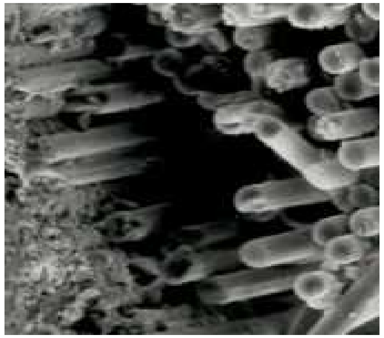
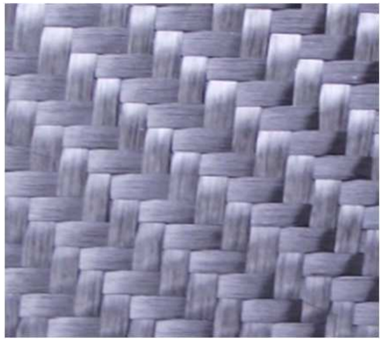




Various aspects of composites modeling in LS-DYNA

Stefan Hartmann

DYNAmore GmbH, Stuttgart

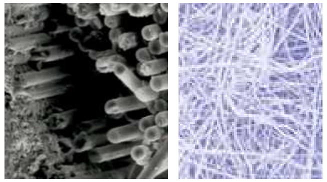
Webinar: Composite Analysis

26.11.2014

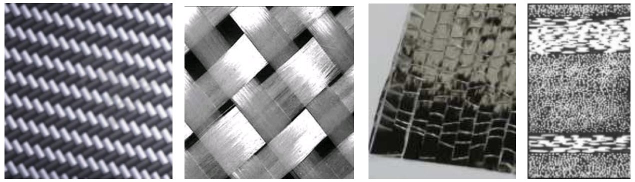
Composites – a very broad term!

- A composite is a combination of two or more materials, differing in form or composition on a macroscale. The constituents do not dissolve or merge completely into one another, but can be physically identified and exhibit an interface.

Concrete
(cement/stone/steel)



Short/long fiber reinforced polymers
(glass/PP)



Endless fiber reinforced polymers
(glass/carbon/PA/PP/EP)

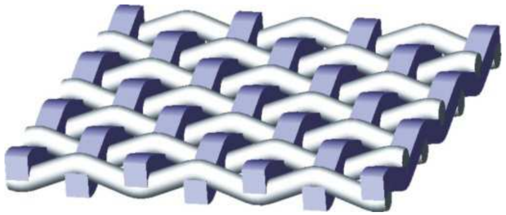
Sandwich/Laminates
(alloy/polymer/..glass/PVB/…)

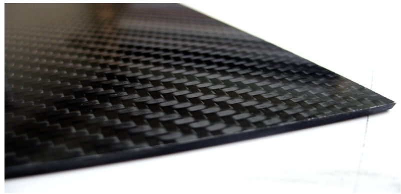
Composites – classification attempts

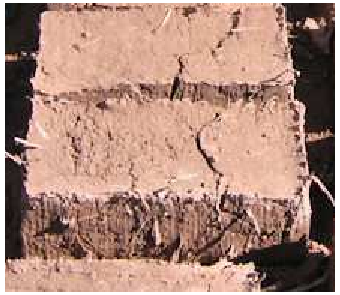
- Based on matrix material
  - Metal Matrix Composites (MMC)
  - Ceramic Matrix Composites (CMC)
  - Polymer Matrix Composites (PMC)

- Based on reinforcing material structure
  - Particulate Composites (particles in a matrix)
  - Fibrous Composites (fibers in a matrix)
  - Laminated Composites (layers of various materials)
  - Combination of all

- … and others

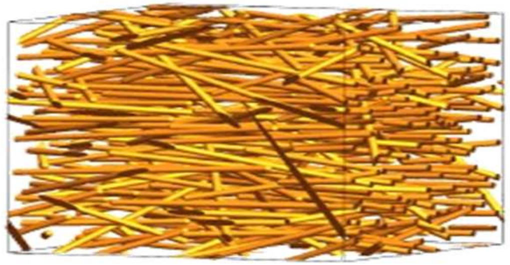




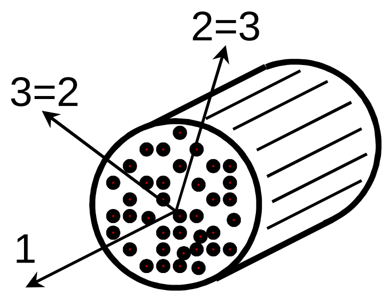


Composites – What do they have in common?

- Inhomogeneous body
  - non-uniform properties in the body



- Non-Isotropic behavior
  - properties depend on orientation in the body
  - distinguish between different levels of anisotropy
    - Anisotropy: properties are different in all directions (no symmetry) (21 unknowns)
    - Orthotropy: properties are different in three perpendicular directions (three planes of material symmetry) (9 unknowns)
    - Transverse Isotropy: properties are symmetric about an axis normal to the plane of isotropy (5 unknowns)



- Needs for FE-modeling
  - appropriate material models (homogenization techniques)
  - possibility to define a material coordinate system

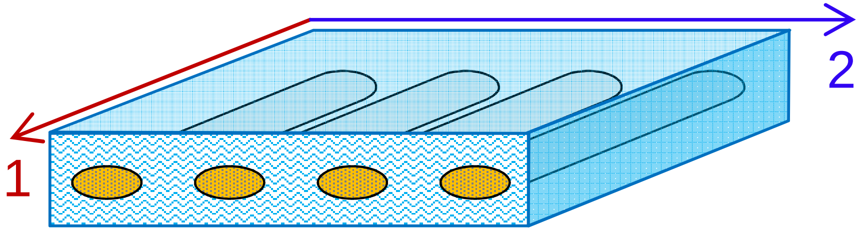
Agenda

- Anisotropic elastic material constants
  - rule of mixture
  - standard tests
  - remark on Poisson's Ratio

- Definition of Material-Coordinate-System
  - *MAT_XXX + AOPT / *ELEMENT_SHELL_BETA / …
  - mapping within the process chain
  - setup using LS-PrePost
    - S-Rail example

