

$$\text{Min}(C(x)) = (u(x))^T f(x) = (u(x))^T K(x)u(x), \text{ where:} \quad (1)$$

$f$  - global load vector containing the nodal forces

$u$  - global displacement vector

$K$  - global stiffness matrix

## 3. Methodology

On this work, the NX Nastran SOL 200 was the only used solver for topological optimization. It works by minimizing an objective function described above. Details of optimization process are described further.

### 3.1. Mesh

During research were analysed following types of elements:

- Brick elements HEXA 8 AND 20

It is brick-type element. The 8-noded has 6 faces and 8 nodes. The second (20-noded) type has midpoints. It can be also called quadratic elements, thus creating a 3D element with 6 faces and 20 nodes. The main advantage of these elements can be related to lower skewness angle on their solid faces. Therefore the distances between nodes are similar in all mesh extension, leading to better results.

- Tetrahedral elements TETRA 4 AND 10

The TETRA 4 is a tetrahedral element with 4 faces and 4 nodes. The second one has 4 faces and 10 nodes, using the same principle (midpoints) as the HEXA 20. The biggest advantage of tetrahedral elements is their capability to mesh complex bodies, despite they are not so precise as hexahedral elements.

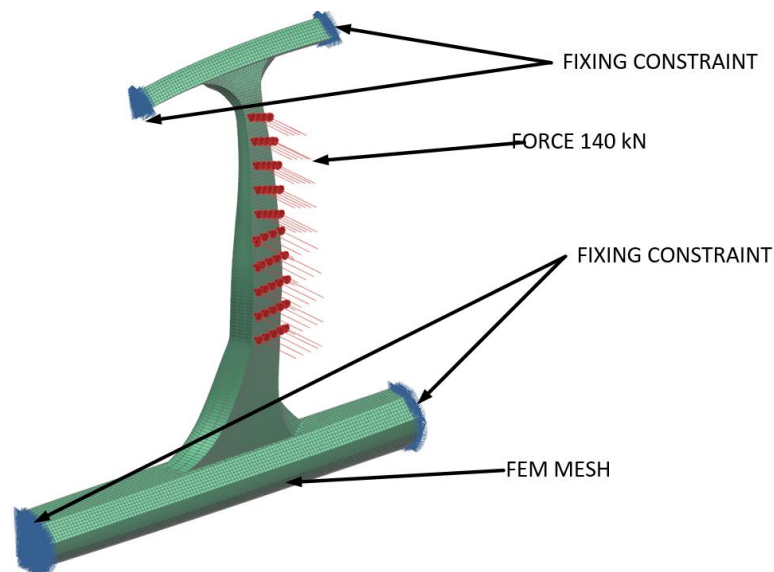
- Combined HYBRID MESH TYPE

This mesh type is combination of previous types. Internal area is created by HEXA elements and it produced accurate results. Complex areas close to surface are meshed by TETRA elements. Transition between both types is created by special pyramidal elements.

### 3.2. Loads and constraints

The initial hypothesis is that the B-Pillar deformation will be greater than the A and C-Pillar during side crash. Thus, it is possible to simulate only the middle body, considering the rigid connection to the rest of car. The B-Pillar side faces are fixed.

Besides that, the loads were applied in frontal faces of the structure, as seen in following figure. The load force of 140 kN was applied on B pillar based upon Euro NCAP standards (Fig. 2). This force is in direction of side impact.



**Figure 2.** Applied loads and constraints

### 3.3. Settings of optimization

All settings of solver are described in following text.

- DESIGN OBJECTIVE

The main goal in the optimization was to obtain a higher stiffness for a lighter B-Pillar. The input was compliance method and the objective function was minimized.

- DESIGN AREA

The design area was whole geometry of B pillar.

- DESIGN CONSTRAINT

This constraint defined the lower and upper limit of weight. The lowest value was set to 1 kg and the highest to 10 kg. The initial value of design area was 122.35 kg.

- MANUFACTURING CONSTRAINT

It was set to constrain the maximum member size to 20 mm.

- MAXIMUM NUMBER OF DESIGN CYCLES (DESMAX)

The number of cycles chosen was 150, in order to get the best solution.

