Analysis and Prediction of Large Composite Structures: Three Case Studies

Xavier Colom Fajula

Airbus A 380 Section 19 Frame

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1) SOLID MODEL GEOMETRY

Cross Section Geometry Ranges

20/40 mm

140/160 mm

Inner Flange:
3mm / 6.8mm

Web*:
1,9mm / 3mm

Outer Flange
3mm / 4.1mm

25/40 mm

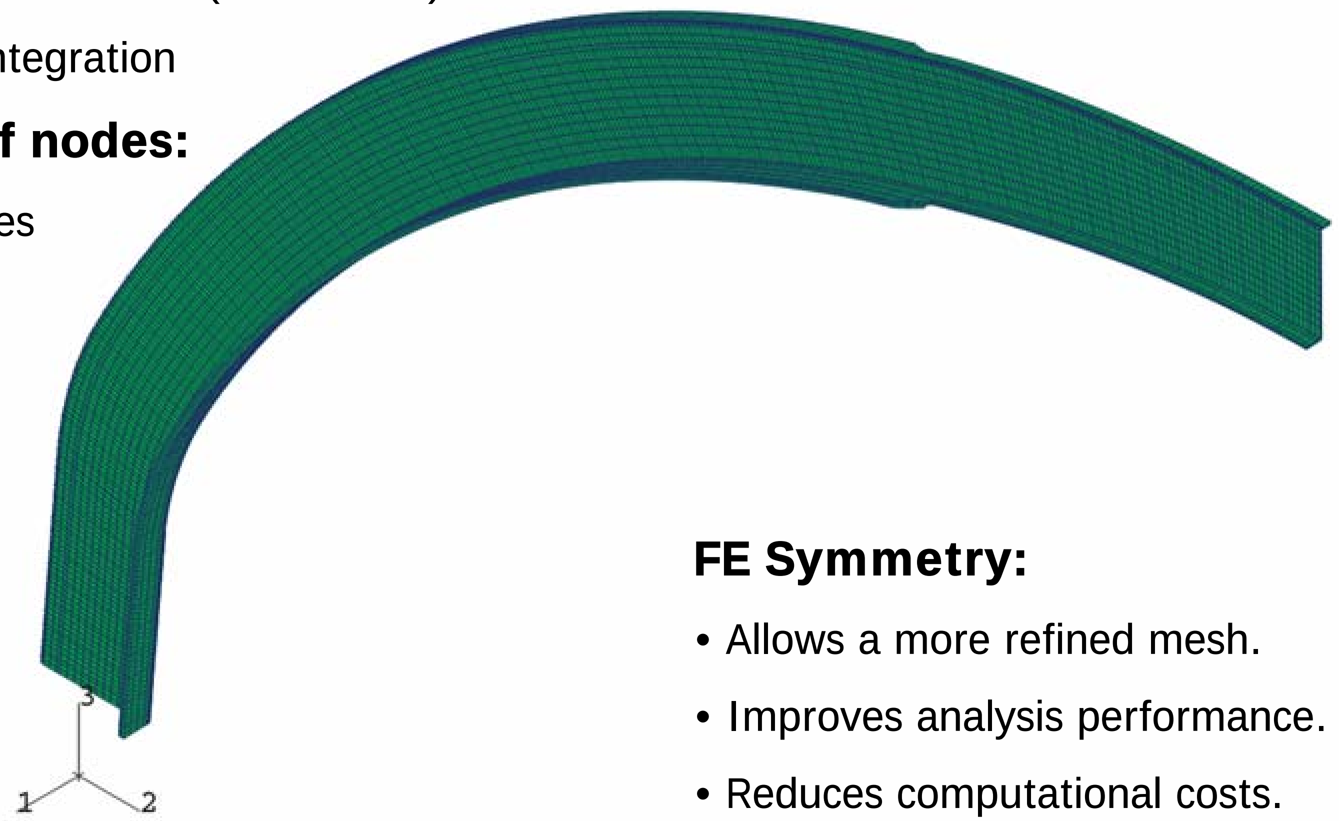
2) GLOBAL FINITE ELEMENT MODEL

Number of elements:

- 17768 solid elements (linear brick)
- Reduced Integration

Number of nodes:

- 28242 nodes

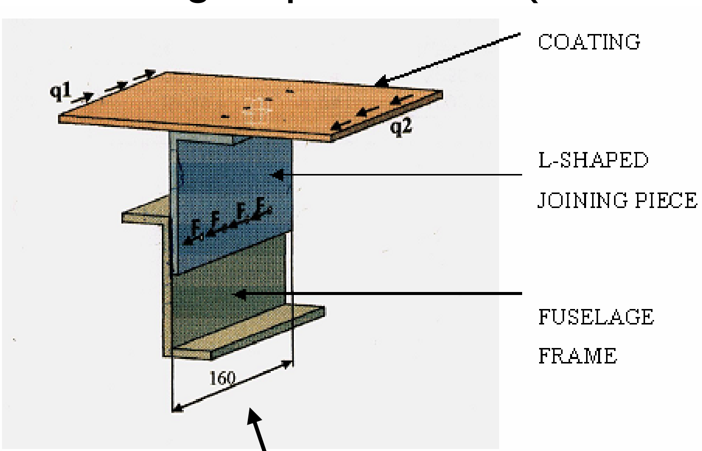


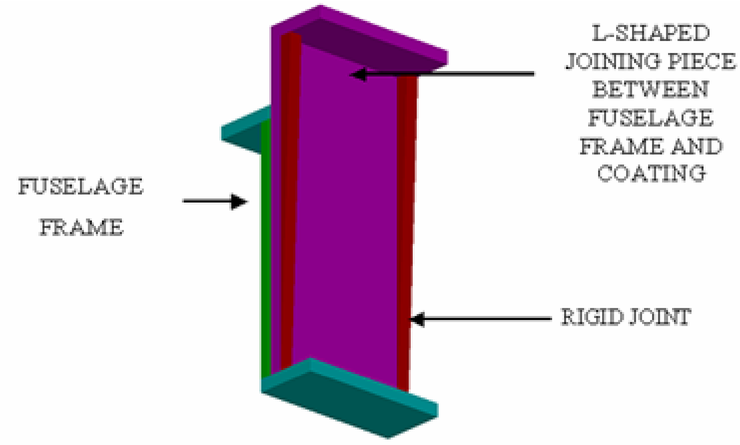
FE Symmetry:

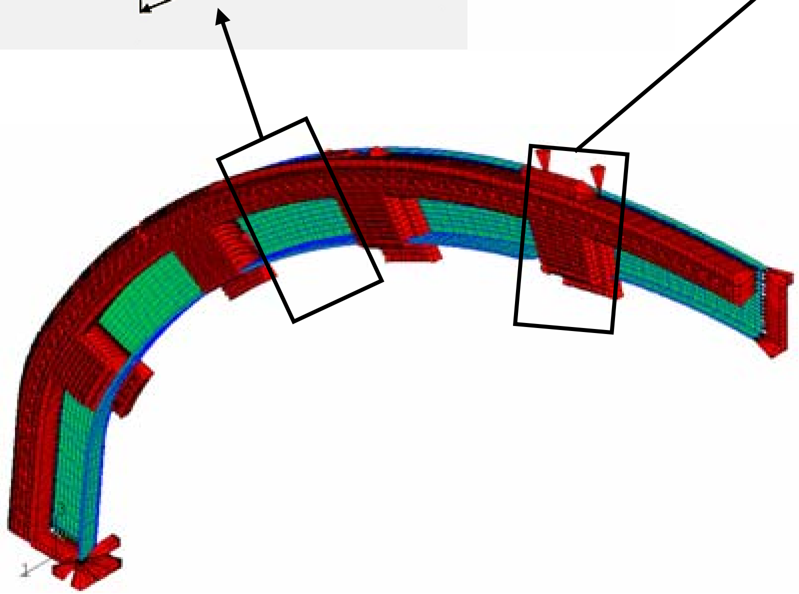
- Allows a more refined mesh.
- Improves analysis performance.
- Reduces computational costs.

BOUNDARY CONDITIONS

Loading requirements (load introduction):







Simple Joining L-shaped Piece:

•X displacements are constrained on nodes corresponding to the contact surface.

Rigid Joining L-shaped Piece:

•X,Y and Z displacements constrained on nodes corresponding to the contact surface.

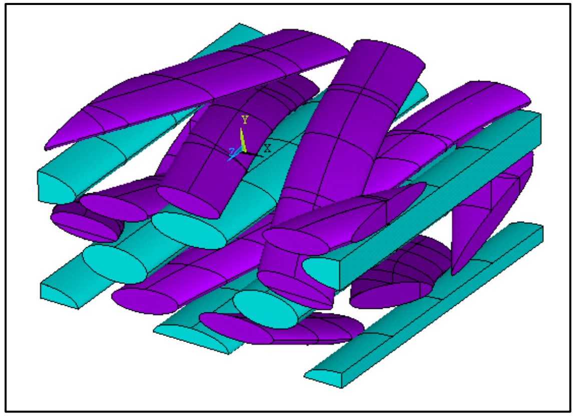
3) MICRO MECHANIC Finite Elements MATERIAL MODEL

Braiding Machine Parameters

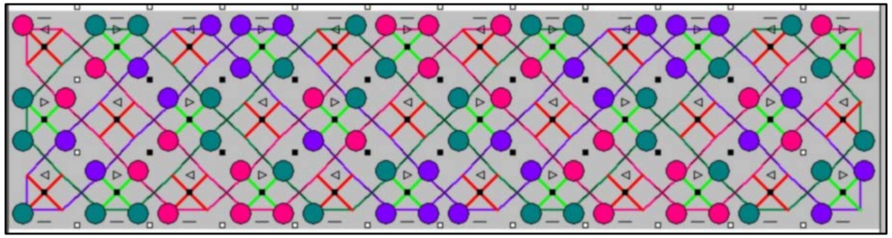
<u>Steps of micro mechanic FE modelling:</u>

- Carbon fibre 3D braided composite.
- Analysis of yarn architecture in unit cell
- FE modelling of unit cell

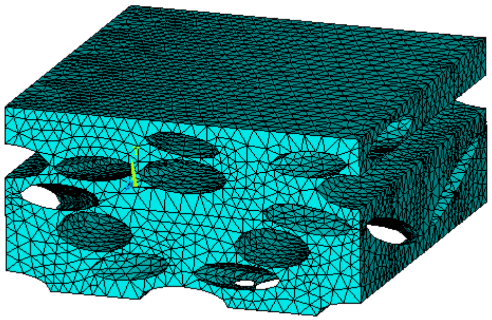
Yarn architecture



Bobbin carrier 2D trajectories developed in space



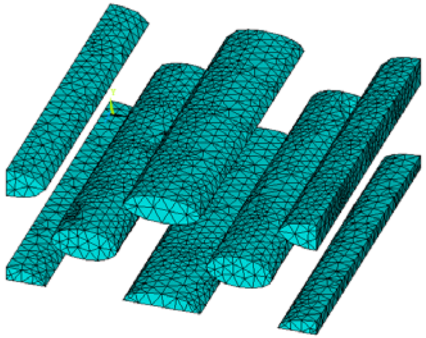
MICRO MECHANIC FE MATERIAL MODEL



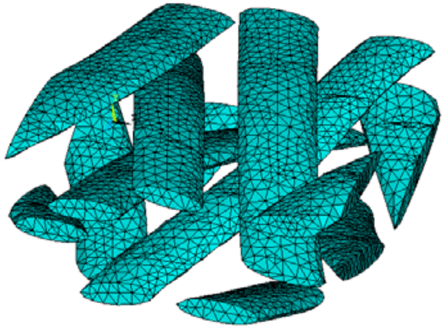
Matrix meshing

Finite Element Model of Unit Cell:

- Automatic parametrized mesh for different braid angles (20º and 30º)
- 110 000 quadratic 10 node elements
- 160 000 nodes
- Fiber volume=35.7%



Standing yarns meshing

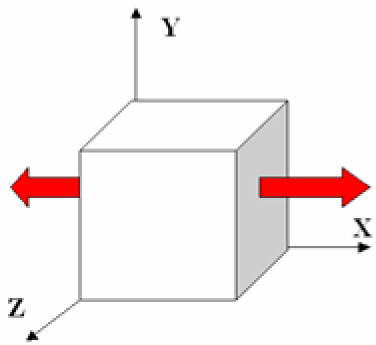
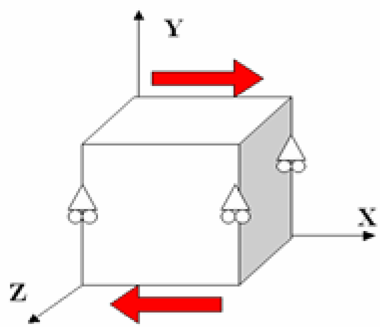


Braiding yarns meshing

MICRO MECHANIC FE MATERIAL MODEL

Homogeneisation:

- Two load cases are to be applied in each direction of the space.

