Introduction to 2nd-order Lagrangian Element in LS-DYNA

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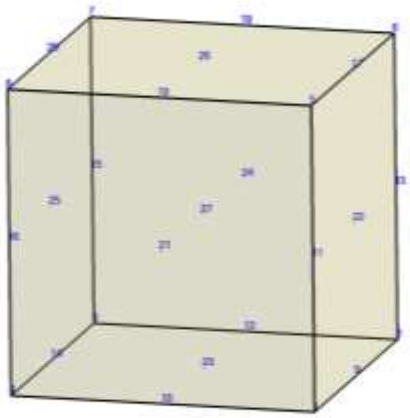
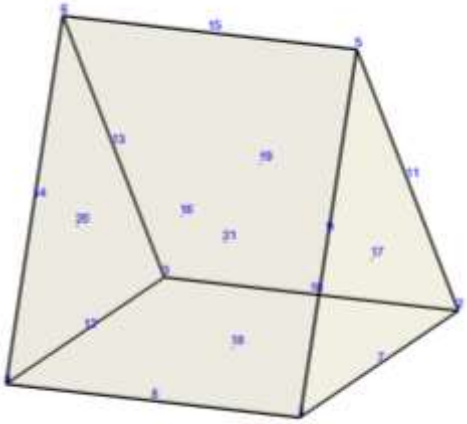
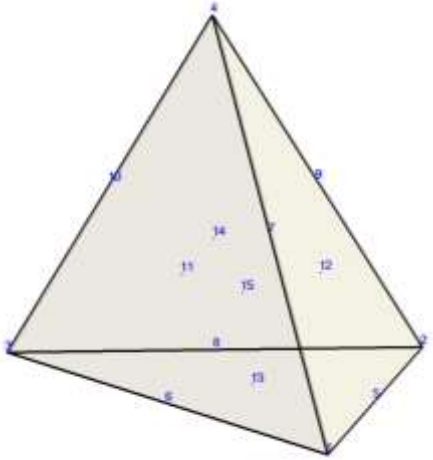
Motivation

- Users are requesting higher order elements for implicit.
- Replace shells.
  - Eliminate transitions between solids and shells for easier meshing.
  - Use 3-D material models.
  - Better kinematics through the thickness.
    - Shell theories use linear displacements.
    - Solid elements use quadratic or cubic displacements.
    - Better accuracy at sharp corners.
  - 3-D material models + better kinematics = better failure predictions.
  - Linear Solid Element?
- Replace linear solids for lower cost and better accuracy.
  - Use 1 27-node solid to replace 8 8-node solids.
  - Use 1 64-node solid to replace 27 8-node solids.

2nd-order Lagrangian Element







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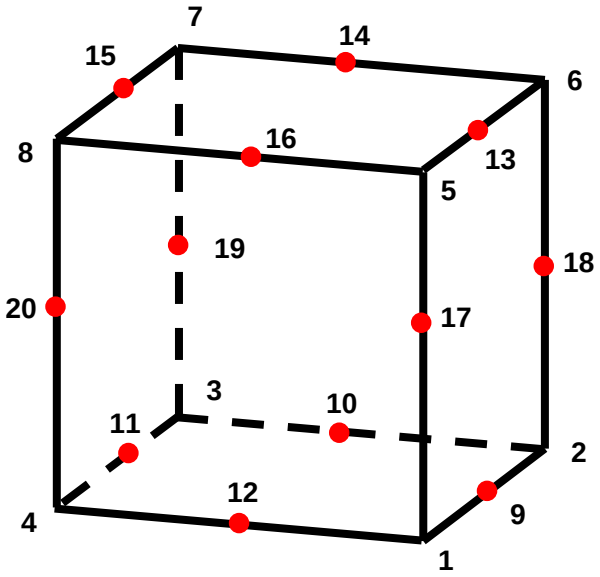
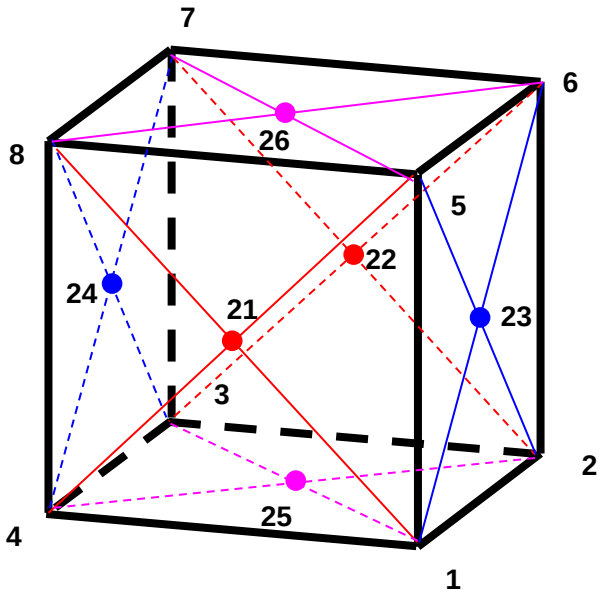
27-Node Hexahedron Element

```
*SECTION_SOLID
$---+----1----+----2----+----3----+----4
$#    SECID     ELFORM        AET
          1         24
```