- General remarks
  - invariant node numbering / history variables / …

Anisotropic elastic material constants



- rule of mixture (i.e. lamina)
  - properties of fiber and matrix
    - cross-section area of fiber: A_f
    - cross-section area of matrix: A_m
    - Young's modulus, shear modulus and Poisson's ratio (fiber): E_f, G_f, ν_f
    - Young's modulus, shear modulus and Poisson's ratio (matrix): E_m, G_m, ν_m
  - mechanical properties of lamina
    - fiber-volume and matrix-volume fraction: V_f, V_m
    - homogenized Young's modulus, shear modulus and Poisson's ratio:

$$E_1 = V_f E_f + V_m E_m \qquad E_2 = \frac{E_f E_m}{V_m E_f + V_f E_m}$$

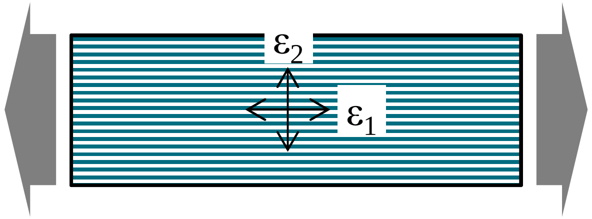
$$G_{12} = \frac{G_f G_m}{V_f G_m + V_m G_f}$$

$$\nu_{12} = V_f \nu_f + V_m \nu_m$$

Anisotropic elastic material constants

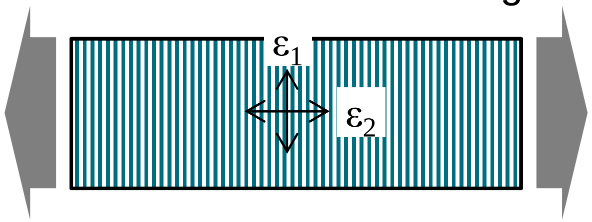
- tests with the actual composite material (the way to be preferred!)
  - necessary tests for i.e. UD-laminates

Uni-axial tensile test in 0 degree



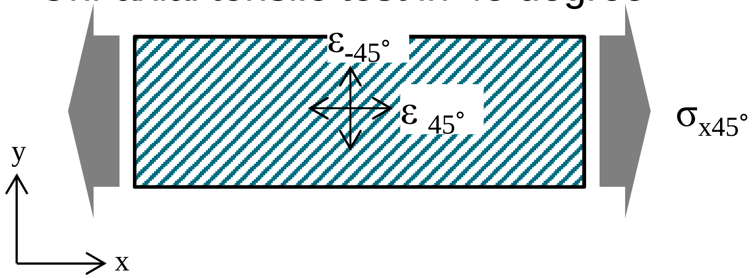
$$E_1 = \frac{\sigma_1}{\varepsilon_1} \qquad \nu_{12} = -\frac{\varepsilon_2}{\varepsilon_1}$$

Uni-axial tensile test in 90 degree



$$E_2 = \frac{\sigma_2}{\varepsilon_2} \qquad \nu_{21} = -\frac{\varepsilon_1}{\varepsilon_2}$$

Uni-axial tensile test in 45 degree



$$E_{45^\circ} = \frac{\sigma_{45^\circ}}{\varepsilon_{45^\circ}} \qquad \nu_{45^\circ} = -\frac{\varepsilon_{-45^\circ}}{\varepsilon_{45^\circ}}$$

$$G_{12} = \frac{1}{\frac{4}{E_{45^\circ}} - \frac{1}{E_1} - \frac{1}{E_2} + \frac{2\nu_{12}}{E_1}}$$

or

$$G_{12} = \frac{E_{45^\circ}}{2\left(1+\nu_{45^\circ}\right)}$$

Anisotropic elastic material constants

- remark on Poisson's Ratio
  - all non-isotropic material models in LS-DYNA request PRBA (ν_{21})
  - symmetry of elastic stiffness matrix yields: $\frac{\nu_{12}}{E_1} = \frac{\nu_{21}}{E_2} \rightarrow \nu_{12} = \frac{E_1}{E_2}\nu_{21}$
  - nomenclature for indices in Poisson's Ratio is not unique

- rule of thumb for using the correct Poisson's Ratio in LS-DYNA
  - make sure $E_1 \geq E_2$
  - the larger Poisson's ratio is called the **major** Poisson's ratio
  - the smaller one is called the **minor** Poisson's ratio
  - set PRBA = **minor** Poisson's ratio

Definition of Material-Coordinate-System

- possibilities in LS-DYNA
  - *MAT_XXX card and AOPT>0
    - all non-isotropic material models allow to specify the definition of a globally oriented material coordinate system
    - this possibility is mainly used in sheet metal forming to initialize the anisotropy in rolling direction
  - *ELEMENT_T/SHELL_BETA (shells and tshells)
    - allows the definition of a locally changing material coordinate system
  - *ELEMENT_SOLID_ORTHO (solids)
    - allows the definition of a locally changing material coordinate system
  - *PART_COMPOSITE(_TSHELL) (shells and tshells)
    - allows the definition of a layered part definition, i.e. for laminated structures
  - *ELEMENT_T/SHELL_COMPOSITE
    - allows the definition of a layered definition on an elemental basis

Definition of Material-Coordinate-System

- mapping within the process chain (i.e. for short fiber reinforced plastics)
  - setting up an injection molding simulation using an appropriate simulation tool (i.e. Moldflow, Moldex3D, SolidWorks Plastic, …)
  - map material directions, orientation tensors, elastic properties, … (using a suitable mapping tool) onto a (re-)meshed model
    - map directly onto the integration points using (i.e. *MAT_157 - *MAT_ANISOTROPIC_ELASTIC_PLASTIC & *INITIAL_STRESS_SHELL/SOLID)
    - Solids (NHISV $= 6a_0 + 21a_1 + 6a_2 + a_3$)

Flag	Description	Variables	#
a_0	Material directions	$q_{11}, q_{12}, q_{13}, q_{31}, q_{32}, q_{33}$	6
a_1	Anisotropic stiffness	Cij	21
a_2	Anisotropic constants	F, G, H, L, M, N	6
a_3	Stress-strain Curve	LCSS	1

- Shells (NHISV $= 2a_0 + 21a_1 + 3a_2 + a_3$)

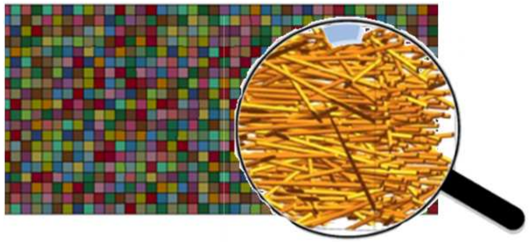
Flag	Description	Variables	#
a_0	Material directions	q_1, q_2	2
a_1	Anisotropic stiffness	Cij	21
a_2	Anisotropic constants	r_{00}, r_{45}, r_{90}	3
a_3	Stress-strain Curve	LCSS	1

Definition of Material-Coordinate-System

- mapping within the process chain (i.e. for short fiber reinforced plastics)
  - example for shells , IHIS=3 ($a_1 = 1$, $a_0 = 1$) → NHISV=2+21=23
  - *INITIAL_STRESS_SHELL

CARD 1	eid	nplane	nthick	nhisv	ntensor	large	nthint	nthhsv
CARD 2	t	sigxx	sigyy	sigzz	sigxy	sigyz	sigzx	eps
CARD 3	hisv1=q_1	hisv2=q_2	#3=C_{11}	#4=C_{12}	#5=C_{13}	#6=C_{14}	#7=C_{15}	#8=C_{16}
CARD 4	#9=C_{22}	#10=C_{23}	#11=C_{24}	#12=C_{25}	#13=C_{26}	#14=C_{33}	#15=C_{34}	#16=C_{35}
CARD 5	#17=C_{36}	#18=C_{44}	#19=C_{45}	#20=C_{46}	#21=C_{55}	#22=C_{56}	#23=C_{66}	