	$\langle \sigma \rangle = \frac{1}{V}\sum_{e=1}^{Ne} \langle \sigma^e \rangle V^e$ where: $\langle\sigma\rangle$: average stress in RVE, V: RVE volume, $\langle\sigma^e\rangle$: average stress in element e, V^e: volume of element e.
	$G_{12}^* = \frac{\langle \sigma_{12} \rangle}{\langle \gamma_{12} \rangle} = \frac{\langle \sigma_{12} \rangle}{\left(U_0 / Y \right)}$, where: $\langle\sigma_{12}\rangle$: average shear stress in RVE, $\langle\gamma_{12}\rangle$: shear strain..

Representative Volume Element

Material description:

• Yarns are considered as transverse isotropic material, with high fiber volume content.

• Matrix itself is considered as isotropic.

Epoxy resin	
Young Modulus [GPa]	3.5
Poisson Coefficient	0.3
Density (gr/cm³)	1.3

Carbon fiber	
Exx [GPa]	210
Eyy=Ezz [GPa]	72
Gxy=Gxz [GPa]	86
Gyz [GPa]	27.7
nuxy=nuxz	0.27
nuyz	0.3

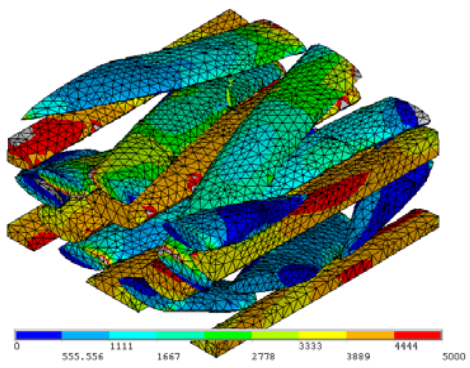
Yarns carbon UD (Vf=90%)	
Exx [GPa]	189.3
Eyy=Ezz [GPa]	25.8
Gxy=Gxz [GPa]	19.5
Gyz [GPa]	9.4
nuxy=nuxz	0.273
nuyz	0.364

Abolinsh approach

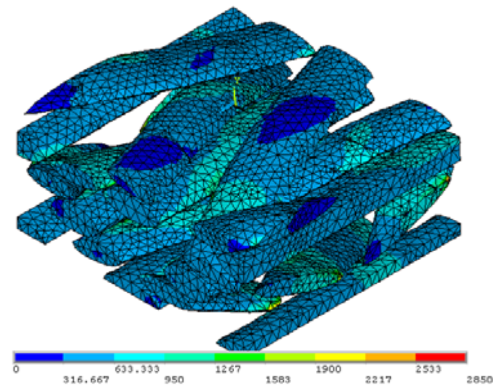
MICRO MECHANIC FE MATERIAL MODEL

Results:

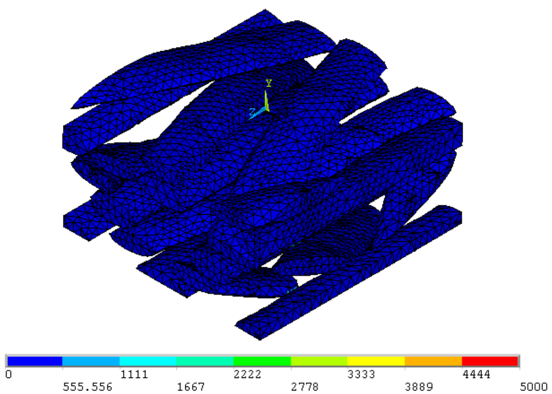
- Results are obtained in the elastic range of the material.



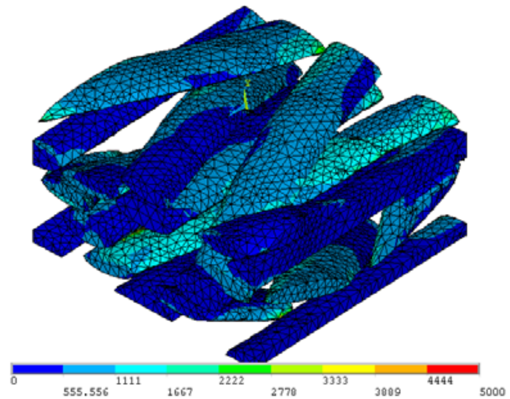
Tensile test in the X direction



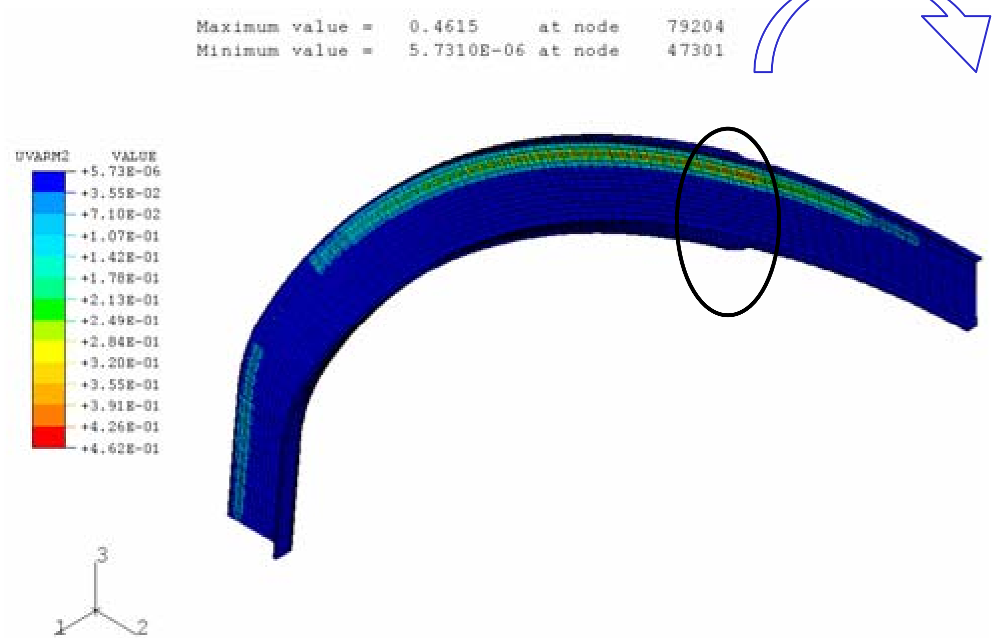
Tensile test in the Y direction



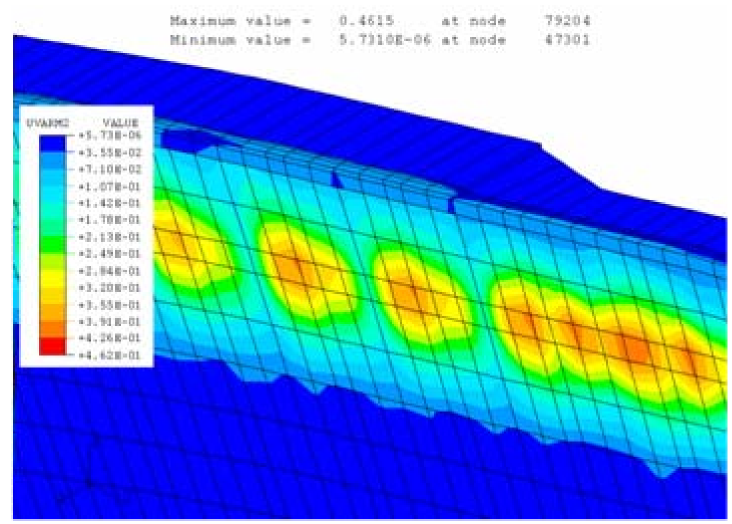
Tensile test in the Z direction



Shear test in the XY plane



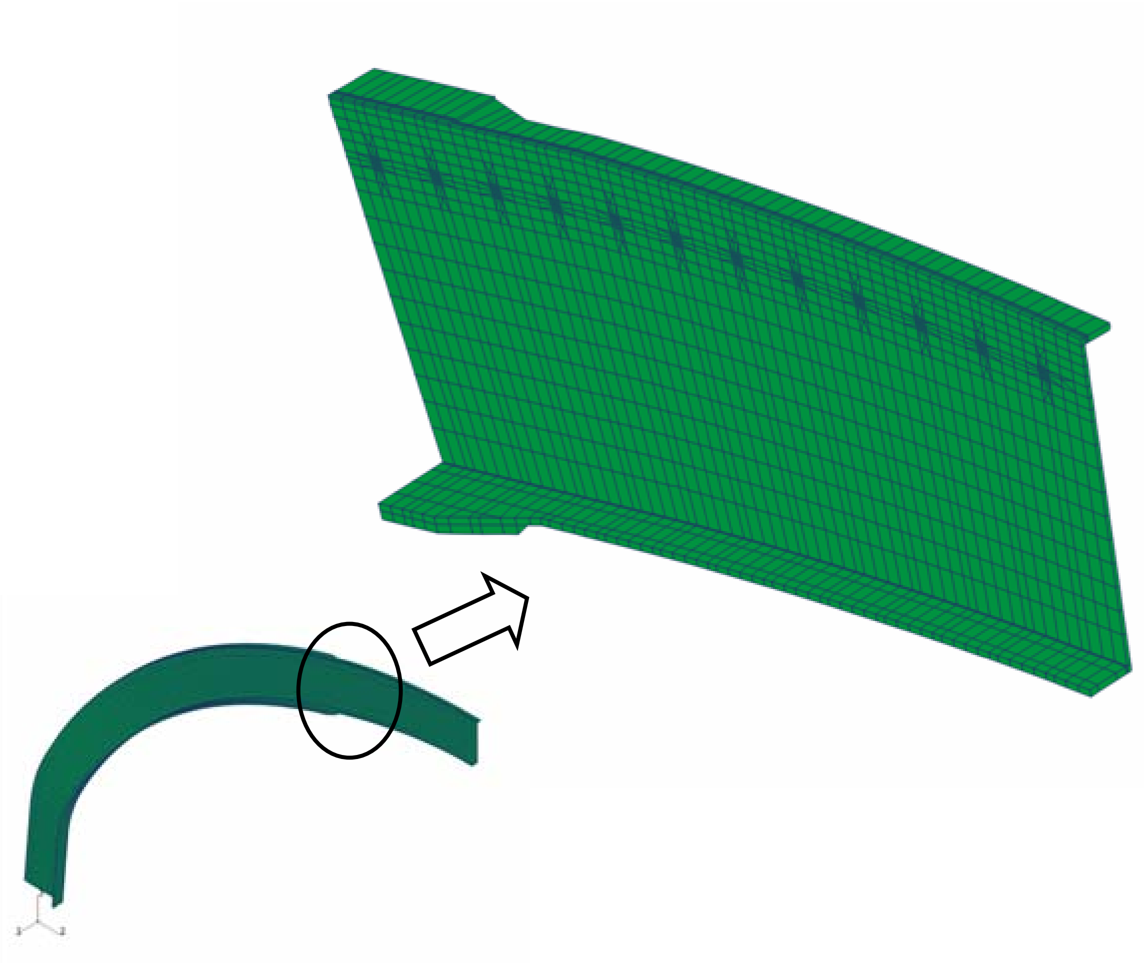
GLOBAL TSAI-WU COEFFICIENT



DETAILED GLOBAL TSAI-WU COEFFICIENT

It has been obtained a safety margin of 2.7, with conservative boundary conditions.

