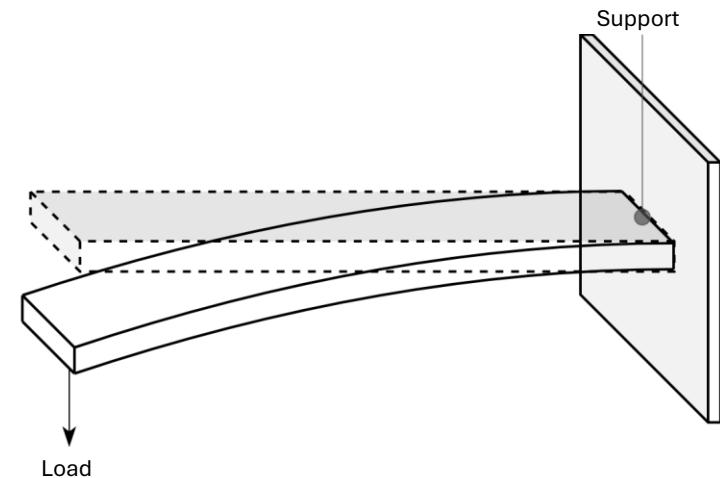


NUMERICAL MODELLING AND SIMULATION – PART A

REPORT 1 CANTILEVER BEAM MODEL



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A.Y. 2024/2025



TARGETS



Validate the convergence of numerical results against the analytical solutions derived from De Saint-Venant's theory.



Compare results obtained using three-node and four-node shell elements.

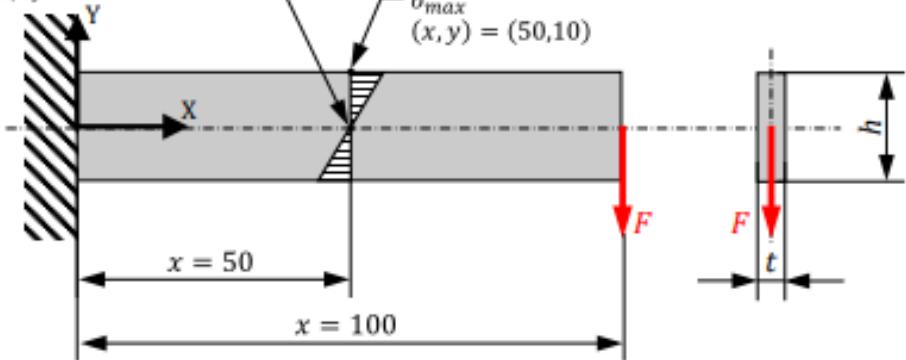


Assess the impact of various boundary conditions on the representation of stress and strain fields.

PROBLEM ILLUSTRATION

CANTILEVER BEAM

Point for the evaluation of the vertical displacement and τ_{max}
 $(x, y) = (50,0)$



Point of evaluation →

beam midpoint
($x = 50 \text{ mm}$ and $y = 0 \text{ mm}$)

Why? → edges results could show a bigger error due to FEM nature

$$J = \frac{t \cdot h^3}{12} = 3333,33 \text{ mm}^4$$

CANTILEVER BEAM

MATERIAL

- Category: Steel
- $E = 206000 \text{ MPa}$
- $\nu = 0,3$
- $\rho = 7,8 \cdot 10^{-9} \text{ Gkg/l}$

DIMENSION

- $t = 5 \text{ mm}$
- $l = 100 \text{ mm}$
- $h = 20 \text{ mm}$

$$\sigma_{max} = \frac{6 F x_p}{t h^2} = 150 \text{ MPa}$$

$$\tau_{max} = \frac{3 F}{2 t h} = 15 \text{ MPa}$$

$$f_p = \frac{F x_p^2}{6 E J} (3 l - x_p) = -0,1517 \text{ mm}$$

METHODS - DISCRETIZATION

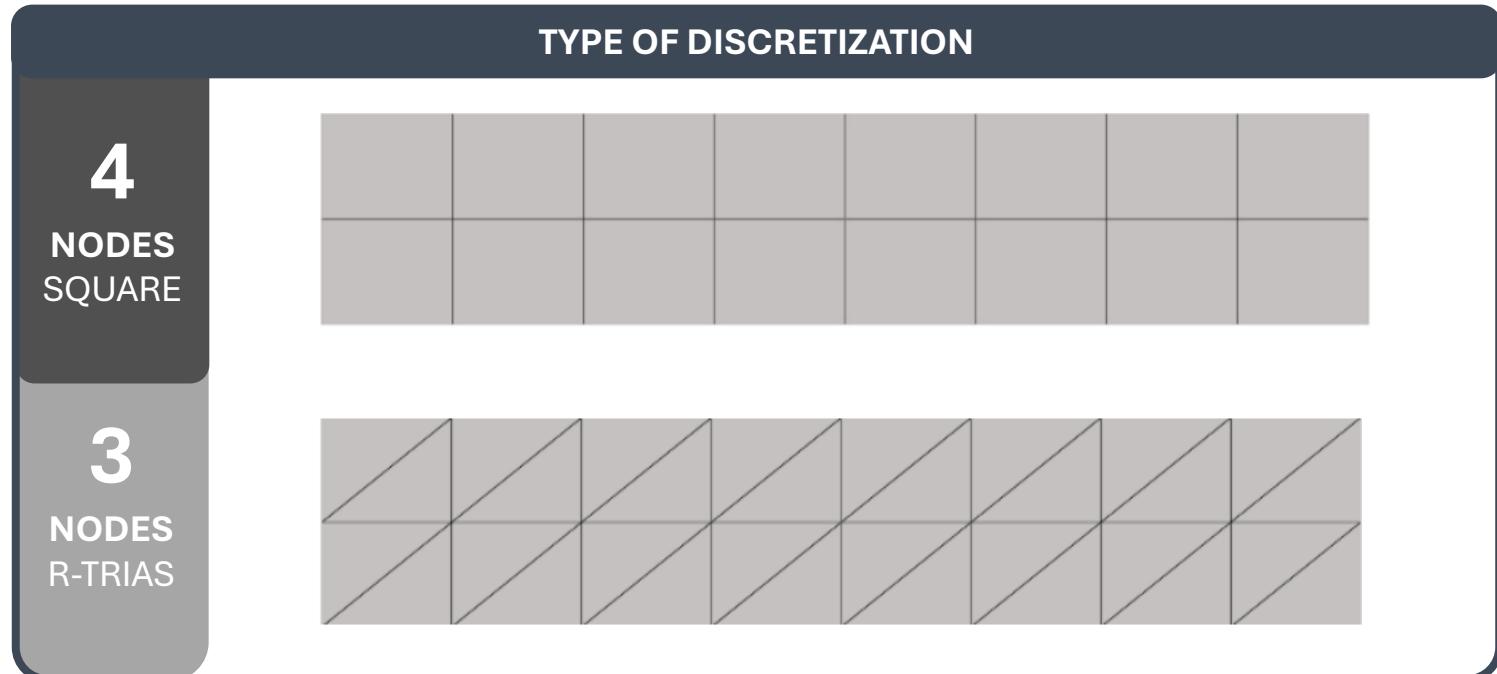
SOFTWARES

- FEA: Hypermesh 2024
- Solver: Optistruct
- Visualizer: Hyperview 2024

Number of elements

height	Width	Total nodes
2	10	33
4	20	105
10	50	561
12	60	793
14	70	1065
16	80	1377
20	100	2121
24	120	3025

Discretization → 2 D model (Shell elements) Why? → $t \ll l$ and h



Density of elements

Density on width = density on lenght
To take into account equal shape of the elements

PROPERTY **PSHELL**

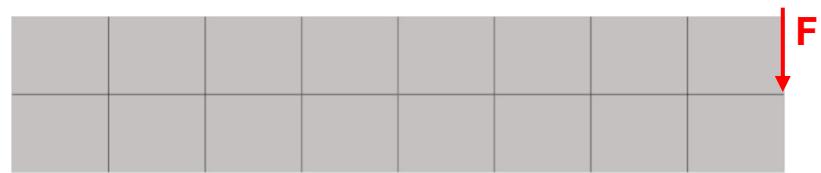


METHODS - BOUNDARY CONDITIONS

LOADS

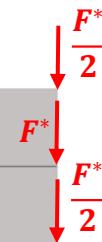
- a) Single load applied on midpoint of right side