In material card



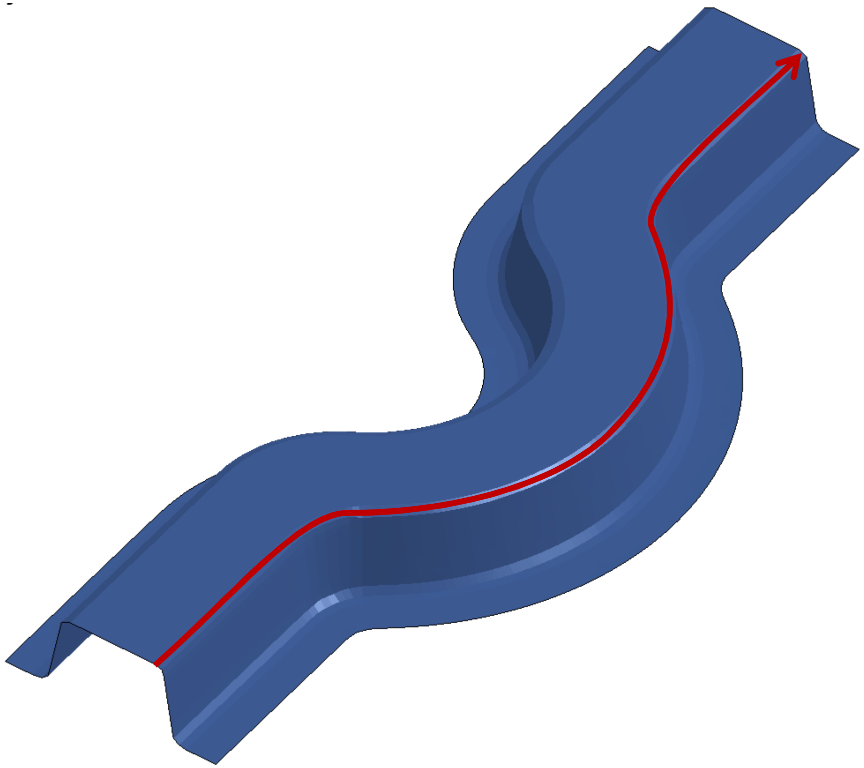
Drawback: inhomogeneous distribution (e.g. from previous short fiber filling simulation) in component needs individual part definition for every element

With *INITIAL_STRESS_SOLID

Only one part definition for whole component. Anisotropic coefficients are part of material's history field and can therefore be initialized for each integration point individually

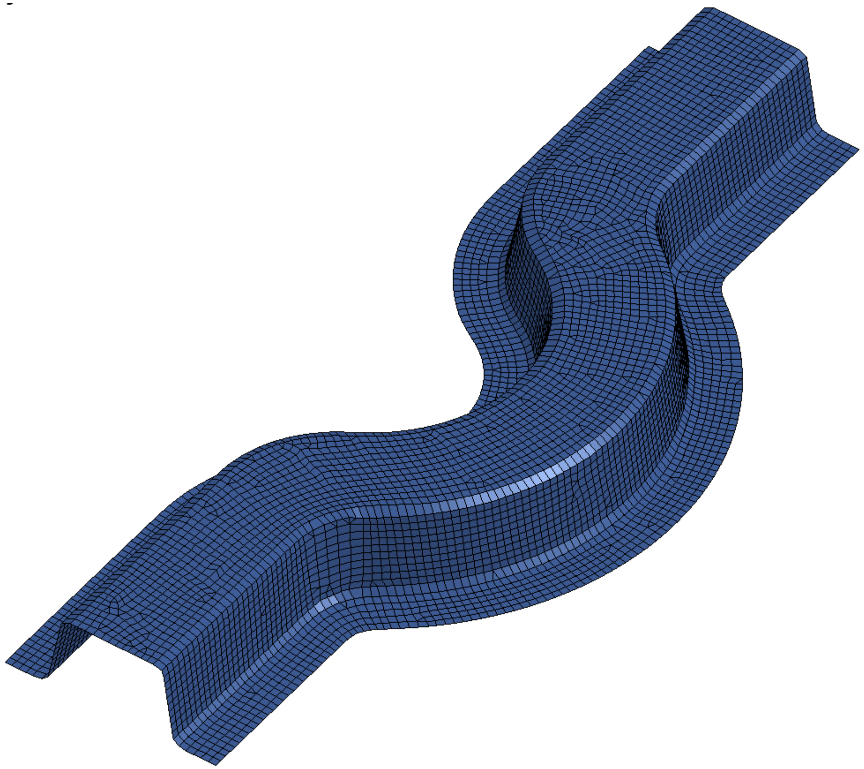
Definition of Material-Coordinate-System

- setup using LS-PrePost – Shells
  - example using a S-Rail geometry (provided by Benteler-SGL)
  - task: define Material-Coordinate-System along the curved boundary lines

