The thick shell element for metalforming and other Applications

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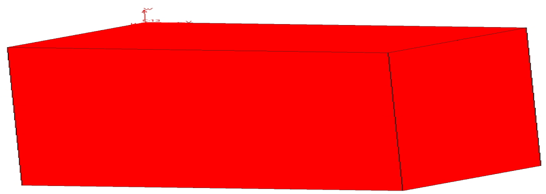
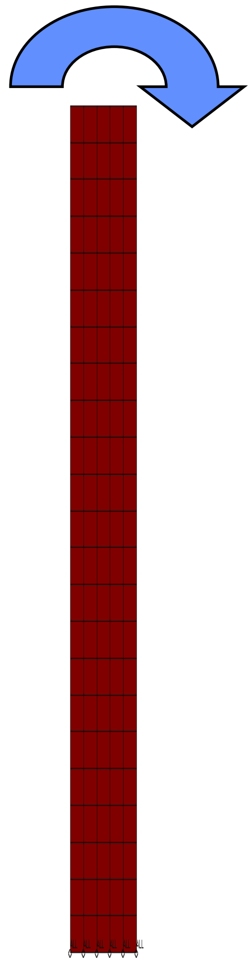
The thick shell element for metalforming and other Applications

Outline

- Element types
- Thick shell vs. thin shell
- Test of thick shell
- Usage for forming simulation
- Tube bending example





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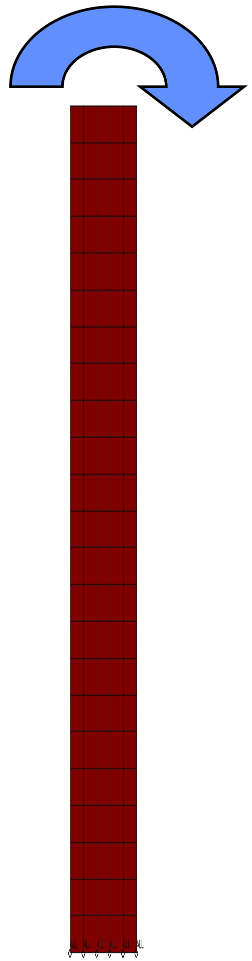
Element types

Beams, Shells and Solids

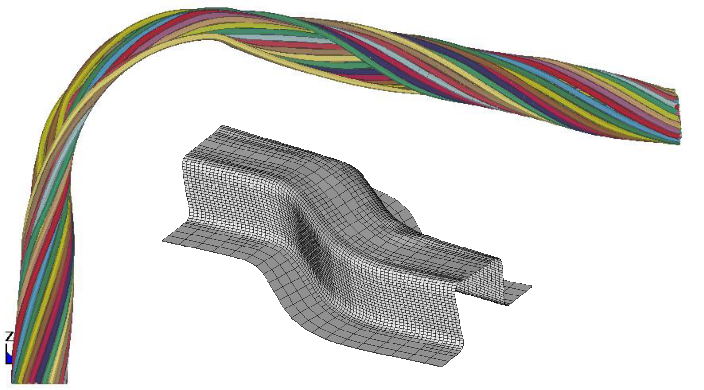
- Finite Elements are developed with several assumptions
- The assumptions are not always met (time consuming modelling, high computational costs)
- Widely used elements are beams, shells, solids

Problem for solid elements: capture bending properly

  - Bending dominated loading of a solid element model, about 5 elements in thickness direction necessary because of locking effects → high computational cost (explicit)
  - Bending with small radius: neutral fiber does not properly change for thin shell, 3D stress state



- In sheet metal forming, shell elements are used
- Bulk forming uses solid elements
- Cable (Wire) forming may use beams



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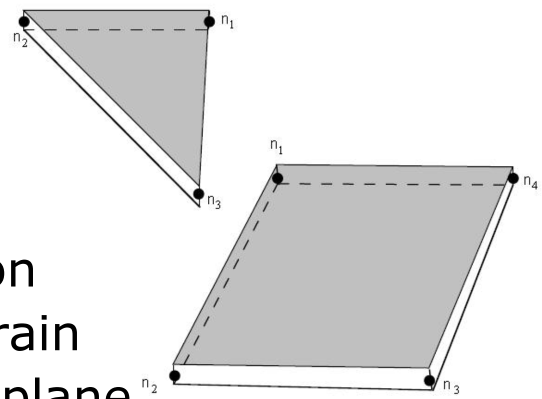
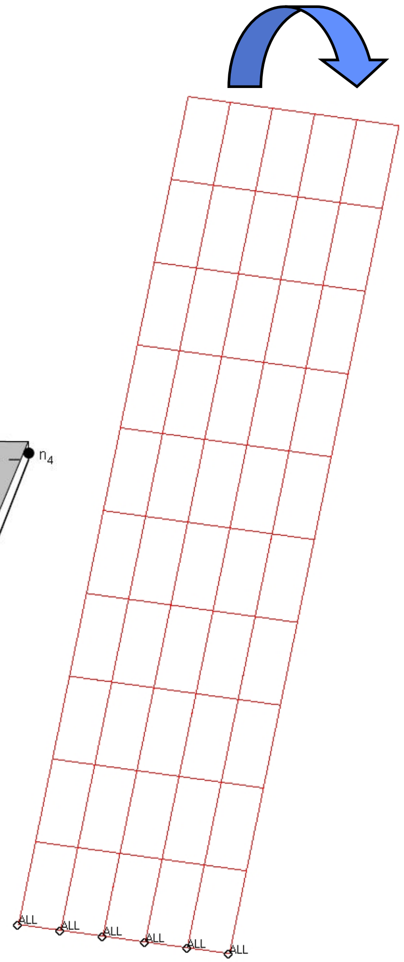
Thin shell theory

But there are processes between sheet metal forming and bulk forming. How may they be modelled?

Thin shell:

- Thin shell performs well for geometry with small thickness compared to width and length.
- 3 or 4 nodes
- Captures out-of plane bending well.
- Neutral fiber in shell middle.
- Plane stress, no stress in thickness direction
- Thickness change caused by membrane strain
- Degree of freedom: translation and out-of plane rotation





Some shells are “moderate thick” shells and overcome some of the mentioned problems, but especially the plane stress state is common for thin to moderate thick shells

  - this is a problem in forming simulation.

Thin shell theory

Applications of FEA not conform with thin shell theory:

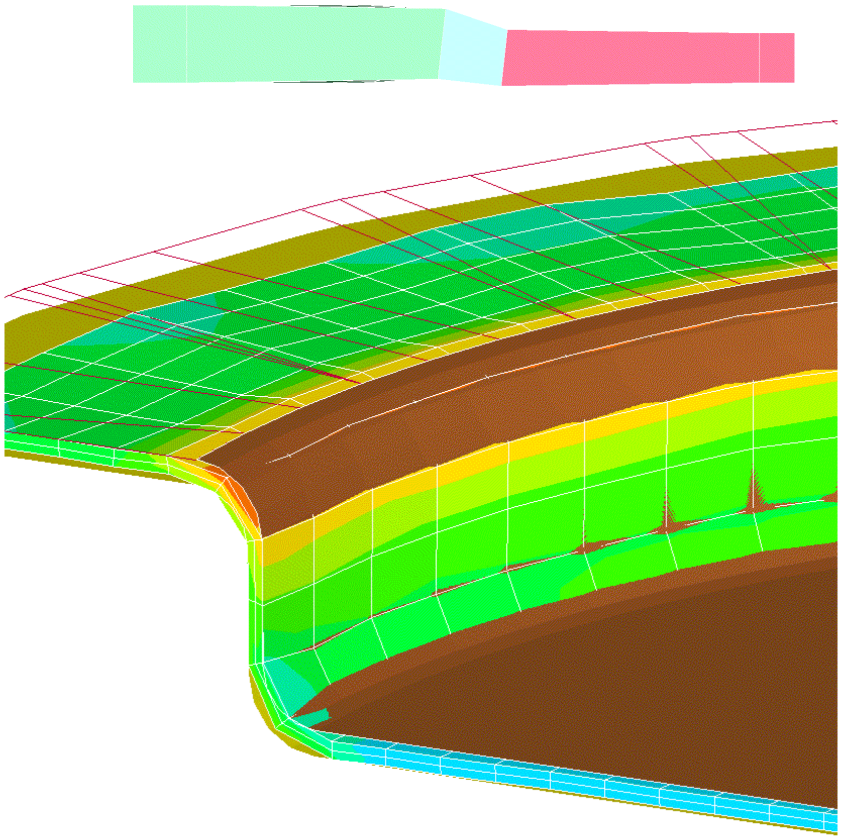
- Small radii compared to thickness → neutral fiber, 3D stress state
- T shape intersections → 3D stress state and missing rotational DOF about element normal
- Jump in thickness → 3D stress state
- High forces normal to shell plane → 3D stress state
  - contact from two sides
  - High pressure (close to yield stress)

- Another problem is variable thickness. Assigning a variable thickness is not supported by most preprocessors.
- In addition: some contact analysis require a more detailled modelling:
  - Contact forces are always applied to the nodes which are located in the shell middle layer → wrong loading

Thin and thick shells in forming analysis

Applications of FEA not conform with thin shell theory regarding forming simulation:

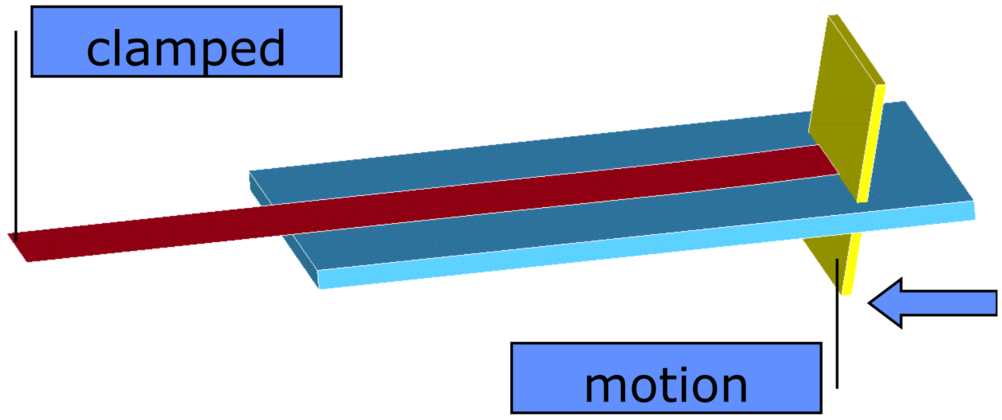
- Small radii compared to thickness → hemming, flanging, thick sheets, small embossments
- T shape intersections → bending and hydroforming extruded profiles
- Jump in thickness → tailor welded blanks
- High forces normal to shell plane
    - contact from two sides → deep drawing (tool gap smaller than thickness); punch closing (affects punch force calculation)
    - High pressure → hydroforming
- variable thickness: tailor rolled sheets and extruded profiles