- Elform .eq. 24 27-node solid formulation



Corner and edge nodes



Corner and face center nodes

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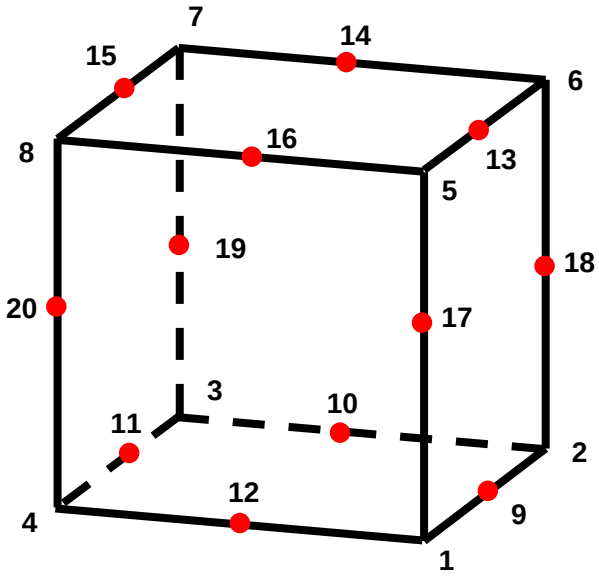
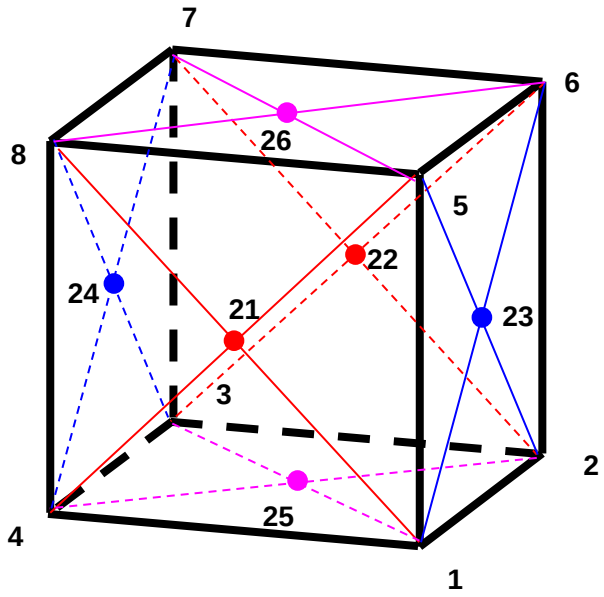
Manually define element connectivity

```
*ELEMENT_SOLID_H27
$#    eid     pid
        1       1
$#     n1      n2      n3      n4      n5      n6      n7      n8      n9     n10
        1       2       3       4       5       6       7       8       9      10
$#    n11     n12     n13     n14     n15     n16     n17     n18     n19     n20
       11      12      13      14      15      16      17      18      19      20
$#    n21     n22     n23     n24     n25     n26     n27
       21      22      23      24      25      26      27
```



Corner and edge nodes



Corner and face center nodes

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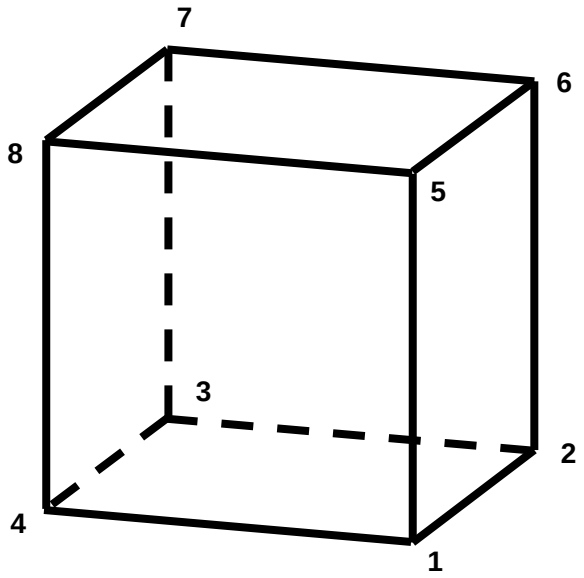
Automatic transfer to 27-node Element

```
*ELEMENT_SOLID_H8TOH27
$#    eid     pid      n1      n2      n3      n4      n5      n6      n7      n8
       1       1       1       2       3       4       5       6       7       8
```