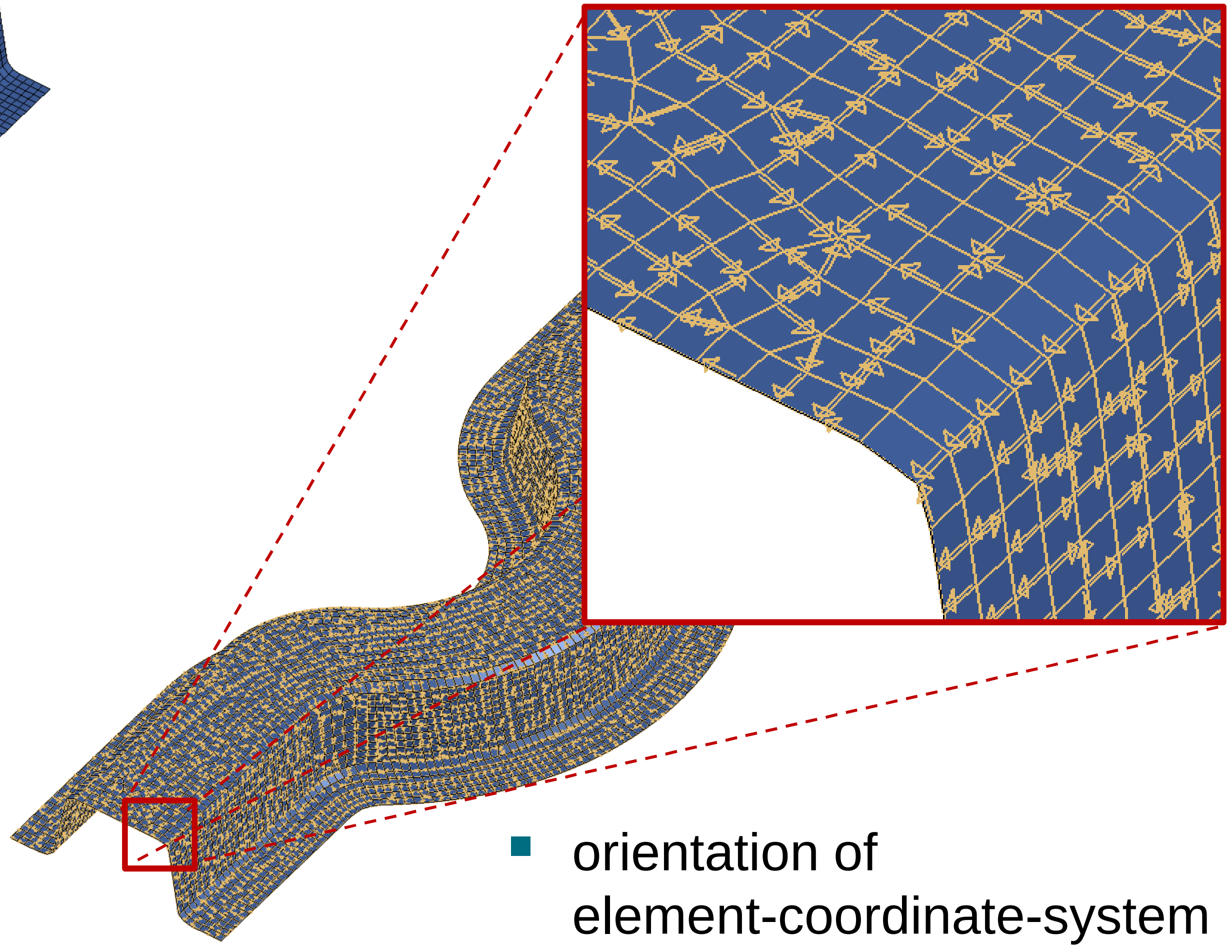


Definition of Material-Coordinate-System

- setup using LS-PrePost – Shells
  - example using a S-Rail geometry (provided by Benteler-SGL)



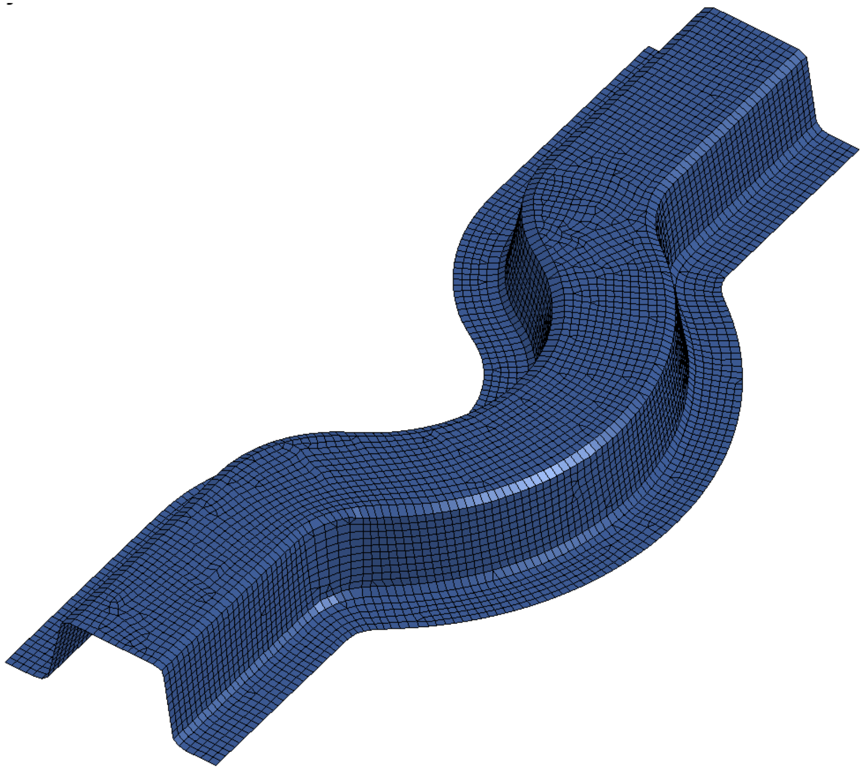
- mesh



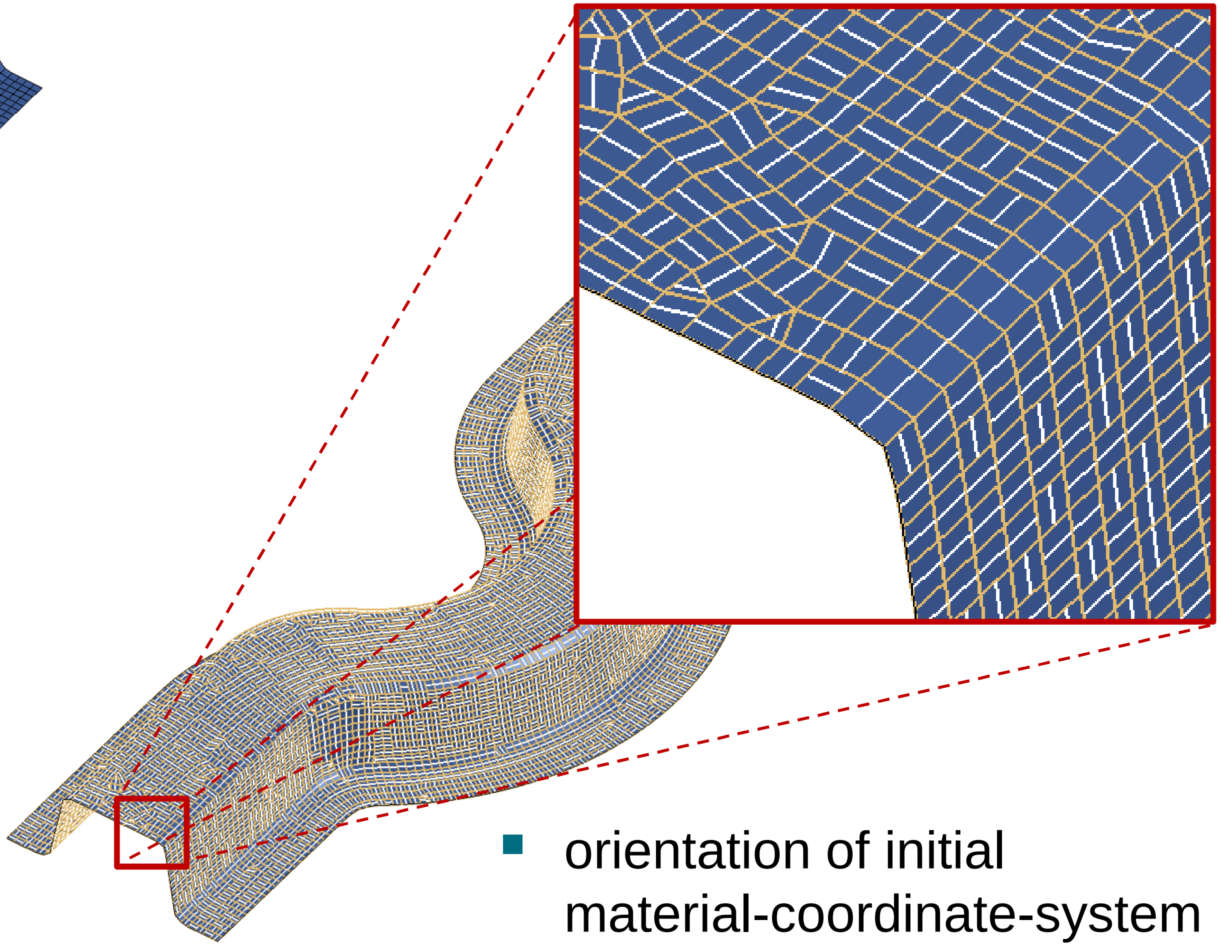
- orientation of element-coordinate-system