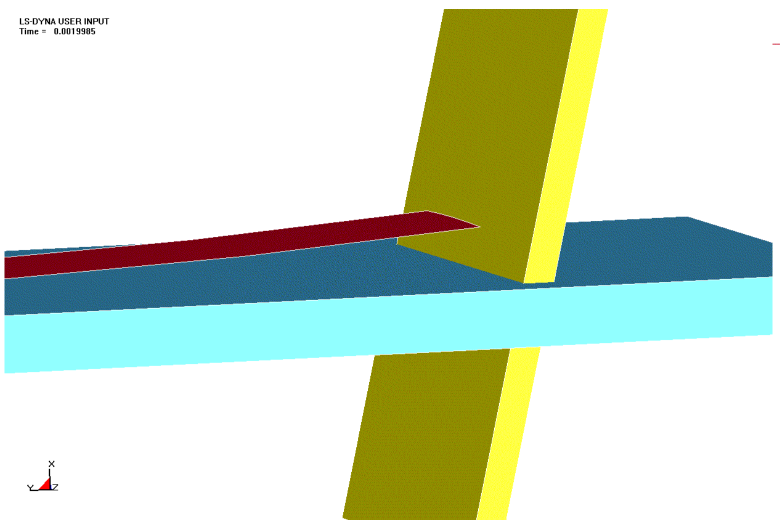


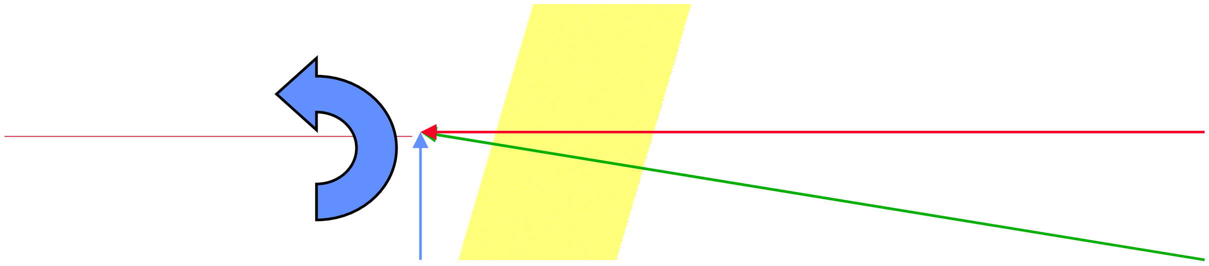
Thin shells for contact analysis

Example: buckling of a plate

- thin shell contact forces are applied to the nodes which are located at the midplane
- Forces cause in-plane compression and bending



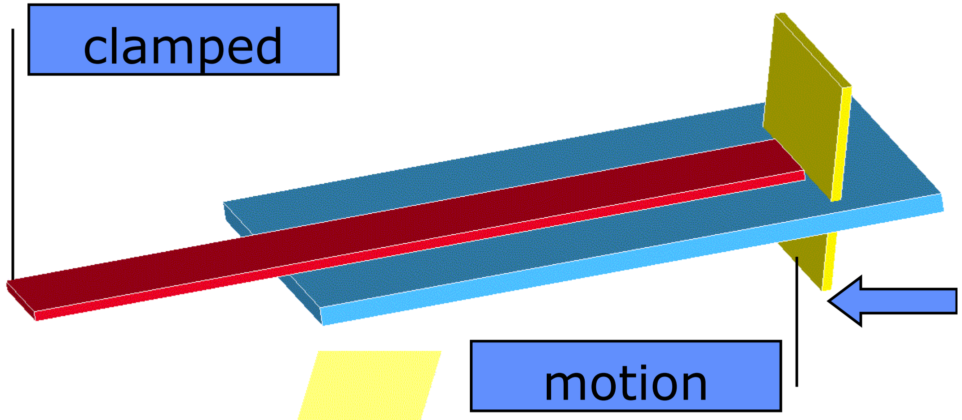


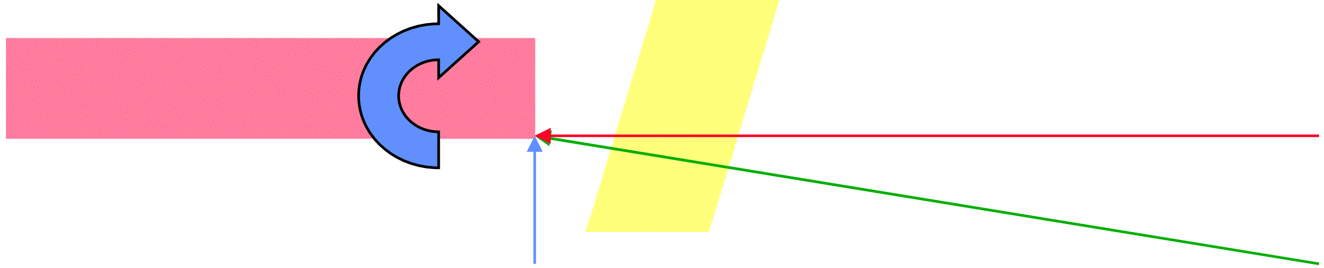


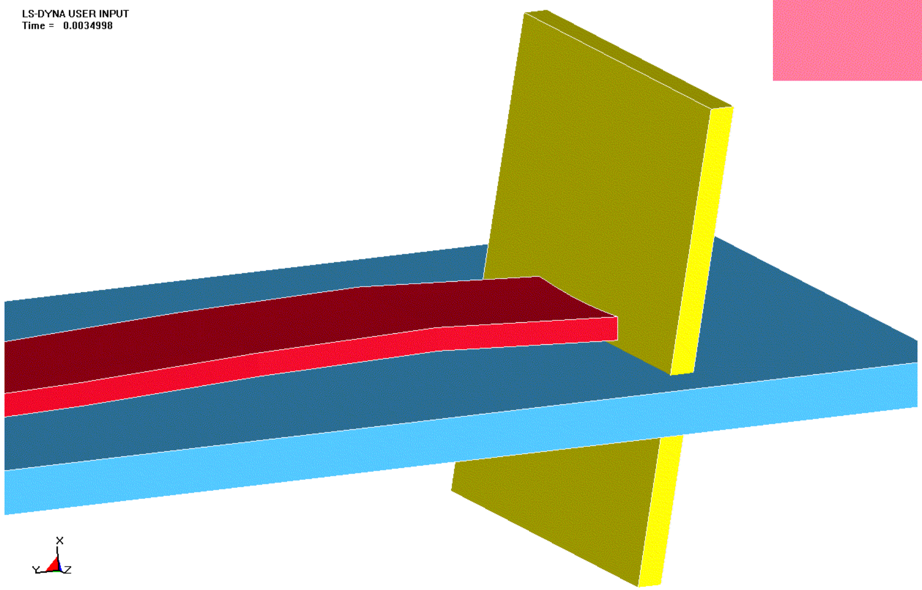
Thick shells for contact analysis

Example: buckling of a plate

- thick shell contact forces are applied to the nodes which are located at the bottom
- Forces area applied out-of-plane

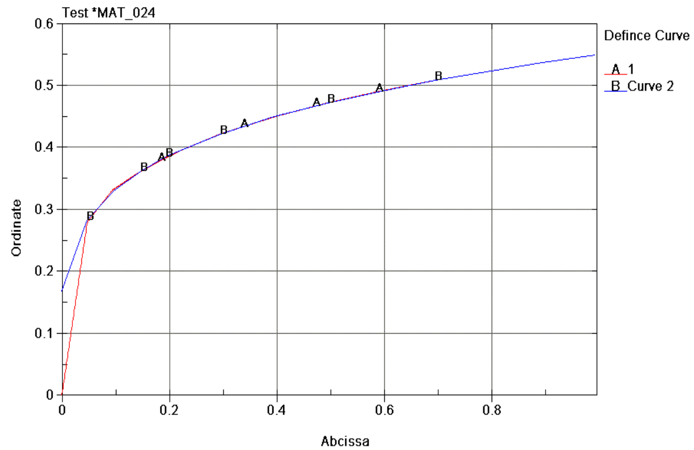






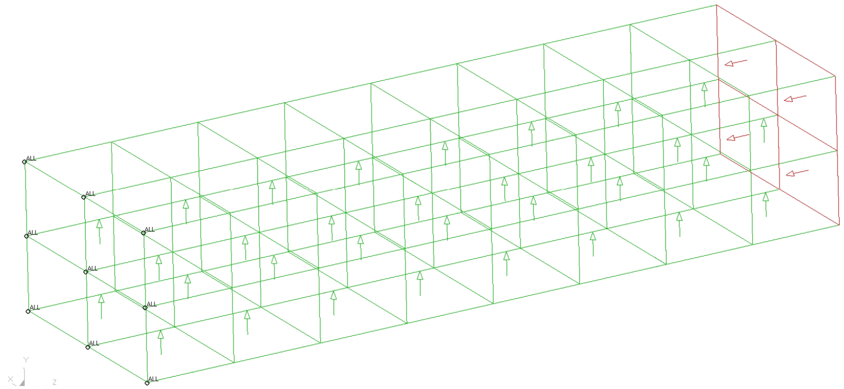
Thick shell element type 3

Thick shell theory



A solution might be a thick shell, sometimes referred to “solid shell”:

- Eight nodes like brick element
- Translation degree of freedom only
- Element shape describes the thickness (no thickness input)
- In LS-DYNA, see *SECTION_TSHELL
- In LS-DYNA three thick shells are available. Type one and two are not really thick shells. They still use plane-stress → no solution for the mentioned problems.
- Thick shell type 3 uses 3D stress state
- Available material models: see solids
- number of integration points in thickness direction: orientation important, NIP
- In-plane 2 X 2

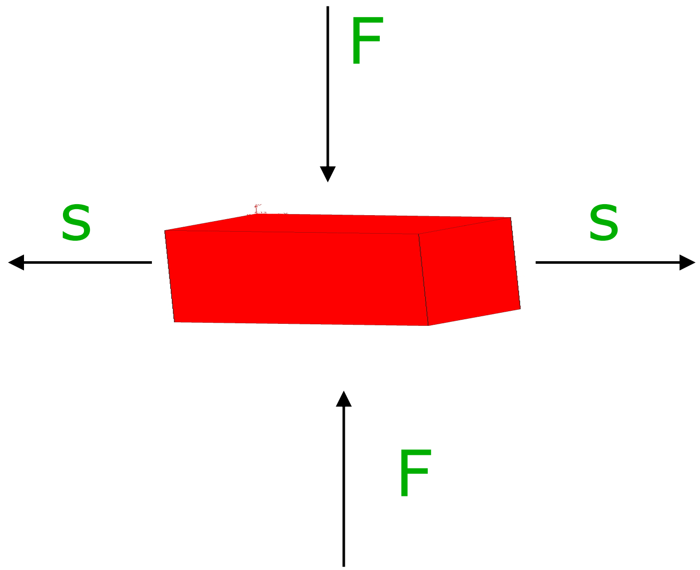


Thick shell element type 3

Thick shell theory

Further advantages of thick shells

- Simplified transition to solid elements
- 3D constitutive material models may be applied directly without plane stress algorithm