$$F = 1000 \text{ N}$$



- b) Distributed load applied on each nodes of right side

$$F^* = \frac{F}{n. \text{nodes} - 1}$$



CONSTRAINTS

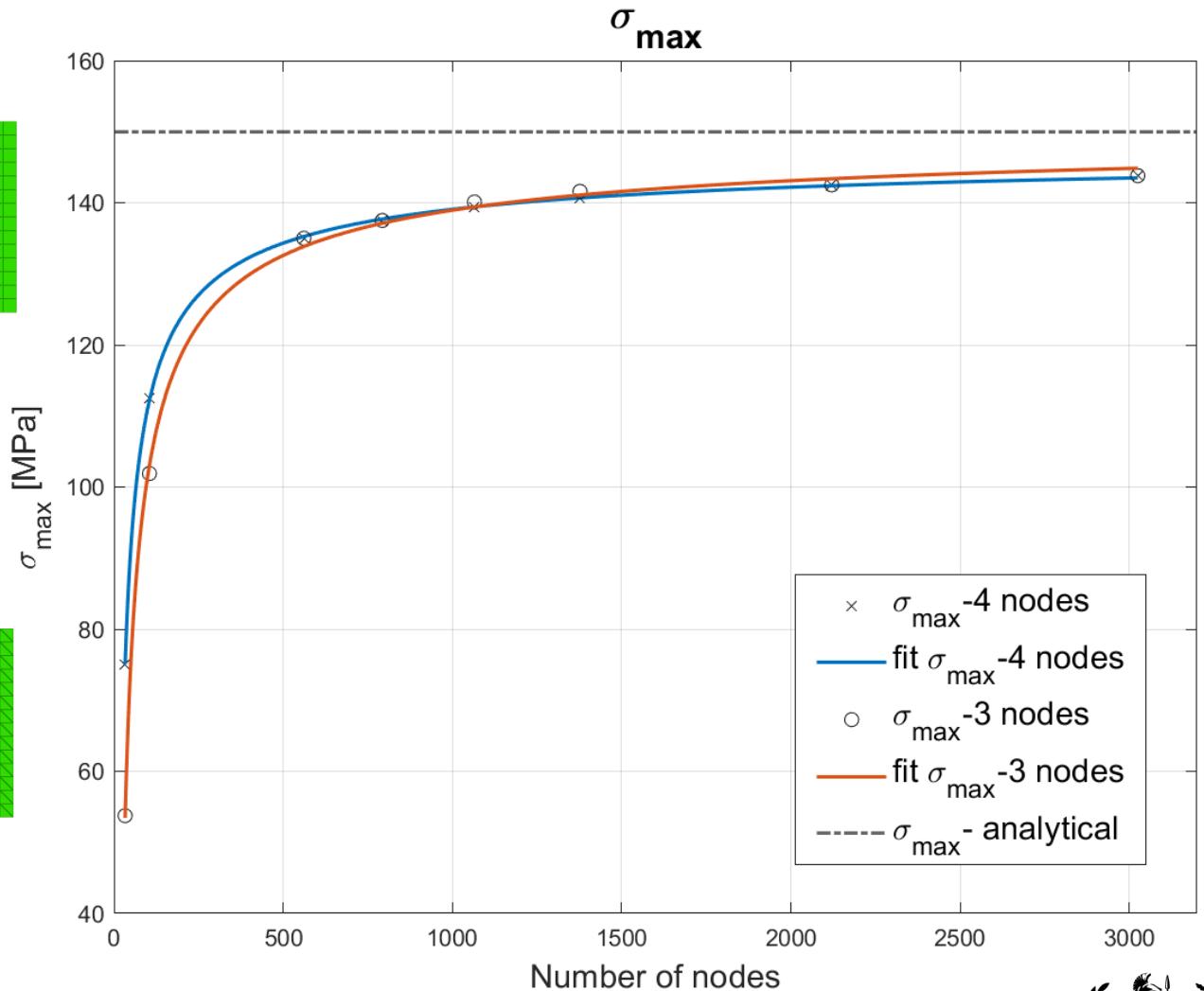
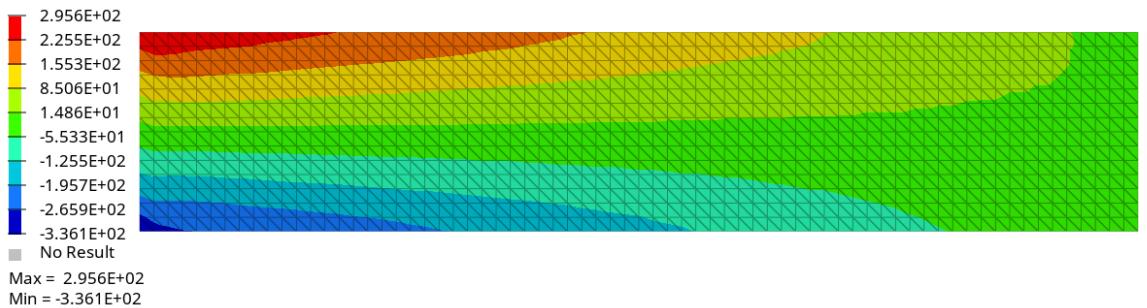
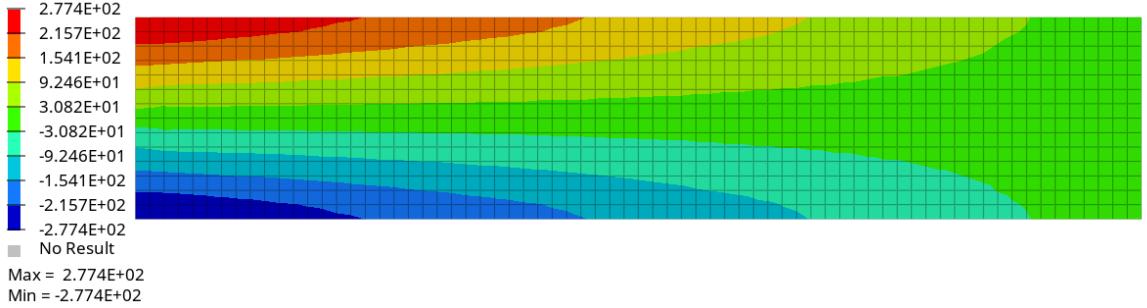
- a) Constraining to 0 the displacements along x and y of all nodes



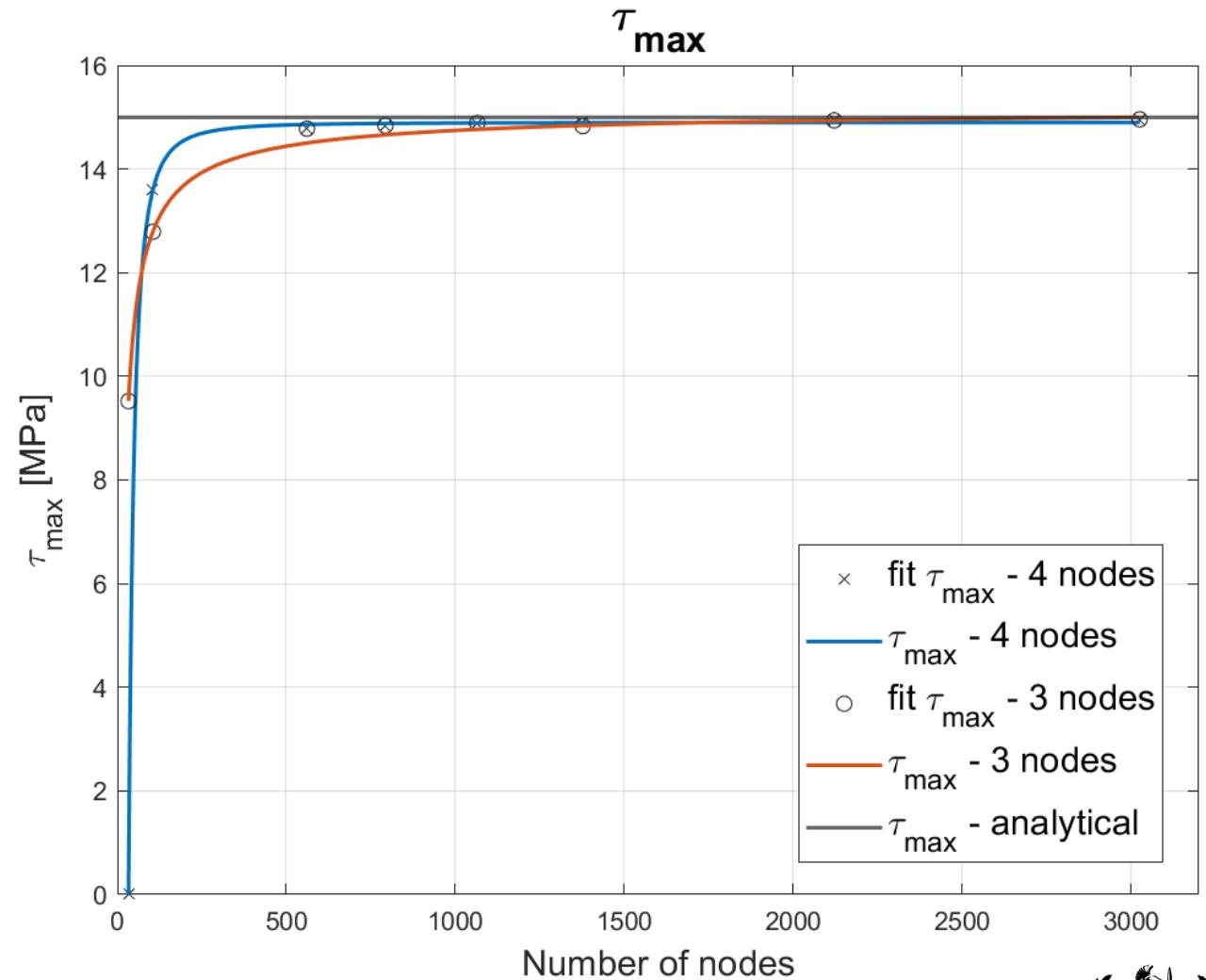
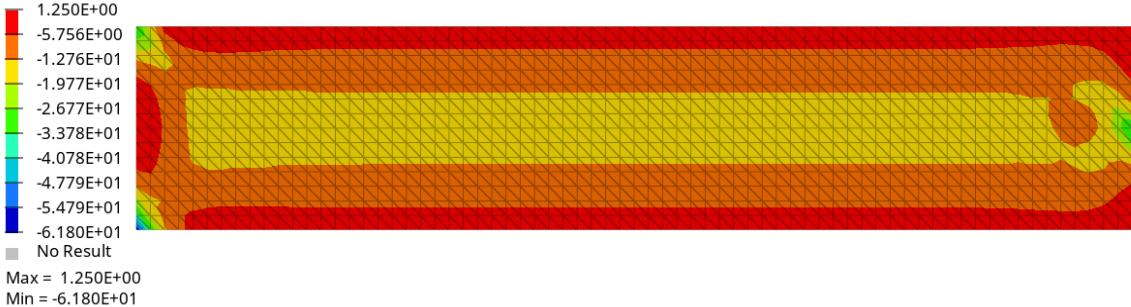
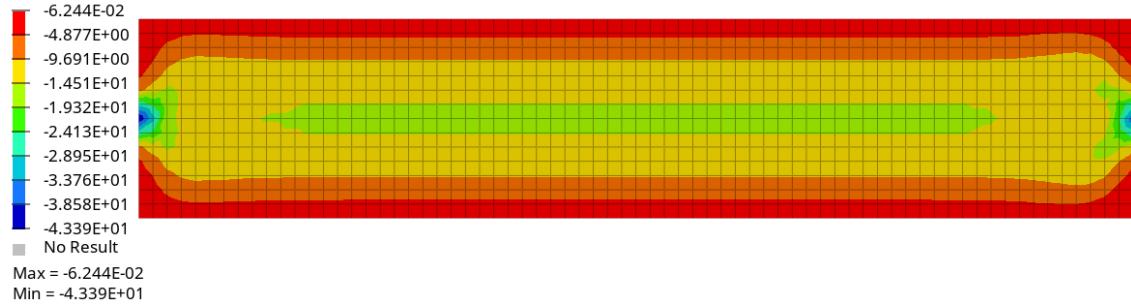
- b) Constraining to 0 the displacements along x of all node and along y of middle node – to simulate deformation in y axis