Definition of Material-Coordinate-System

- setup using LS-PrePost – Shells
  - example using a S-Rail geometry (provided by Benteler-SGL)



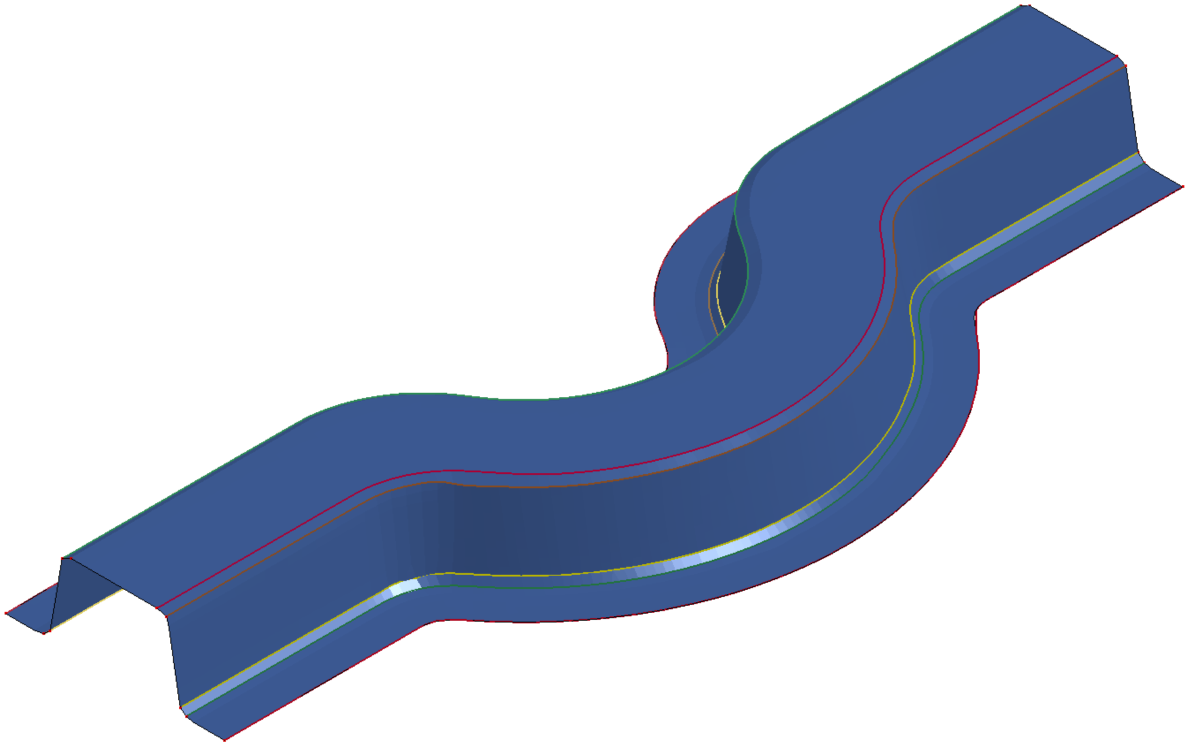
- mesh



- orientation of initial material-coordinate-system

Definition of Material-Coordinate-System

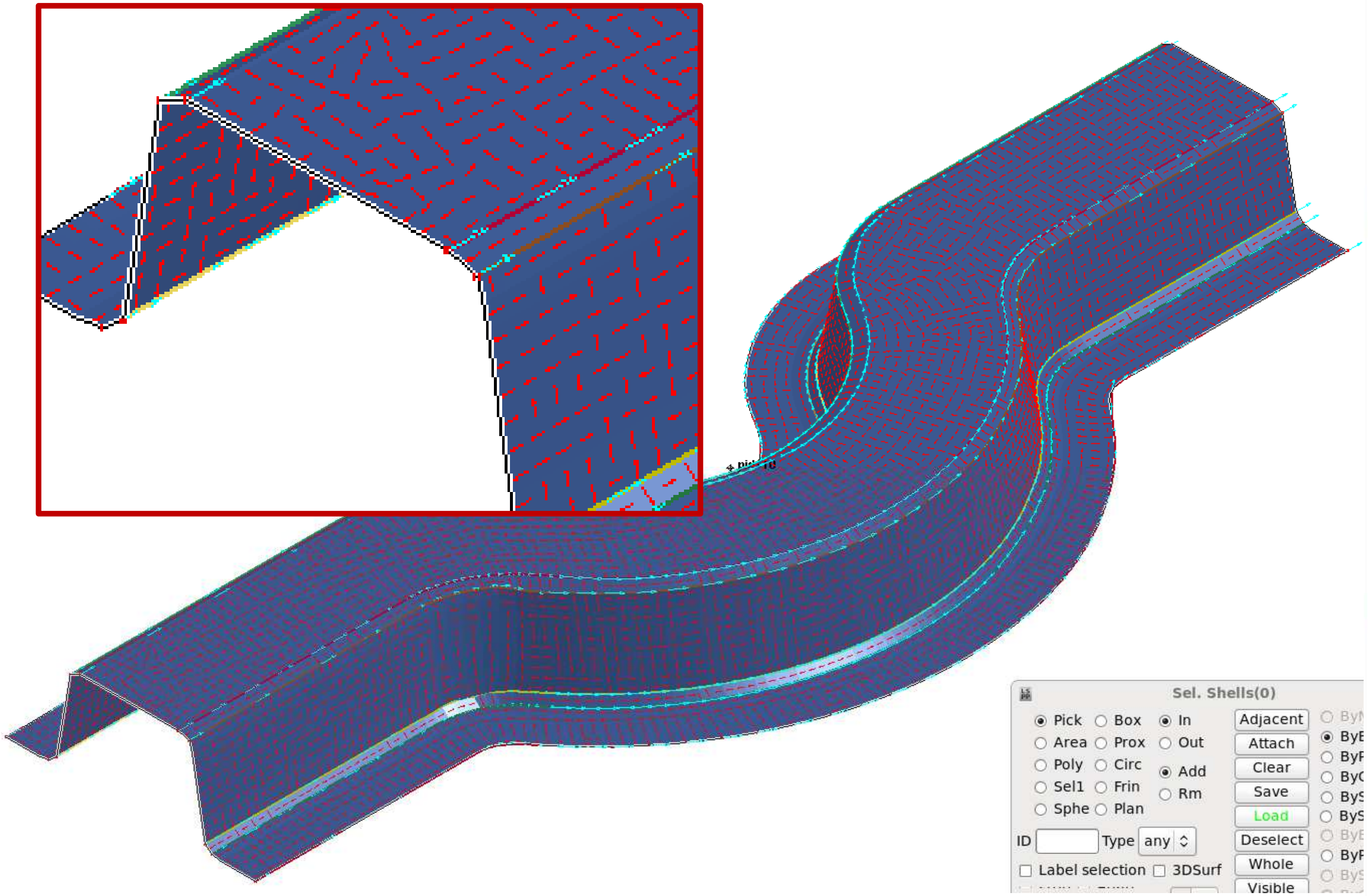
- setup using LS-PrePost – Shells
  - example using a S-Rail geometry (provided by Benteler-SGL)