Disadvantage:

- More than one element in thickness direction needed, two are recommended
- hex meshing
- Wedge only as filling elements
- Type 3 is distortion sensitive
- Some options regarding thin shells are not available
  - No trimming
  - No adaptivity
  - No dynain

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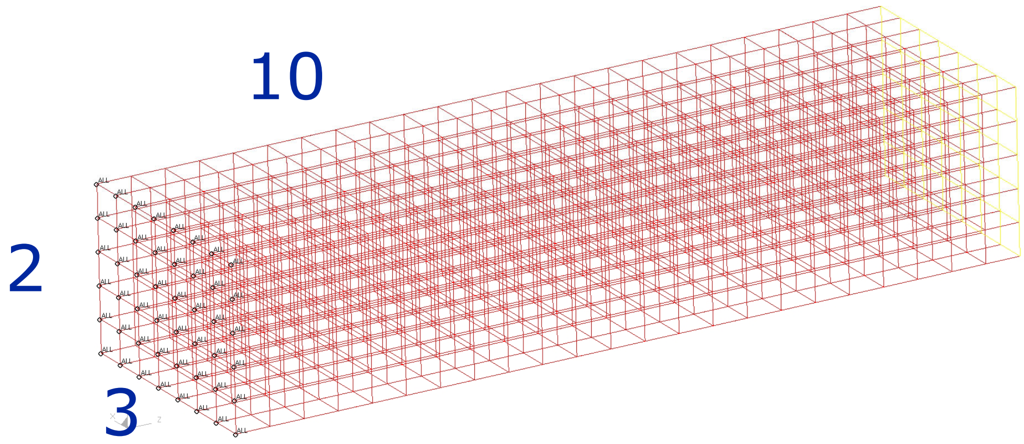
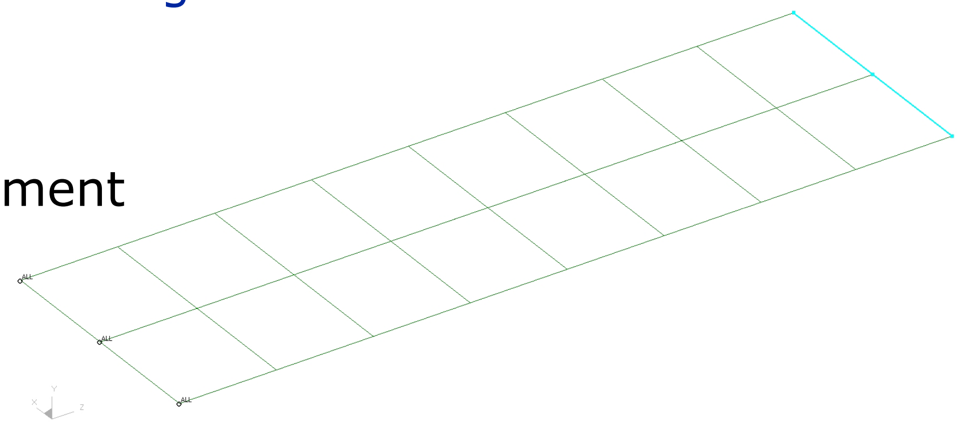
Thick shell element type 3

Analysis of short cantilever beam

Reference solutions:

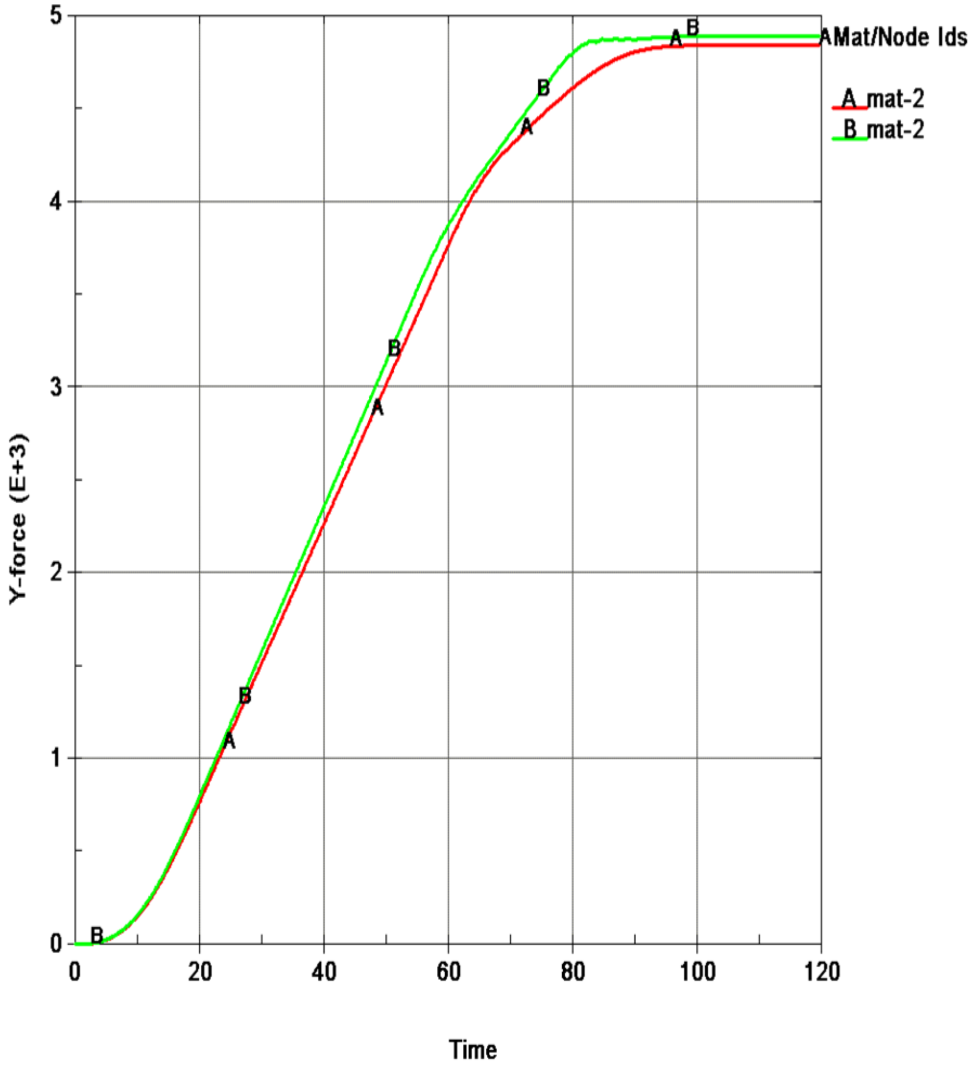
- Solid element type 1
  - hourglass type 6
  - 5 elements in thickness direction
- Shell element type 16
  - 2 by 8 elements
  - 5 integration points
- Ratio thickness x width x length = 2 x 3 x 10
- Loading:
  - left side clamped
  - right side displacement





Thick shell element type 3

Analysis of short cantilever beam



Reference solution:

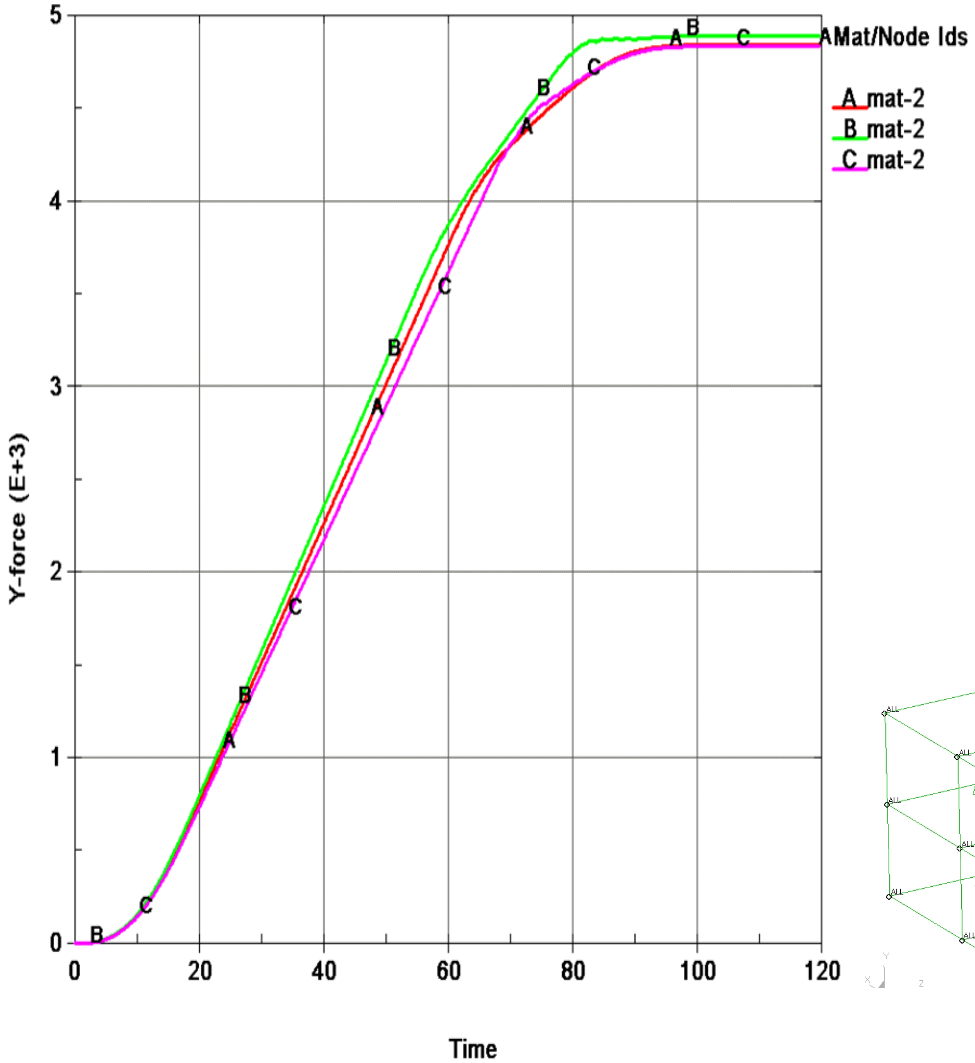
A- Solid element

B- Thin shell 16

Results show force vs. Time (displacement)

Thick shell element type 3

Analysis of short cantilever beam



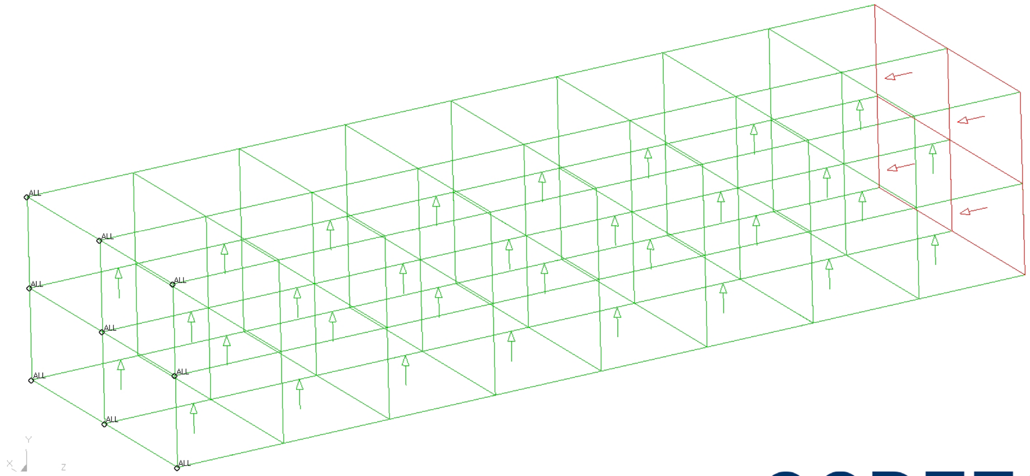
Comparison to thick shell:

A- Solid element

B- Thin shell 16

C- Tshell 3, NIP=3, 2 Elements in thickness direction, Gauss integration

Close to solid element solution.