- PENALTY LAW (DMRLAW)

Different types and sizes of elements were used with one penalty law SIMP in the first part of research.

All penalty laws (RAMP, LINEAR, LATTICE) were used with HYBRID mesh and size was kept constant at 10 mm. The main goal here was to observe the influence of different TO methods in the final result. [7, 8, 9, 10]

## 4. Element size and type influence

It possible to see influence of element type (constant size 10mm) on computational time (Tab. 1).

**Table 1.** Comparing of solution time for meshes with 10mm element size

	HEXA 8	HEXA 20	TETRA 4	TETRA 10	HYBRID
<b>Number of Nodes</b>	36071	132244	57124	428601	350403
<b>Time (min)</b>	65,7	262,3	96,9	1229,7	591,89
<b>Time per Node (s/nodes)</b>	0,109	0,119	0,102	0,172	0,101

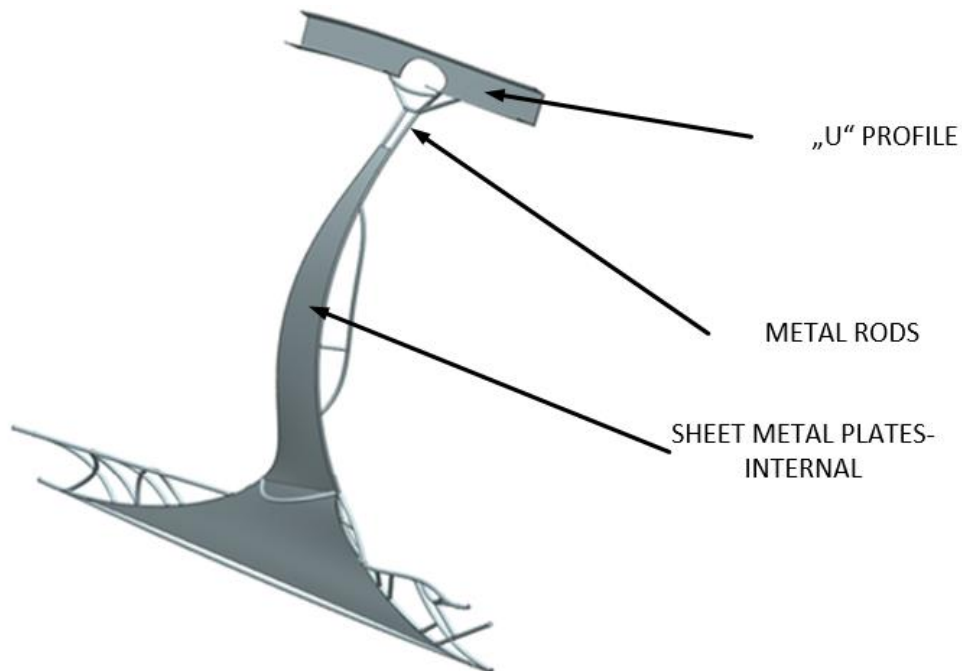
Following figure (Fig. 3) shows results from topology optimization. It is obvious, that smaller elements leads to smoother results with higher number of material flows. Element size 20 mm is too high to get correct results. Results showed, that most suitable is usage of HEXA 20 elements. Results are better with HEXA20 comparing to HEXA 8 and computational time is lower comparing to TETRA elements.

It is possible to use HYBRID mesh type, which is combination of both element types. Internal areas are created by HEXA elements which leads to good results.



**Figure 3.** Results with HEXA 8- size 20mm (left), hybrid mesh – size 10mm (middle), HEXA 8- size 5mm (right)

Topology optimization gives results which has to be re-modelled for further usage. How can internal structure of B pillar look like is obvious from following figure (Fig. 4). This B pillar has 12 kg and can be used for modification of commonly used B pillar. This structure has to be covered by the sheet metal to look like the regular B pillar.