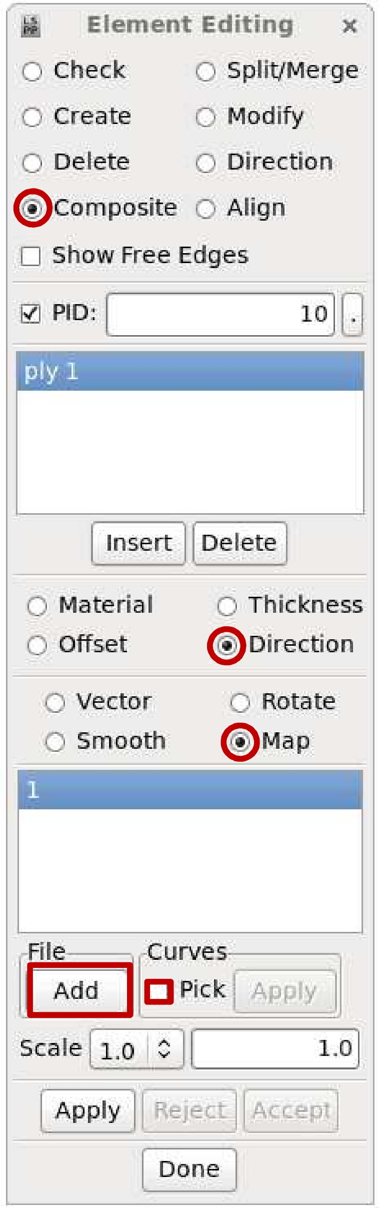


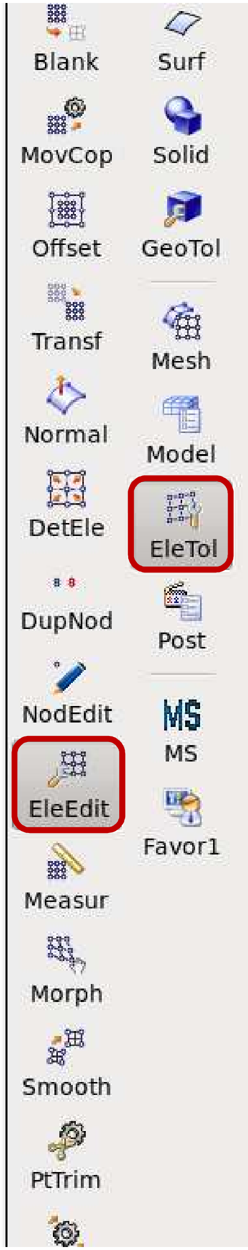
- create Spline Curves

Definition of Material-Coordinate-System

- setup using LS-PrePost – Shells



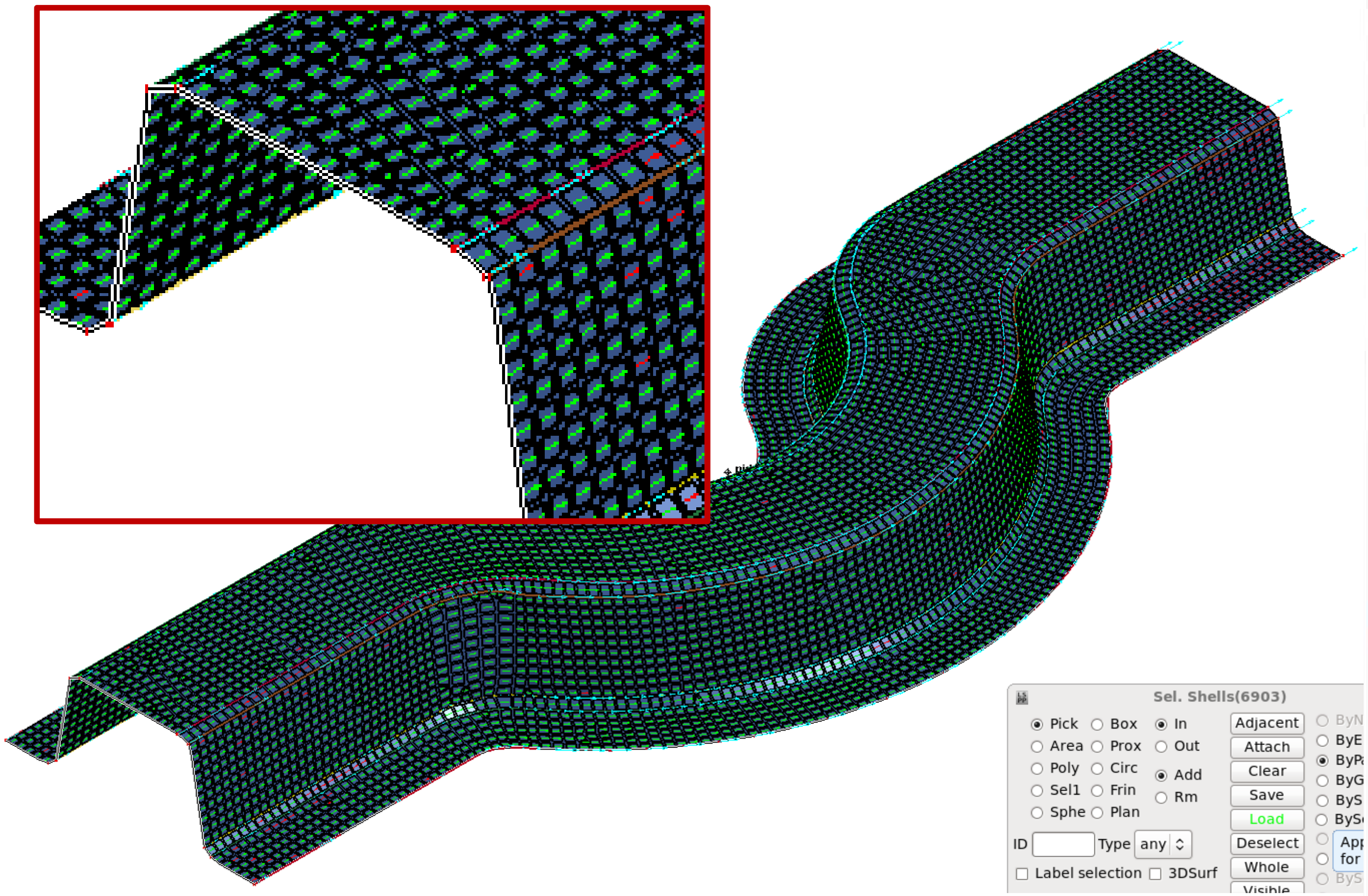