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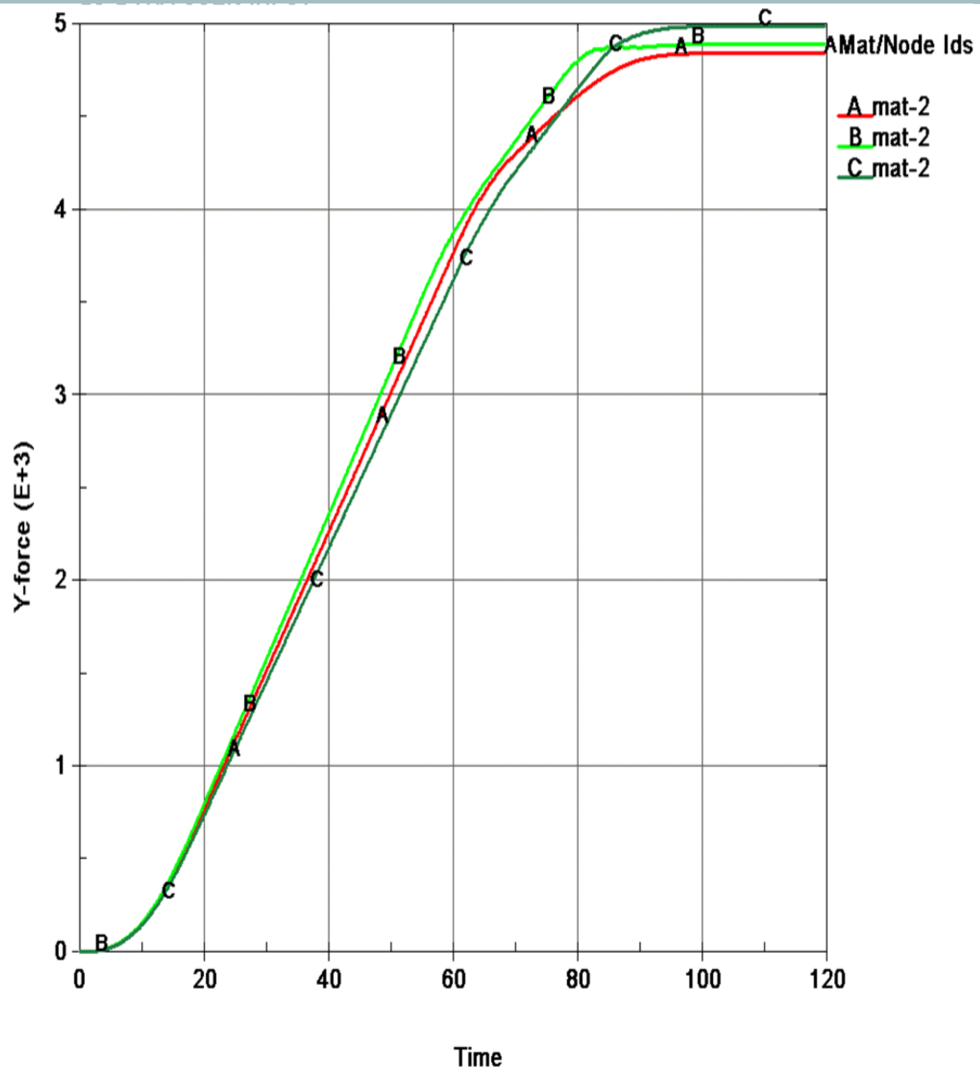
Thick shell element type 3

Analysis of short cantilever beam



Effect of through thickness integration:

A- Solid element

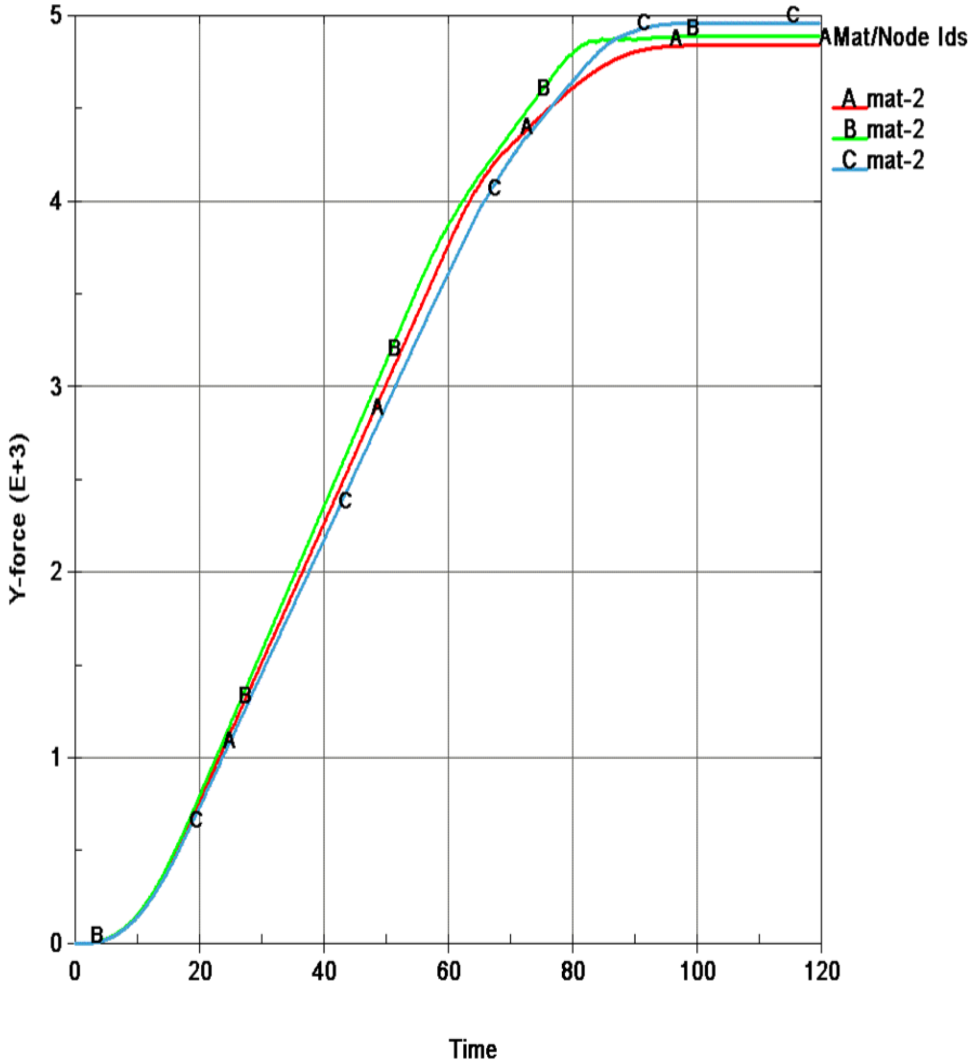
B- Thin shell 16

C- Tshell 3, NIP=3, 2 Elements in thickness direction, Lobatto integration

Stiffer than shell and solid. Lobatto seems to stiffen the thick shell.

Thick shell element type 3

Analysis of short cantilever beam



Effect of through thickness integration:

A- Solid element

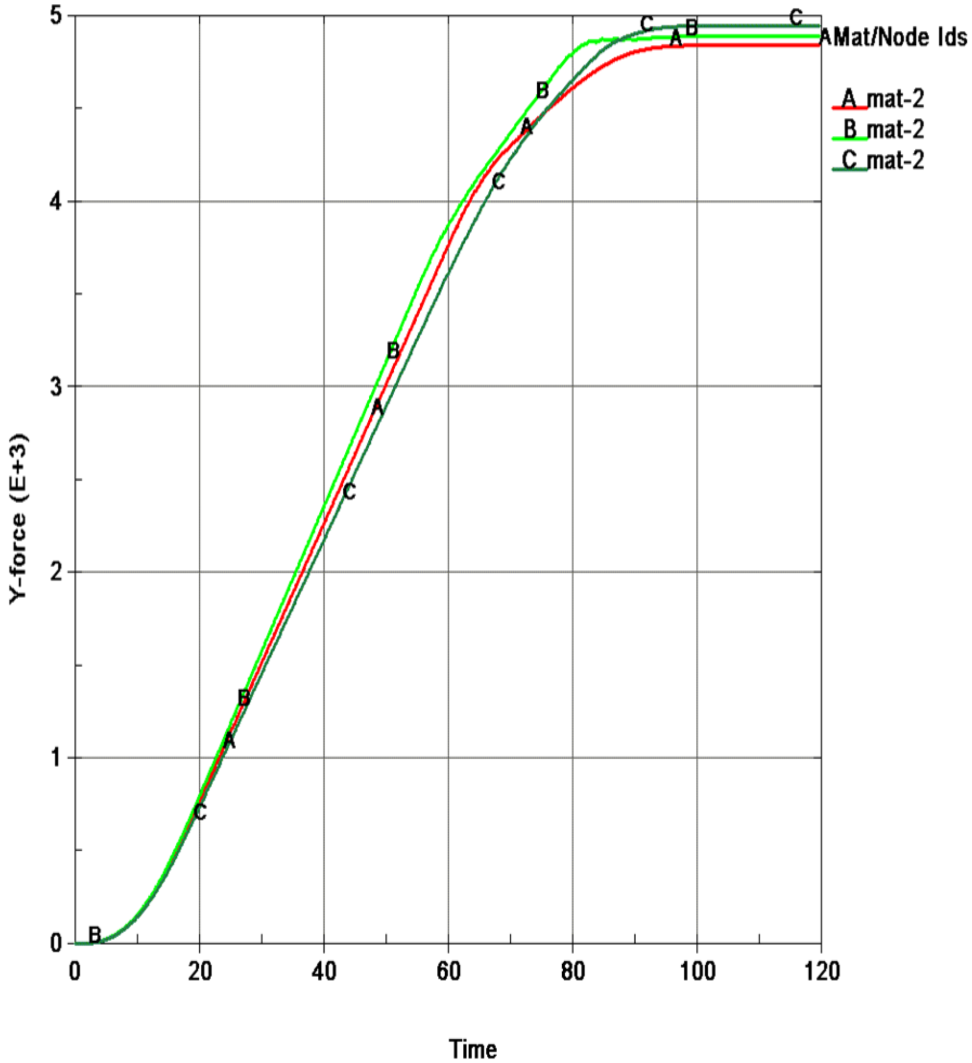
B- Thin shell 16

C- Tshell 3, Lobatto integration, NIP=5

Tshell stiffer than shell and solid. Lobatto with additional integration points reduces the higher stiffness slightly.