**Figure 4.** Remodelling of B pillar structure

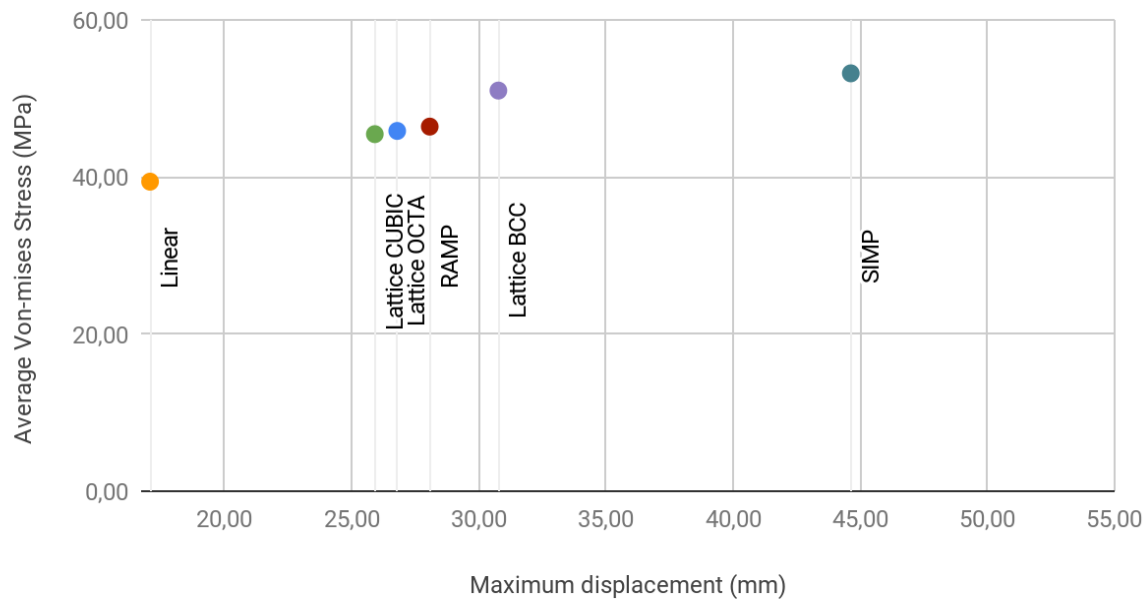
### 5. Solver influence

Different result was obtained for each solver. The solvers RAMP, LINEAR and LATTICE CUBIC achieved the upper weight constraint of 10 kg. The SIMP and the LATTICE BCC solver did not get this value, with a difference around 5 %.

All solvers except the LINEAR got a structure appearance, this can be seen as difficult for this method, showing that it is not the best solver to use with complex geometries.

It was also noticeable that the SIMP predict the highest values for von-Mises stress and maximum displacement, while the solver RAMP, LATTICE CUBIC, and OCTA had values close to the solvers average value of 46,88 MPa and 28,87 mm.

Difference between all solvers in terms of maximal displacement and stress can be shown from following graph (Graph. 1).



**Graph 1.** Influence of solver on maximal stress and displacement

## 6. Conclusion

The main goal of this research was to find out the influences solver method, mesh type, and size in topology optimization.

It was discovered that the HYBRID mesh had the fastest time per node, with an average of 0,101 seconds per node while the TETRA 10 mesh had the largest amount of nodes, with approximately 430.000 nodes.

For the quantitative results, the TETRA 4,10 and HYBRID mesh had close results due to FEA accuracy, whilst the HEXA 8 and 20 meshes achieved disperse results.

The mass reduction was proved to be mesh dependent for most of the meshes, despite the hybrid that had a variation of only 3 % on average, proving to be stable for different mesh sizes.

The material density results, we could see that most of the mesh types performed well while using small sizes, in the other hand, the HYBRID mesh was the only one keeping the same appearance as the mesh was reduced.

The remaining topic is the solver influence, it was found that most of them had similar results, again, due to the FEA accuracy, still, the LINEAR and SIMP solver had very different results in the displacement prediction, being over 25 %.

In the end, the main goals of the research were achieved, as can be seen, it was possible to identify those mesh and solver influences in the topology optimization process. For a future work would be promising to simulate the crashworthiness of the final CAD models and verify if the modifications were good enough to achieve the main objective. This has to be done by usage of explicit solver and non-linear simulation of side crash.

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