5) SUB- MODEL OF THE MOST UNFAVOURABLE SECTION



Number of elements:

•2347 linear solid elements

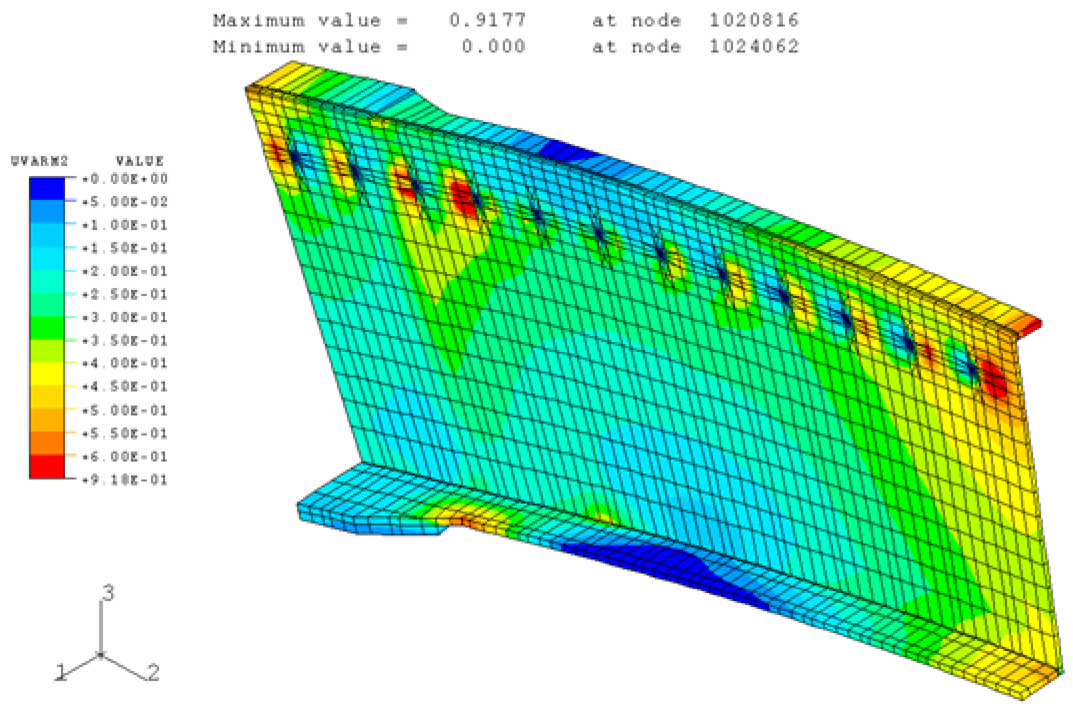
Number of nodes:

•4382 nodes

Detailed meshing of the zone of the rivet line.

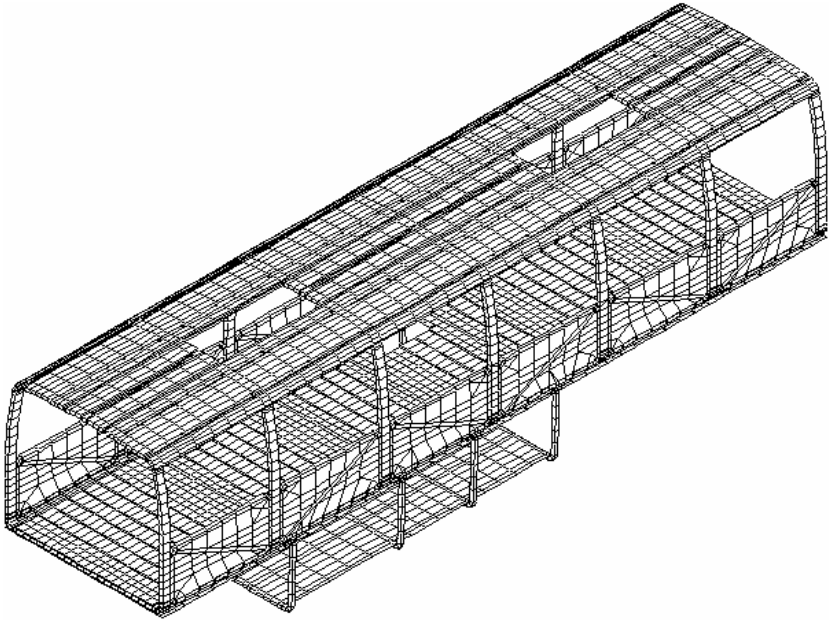
Boundary Conditions of Supported Contact.

RESULTS (LINEAR STATIC ANALYSES)