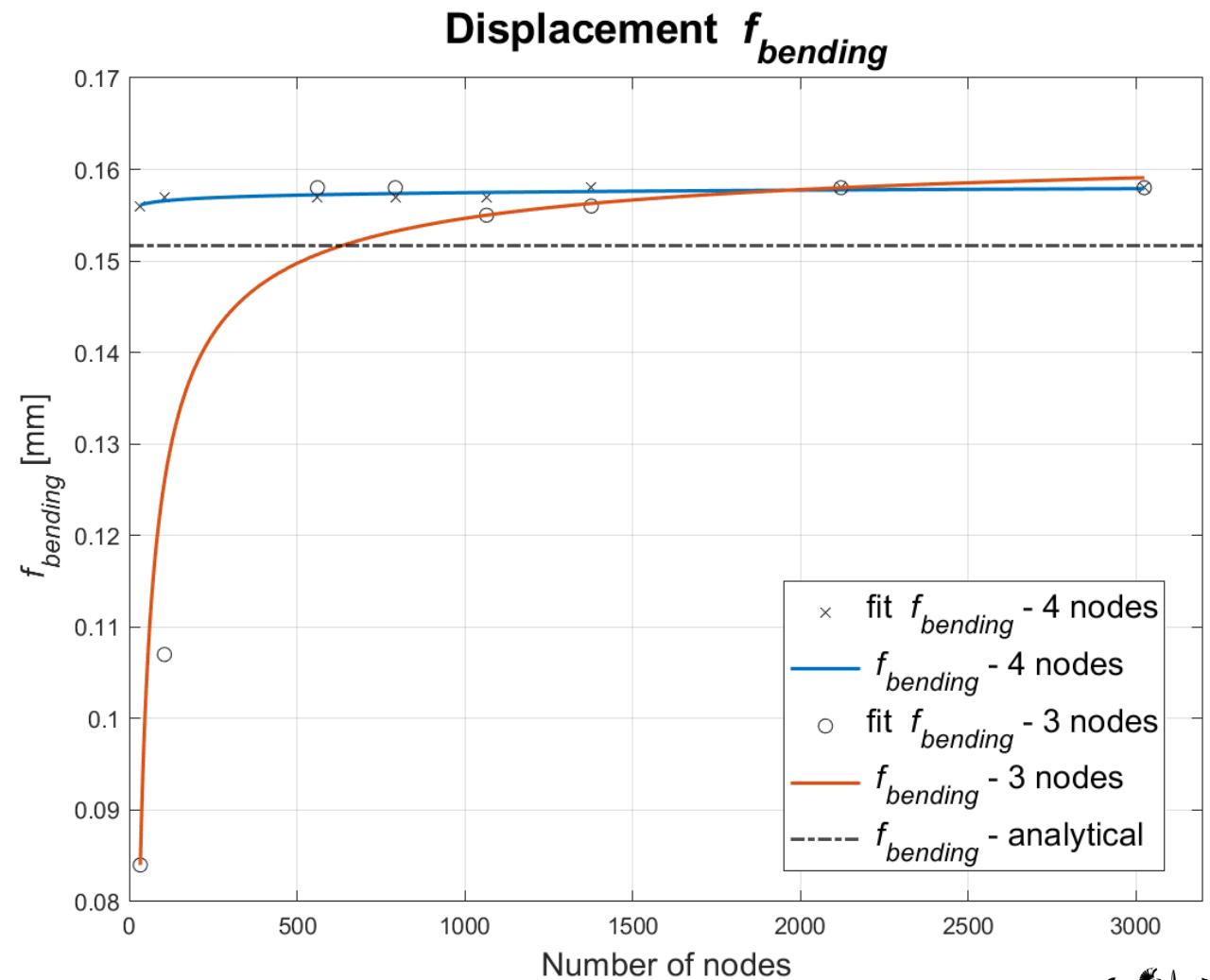
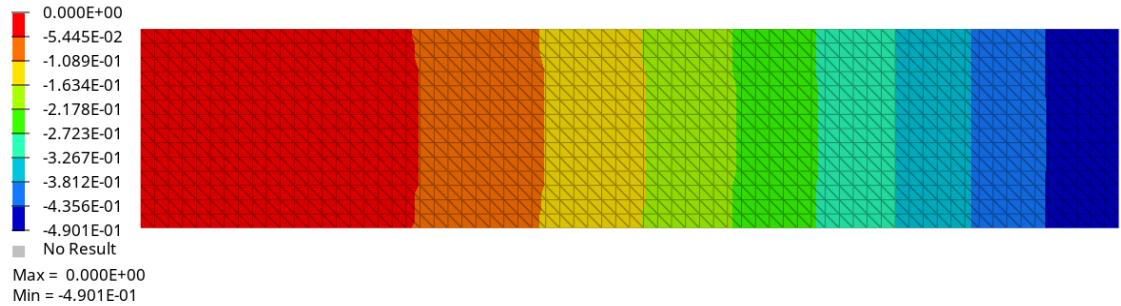
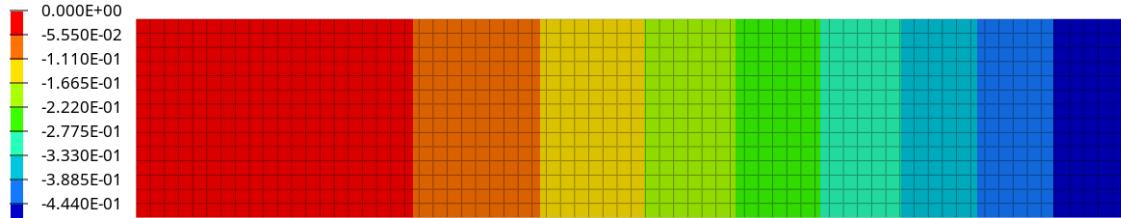
RESULTS – σ_{MAX} GRAPH



RESULTS – τ_{MAX} GRAPH



RESULTS – DISPLACEMENT GRAPH



RESULTS – RIEPILOGATION

Elements type	Elements number	σ_{MAX} [Mpa]	Err% σ_{MAX}	τ_{MAX} [Mpa]	Err% τ_{MAX}	$f_{bending}$ [mm]	Err% $f_{bending}$	Reference values		
								σ_{MAX} [Mpa]	τ_{MAX} [Mpa]	$f_{bending}$ [mm]
4 nodes	2 x 10	75	50%	0	100%	0,156	2,84%	150	15	0,152
	4 x 20	112,5	25%	13,6	9,33%	0,157	3,49%			
	10 x 50	135	10%	14,78	1,47%	0,157	3,49%			
	12 x 60	137,5	8,33%	14,84	1,07%	0,157	3,49%			
	14 x 70	139,3	7,13%	14,89	0,73%	0,157	3,49%			
	16 x 80	140,6	6,27%	14,91	0,6%	0,158	4,15%			
	20 x 100	142,5	5%	14,94	0,4%	0,158	4,15%			
3 nodes	24 x 120	143,8	4,13%	14,96	0,27%	0,158	4,15%			
	2 x 10	53,76	64,16%	9,52	36,53%	0,084	44,63%			
	4 x 20	101,9	32,07%	12,79	14,73%	0,107	29,47%			
	10 x 50	135	10,00%	14,78	1,47%	0,158	4,15%			
	12 x 60	137,5	8,33%	14,84	1,07%	0,158	4,15%			
	14 x 70	140,1	6,60%	14,78	1,47%	0,155	2,18%			
	16 x 80	141,6	5,60%	14,83	1,13%	0,156	2,84%			
	20 x 100	142,5	5,00%	14,94	0,40%	0,158	4,15%			
	24 x 120	14,8	4,13%	14,96	0,27%	0,158	4,15%			

The better overall approximation is achieved with the four-node element with a 14x70 discretization, as shown in the table.

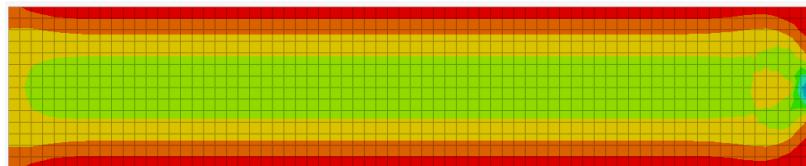


RESULTS - BOUNDARY CONDITIONS

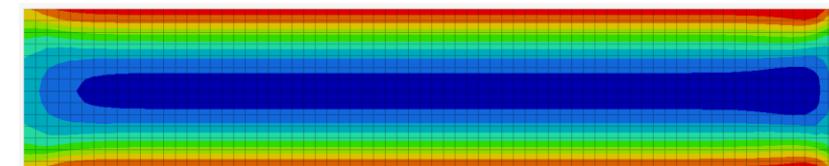
LOADS

In case b) result shows a better distribution of τ_{xy} on the right side where the load is applied.

a) Single force



b) Distributed forces



CONSTRAINTS

In case a) result shows a better distribution of τ_{xy} on the left side where the constraints are applied.

a) All nodes fully constrained



b) Only middle node fully constrained



CONCLUSIONS



Stresses: 4-node elements yield more accurate results than three-node elements with a lower discretization, while with a higher one both approaches converge to the analytical values with no significant differences.



Displacement: 4 nodes elements give good approximation already with minimum elements (2x10) whereas 3 nodes need higher discretization.



Boundary conditions: Overall, a distributed load and constraints tend to produce a better approximation of τ_{xy} near the application point.

NUMERICAL MODELLING AND SIMULATION – PART A

REPORT 2 ROD ENGINE



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TARGETS



To perform a **linear static analysis** of the most **critical load conditions** for the rod (slightly before and after Top Dead Center).

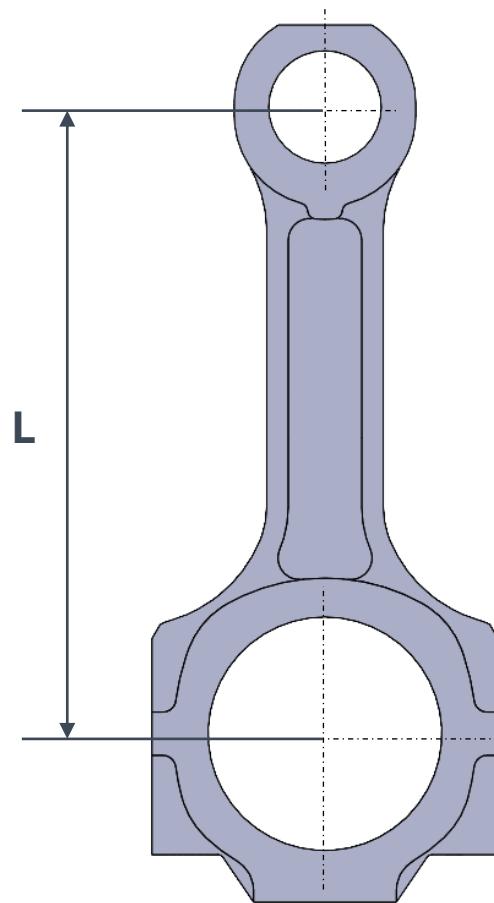


To go into **detail** of the **most stressed areas**.



To evaluate the **influence** of **different meshes** and how **boundary conditions** are applied.

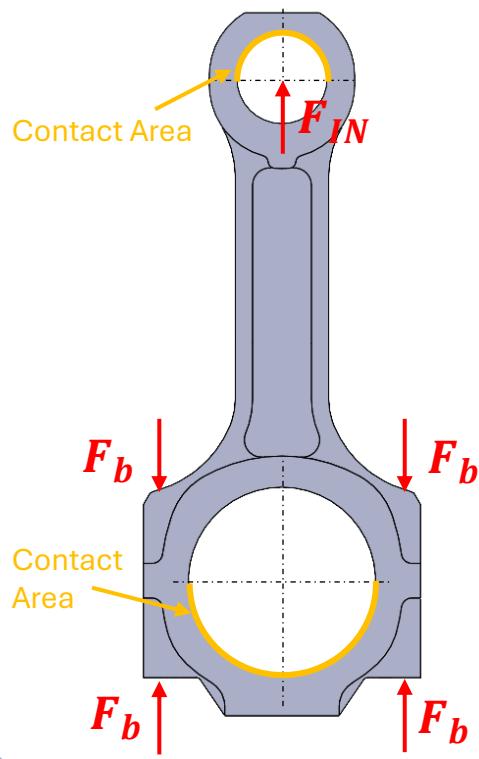
PROBLEM ILLUSTRATION



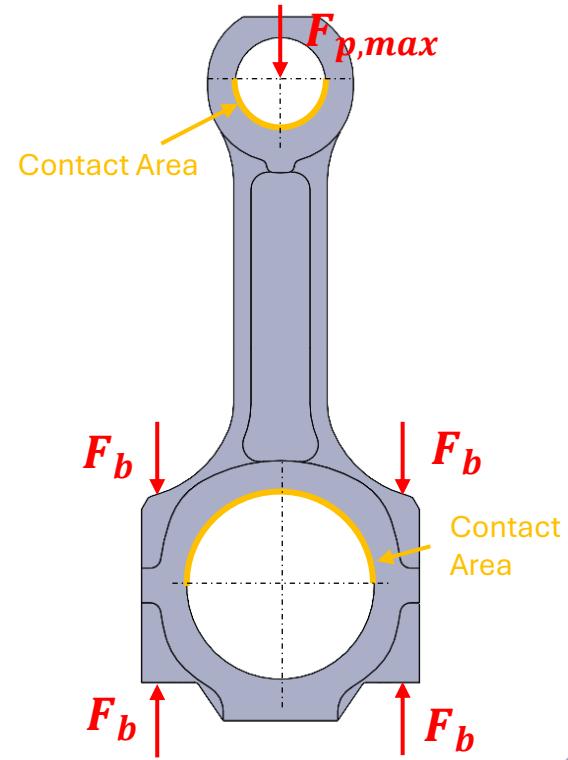
MATERIAL	PROPRIETIES
DIMENSIONS	<ul style="list-style-type: none">• Category: cast iron• $E = 165000 \text{ MPa}$• $\nu = 0,28$• $\rho = 7,2 \cdot 10^{-9} \text{ Gkg/l}$• $\text{Stroke} = 90,4 \text{ mm}$• $\text{bore} = 80 \text{ mm}$• $L = 145 \text{ mm}$• $\text{bolts} = M8 \times 1,25$• $\text{Mass} = 0,81 \text{ kg}$