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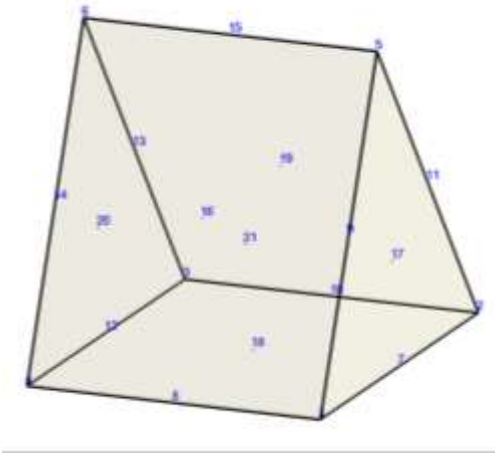
21-node & 15-node element

21-node Pentahedron

```
*SECTION_SOLID
$---+----1----+----2----+----3----+----4
$#    SECID     ELFORM        AET
          1         25
```

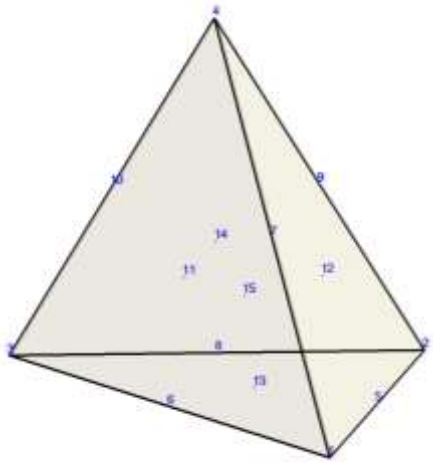


*ELEMENT_SOLID_P21

1	1	0							
1	2	3	4	5	6	7	7	9	10
11	12	13	14	15	16	17	18	19	20
21									

15-node Tetrahedral

```
*SECTION_SOLID
$---+----1----+----2----+----3----+----4
$#    SECID     ELFORM        AET
          1         26
```



*ELEMENT_SOLID_T15

1	1	0							
1	2	3	4	5	6	7	7	9	10
11	12	13	14	15					

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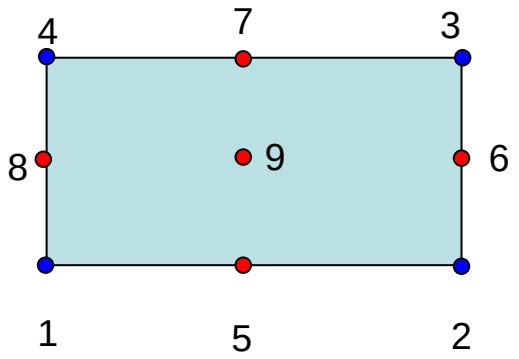
BC's for newly added node

- If BC's of existing node is defined with *NODE

```
*ELEMENT_SOLID_H8TOH27
$#    eid     pid      n1      n2      n3      n4      n5      n6      n7      n8
        1       1       1       2       3       4       5       6       7       8
....
*NODE
$#    nid               x               y               z      tc      rc
        1     94.82546997     1.24142838           400.0       7       0
        2     98.82546997     1.24142838           400.0       4       0
        3     98.82546997     3.24142838           400.0       6       0
        4     94.82546997     3.24142838           400.0       5       0
```

- BC's for newly added node

```
*NODE
$#    nid    constrained x    constrained y    constrained z
        1                1                1                1
        2                1                1                0
        3                1                0                1
        4                0                1                1
        5                1                1                0
        6                1                0                0
        7                0                0                1
        8                0                1                1
        9                0                0                0
```



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BC's for newly added node

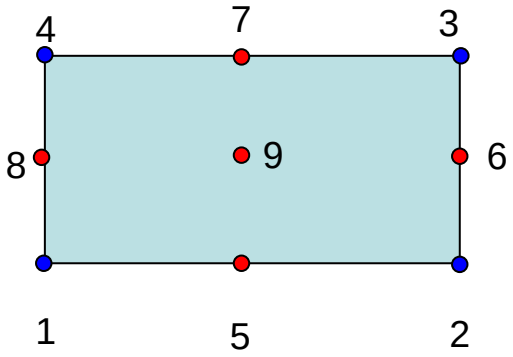
- If BC's of existing node is defined with node set

```
*SET_NODE_LIST
$#
       1
       1       2       3
*SET_NODE_LIST
$#
       2
       1       3       4
*SET_NODE_LIST
$#
       3
       1       2       3       4
```

```
*BOUNDARY_SPC_SET
$#   nsid      cid     dofx     dofy     dofz
       1                1        0        0
*BOUNDARY_SPC_SET
$#   nsid      cid     dofx     dofy     dofz
       2                0        1        0
*BOUNDARY_SPC_SET
$#   nsid      cid     dofx     dofy     dofz
       3                0        0        1
```

- BC's for newly added node

```
*NODE
$#    nid     constrained x    constrained y     constrained z
       1                  1                1                 1
       2                  1                0                 1
       3                  1                1                 1
       4                  0                1                 1
       5                  1                0                 1
       6                  1                0                 1
       7                  0                1                 1
       8                  0                1                 1
       9                  0                0                 1
```