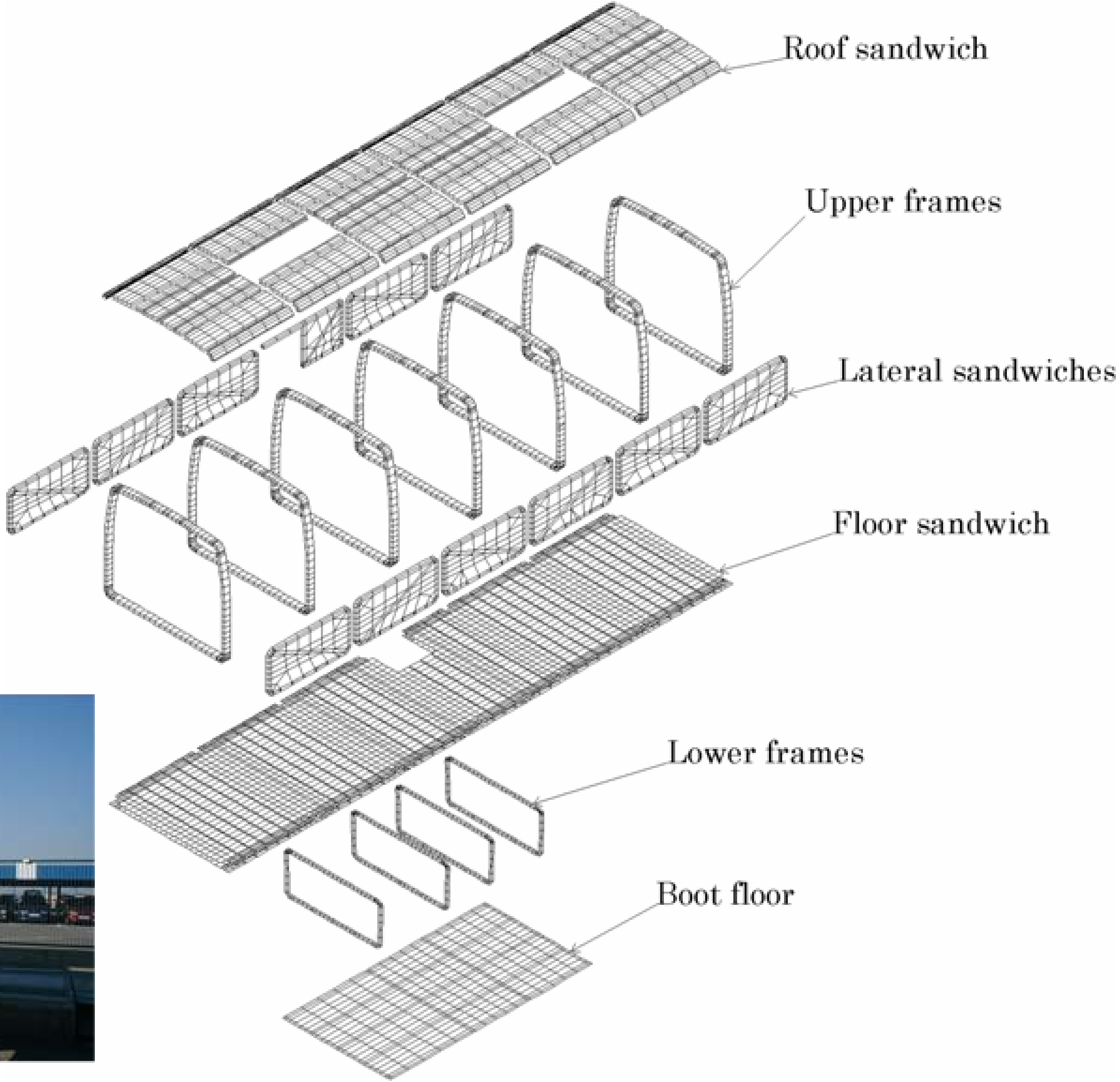


GLOBAL TSAI-WU COEFFICIENT

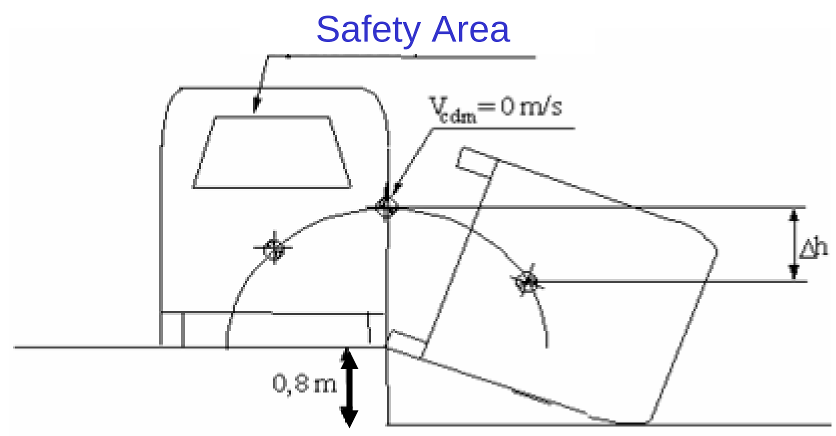
Full Composite Bus Structure

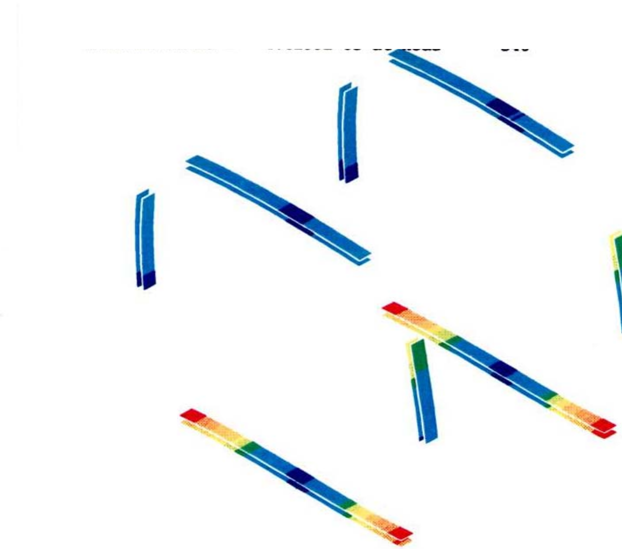


Full Composite Bus Structure



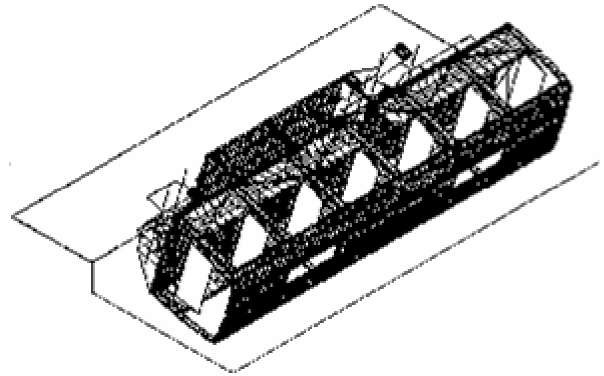
1) MODULUS ROLL OVER

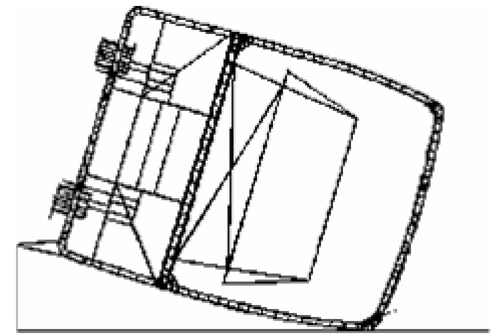




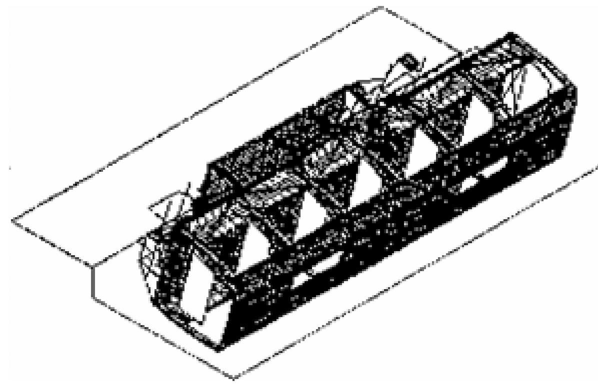
2) BUS ROLL OVER

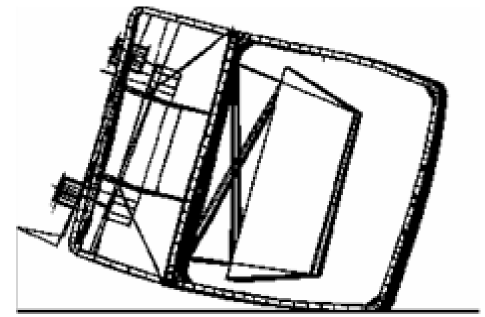
0.05 seg



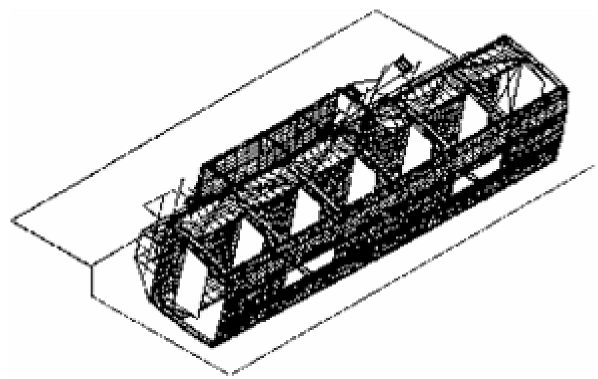


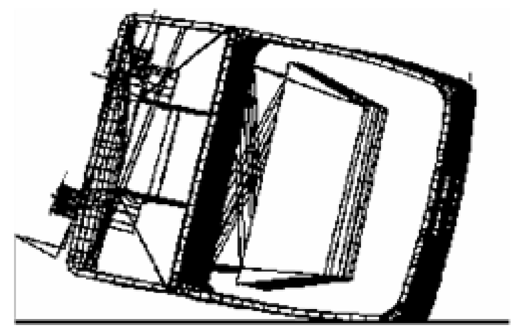
0.0 8 seg



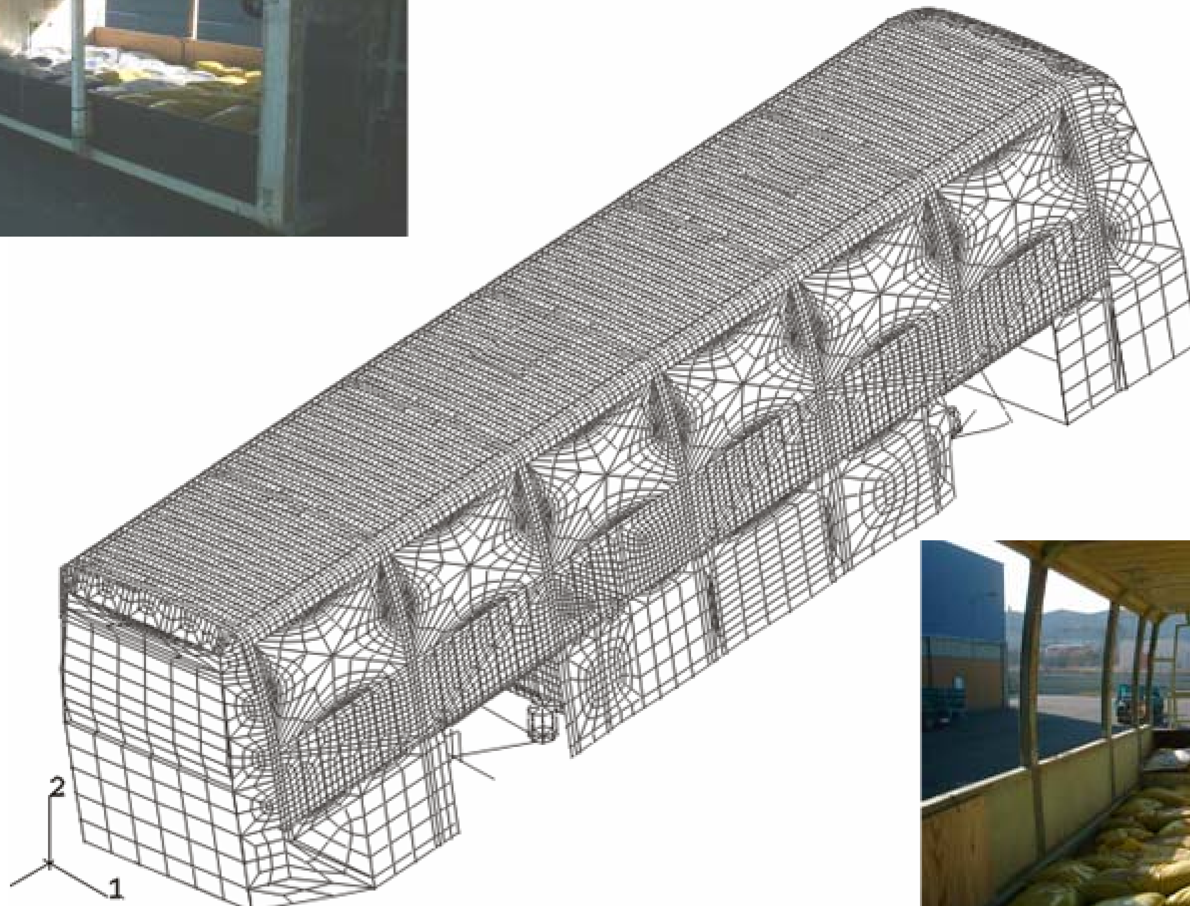


0.115 seg