METHODS - FORCES

BEFORE TDC



AFTER TDC



$$F_{p,max} = \frac{\pi D^2}{4} * p_{max} = 73,93 * 10^6 N$$

$$J = \frac{t h^3}{12} = 3333,33 mm^4$$

$$F_b = 32000N$$

$$R = \frac{Stroke}{2} = 45,2 mm$$

$$n_{max} = 5000 rpm$$

$$\lambda = \frac{R}{L} = 0,3117$$

$$a_{TDC} = (1 + \lambda)R\omega^2 = 16255 m/s$$

$$F_{IN} = m_{ROD} \cdot a_{TDC} = 13166,28N$$

METHODS - DISCRETIZATION

SOFTWARES

- FEA: Hypermesh 2024
- Solver: Optistruct
- Visualizer: Hyperview 2024

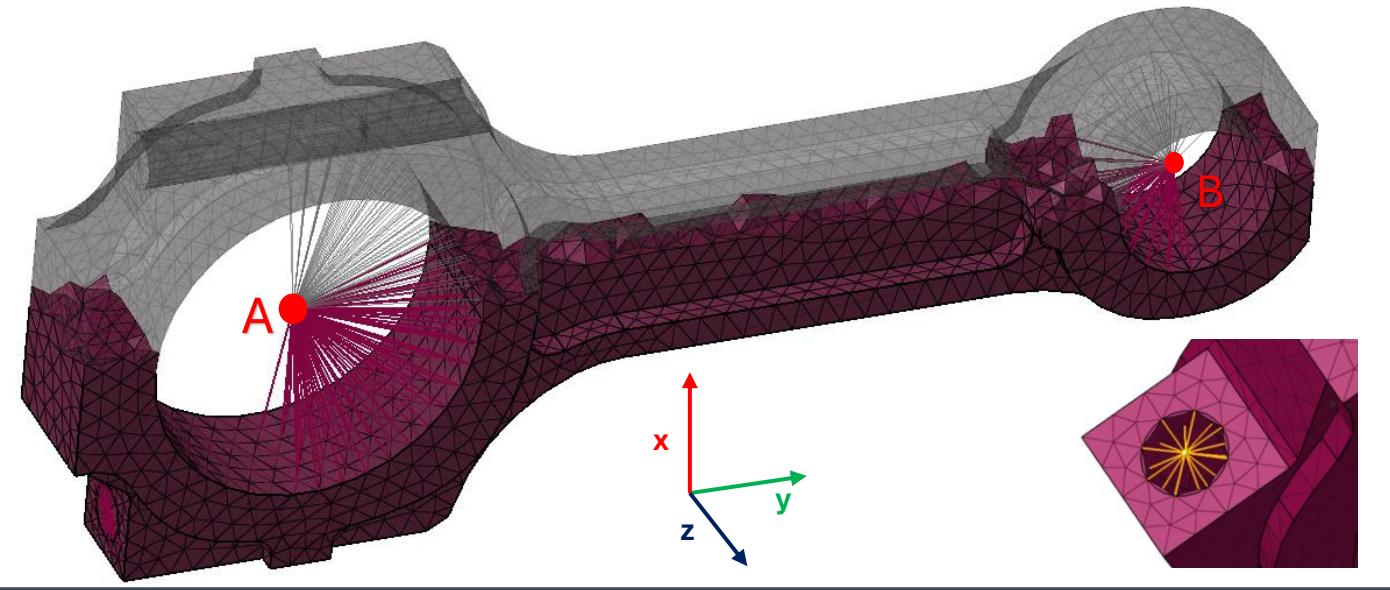
MESH

- Type: 3D - Tetrahedral elements
- Size: 4 mm

CONNECTORS: RBE2

Loads and constraints are applied to the model through rigid connectors (big and small eyes and bolts)

TYPE OF DISCRETIZATION



TYPE OF CONSTRAINTS

Big eye (A): All constrained

Small eye (B): x and z displacement constrained

PROPERTY

PSOLID

RESULTS – BEFORE TDC (INERTIA)

Big end is the most stressed part due to bolts tightening



Compressive load in the big end

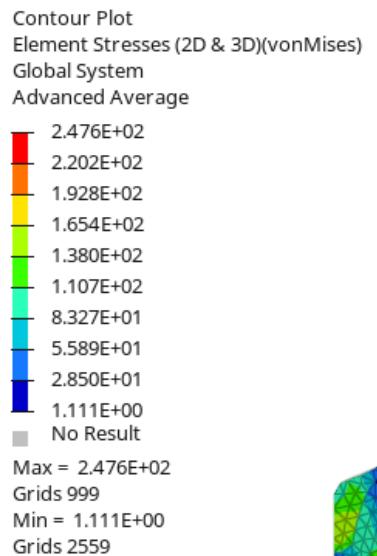
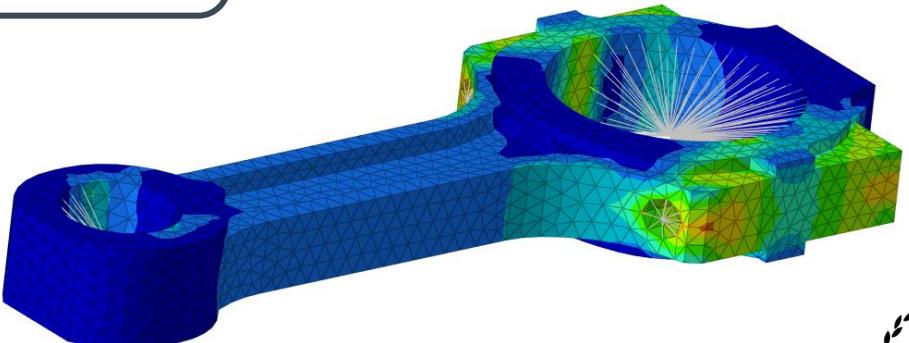
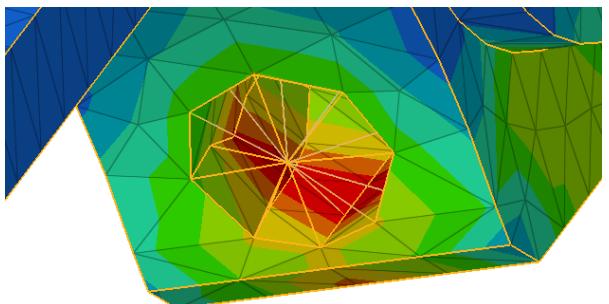


Maximum stress in the fillets where bolts are screwed → 248 MPa



Stress concentration in notch

Connecting rod loaded with tensile stress



RESULTS – AFTER TDC (GAS PRESSURE)

Connecting rod is the most stressed part due to gas pressure load



Compressive load along connecting rod

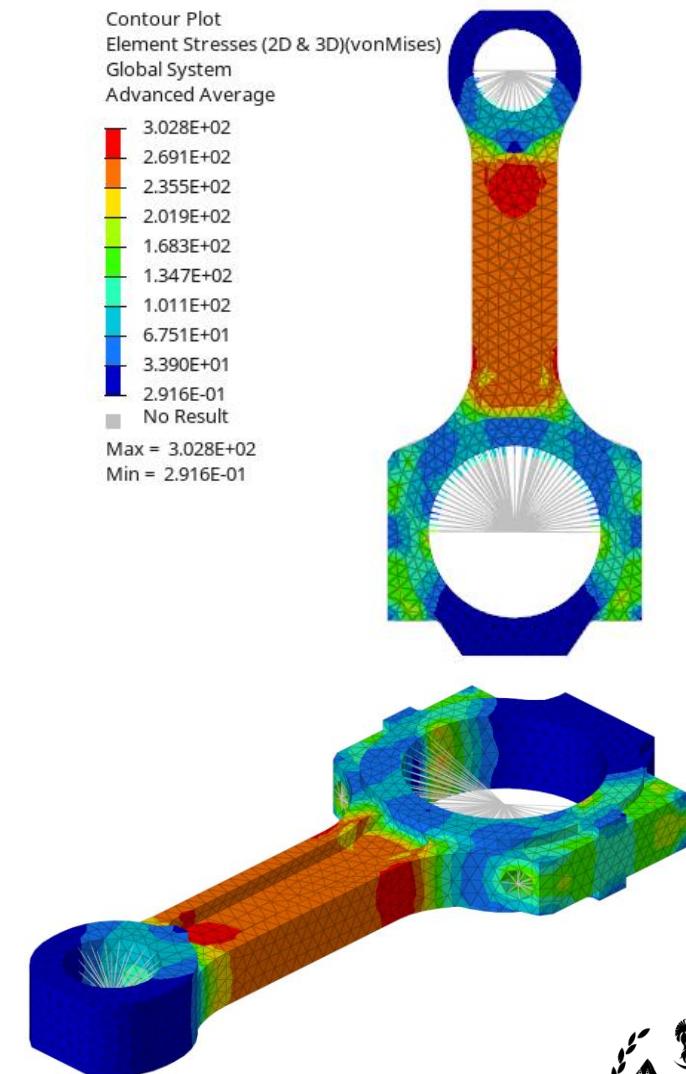
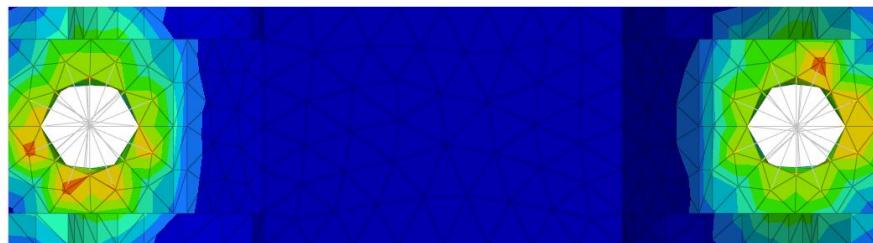


Maximum stress in the external fillet between connecting rod and big end
→(302MPa)