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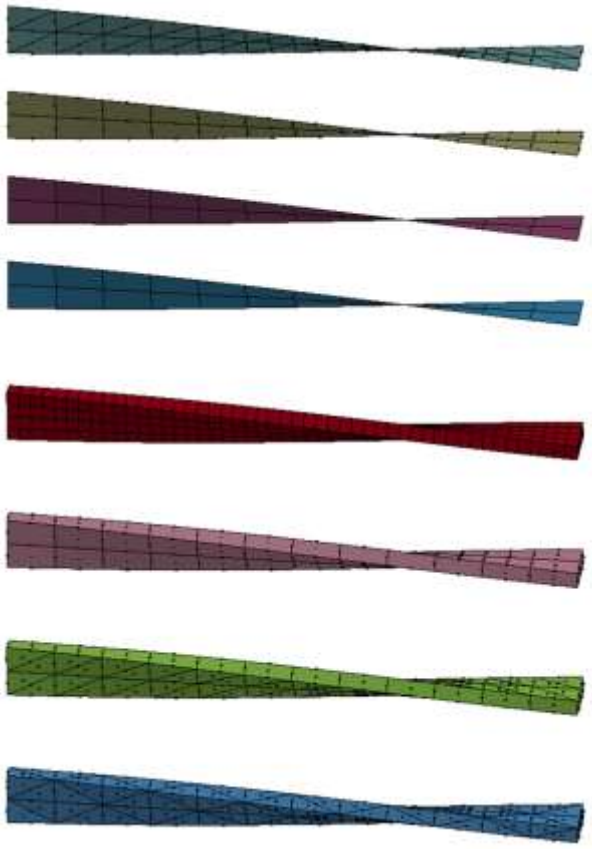
Model Description

- To test the effect of wrap

- The straight beam is discretized by 12x2 elements
- Length=12.0; width=1.1;depth=0.32; twist=90^{o};
- One end is clamped, with unit forces at tip: extension, in-plane shear, and out-of-plane shear loading
- This problem is modeled with shell formulation 2,16,23, and 24 as well as solid formulation 2,24,25,and 26



MacNeal, R. H. et al.," Proposed Standard Set of Problemsto Test Finite Element Accuracy", *Finite Elements in Analysis and Design*, 1985'

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Model Description

E-Type	In-plane	Out of plane
Shell Elform 2	5.80708E-3(7.06%)	1.81453E-3(3.45%)
Shell Elform16	5.74599E-3(5.94%)	1.85316E-3(5.65%)
Shell Elform23	5.41806E-3(0.11%)	1.71941E-3(1.97%)
Shell Elform24	6.43572E-3(18.65%)	2.09962E-3(19.71%)
Solid Elform 2	7.52991E-3(38.83%)	2.48888E-3(41.89%)
Solid Elform24	5.42513E-3(0.02%)	1.72386E-3(1.72%)
Solid Elform25	5.34353E-3(1.48%)	1.69729E-3(3.23%)
Solid Elform26	5.39546E-3(0.53%)	1.71724E-3(2.10%)

Exact static solution:

In-plane shear=0.005424

Out-of-plane shear=0.001754

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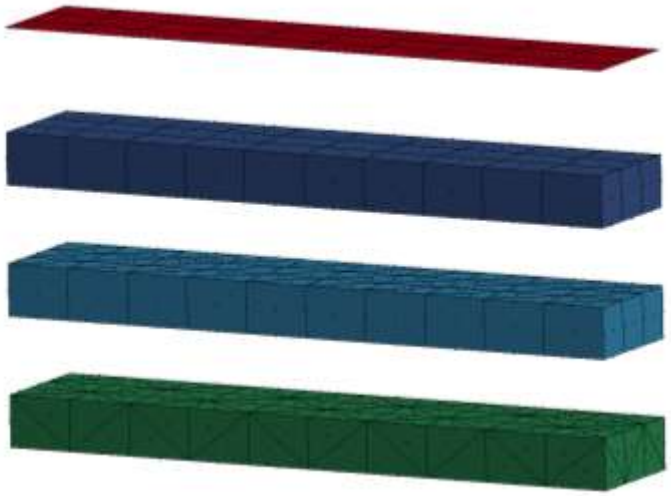
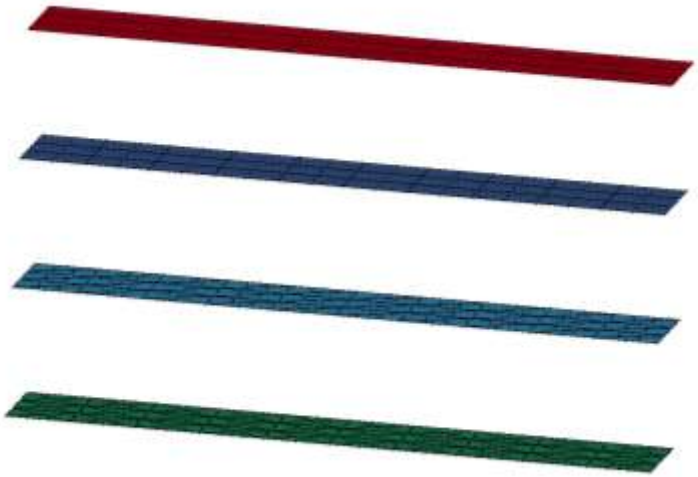
Model Description