Thick shell element type 3

Analysis of short cantilever beam



Effect of through thickness integration:

A- Solid element

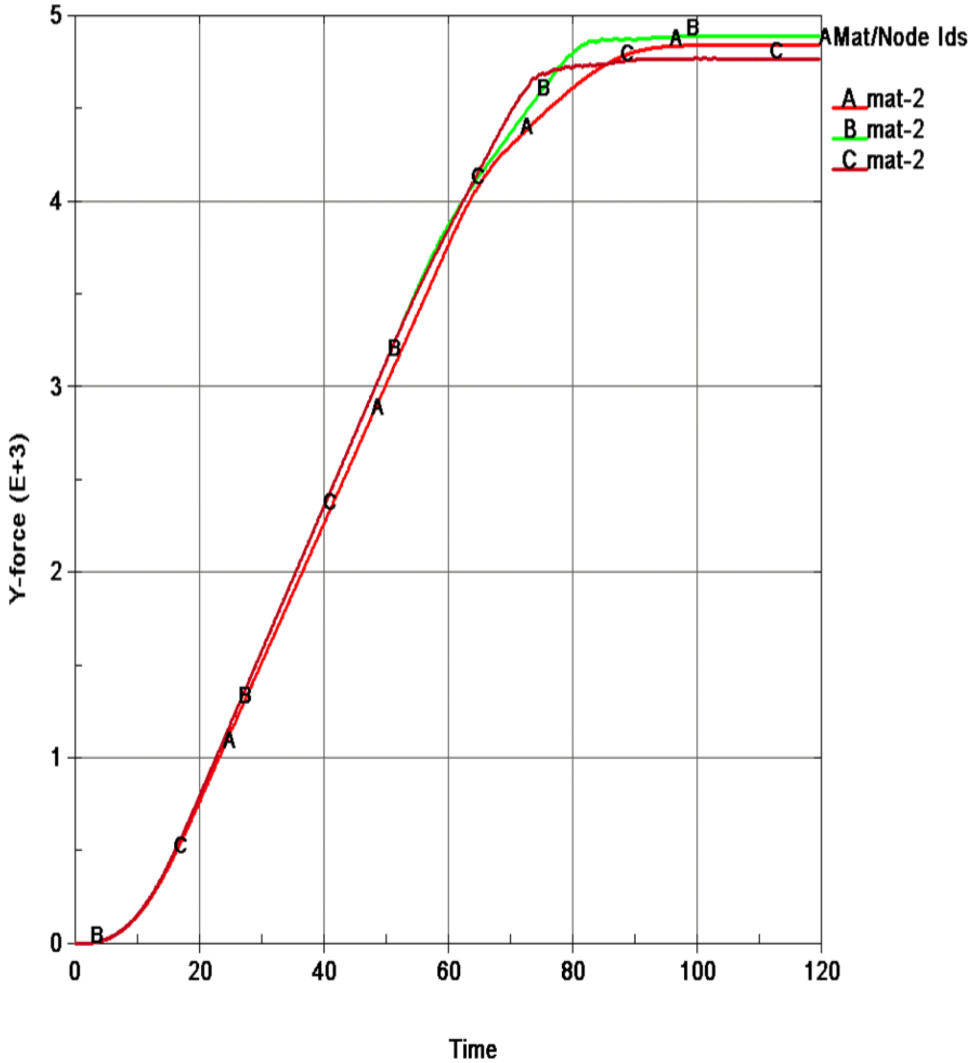
B- Thin shell 16

C- Tshell 3, Gauss integration, NIP=5

Stiffer than shell and solid. Gauss with 5 integration points is close to Lobatto.

Thick shell element type 3

Analysis of short cantilever beam



Effect of through thickness integration:

A- Solid element

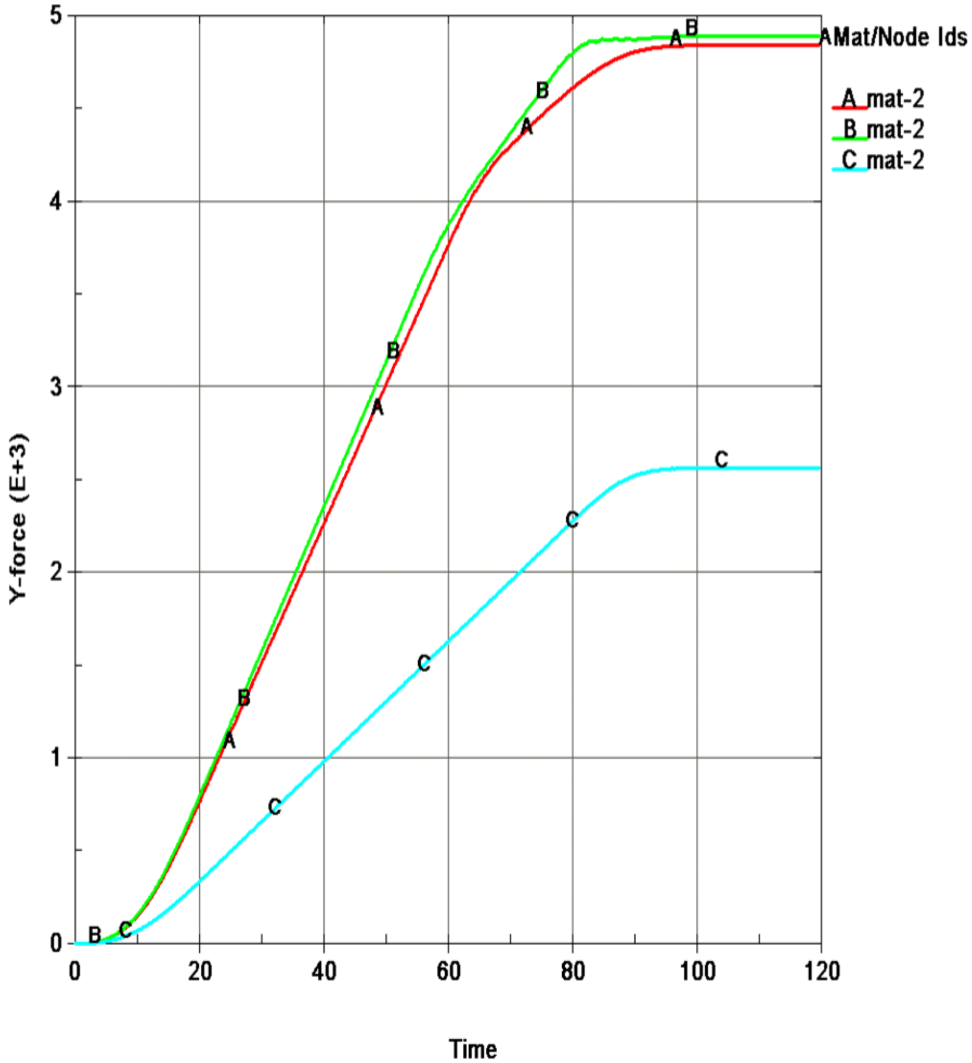
B- Thin shell 16

C- Thin shell 16, Lobatto integration

Softer than shell and solid reference. Lobatto softens the thin shell.

Thick shell element type 3

Analysis of short cantilever beam



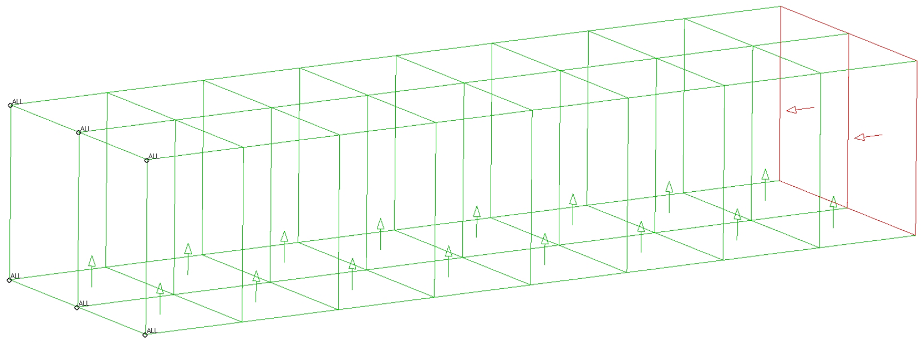
Number of elements in thickness direction:

A- Solid element

B- Thin shell 16

C- Tshell 3, 1 element in thickness direction

Excessive softness!!



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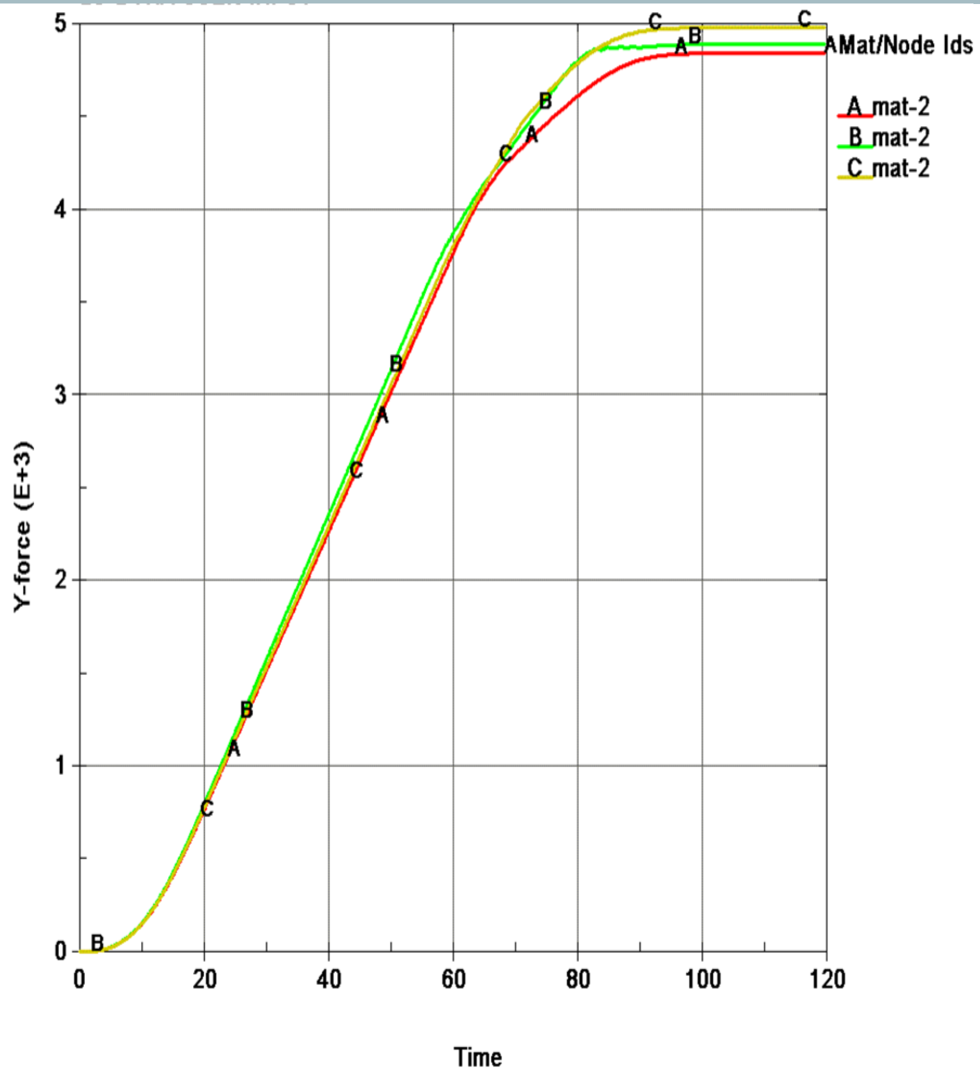
Thick shell element type 3