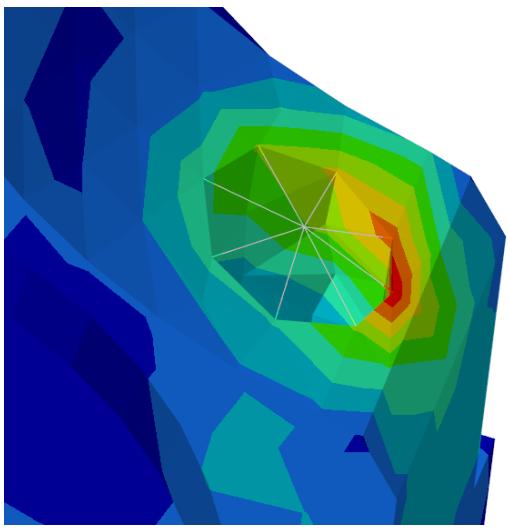


Stress concentration below small end due to material deformation → 270 MPa

Bolt holes are the second most stressed zone → 250MPa



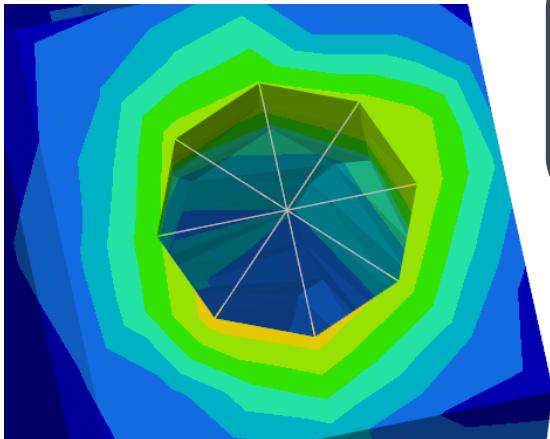
IMPROVEMENT - BOUNDARY CONDITIONS



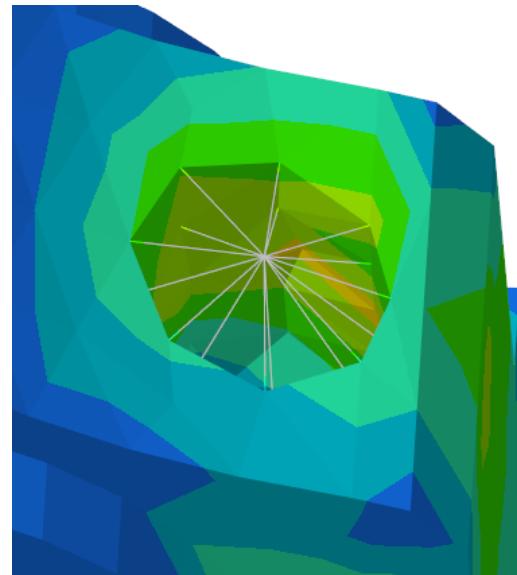
CASE A

Case A: stress distributed along the edge

Case B: stress applied in a surface



Resulting effect: Case B better distribution of the load, near to reality

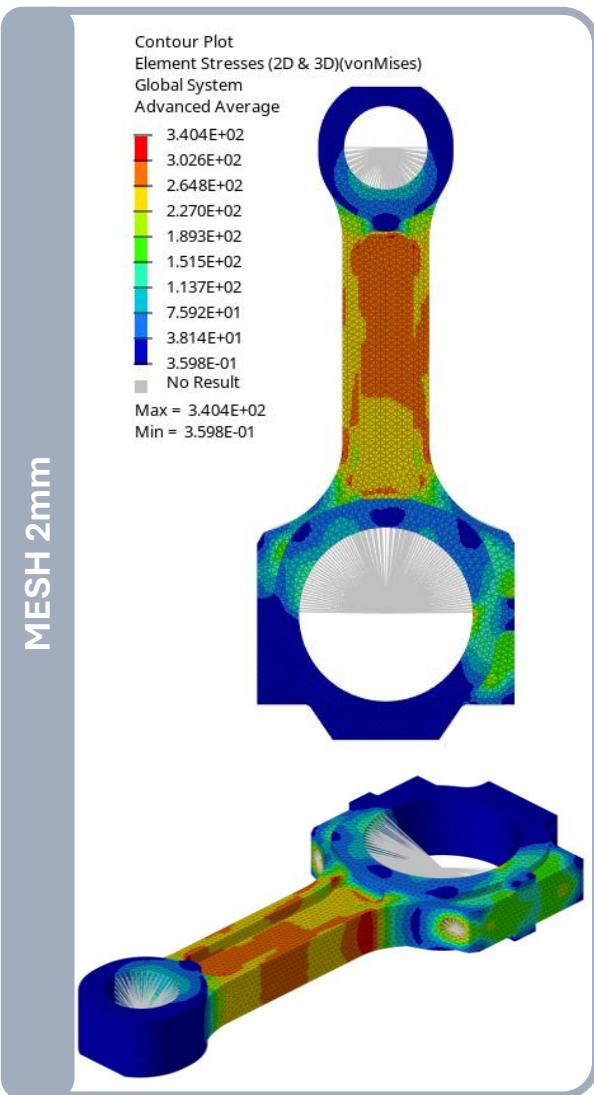


CASE B

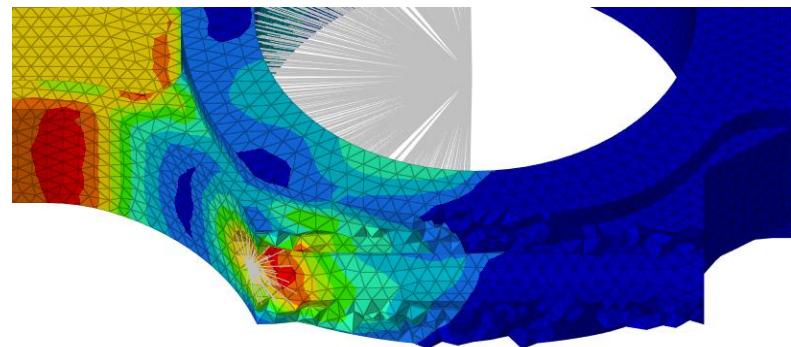


IMPROVEMENT - MESH

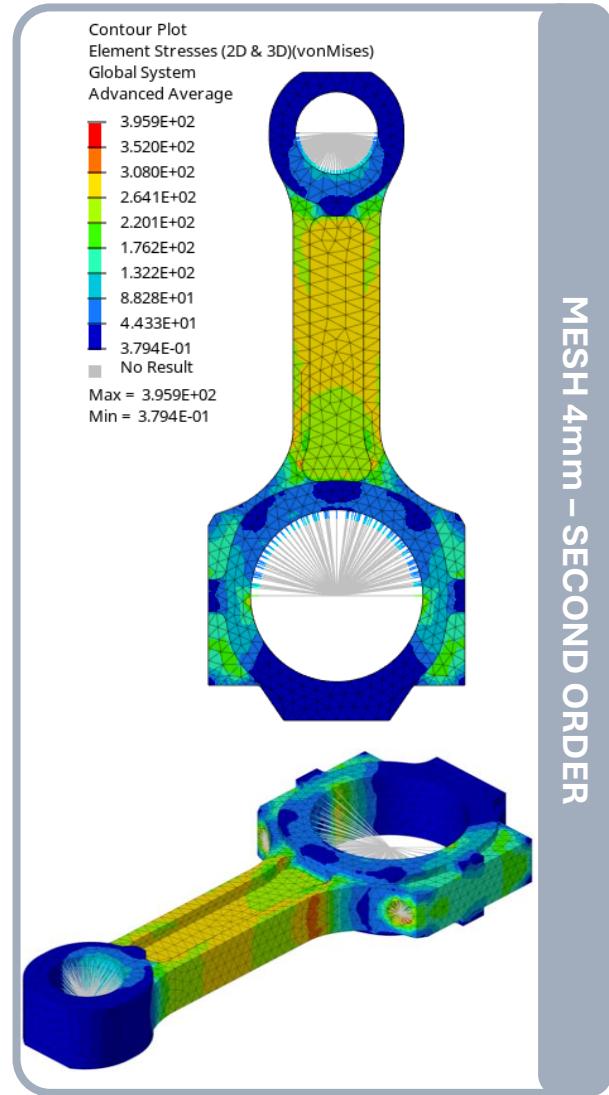
MESH 2mm



Overall, improving the mesh quality results in an **increase in stress** at the same critical points, especially at the **fillet between the big end and the rod**, as well as the **bolt connection**.



MESH 4mm - SECOND ORDER



CONCLUSION



Stresses: the **rod after TDC** (gas pressure case) appears to be **more stressed**, particularly the connecting rod and the screw holes have high compression load.



Boundary conditions: application of **small eye constraint** and **redistribution of rigid connectors** for the bolts have **improved the reliability** of the simulation.

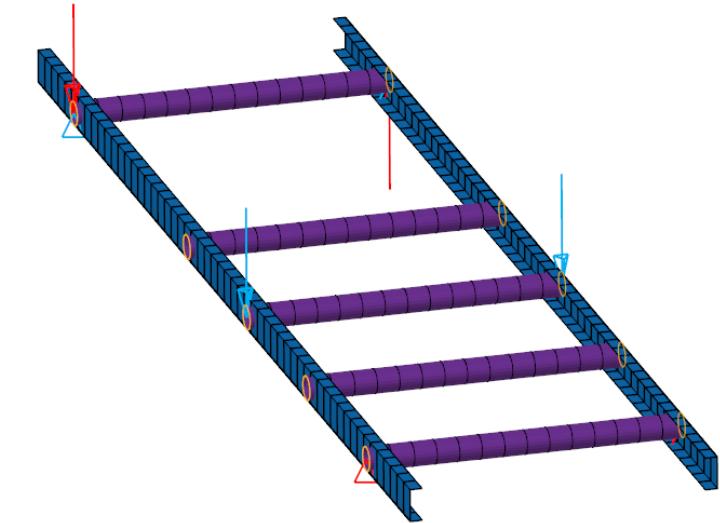


Mesh: **Improving** the **mesh quality** generally leads to an **increase in stress** throughout the rod, with a more pronounced effect at critical points.

NUMERICAL MODELLING AND SIMULATION – PART A

REPORT 3

**STUDY OF A COMMERCIAL
VEHICLE CHASSIS**



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TARGETS



To understand the **1D behavior**.

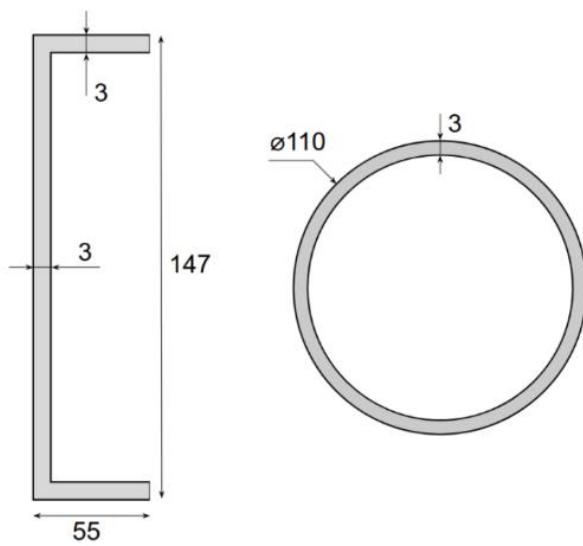
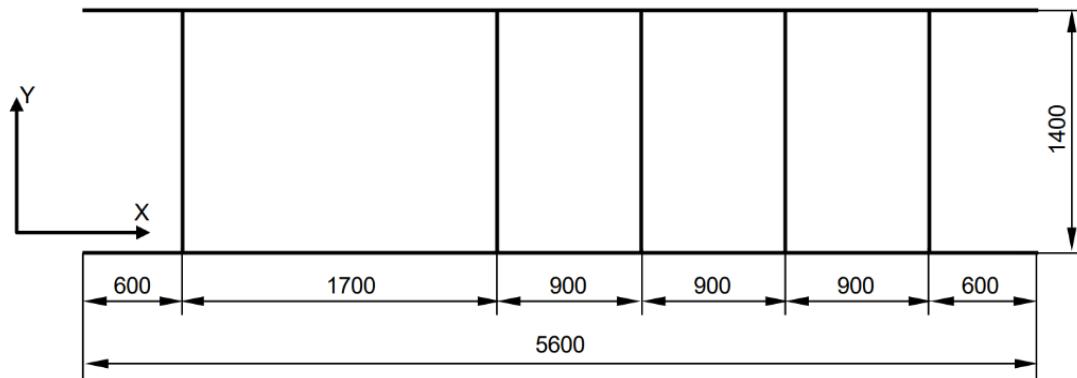


To evaluate **bending and torsional stiffness** of the frame.