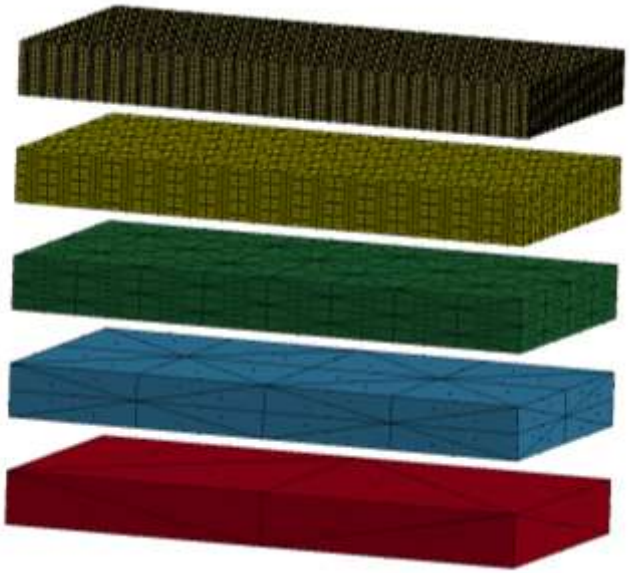




Thickness/ Aspect ratio	8.E-2 /1.25	8.E-3 /12.5	8.E-4 /125	8.E-4 /250
SHELL	7.47E-4	7.42E-4	7.42E-4	7.42E-4
Elform24	7.46E-4(0.22%)	7.32E-4(1.41%)	7.29E-4(1.75%)	7.27E-4(1.77%)
Elform25	7.44E-4(0.37%)	7.27E-4(1.98%)	7.12E-4(4.05%)	7.12E-4(4.19%)
Elform26	7.44E-4(0.43%)	7.05E-4(5.07%)	6.82E-4(8.16%)	6.82E-4(8.17%)

Implicit elastic bending

- Clamped plate of dimensions 10x5x1 mm
- Subjected to 1Nm torque at the free end
- E=210 Gpa
- Analytical solution for end tip deflection:0.57143mm
- Convergence study with aspect ratio 5:1 kept constant



Discretization	Elform 2*	Elform -2*	**Elform 26**	Elform 24
2x1x1	0.0564(90.1%)	0.6711(17.4%)	**0.5266(7.8%)**	0.5525(3.3%)
4x2x2	0.1699(70.3%)	0.5466(4.3%)	**0.5441(4.8%)**	0.5534((3.1%)
8x4x4	0.3469(39.3%)	0.5472(4.2%)	**0.5512(3.5%)**	0.5541(3.0%)
16x8x8	0.4820(15.7%)	0.5516(3.5%)	**0.5536(3.2%)**	0.5543(3.0%)
32x16x16	0.5340(6.6%)	0.5535(3.1%)	**0.5540(3.0%)**	0.5545(3.0%)

End tip deflection for different mesh discretization and element types, error in parenthesis.

*From *Review of Solid Element formulations in LS-DYNA*, toibas.erhart@dynamore.se

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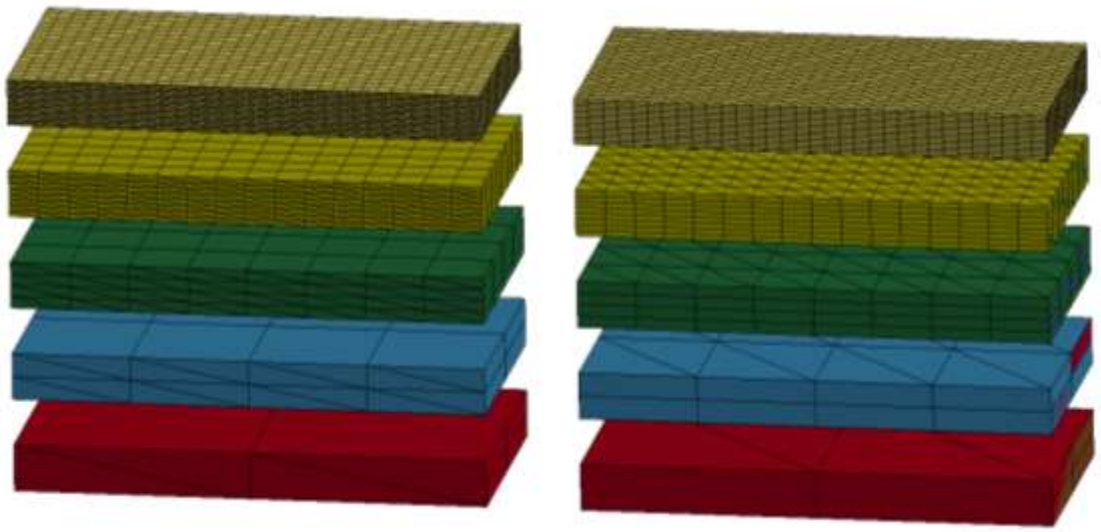
Implicit elastic bending: 21-node Tet Element