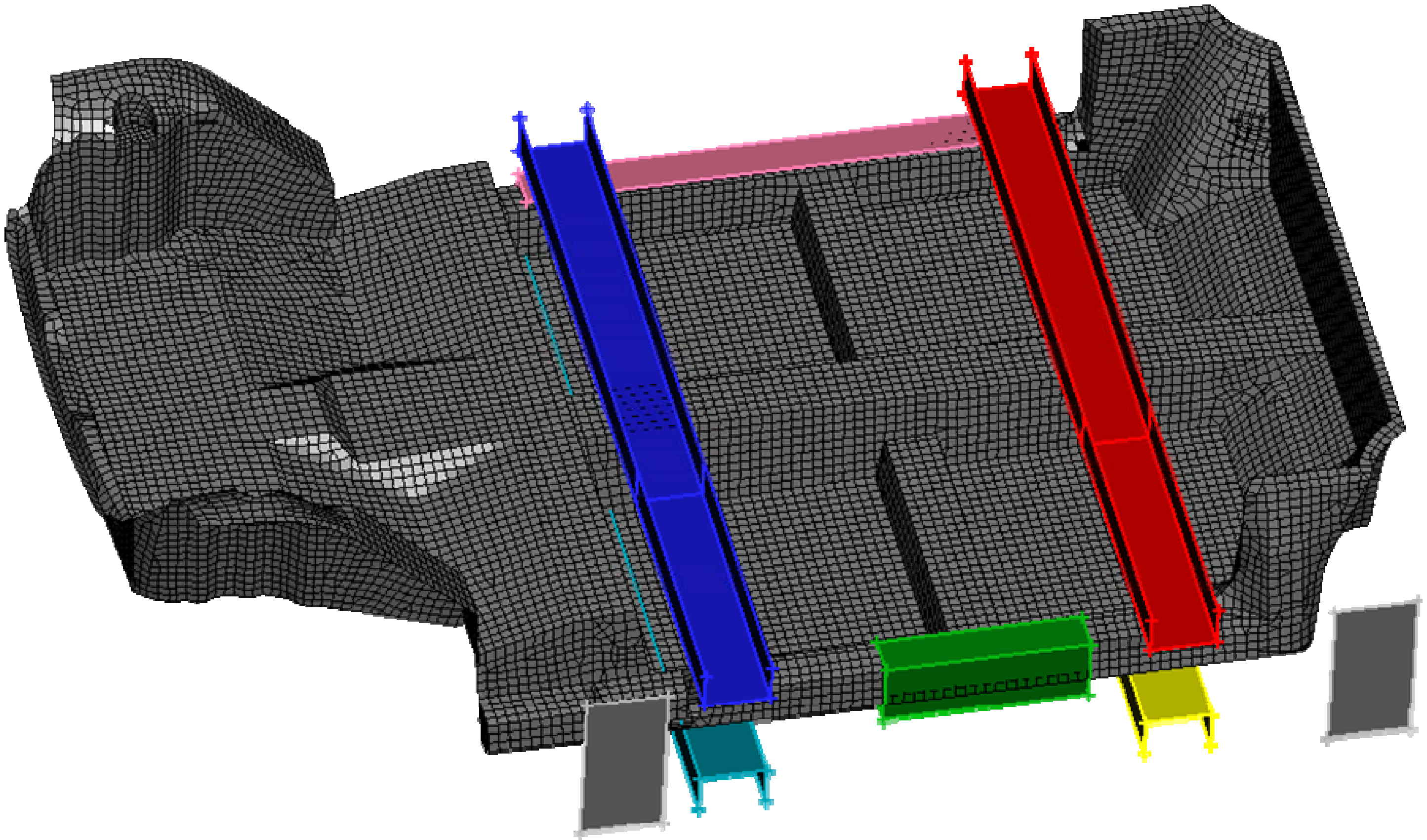




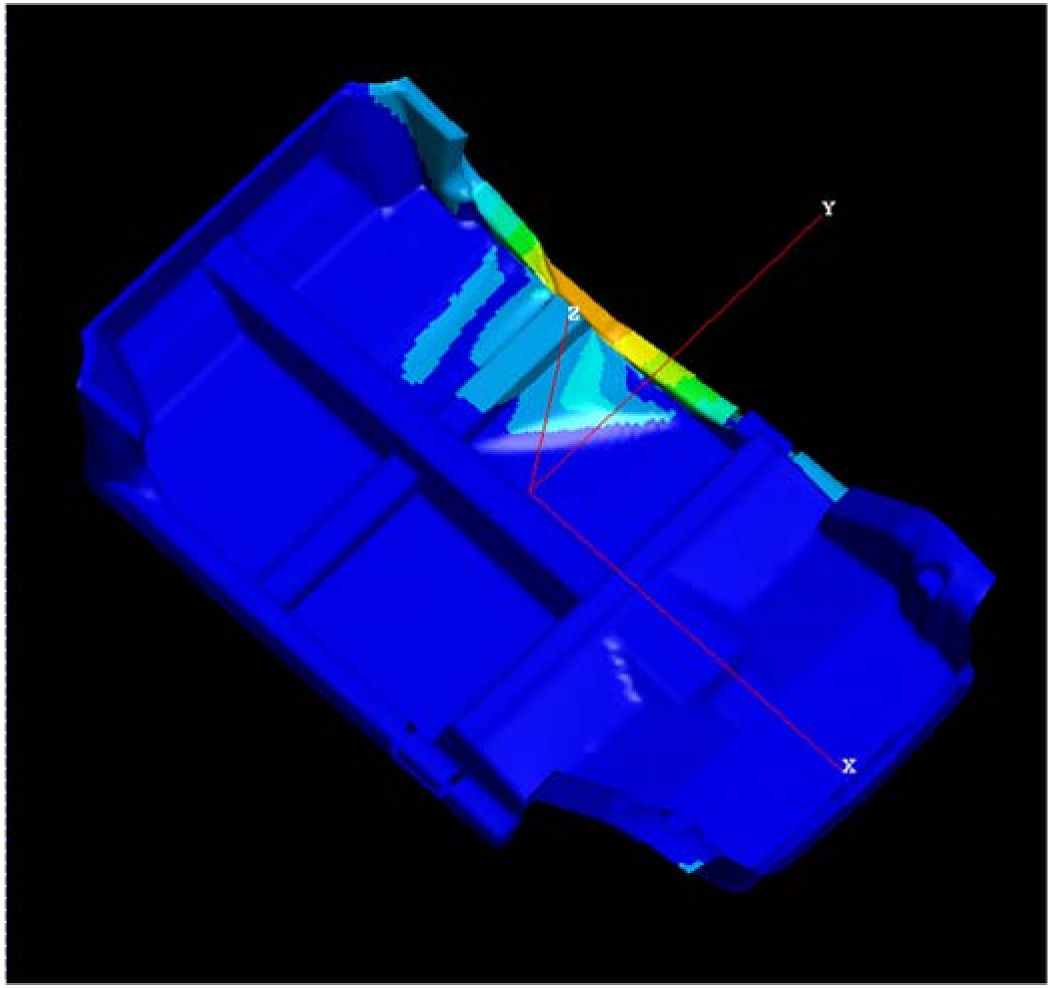
3) DYNAMIC ANALYSIS



Composite Car Modular Body



Composite Car Modular Body



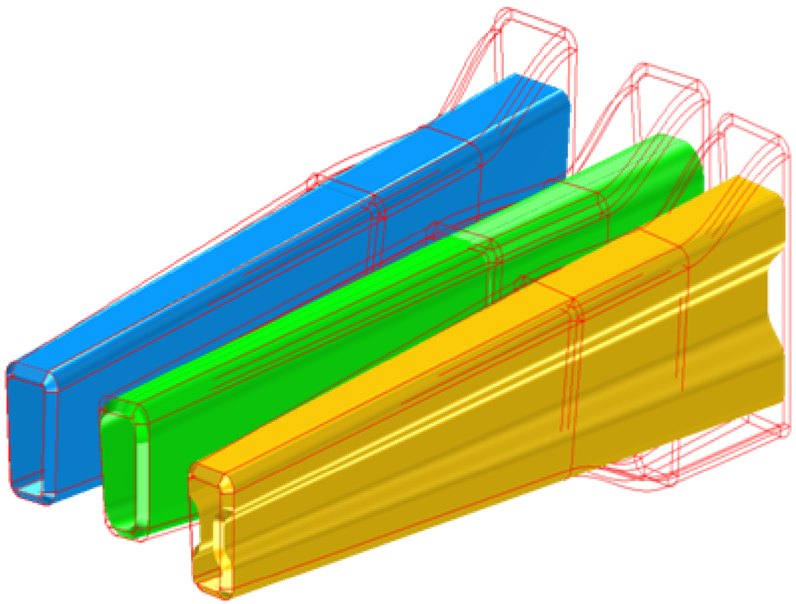
Non-linear Analysis

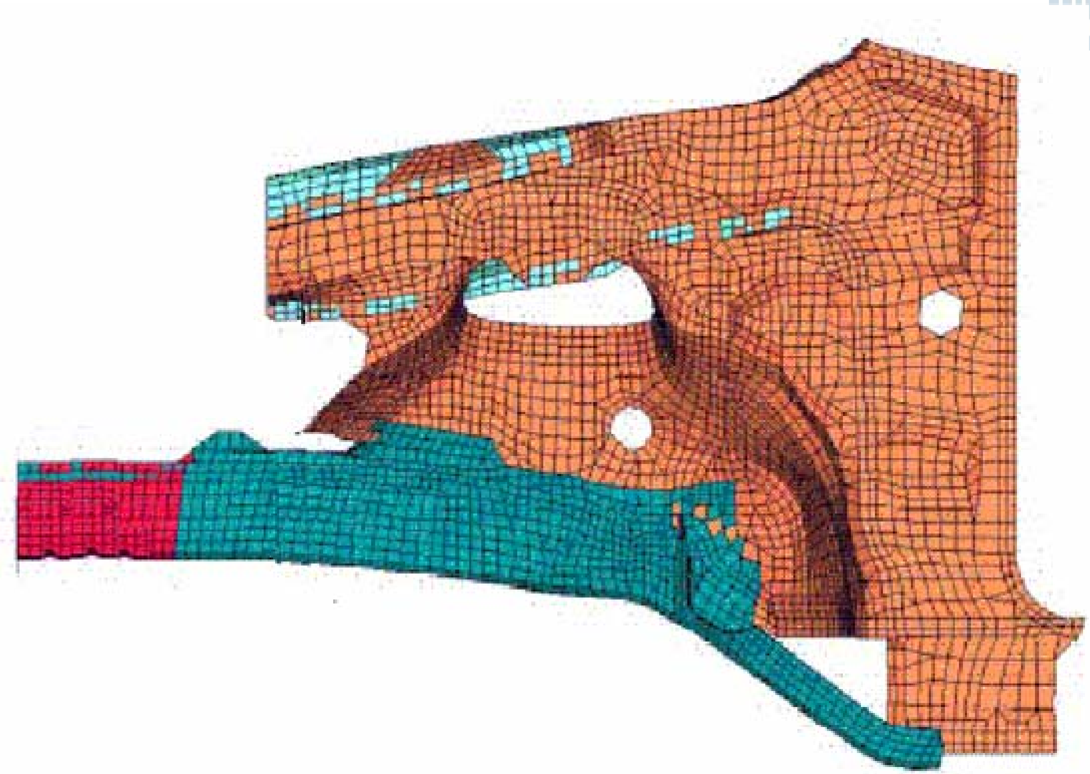
* Floor panel

* Transverse Beams

* Longitudinal Beams

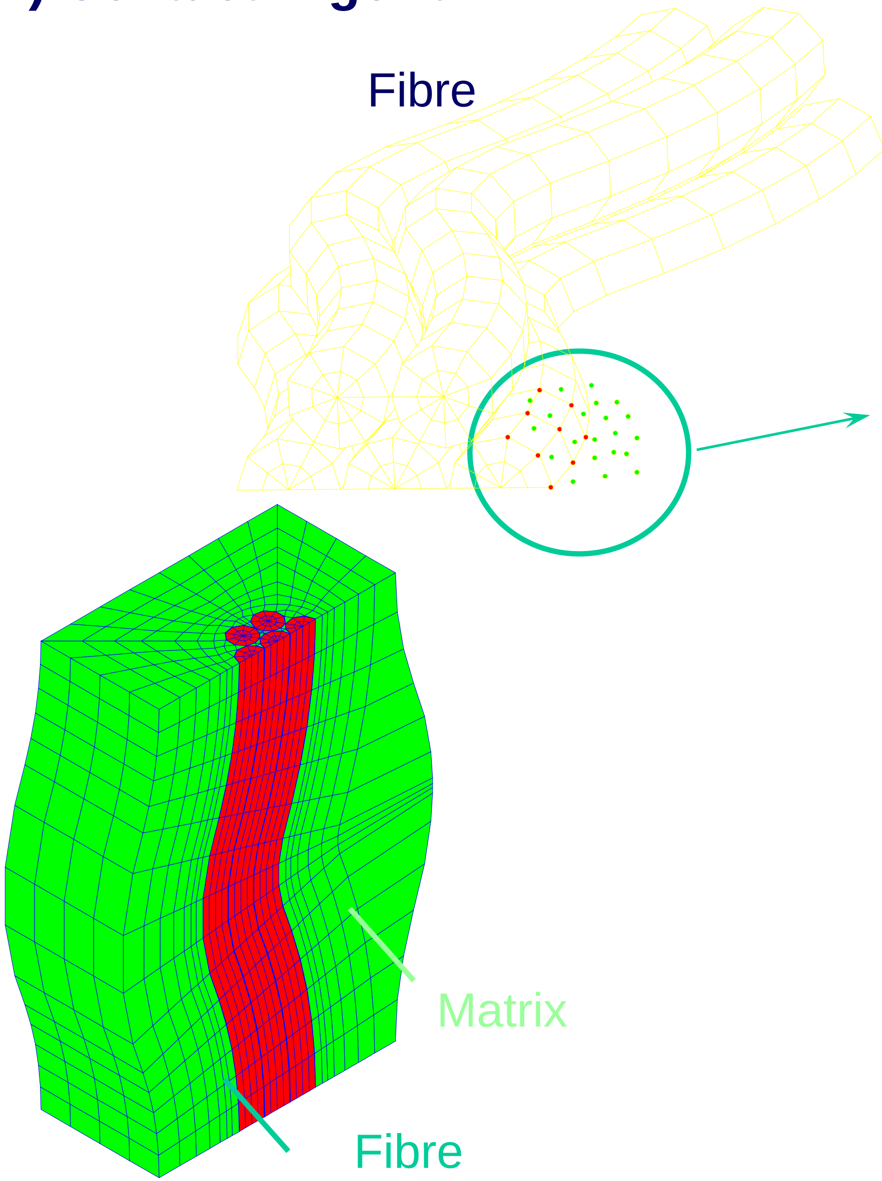
Calibration of Longitudinal Beams Analysis for Crash Simulation

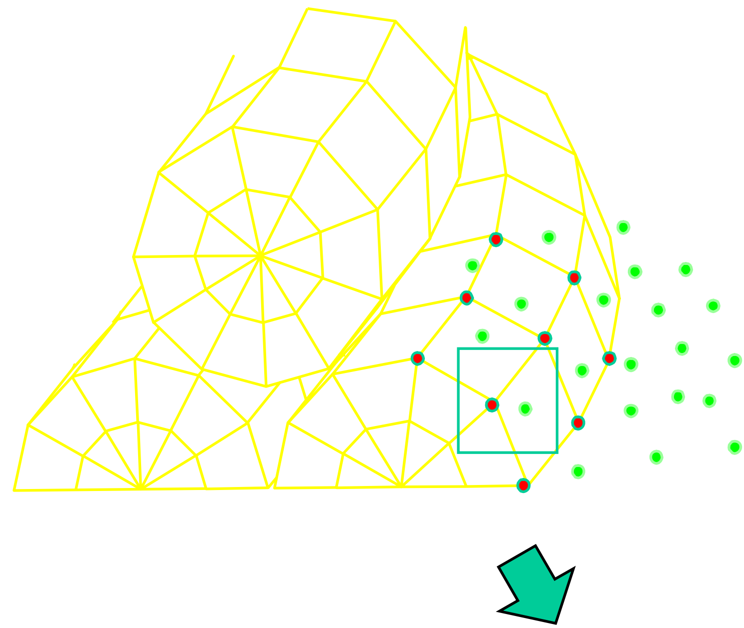


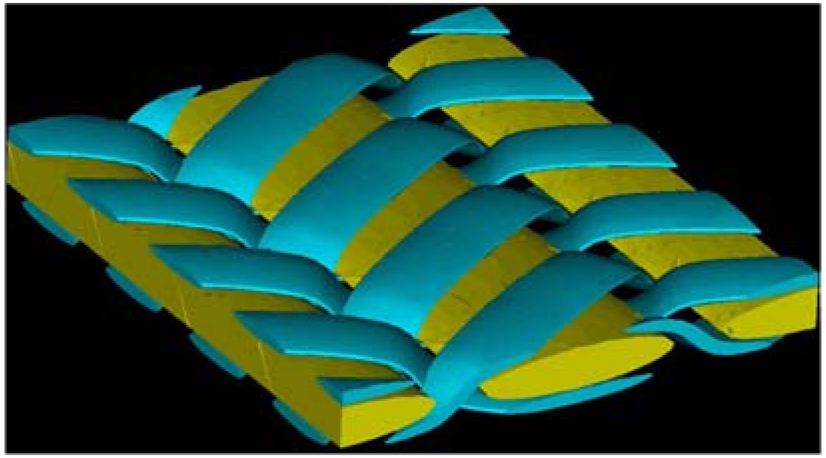


1) Contact Algorithm

- Nodes of fibre surface (red) : Master
- Nodes of matrix elements (green): Slave