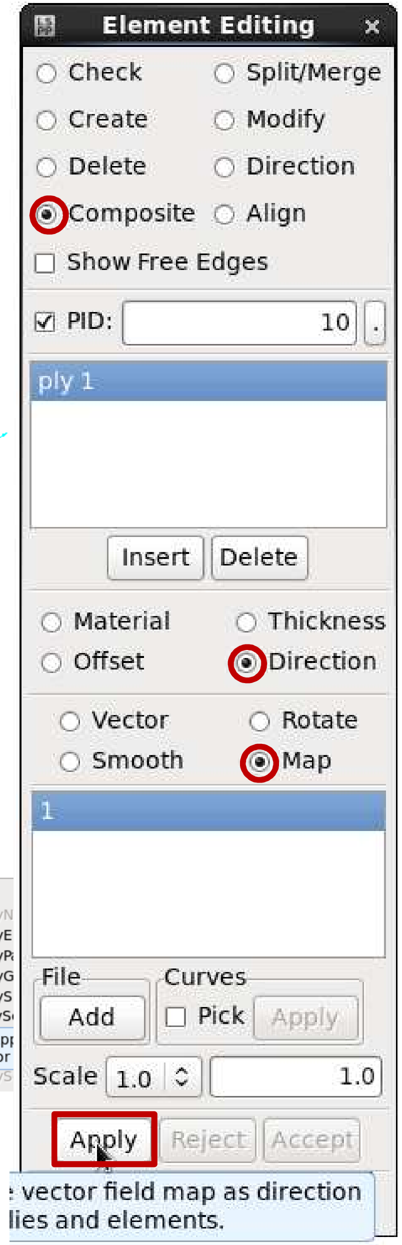


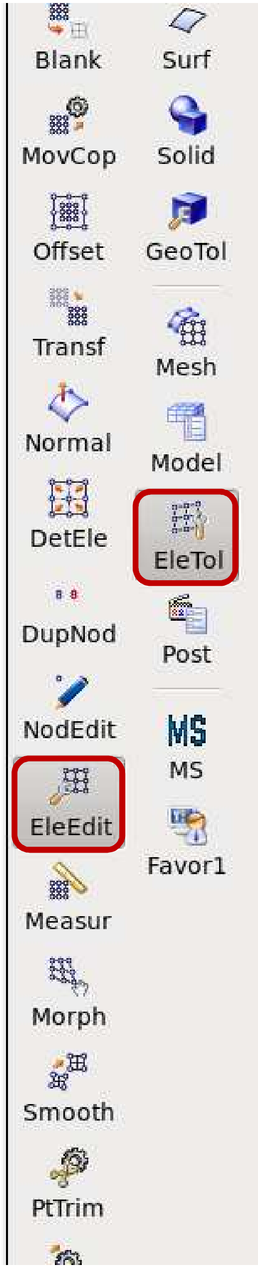
- pick spline curves and “Add”

Definition of Material-Coordinate-System

- setup using LS-PrePost – Shells



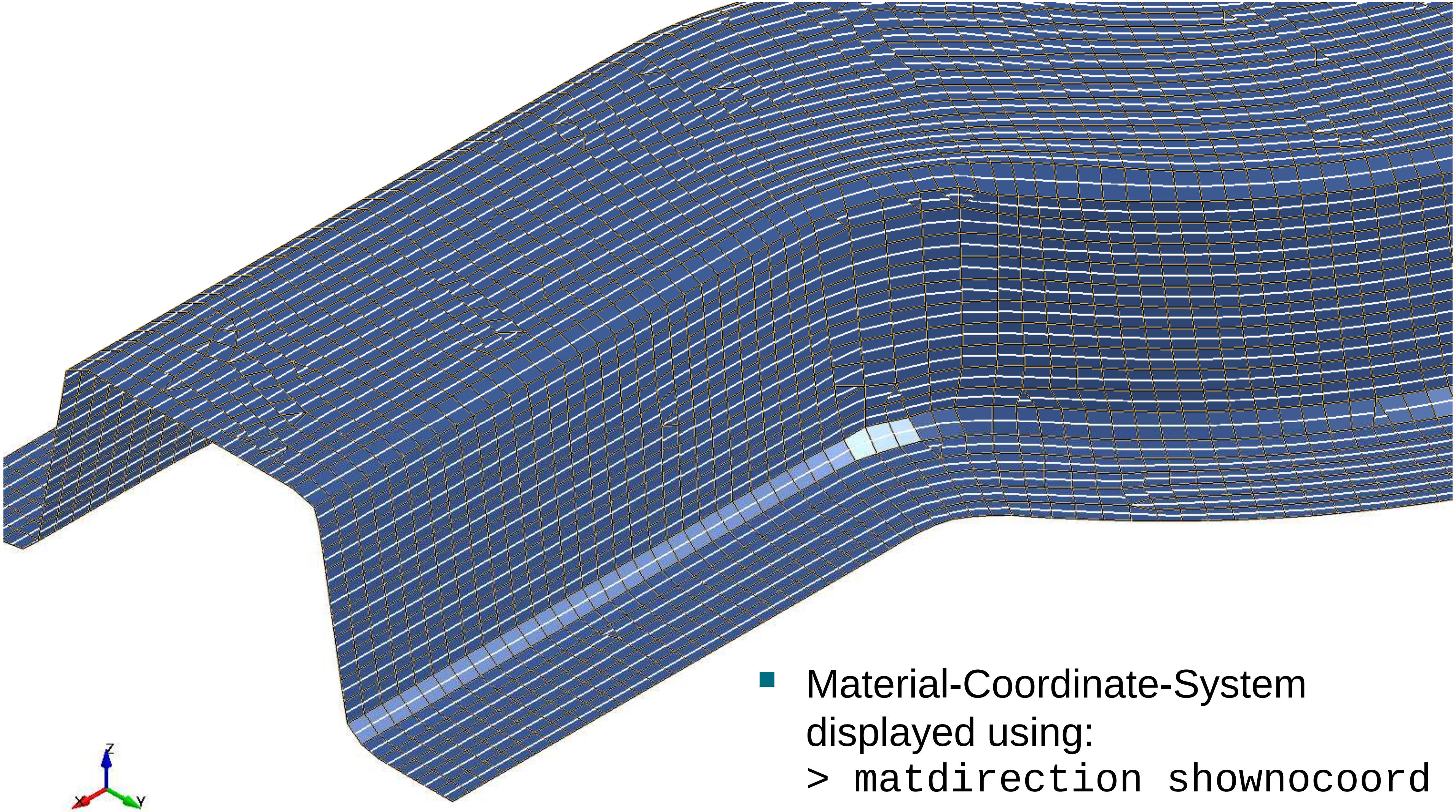




- “Apply”