Discretization	**Elform 25[1]**	**Elform 25[2]**	Elform 26	Elform 24
2x1x1	**0.5433(4.9%)**	**0.5454(4.5%)**	0.5266(7.8%)	0.5525(3.3%)
4x2x2	**0.5484 (4.0%)**	**0.5499(3.8%)**	0.5441(4.8%)	0.5534((3.1%)
8x4x4	**0.5518(3.4%)**	**0.5528(3.3%)**	0.5512(3.5%)	0.5541(3.0%)
16x8x8	**0.5533(3.2%)**	**0.5539(3.1%)**	0.5536(3.2%)	0.5543(3.0%)
32x16x16	**0.5540(3.0%)**	**0.5542(3.0%)**	0.5540(3.0%)	0.5545(3.0%)

End tip deflection for different mesh discretization and element types, error in parenthesis.

*From *Review of Solid Element formulations in LS-DYNA*, toibas.erhart@dynamore.se

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Model Description

- A quarter model of a Taylor bar impacting a rigid wall.
- Impacting velocity 227m/s
- The Taylor bar is used in experiments to determine strain rate effects in metals.
- Elements at the bottom of the bar get highly deformed

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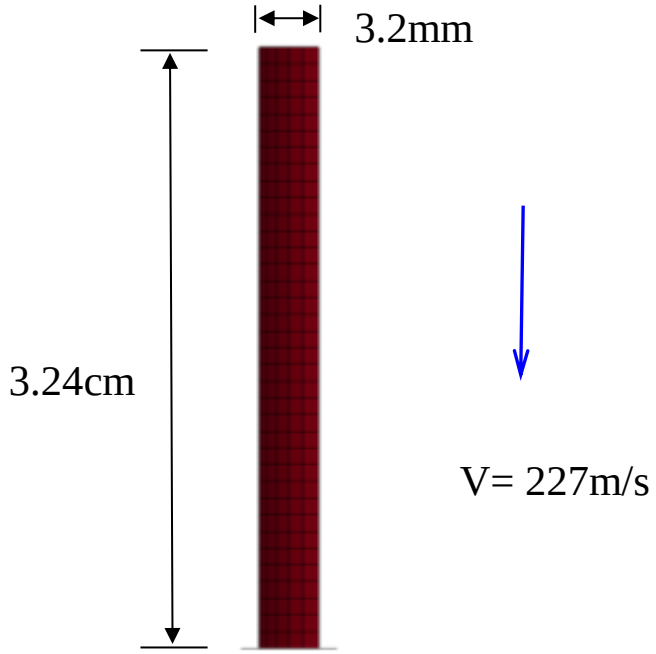
Model Description



Young's Modulus	1.17E11
Poisson's Ratio	0.33
Tangent Modulus	1.0E8
Yiield Stress	4.0E8
Density	8930

Material Properties: SI units

Wilkins, ML et al.," Impact of cylinders on a rigid boundary", *Journal of Applied Physics*, 1973