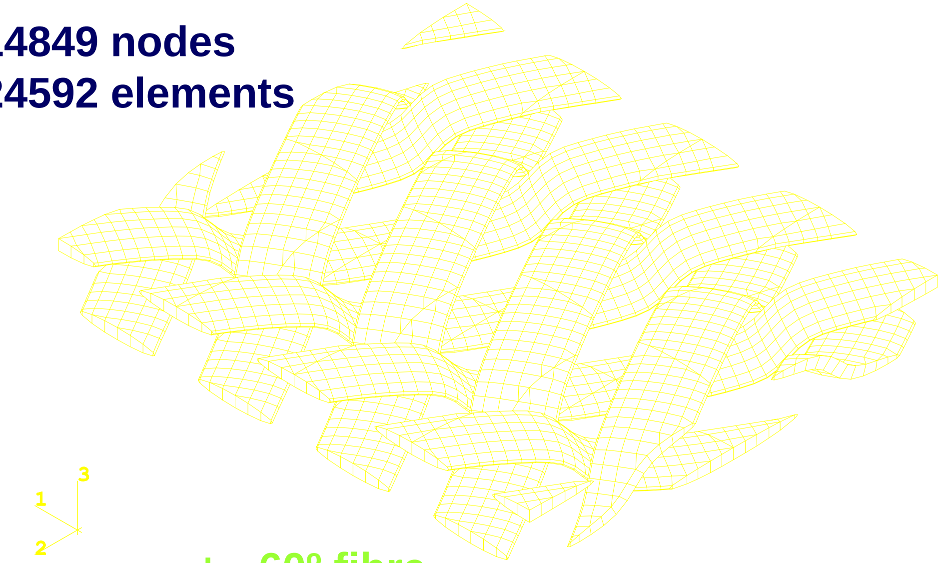






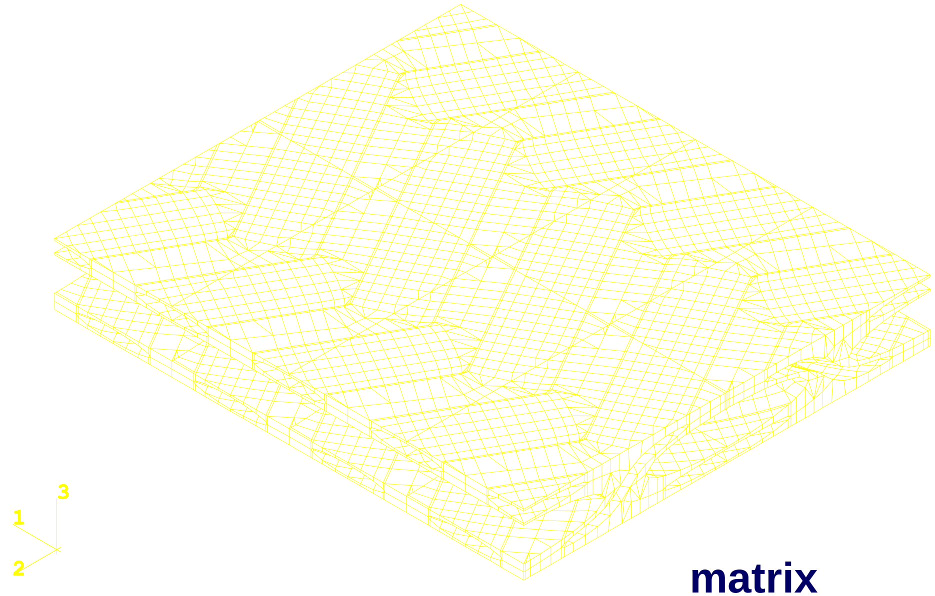
Fiber sketch

14849 nodes
24592 elements



+ - 60º fibre

0º fibre



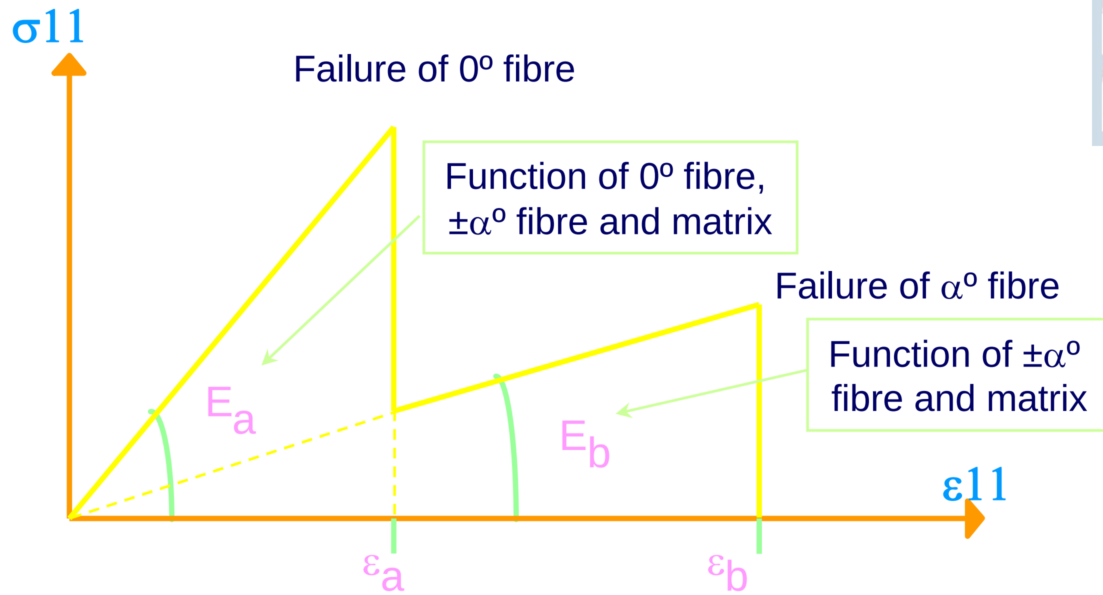
matrix

2) Material Model

Parameters used on the 2D Braiding analytical predictive expressions :

α = braiding angle of some fibres
V_0 = 0º fibre volume percentage
Vα = αº fibre volume percentage
Vf = V_0 + Vα = fibre volume percentage
Vm = matrix volume percentage,
Ef = Young's modulus of fibre
Em = Young's modulus of matrix
ε_{maxf} = failure strain of fibre
ε_{maxm} = failure strain of matrix
Gf = Shear modulus of fibre
Gm = Shear modulus of matrix
γ_{maxm} = failure angular strain of matrix
νm = Poisson coefficient of matrix

Direction 1 (Parallel to 0º fibre):



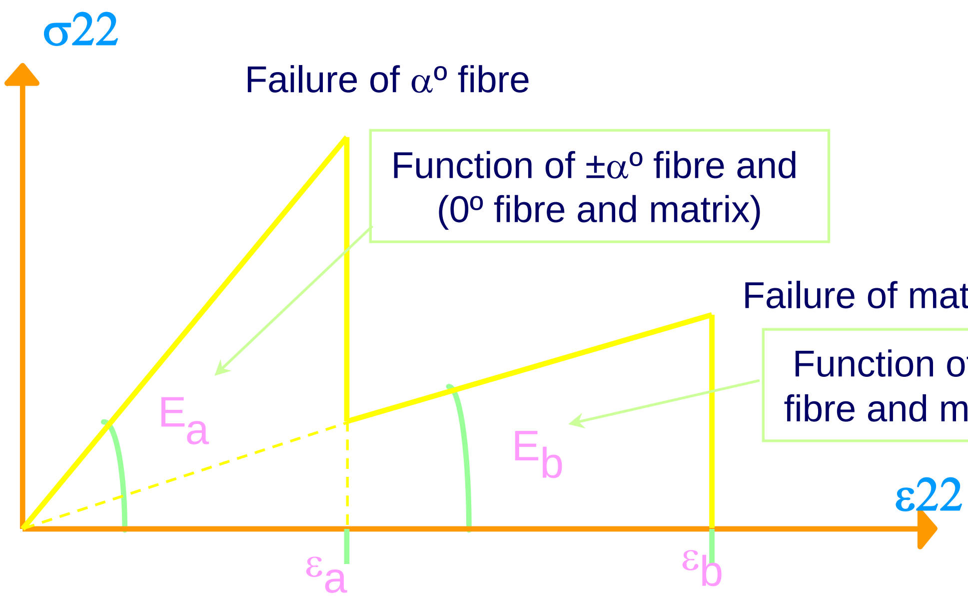
$$Ea = Ef \cos^4\alpha\ V\alpha + Ef\ V_0 + Em\ Vm$$

$$\varepsilon a = \varepsilon_{maxf}$$

$$Eb = Ef \cos^4\alpha\ V\alpha + Em\ Vm$$

$$\varepsilon b = \varepsilon_{maxf} / \cos 2\alpha$$

Direction 2 (Perpendicular to 0º fibre):



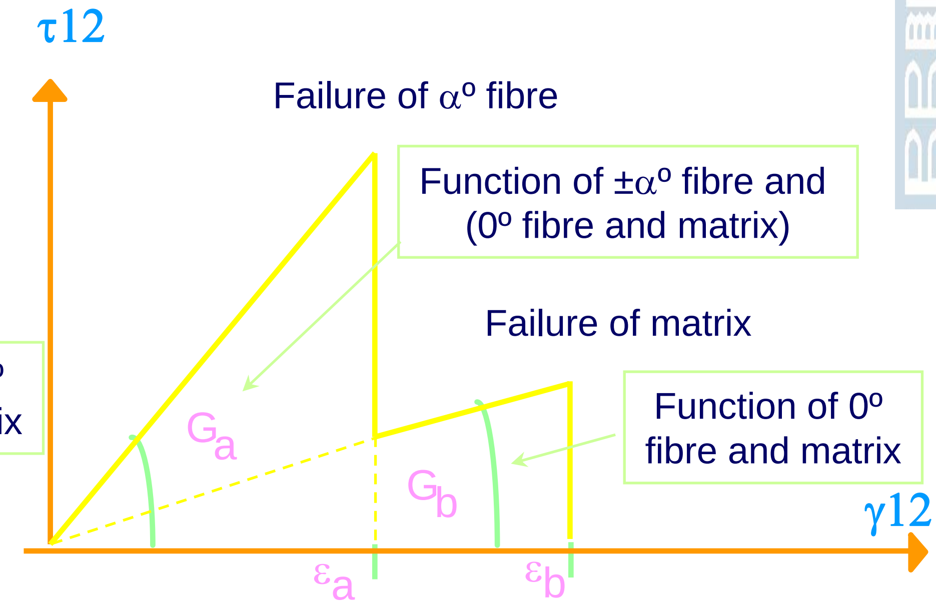
$$E_a = E_f \, sen^4\alpha \, V\alpha + \frac{E_f \, E_m(V_m + V_0)}{E_f \, V'_m + E_m \, V'_0}$$

$$E_b = \frac{E_f \, E_m(V_m + V_0)}{E_f \, V'_m + E_m \, V'_0}$$

$\varepsilon a = \varepsilon_{maxf} / sen2\alpha$ $\quad$ $\varepsilon b = \varepsilon_{maxm}$

$$V'_m = \frac{V_m}{V_m + V_0} \qquad V'_0 = \frac{V_0}{V_m + V_0}$$

In plane 1-2 shear stress:



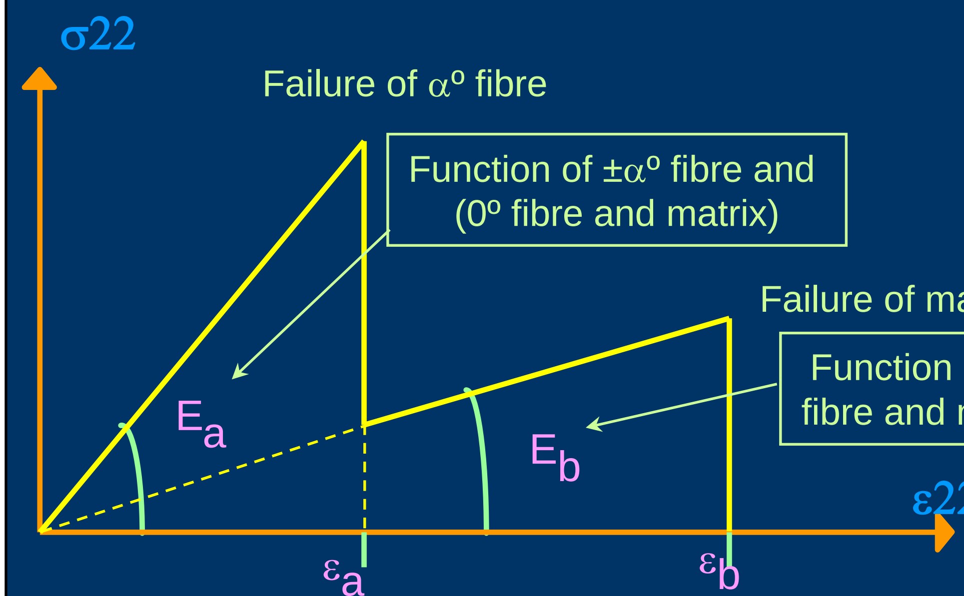
$$G_a = E_f \, sen^2\alpha \, cos^2\alpha \, V\alpha + \frac{G_f \, G_m(V_m + V_0)}{G_f \, V'_m + G_m \, V'_0}$$

$$G_b = \frac{G_f \, G_m(V_m + V_0)}{G_f \, V'_m + G_m \, V'_0}$$

$$\gamma_a = \frac{\varepsilon_{maxf}}{sen\alpha \, cos\alpha} \qquad \gamma_b = \gamma_{maxm} = \frac{\varepsilon_{maxm}(1 + \upsilon_m)2}{\sqrt{3}}$$

$$V'_m = \frac{V_m}{V_m + V_0} \qquad V'_0 = \frac{V_0}{V_m + V_0}$$

Direction 2 (Perpendicular to 0º fibre):