Analysis of short cantilever beam



Number of elements in thickness direction:

A- Solid element

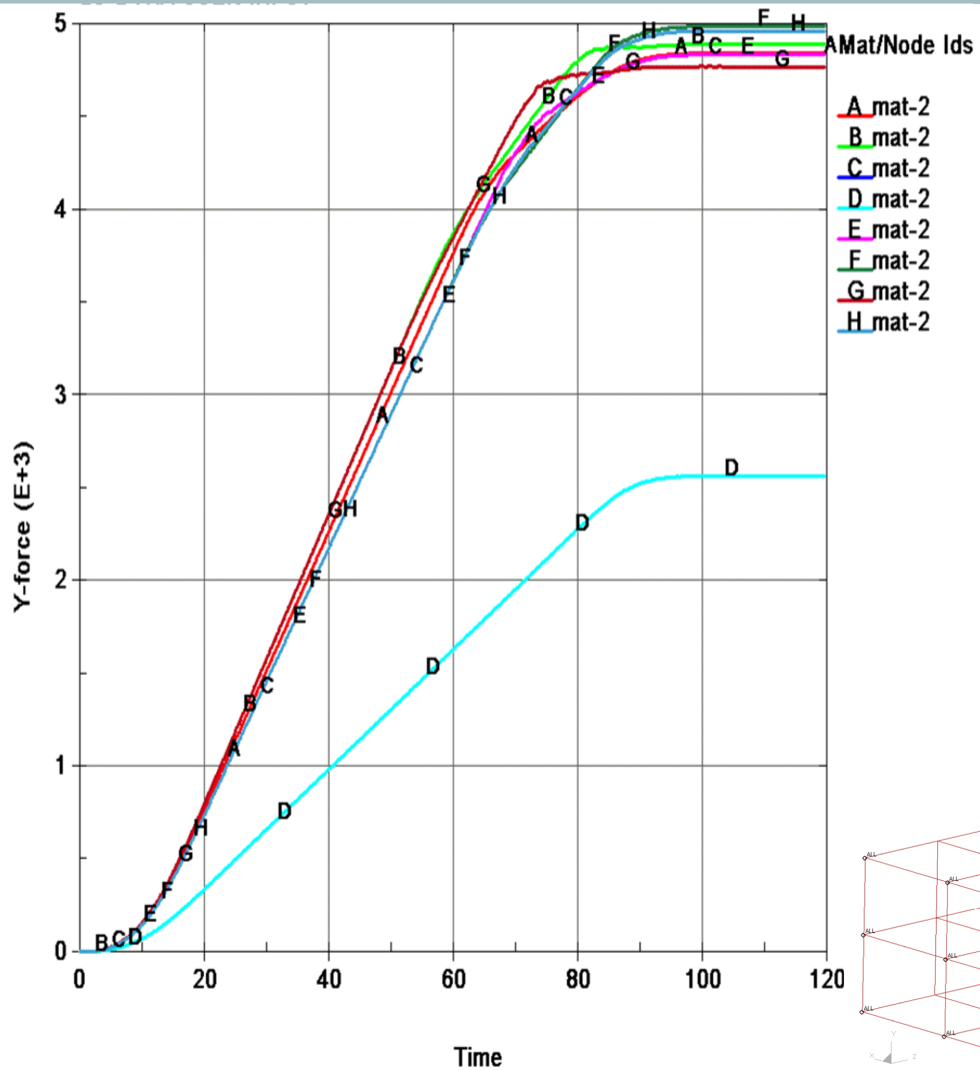
B- Thin shell 16

C- Tshell 3, 3 elements in thickness direction

Stiffer than reference solutions.

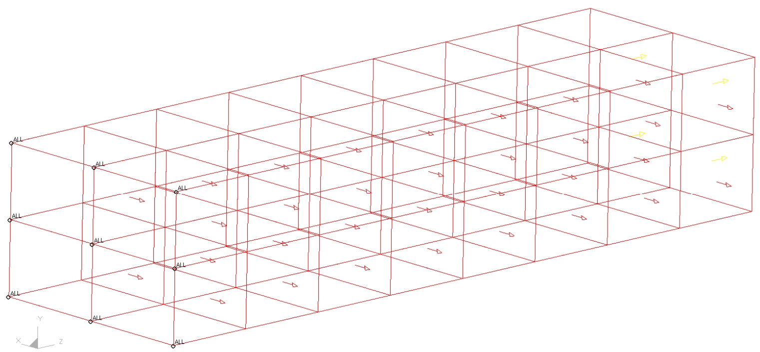
Thick shell element type 3

Analysis of short cantilever beam



Summary of results, element formulations:

- A- solid 1
- B- shell 16
- C- Tshell in-plane, 2 elements
- D- tshell, 1 element
- E- tshell, nip=3, Gauss
- F- tshell, Lobatto, nip=3
- G- shell 16, intgrd=1
- H- tshell, Lobatto, nip=5



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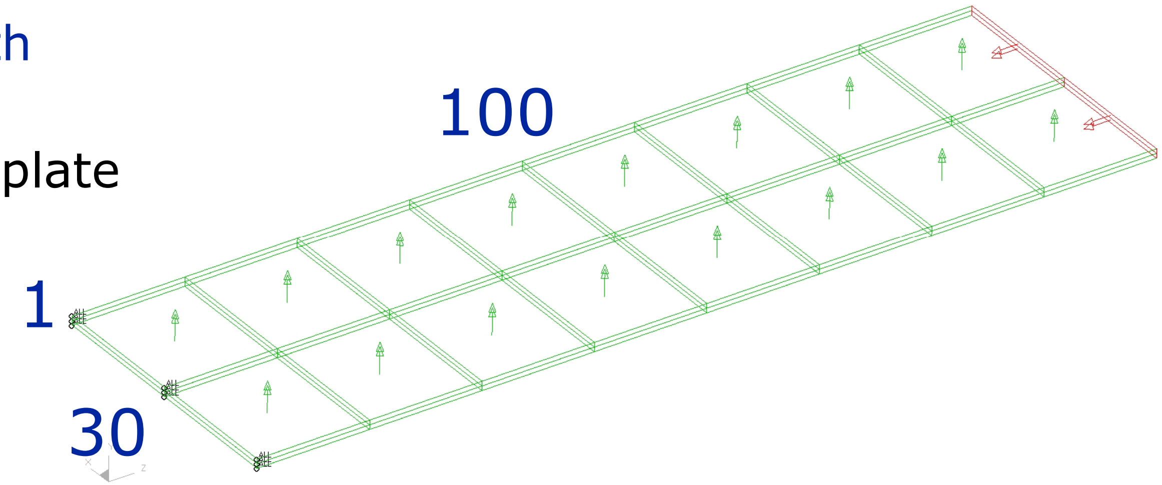
Thick shell element type 3

Analysis of thin plate

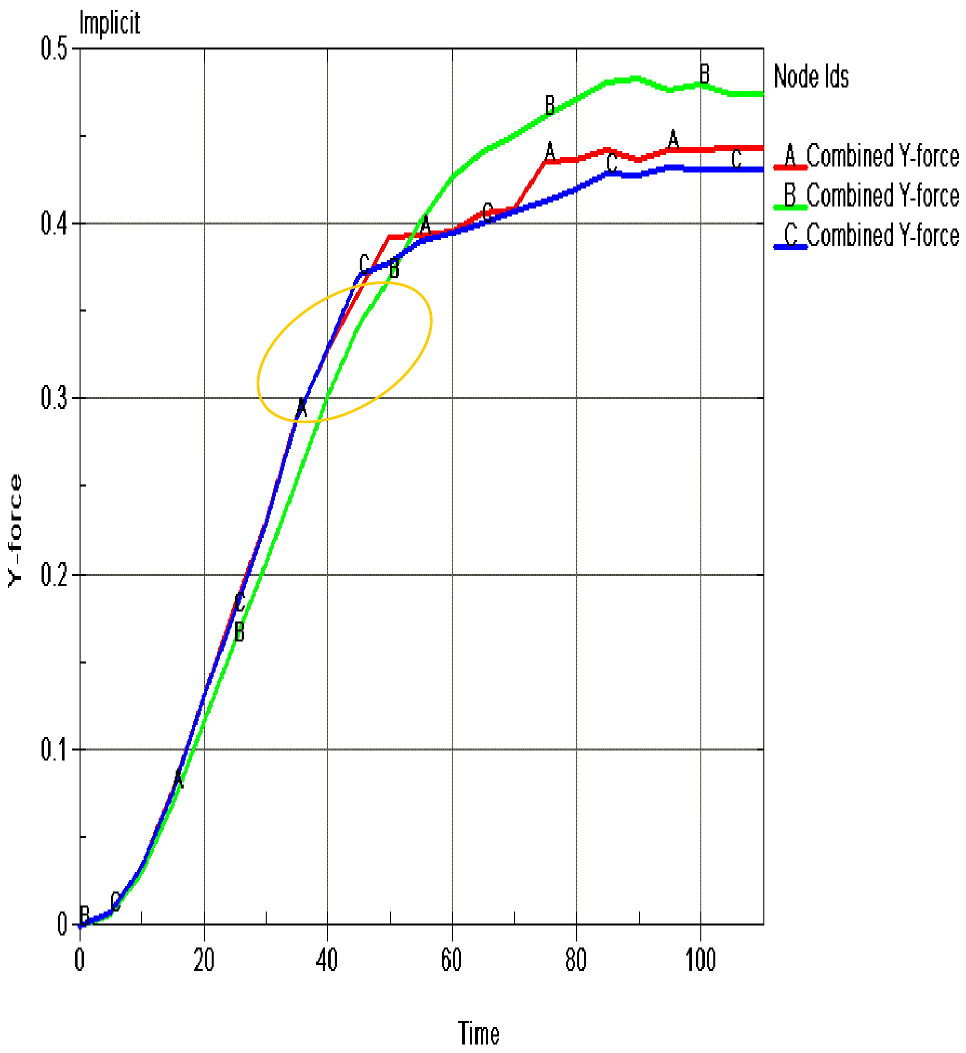
Thin plate

- Ratio thickness x width x length
  = 1 x 30 x 100
- Boundary conditions like thick plate