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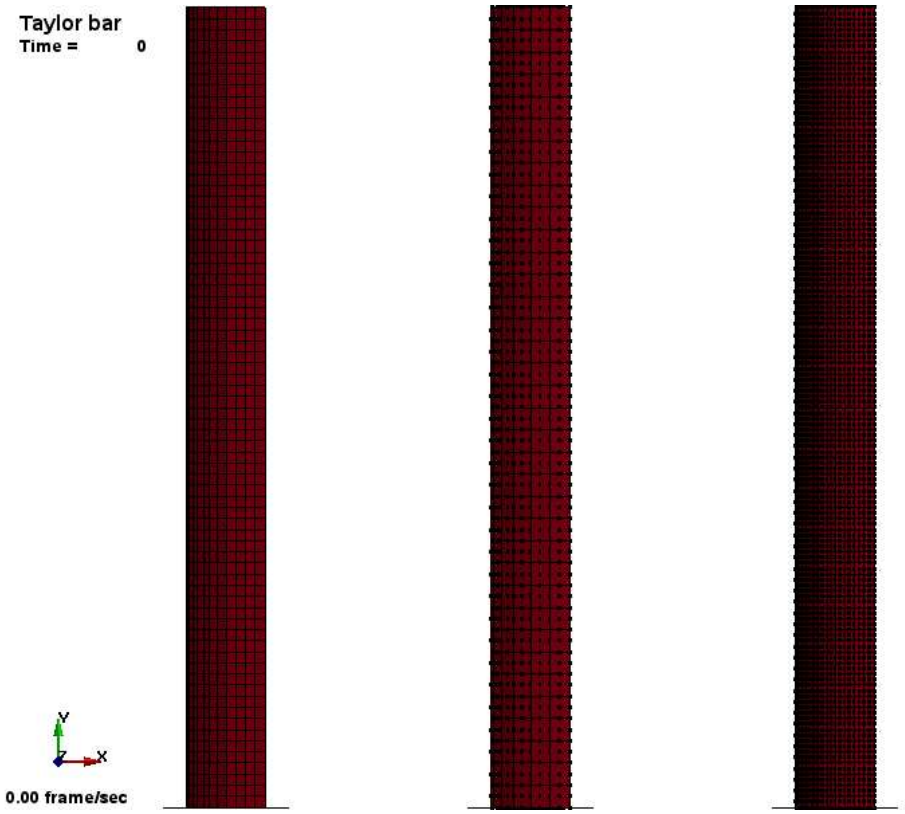
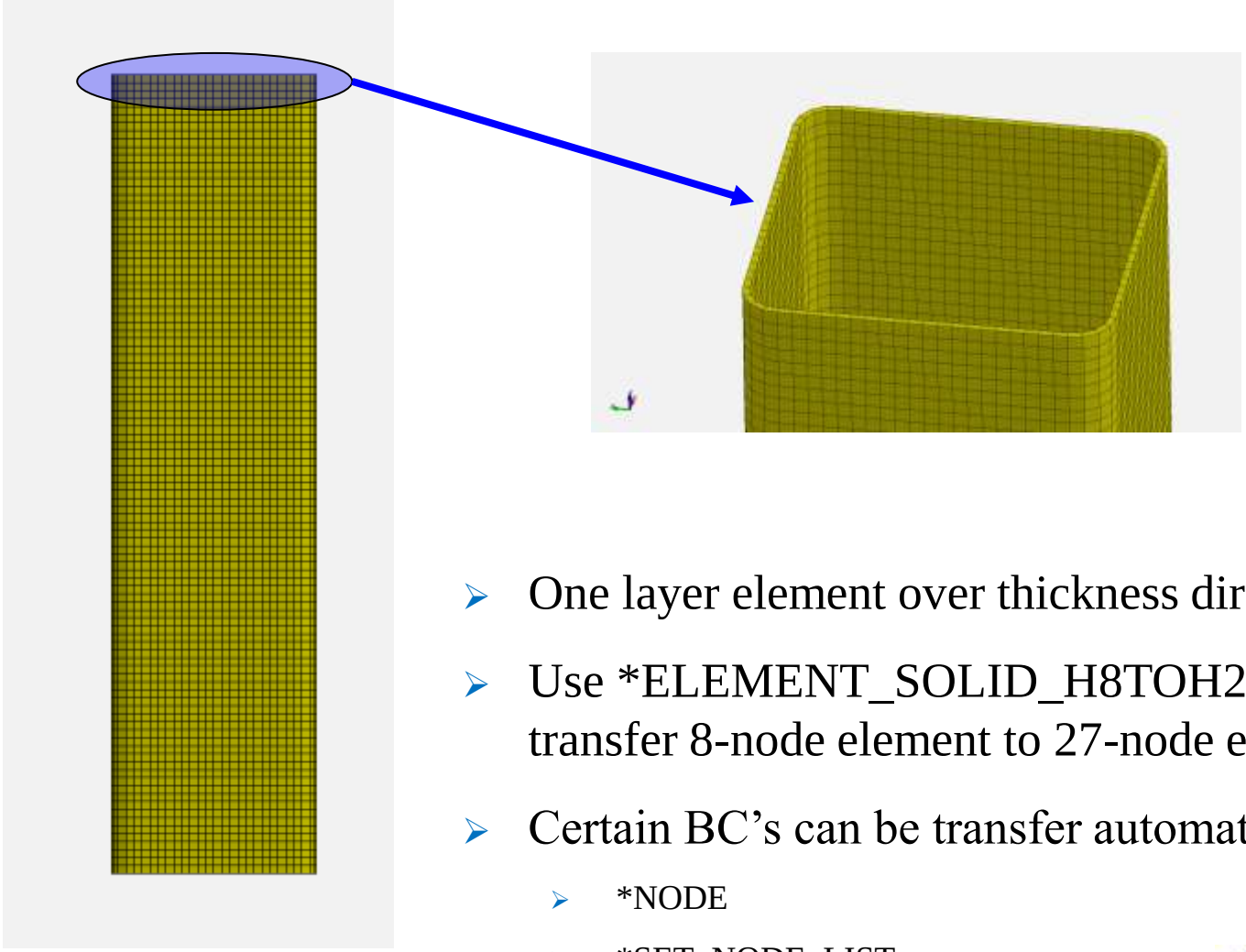
Deformed Model