Definition of Material-Coordinate-System

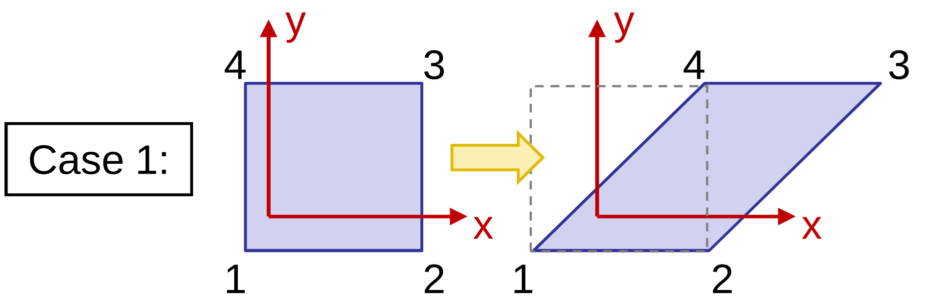
- setup using LS-PrePost – Shells



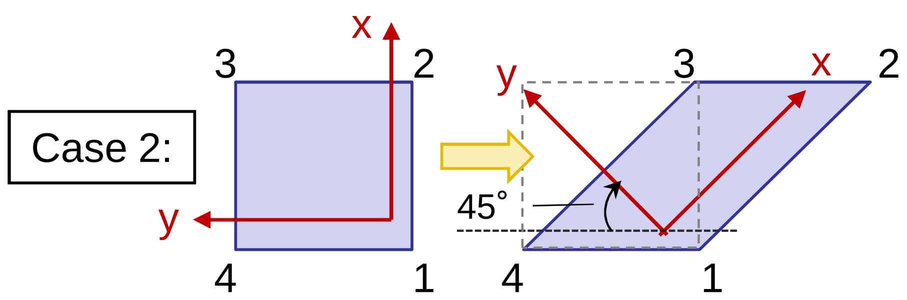
- Material-Coordinate-System displayed using:
  `> matdirection shownocoord 0`

General remarks

- we strongly recommend to use of Invariant Node Numbering
  - *CONTROL_ACCURACY, parameter INN
  - example: rotation of coordinate system during deformation
    - Default: without invariant node numbering

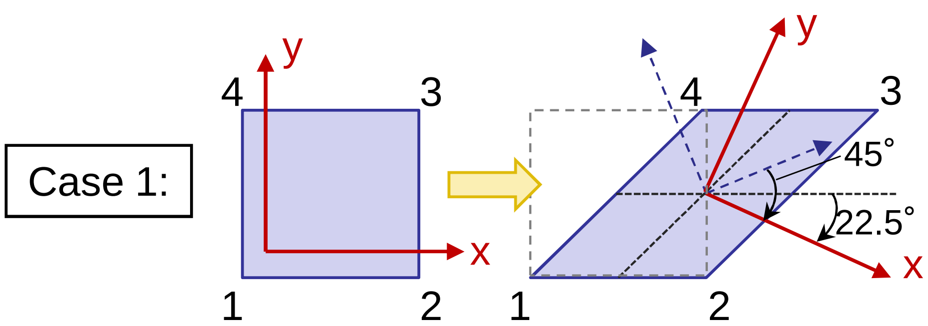


Rotation of COOS: 0°

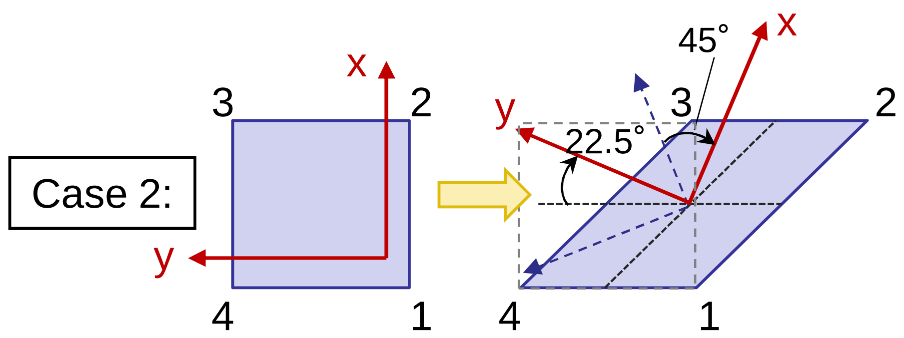


Rotation of COOS: 45°

- with invariant node numbering (INN=2 in *CONTROL_ACCURACY)



Rotation of COOS: 22.5°



Rotation of COOS: 22.5°

General remarks

- extra history variables
  - Many material models have extra history variables that help to track failure modes. A list of history variables is given here:

    http://www.dynasupport.com/howtos/material/history-variables

  - Set number of extra history variables to be written to d3plot with NEIPS (shells) or NEIPH (solids) in *DATABASE_EXTENT_BINARY

- Output of stresses and strains in the local material coordinate system use CMPFLG=1 in *DATABASE_EXTENT_BINARY

	binout	d3plot	
		global	local
CMPLFG=0	Element COOS	Global COOS	Element COOS
CMPFLG=1	Material COOS	Material COOS	Undefined

General remarks

- For detailed post-processing request all through thickness IPs with MAXINT in *DATABASE_EXTENT_BINARY
- *DATABASE_BINARY_D3PART & *DATABASE_EXTENT_D3PART allow to specify (detailed) output settings for selected parts
- Shell bulk viscosity may aid stability
  use *CONTROL_BULK_VISCOSITY, TYPE=-1 or -2
- Adding *DAMPING_PART_STIFFNESS to composite parts may decrease noise when elements start to fail
- Use NFAIL1 (under-integrated shells) and NFAIL4 (fully-integrated shells) in *CONTROL_SHELL to remove highly distorted elements
- New options W-MODE & STRETCH (Card 3 in *CONTROL_SHELL) may help to remove highly distorted elements, too

Thank you very much for your attention!