To evaluate of **influence of different parameters** (material, geometry, dimensions, orientation).

PROBLEM ILLUSTRATION



MATERIAL

- Category: Steel
- $E = 206000 \text{ MPa}$
- $\nu = 0,3$
- $\rho = 7,85 \cdot 10^{-9} \text{ Gkg/m}^3$

GEOMETRY

- **Longitudinal beams:** C section, open sides oriented towards center of structure.
- **Cross beams:** hollow circular cross section.

METHODS - DISCRETIZATION

SOFTWARES

- FEA: Hypermesh 2024
- Solver: Optistruct
- Visualizer: Hyperview 2024

MESH

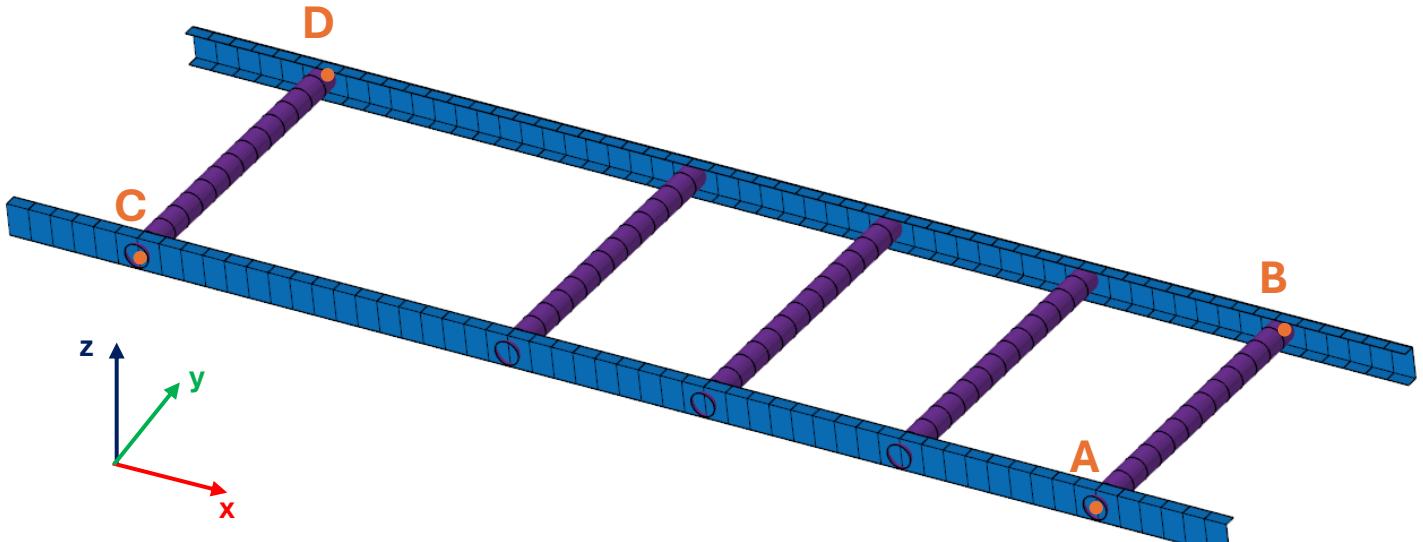
- Type: 1D
- Size: 100 mm

TYPE OF CONSTRAINTS

displacement along x,y,z and rotation around z and x constrained:

Torsion case: nodes A and B

Bending case: nodes A,B,C,D



SECTION TYPE

Longitudinal beam: CHAN

Cross beam: TUBE

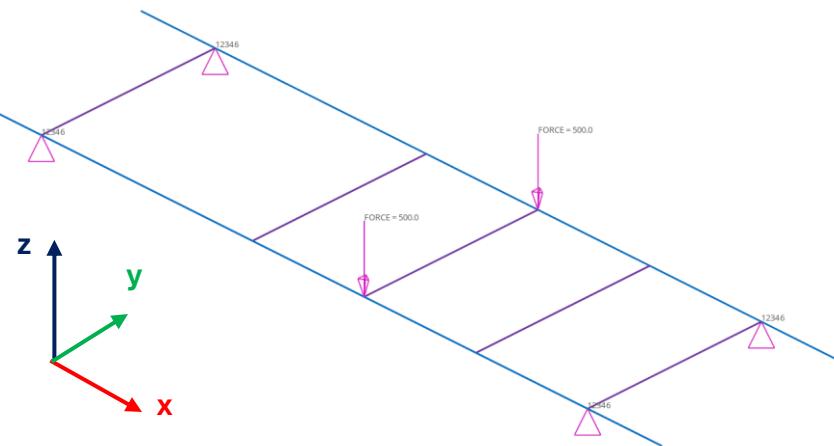
PROPERTY

PBEAML

LOAD CASES AND FORMULAS

Linear field: to calculate the stiffnesses a generic test force of 500 N is used

BENDING



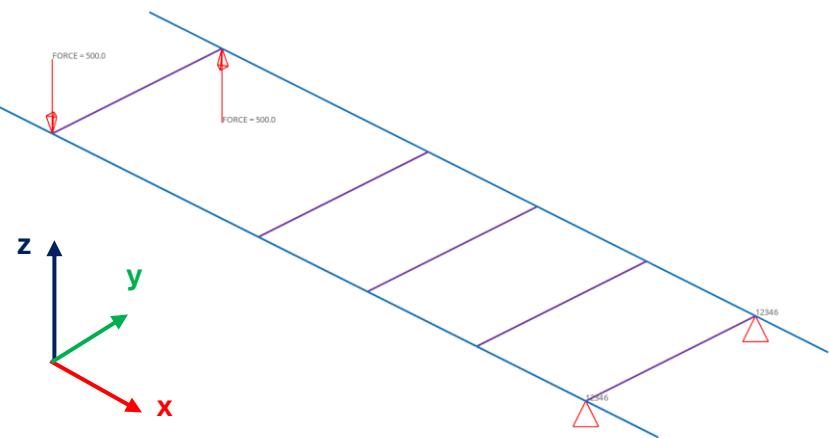
Forces applied in the **middle of longitudinal beam** to generate a **bending moment**

Δz = maximum z displacement in the node where the structure is loaded

$$F = 500 \text{ N}$$

$$K_b = \frac{F}{\Delta z}$$

TORSION



Couple of forces applied in junction point between **suspension** of an axle and chassis to generate a **torsion moment**

$$F = 500 \text{ N}$$

$$\text{H}\ddot{\text{o}}\text{p: small angles} \rightarrow \tan(\vartheta) \cong \vartheta \rightarrow \vartheta = \frac{\Delta z}{b}$$

$$b = 1400 \text{ mm}$$

$$M_t = F \cdot b = 700000 \text{ Nmm}$$

$$K_t = \frac{M_t}{\vartheta}$$

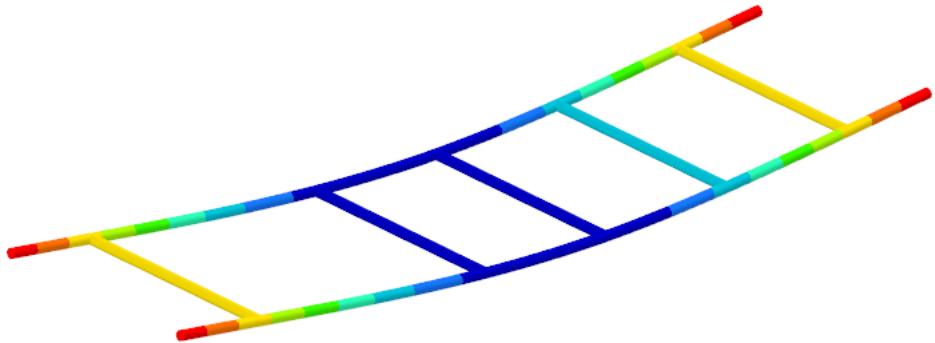
RESULTS

BENDING

Contour Plot
Displacement(Z)
Analysis system

7.493E-01
4.753E-01
2.012E-01
-7.282E-02
-3.469E-01
-6.209E-01
-8.950E-01
-1.169E+00
-1.443E+00
-1.717E+00
No Result

Max = 7.493E-01
Min = -1.717E+00



$$\Delta z = 1,717 \text{ mm}$$

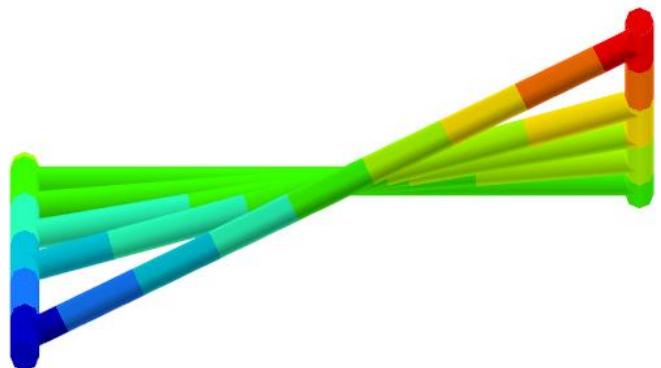
$$K_b = \frac{F}{\Delta z} = 291,21 \text{ N/mm}$$

TORSION

Contour Plot
Displacement(Z)
Analysis system

7.249E+00
5.555E+00
3.860E+00
2.166E+00
4.717E-01
-1.223E+00
-2.917E+00
-4.611E+00
-6.305E+00
-8.000E+00
No Result

Max = 7.249E+00
Min = -8.000E+00



$$\Delta z_{left} = 8 \text{ mm} \quad \Delta z_{right} = 7,249 \text{ mm}$$

$$\Delta z_{average} = 7,623 \text{ mm} \quad \vartheta = \frac{\Delta z_{average}}{b} = 1,09 \cdot 10^{-2} \text{ rad}$$

$$K_t = \frac{M_t}{\vartheta} = 6,43 \cdot 10^7 \text{ Nmm}$$

PARAMETERS INFLUENCE

Case	Description
a.	Reference- Mesh 100 mm
b.	Mesh 25 mm
c.	Al 7075 T6
d.	Rotated long. beam
e.	Double thickness cross beam
f.	Double thickness long. beam
g.	Half diameter cross (same thickness)
h.	Double section dimensions long. beam (same thickness)
i.	box section (cross beam)

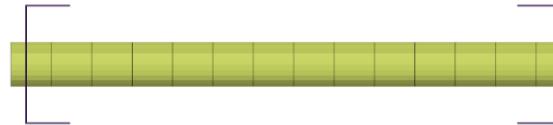
Case d.