Thick shell element type 3

Analysis of thin plate, implicit



Summary of results, element formulations:

A- shell 16, Gauss

B- Tshell 3

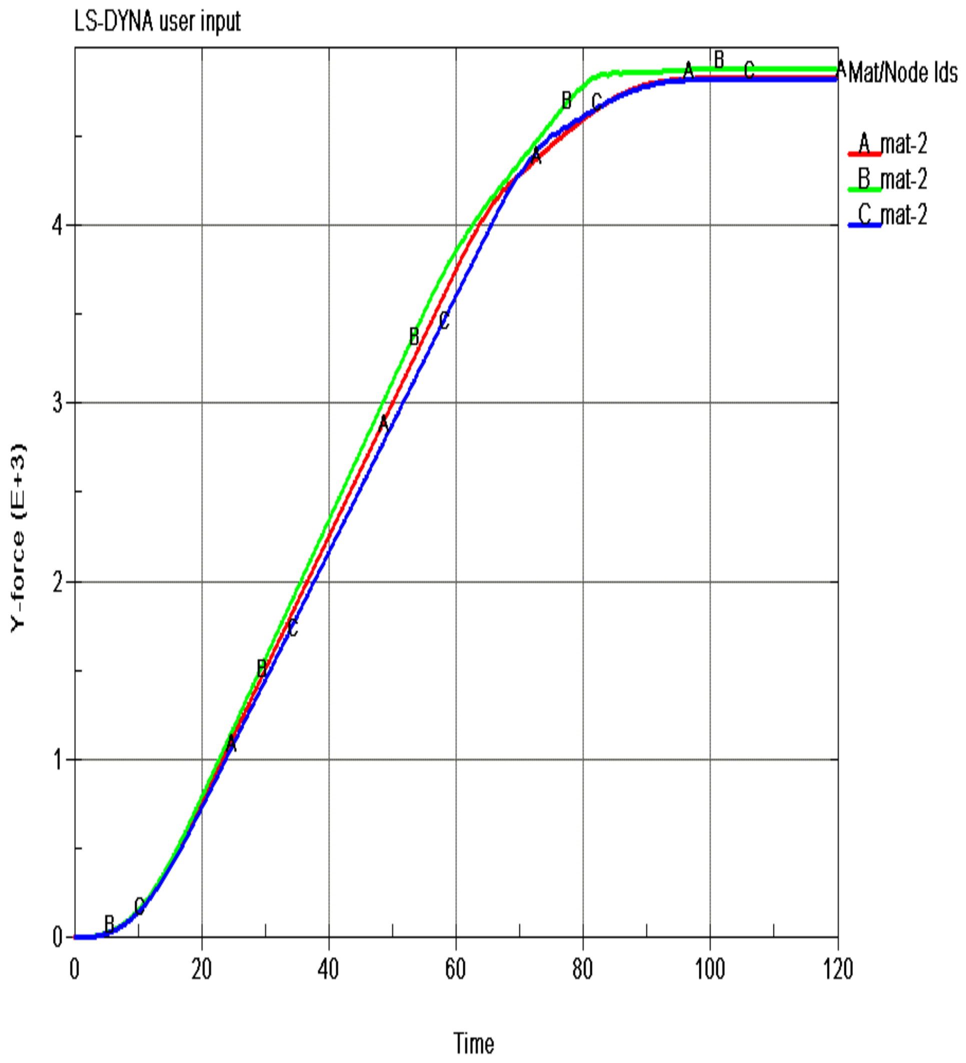
C- shell 16, Lobatto

Plasticity occurs with shell 16 earlier than Tshell (time 40 vs. Time 45).

Tshell is softer in elastic region, stiffer while plasticity increases.

Thick shell element type 3

Analysis of in-plane bending



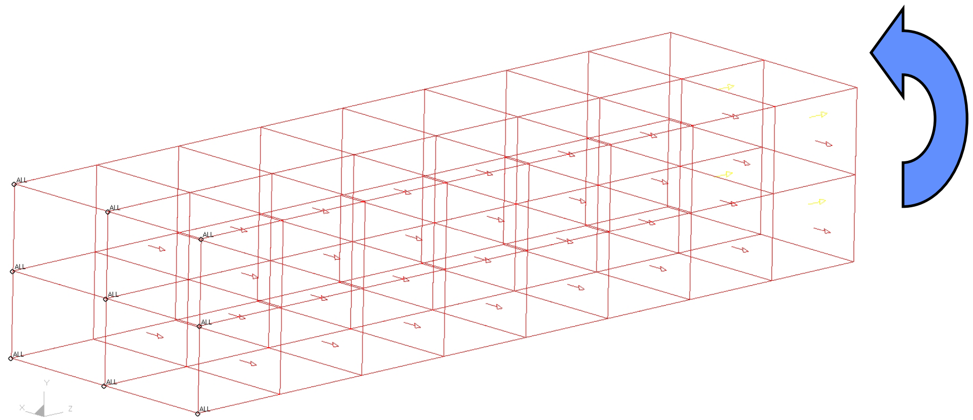
Summary of results, element formulations:

A- Solid element

B- Thin shell 16

C- Tshell 3, NIP=3, 2 Elements in thickness direction, Gauss integration

Close to reference solution.



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Thick shell element type 3

Summary of tests

- Thick shell type 3 gives similar results compared to reference solutions.
- Works for thin and thick plates
- Less stiff than shell 16
- Agrees with solid element result for thick plates.
- Default Gauss integration and 3 integration points sufficient
- 2 elements necessary for in-plane and out-out plane bending
- May be used if shell mesh size reaches element‘s thickness
  - else very expensive due to small time step in explicit

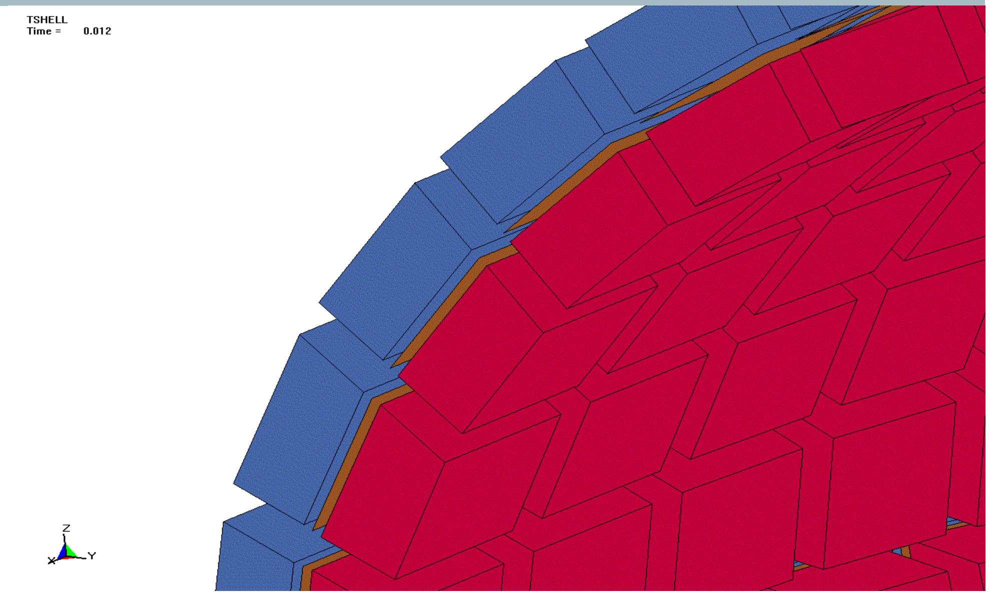
Note: shear factor does not apply to thick shell type 3.

Thick shell element type 3

Usage of Tshell in Forming Simulation

Usage in forming simulation:

- FLD does not work in LS-PREPOST
- The thickness is not a fringe result
- Workaround:
  - add a thin „dummy“ shell between the two thick shell layers with reduced stiffness (factor 1000) to measure strain
    - Disadvantage: computational more expensive
  - or put Null shells on top and bottom and measure the part seperation in normal direction
    - Disadvantage: no FLD available
- No adaptivity available
- No trimming available
- No results mapping available



How to mesh:

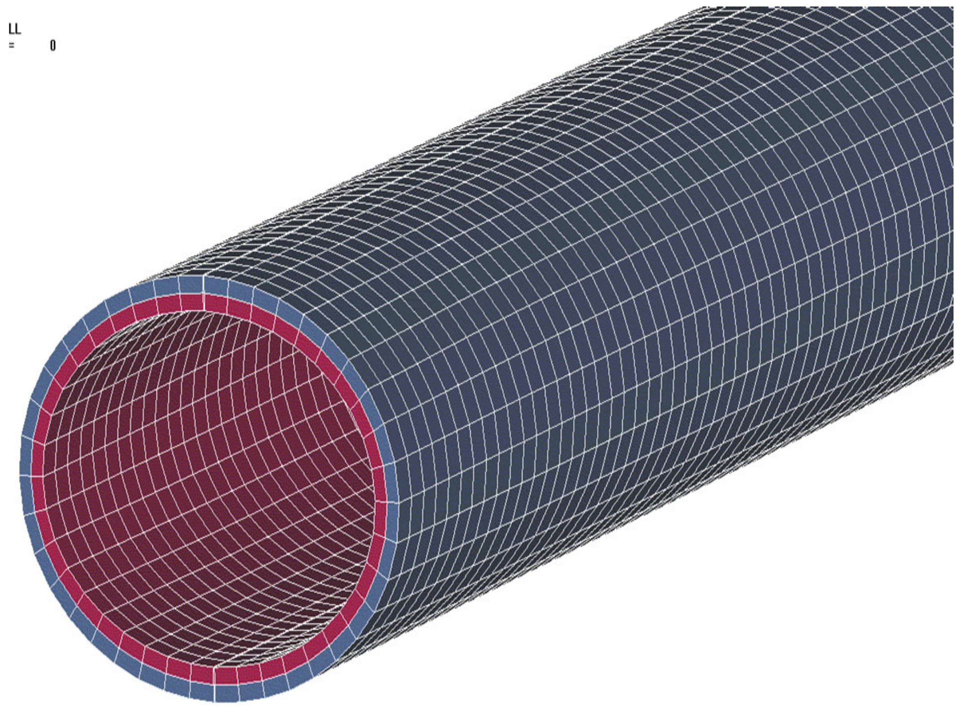
1. Surface mesh
2. Drag elements into normal direction (half thickness)
3. Reverse surface‘s mesh normal
4. Drag elements into normal direction (half thickness)

Thick shell element type 3

Analysis of the bending of a thick tube

But more results compared to experiment are necessary. One real-world example is presented here.