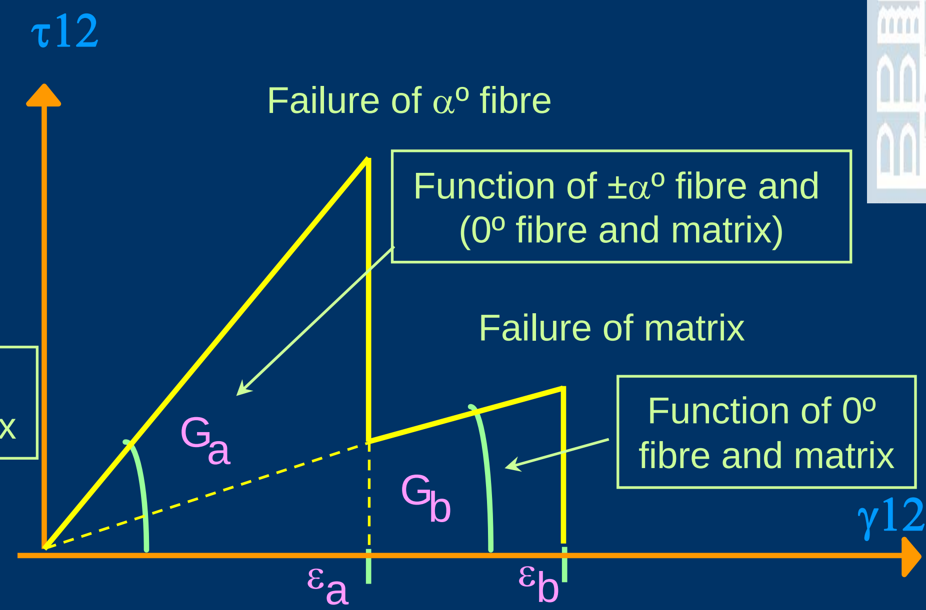
$$E_a = E_f \, sen^4\alpha \, V\alpha + \frac{E_f \, E_m (V_m + V_0)}{E_f \, V'_m + E_m \, V'_0}$$

$$E_b = \frac{E_f \, E_m (V_m + V_0)}{E_f \, V'_m + E_m \, V'_0}$$

$\varepsilon a = \varepsilon_{maxf} \, / \, sen2\alpha$ $\quad$ $\varepsilon b = \varepsilon_{maxm}$

$$V'_m = \frac{V_m}{V_m + V_0} \qquad V'_0 = \frac{V_0}{V_m + V_0}$$

In plane 1-2 shear stress:



$$G_a = E_f \, sen^2\alpha \, cos^2\alpha \, V\alpha + \frac{G_f \, G_m (V_m + V_0)}{G_f \, V'_m + G_m \, V'_0}$$

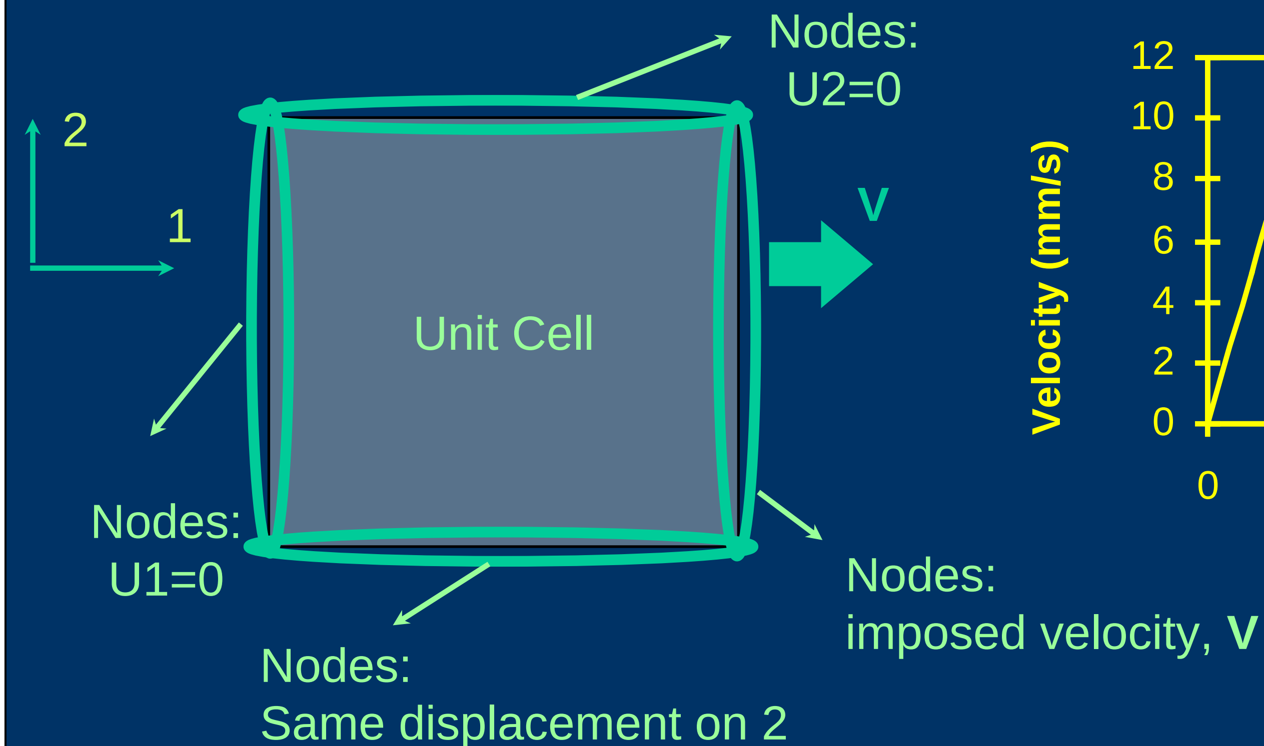
$$G_b = \frac{G_f \, G_m (V_m + V_0)}{G_f \, V'_m + G_m \, V'_0}$$

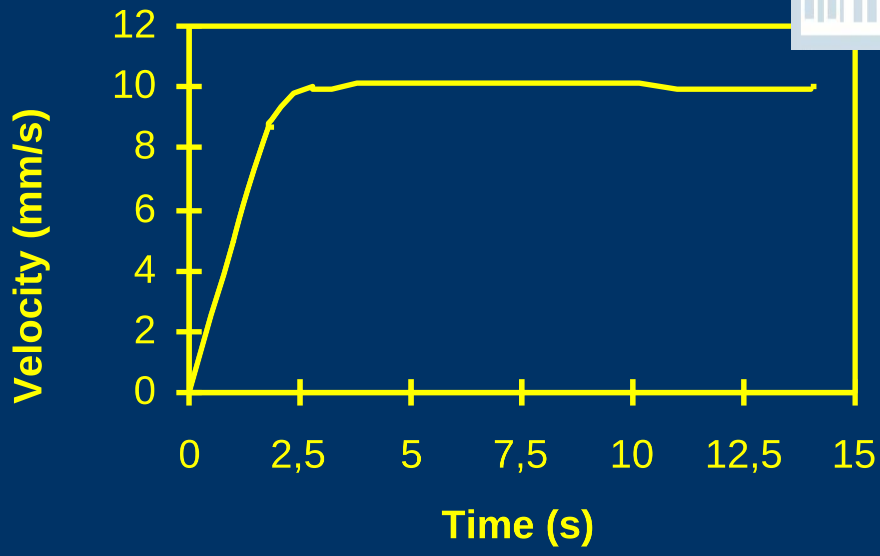
$$\gamma_a = \frac{\varepsilon_{maxf}}{sen\alpha \, cos\alpha} \qquad \gamma_b = \gamma_{maxm} = \frac{\varepsilon_{maxm}(1 + \upsilon_m)2}{\sqrt{3}}$$

$$V'_m = \frac{V_m}{V_m + V_0} \qquad V'_0 = \frac{V_0}{V_m + V_0}$$

3) Calculation Procedure

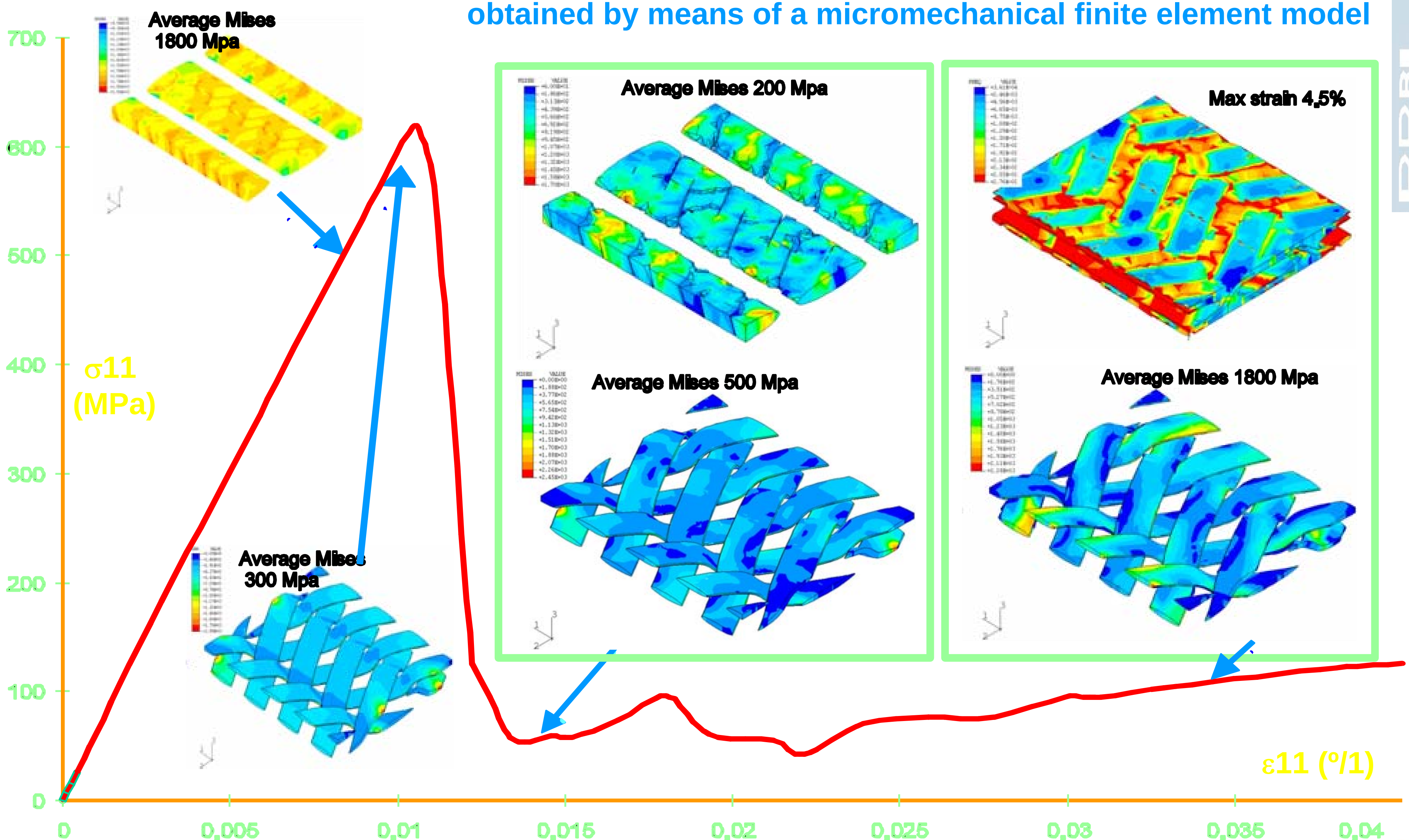
- Explicit integration: ABAQUS EXPLICIT 5.6
- Boundary conditions:

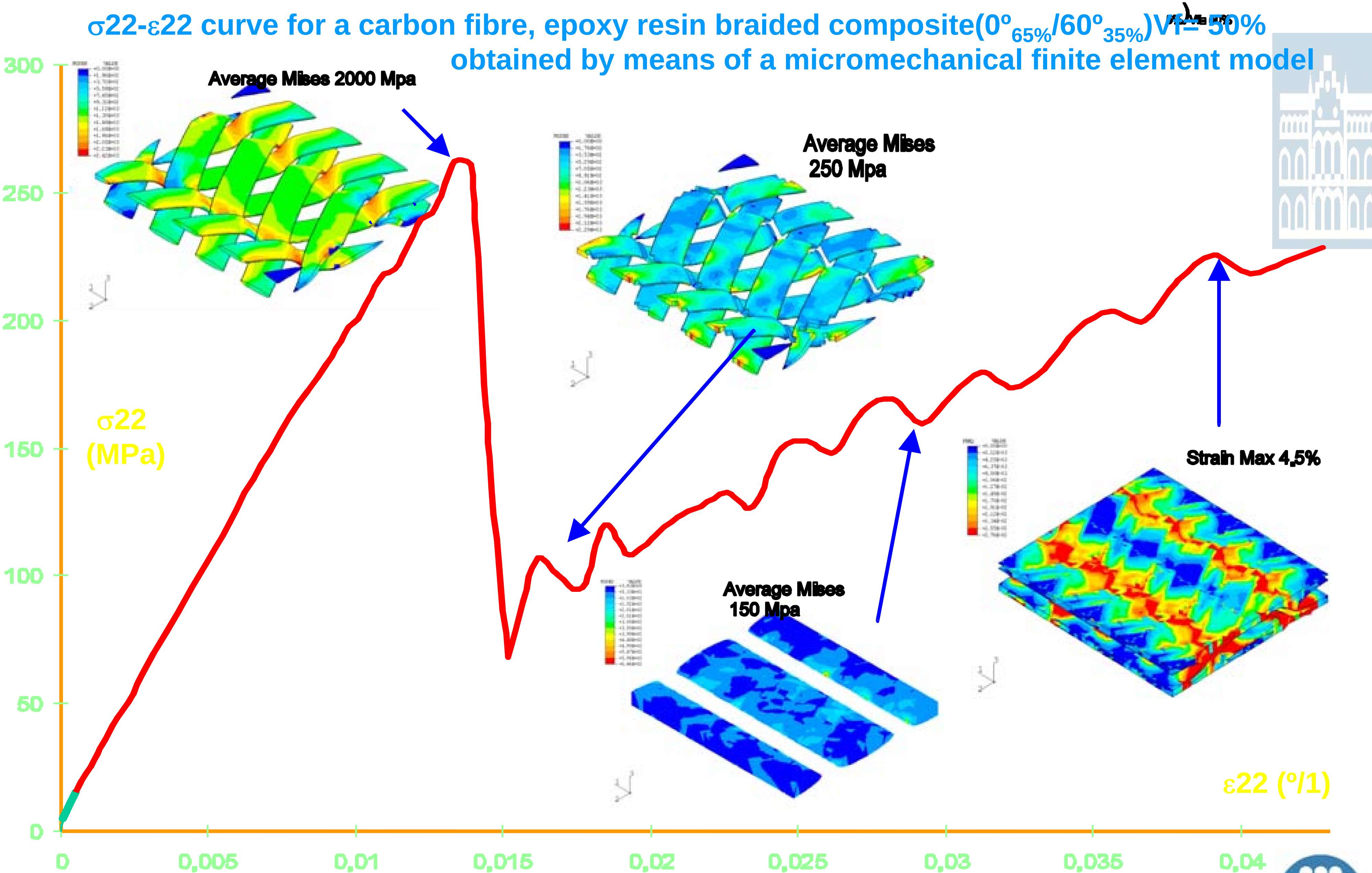




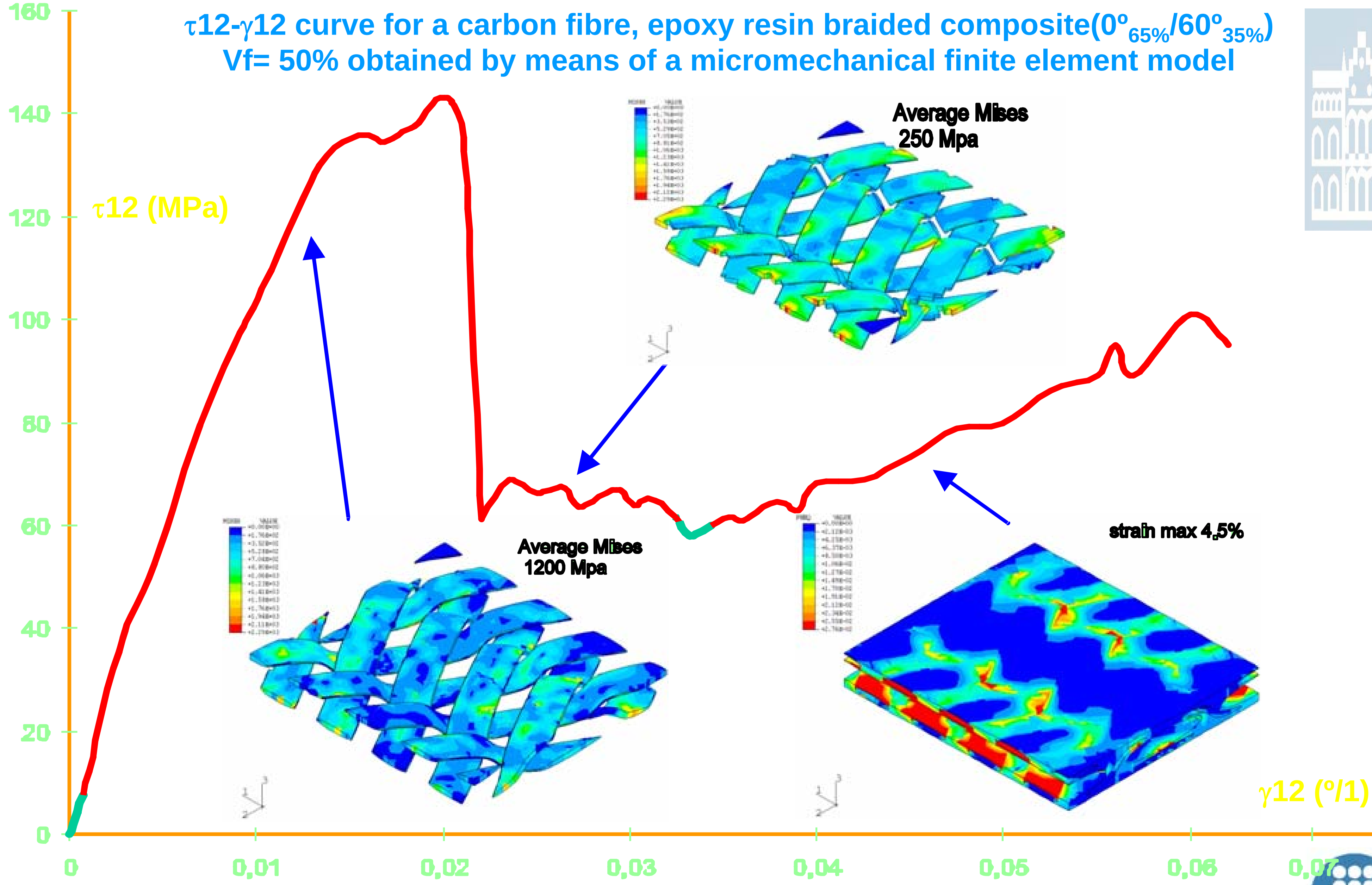
- Contacts:
  - Between surfaces of the elements of the threads
  - Between surfaces of the elements of the threads (master) and the nodes of matrix (slave)

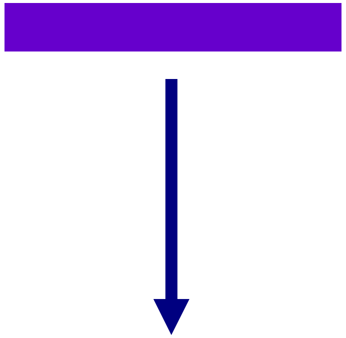
σ11-ε11 curve for a carbon fibre, epoxy resin braided composite($0^o_{65\%}/60^o_{35\%}$)Vf= 50% obtained by means of a micromechanical finite element model




σ22-ε22 curve for a carbon fibre, epoxy resin braided composite(0º65%/60º35%)Vf= 50%
obtained by means of a micromechanical finite element model
Average Mises 2000 Mpa
Average Mises
250 Mpa
Average Mises
150 Mpa
Strain Max 4,5%
σ22
(MPa)
ε22 (º/1)
300
250
200
150
100
50
0
0
0,005
0,01
0,015
0,02
0,025
0,03
0,035
0,04

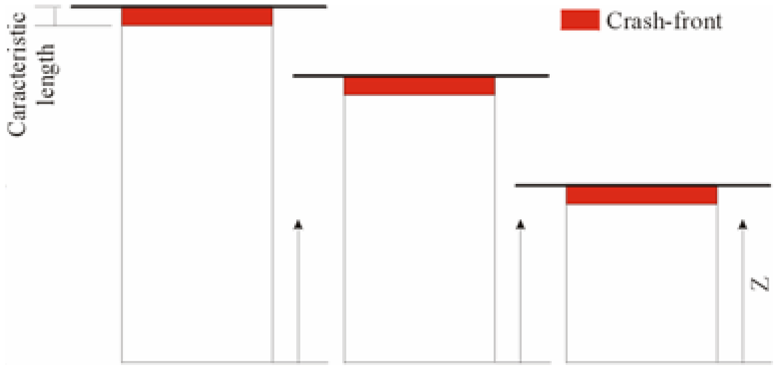
τ12-γ12 curve for a carbon fibre, epoxy resin braided composite($0^o_{65\%}/60^o_{35\%}$) Vf= 50% obtained by means of a micromechanical finite element model

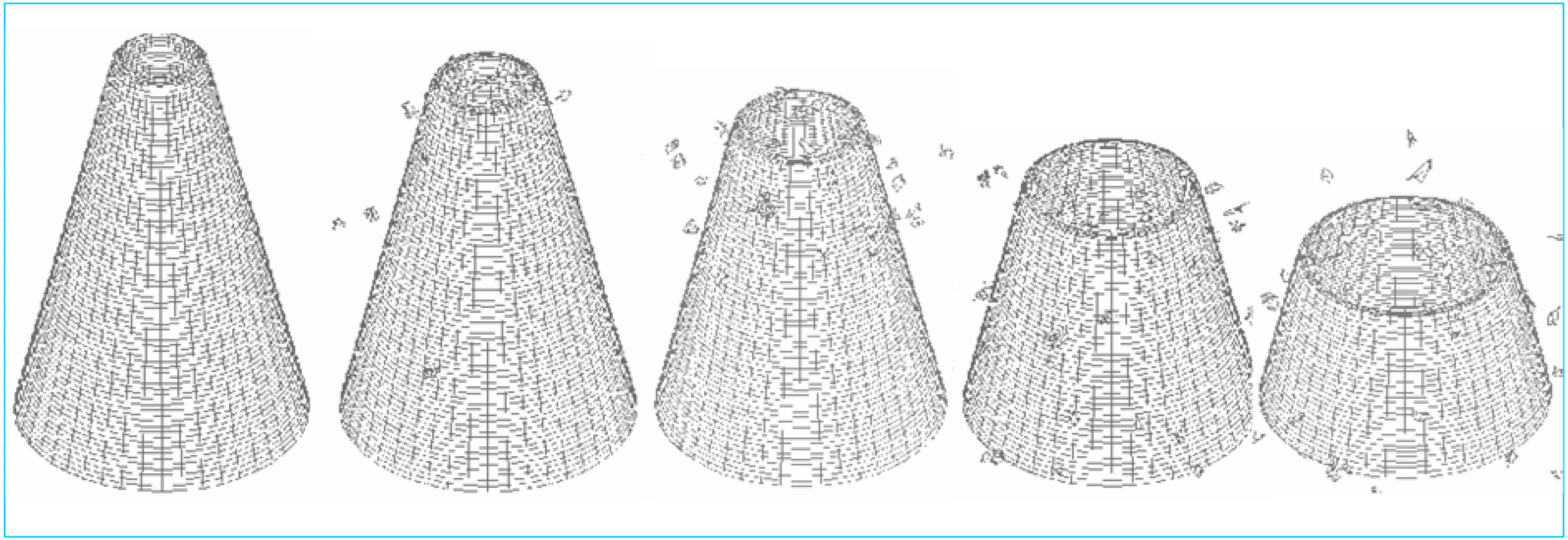




200 kg

10 m/s





4) Numerical-Experiment Correlation