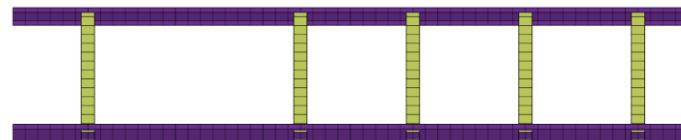
Case g.



Case h.



Case i.



PARAMETERS INFLUENCE

Case	Description	Torsion case					Bending case	
		Δz_{left}	Δz_{right}	$\Delta z_{average}$	ϑ	K_t	Δz	K_b
		[mm]	[mm]	[mm]	[rad]	[Nmm ²]	[mm]	[N/mm]
a.	Reference- Mesh 100 mm	8	7,249	6,7675	9,67E-03	7,24E+07	1,717	291,21
b.	Mesh 25 mm	7,909	6,883	6,7675	9,67E-03	7,24E+07	1,717	291,21
c.	Al 7075 T6	21,25	23,48	19,84	2,83E-02	2,47E+07	4,934	101,34
d.	Rotated long. beam	6,768	8,481	6,767	9,67E-03	7,24E+07	1,717	291,21
e.	Double thickness cross beam	3,917	5,018	4,006	5,72E-03	1,22E+08	1,717	291,21
f.	Double thickness long. beam	7,038	7,375	6,358	9,08E-03	7,71E+07	0,9175	544,96
g.	Half diameter cross (same thickness)	55,83	62,53	52,035	7,42E-02	9,43E+06	1,717	291,21
h.	Double section dimensions long. beam (same thickness)	5,957	7,793	6,0475	8,64E-03	8,10E+07	0,09061	5518,15
i.	box section (cross beam)	5,613	6,687	5,478	7,83E-03	8,95E+07	1,717	291,21

No significatively changes

Improvement

Worsening

CONCLUSIONS



Torsional stiffness: primarily influenced by the **inertia moment of the crossbeam section**, with a higher value corresponding to a greater torsional stiffness.



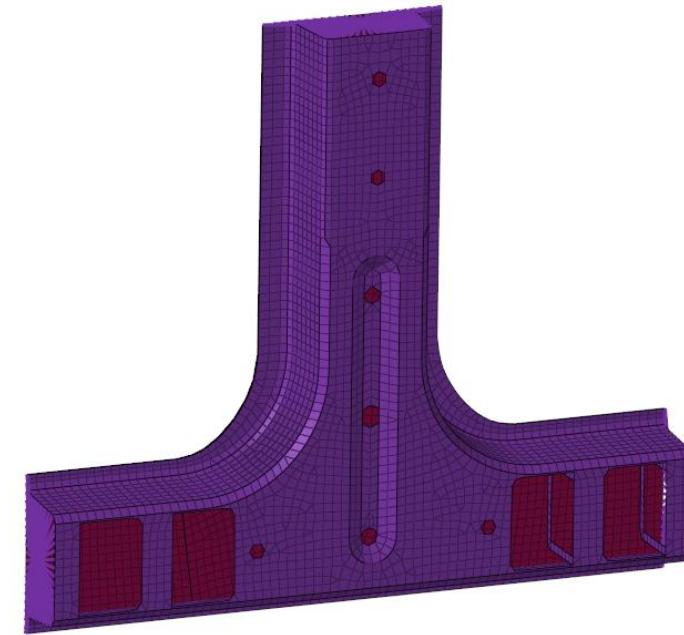
Bending stiffness: largely **depends** on the **inertia moment of the longitudinal beam section**; a greater moment of inertia results in increased bending stiffness.



Material: overall, both torsional and bending **stiffnesses** are directly **depended on mechanic characteristics** of the material.

NUMERICAL MODELLING AND SIMULATION – PART A

REPORT 4
Car body T-joint



PROBLEM ILLUSTRATION

HAT



PLATE

MATERIAL

- Category: Steel
- $E = 206000 \text{ MPa}$
- $\nu = 0,3$
- $\rho = 7,85 \cdot 10^{-9} \text{ Gkg/m}^3$

TARGETS

- To describe the main steps to create the welding.
- To calculate torsional stiffness (on Y axis) and bending stiffness (on X and Z axis).
- To evaluate the influence of number of spotwelds on the stiffnesses.

THICKNESS

$t = 1 \text{ mm}$

METHODS – STEPS OF CREATION

MIDLINE between the **border** and the end of the **curve surface**

IMPRINT between **hat** and **plate**

MESH

TRANSFORMATION TOOL - REFLECT
the half model on the X axe

POINTS on the **midlines**, after creating
the **setup** with the proper settings

EQUIVALENCE to bond
the two halves.

METHODS - DISCRETIZATION

SOFTWARES

- FEA: Hypermesh 2024
- Solver: Optistruct
- Visualizer: Hyperview 2024

MESH

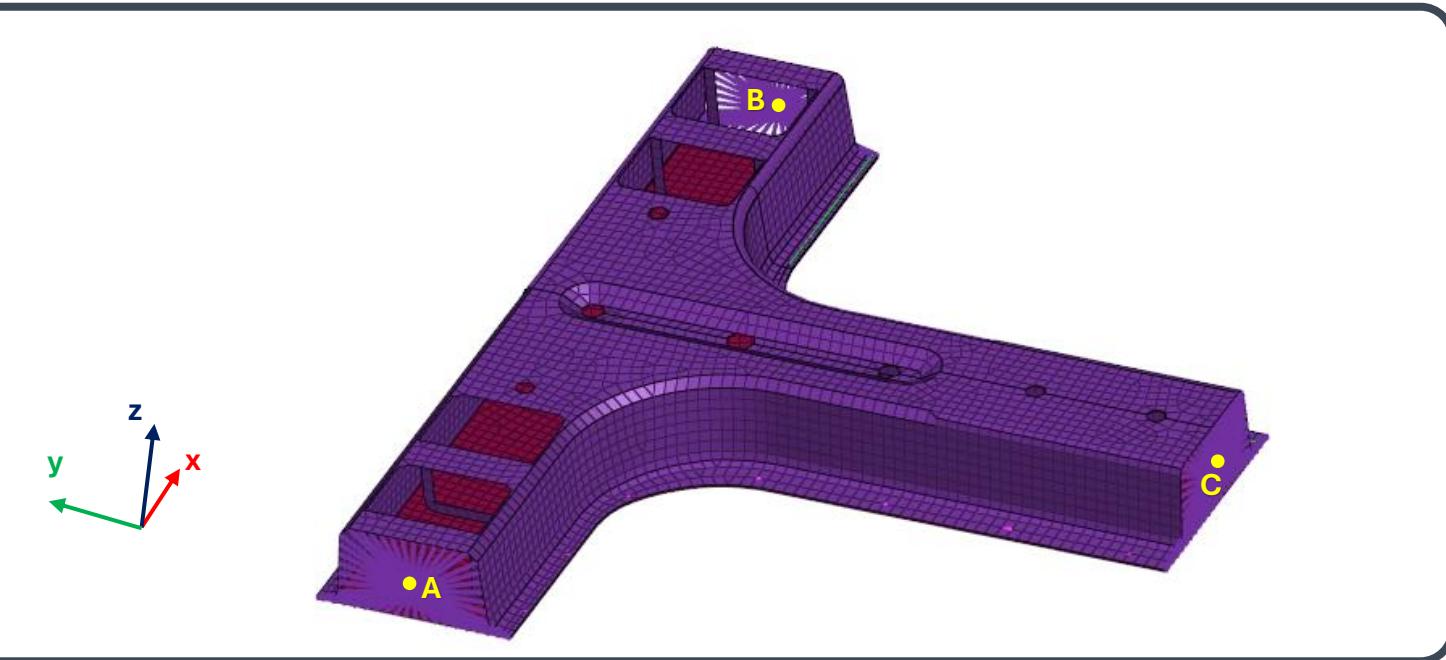
- Type: 2D – 4 nodes
- Size: 5 mm

PROPERTY

PSHELL

CONNECTORS

RBE2



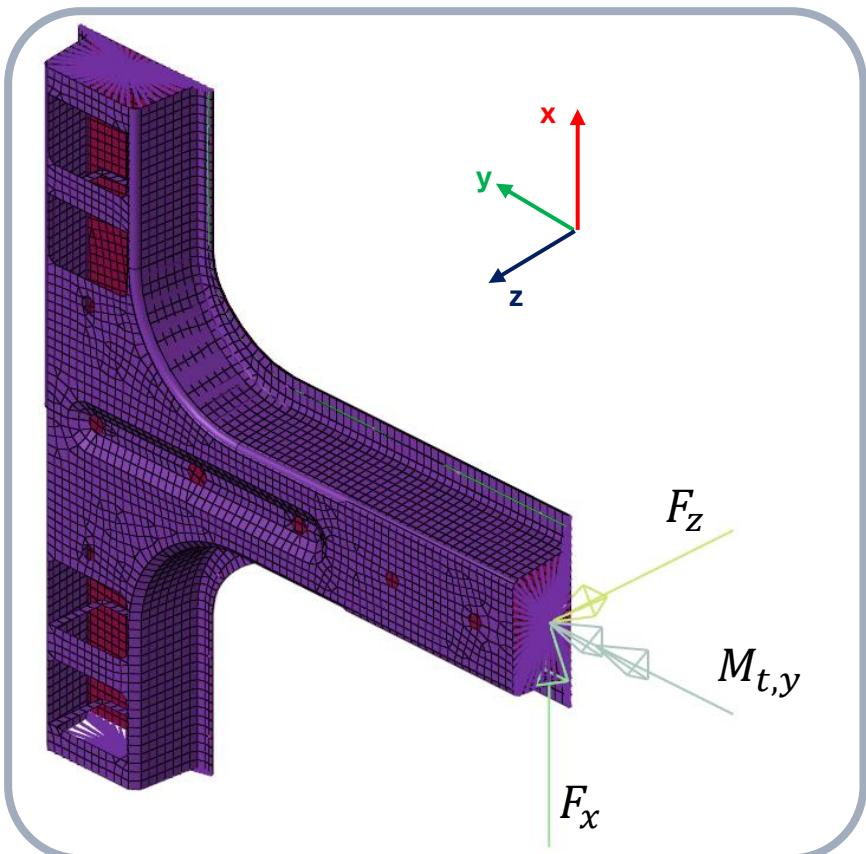
TYPE OF CONSTRAINTS – APPLIED ON MASTER NODES

Torsion case: A, B fully constrained, C only rotation around Y unconstrained.

Bending case: A, B fully constrained.

LOAD CASES AND FORMULAS

Linear field: **test loads** are applied on the **master node** of the rigid element of the **upper arm section**.



BENDING

Δz = max displacement in the node where the structure is loaded.

Shear forces applied to obtain **bending stress**

$$F_x = 1000 \text{ N} \quad F_z = 100 \text{ N} \quad K_{b,i} = \frac{F_i}{\Delta z_i}$$

TORSION

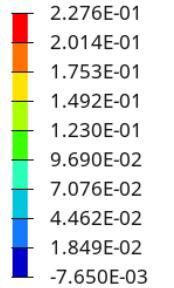
Momentum applied to generate a **torsional moment**.