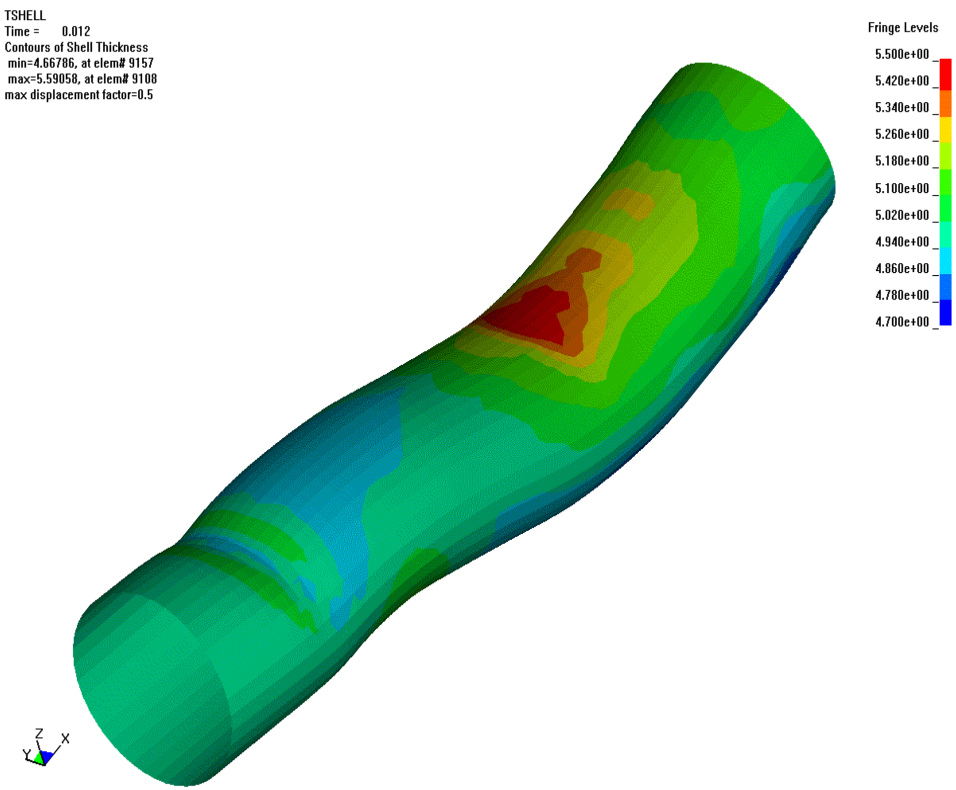
- Bending of a tube with internal pressure
- Ratio outer diameter/thickness = 10
- Pressure 10% of yield stress



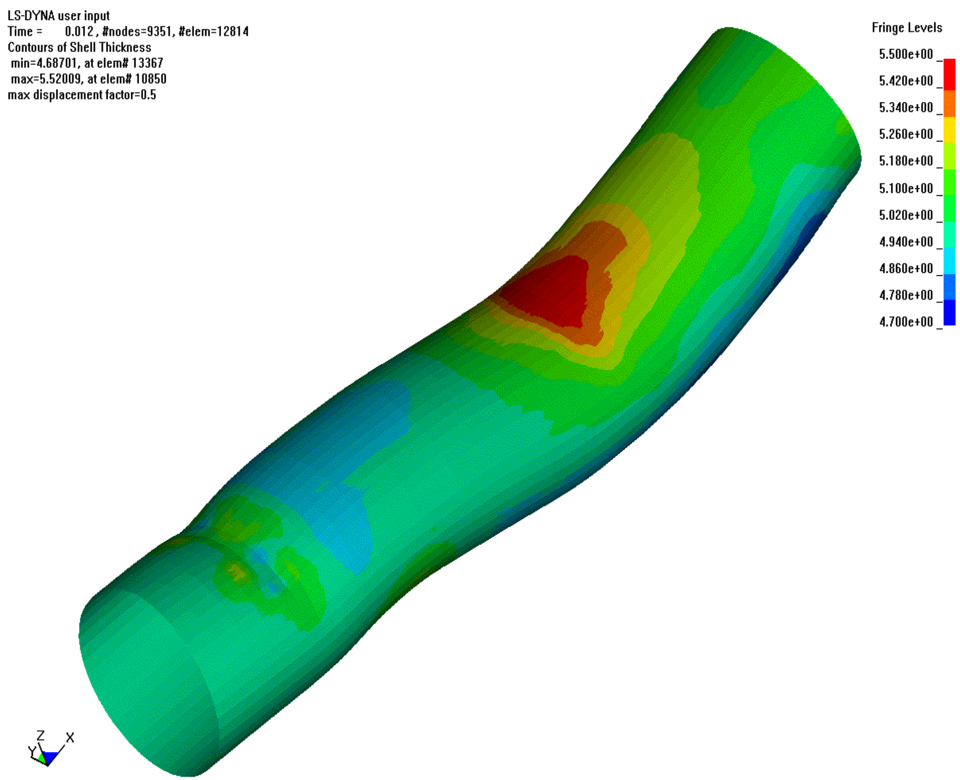
Thick shell element type 3

Analysis of the bending of a thick tube

Comparison: thick shell



thin shell



Result of „dummy“ shell: tmax=5.59, tmin=4.67

Result of B-T shell: tmax=5.52, tmin=4.69

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Thick shell element type 3

Analysis of the bending of a thick tube

	thick shell	thin shell
Analysis time:		
	170 min	16 min
Time step:		
	3.09E-07	3.60E-07

→ Thin shell ten times faster

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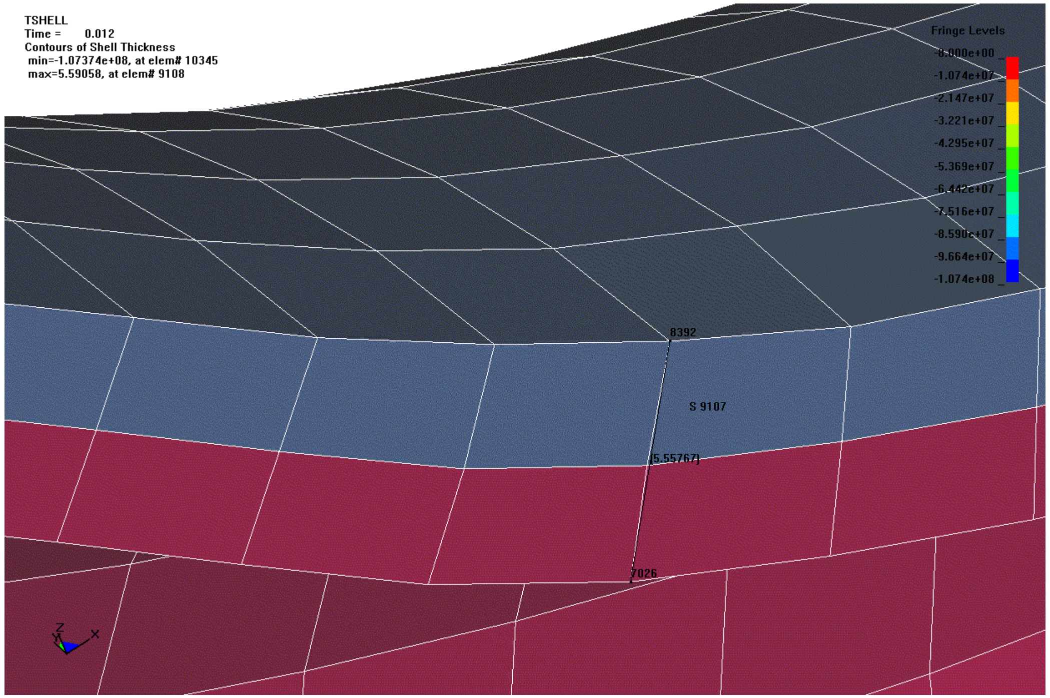
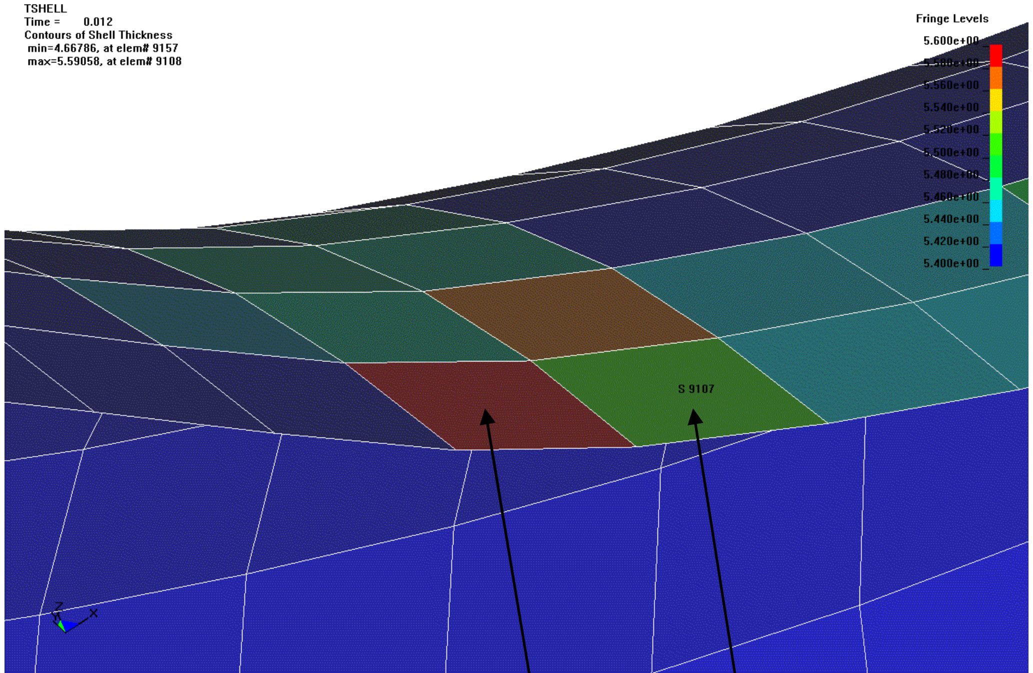
Thick shell element type 3

Analysis of the bending of a thick tube

Thick shell element results





Result of „dummy“ shells: t=5.59, t=5.50

Result of Tshell: t=5.56

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Thick shell element type 3

Analysis of the bending of a thick tube

Conclusion

- The thick shell gives reasonable results
- Thin shell for this geometry is still valid
- Low pressure does not affect the results
- For most applications the thin shells are still the right choice. Only in some rare cases the thick shell is need.
- The thick shell may be used to validate thin shell results; the forming process should be optimized with thin shells.

Summary

- The thick shell element results agree with solid and shell elements results.
- A tube bending example shows good agreement between thin and thick element results.
- The thick shell may be used in future analysis if thin shell element results are a concern.
- A disadvantage are timestep and computational costs.

Some enhancements are necessary for the future:

Trimming, FLD, adaptivity, thickness and thinning fringe plot

The thick shell element for metalforming and other Applications

Thank you very much for your attention!

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