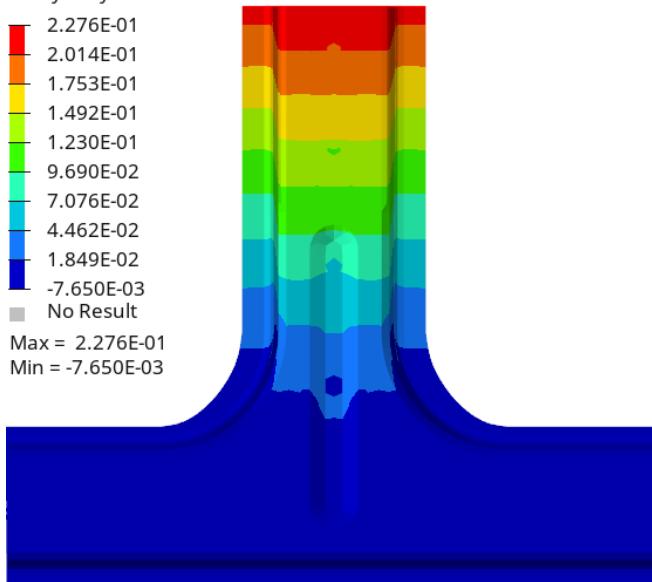
Hp: small angles $\rightarrow \tan(\vartheta) \approx \vartheta \rightarrow \vartheta = \frac{\Delta z}{b}$

$$M_{t,y} = 1000 \text{ Nm} \quad K_{t,y} = \frac{M_t}{\vartheta}$$

RESULTS

BENDING – $K_{b,x}$

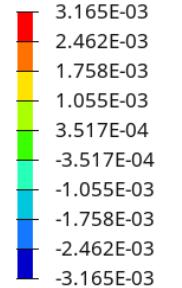
Contour Plot
Displacement(X)
Analysis system

2.276E-01
2.014E-01
1.753E-01
1.492E-01
1.230E-01
9.690E-02
7.076E-02
4.462E-02
1.849E-02
-7.650E-03
No Result
Max = 2.276E-01
Min = -7.650E-03

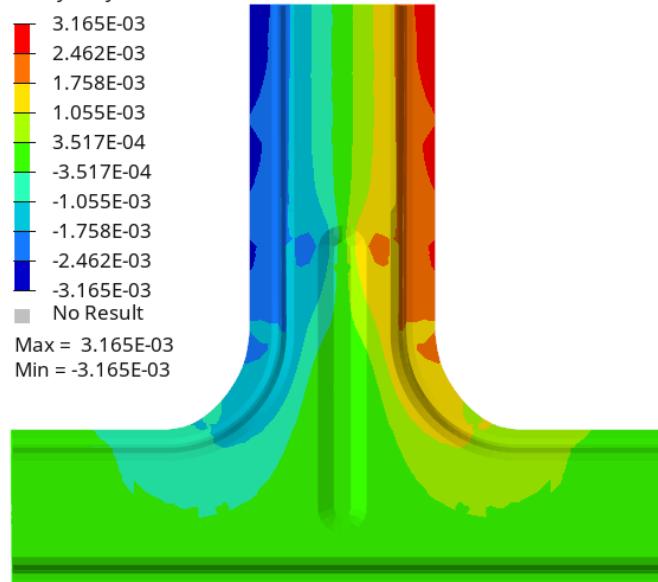


$$\Delta x = 0,2276 \text{ mm}$$

$$K_{b,x} = 439,37 \text{ N/mm}$$

TORSION – $K_{t,y}$

Contour Plot
Displacement(Z)
Analysis system

3.165E-03
2.462E-03
1.758E-03
1.055E-03
3.517E-04
-3.517E-04
-1.055E-03
-1.758E-03
-2.462E-03
-3.165E-03
No Result
Max = 3.165E-03
Min = -3.165E-03

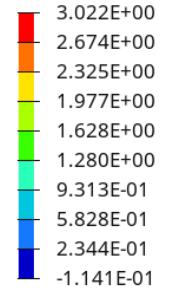


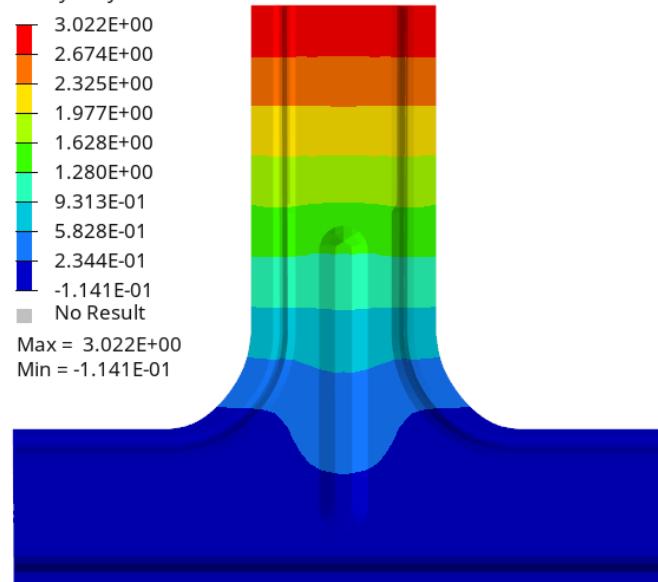
$$\Delta z_t = 3,17 \cdot 10^{-3} \text{ mm}$$

$$\vartheta_t = 4,82 \cdot 10^{-5} \text{ rad}$$

$$K_{t,y} = 1,71 \cdot 10^7 \text{ N} \cdot \text{mm/rad}$$

BENDING – $K_{b,z}$

Contour Plot
Displacement(Z)
Analysis system

3.022E+00
2.674E+00
2.325E+00
1.977E+00
1.628E+00
1.280E+00
9.313E-01
5.828E-01
2.344E-01
-1.141E-01
No Result
Max = 3.022E+00
Min = -1.141E-01



$$\Delta z = 3,022 \text{ mm}$$

$$K_{b,z} = 33,09 \text{ N/mm}$$

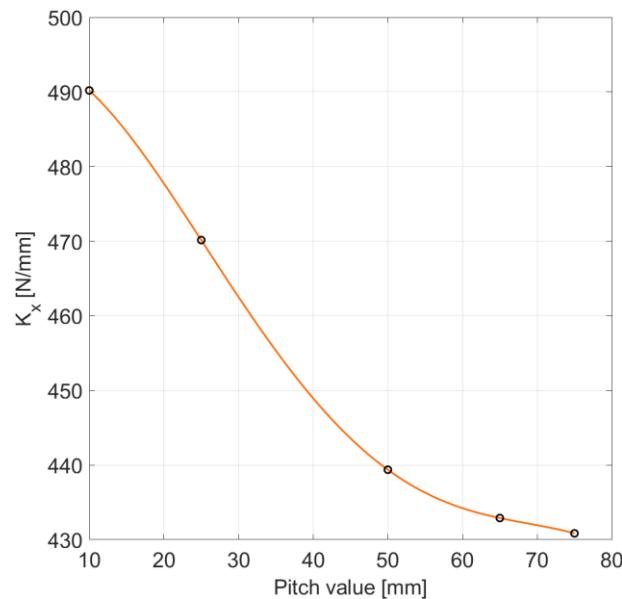
PARAMETERS INFLUENCE

Several analysis were performed **varying** the **pitch distance** to understand the **influence** of spot **welds** density on **stiffness**.

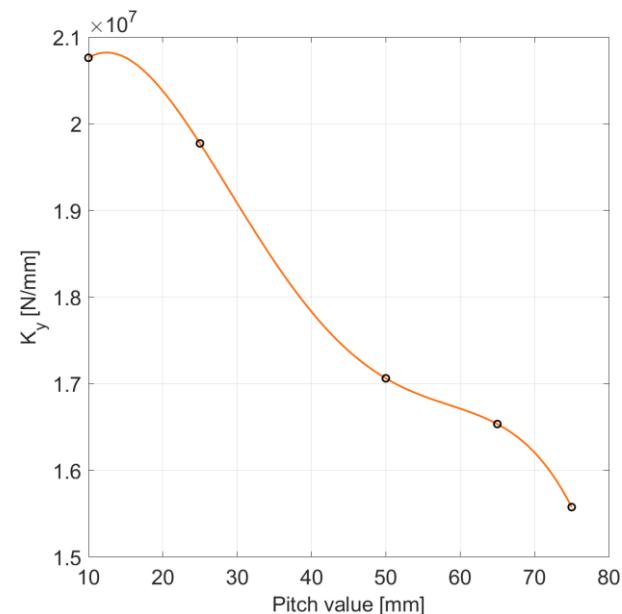
Case	Pitch value [mm]	Bending - z		Bending - x		Torsion - y		
		Δz	$K_{b,z}$ [N/mm]	Δx	$K_{b,x}$ [N/mm]	Δz_t	ϑ_t	$K_{t,y}$ [Nm/mm/rad]
		[mm]	[mm]	[mm]	[N/mm]	[mm]	[N/mm]	[Nm/mm/rad]
a	10	2,875	34,78	0,204	490,20	2,60E-03	4,82E-05	2,08E+07
b	25	2,944	33,97	0,2127	470,15	2,73E-03	5,06E-05	1,98E+07
c	50	3,022	33,09	0,2276	439,37	3,17E-03	5,86E-05	1,71E+07
d	65	3,064	32,64	0,231	432,90	3,27E-03	6,05E-05	1,65E+07
e	75	3,066	32,62	0,2321	430,85	3,47E-03	6,42E-05	1,56E+07

PARAMETERS INFLUENCE

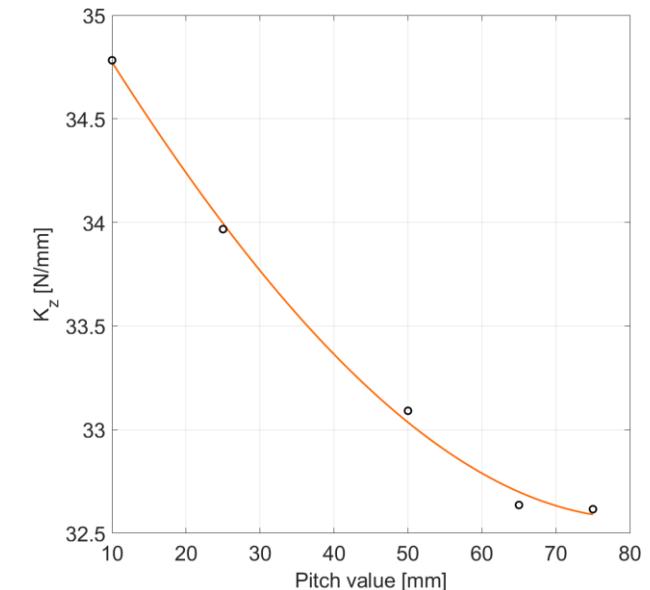
BENDING – $K_{b,x}$



TORSION – $K_{t,y}$



BENDING – $K_{b,z}$



Overall, reducing the pitch distance results in increased stiffness in all directions.

CONCLUSIONS



Torsion: The results indicate exceptionally **high torsional stiffness** along the **Y-axis**, demonstrating strong resistance to torsional loads.



Bending: Along the **X-axis**, the bending stiffness **is significantly higher** than along the **Z-axis**, indicating that the T-joint is better suited to withstand frontal stress compared to lateral stress.



Pitch value: **increasing the number of spot welds enhances the stiffness** of the structure in both torsional and bending scenarios. However, it is important to note that the correlation is not linear.