Elform2: fine Elform24: coarse Elform24:fine

Elform2 fine	27 node coarse	27 node fine
1	1.0	20



- One layer element over thickness direction
- Use *ELEMENT_SOLID_H8TOH27 automatically transfer 8-node element to 27-node element
- Certain BC’s can be transfer automatically
  - *NODE
  - *SET_NODE_LIST

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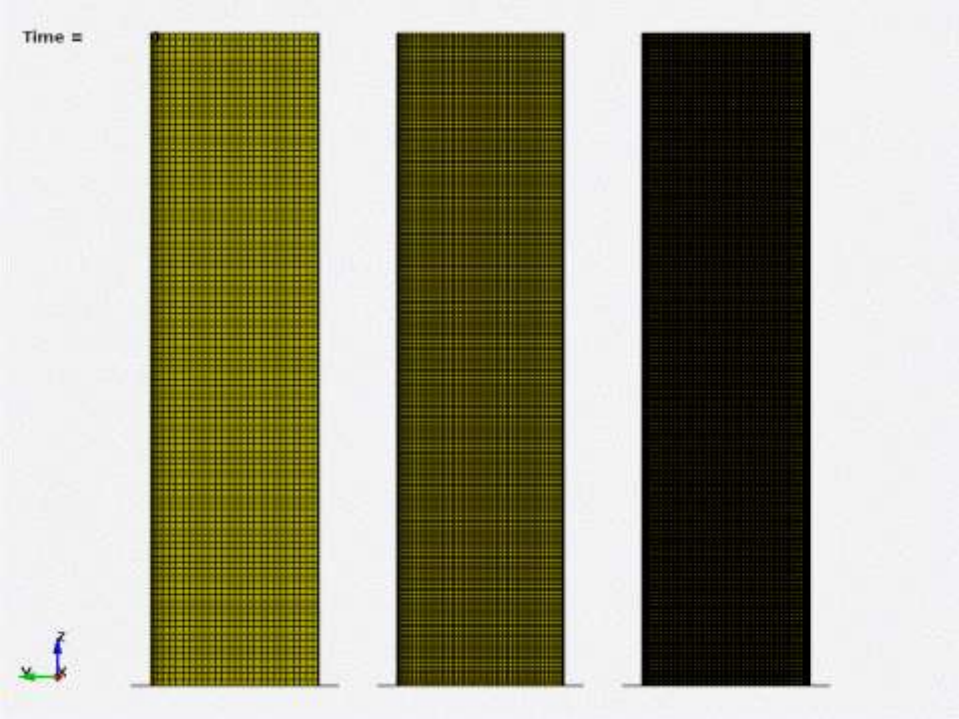
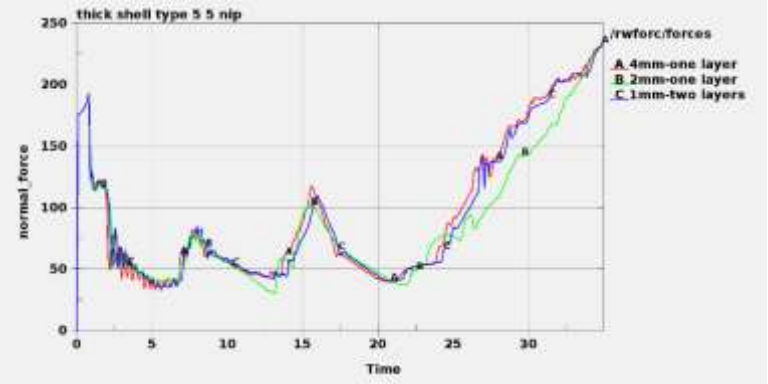
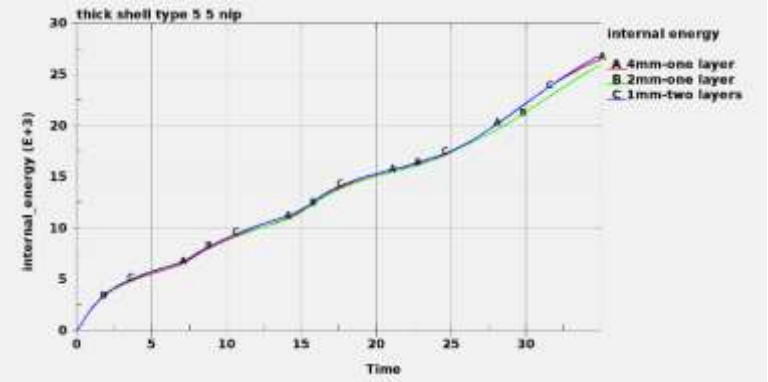


4mm 2mm 1mm



Contact Force



Internal energy

Relative coarse mesh can get converged results

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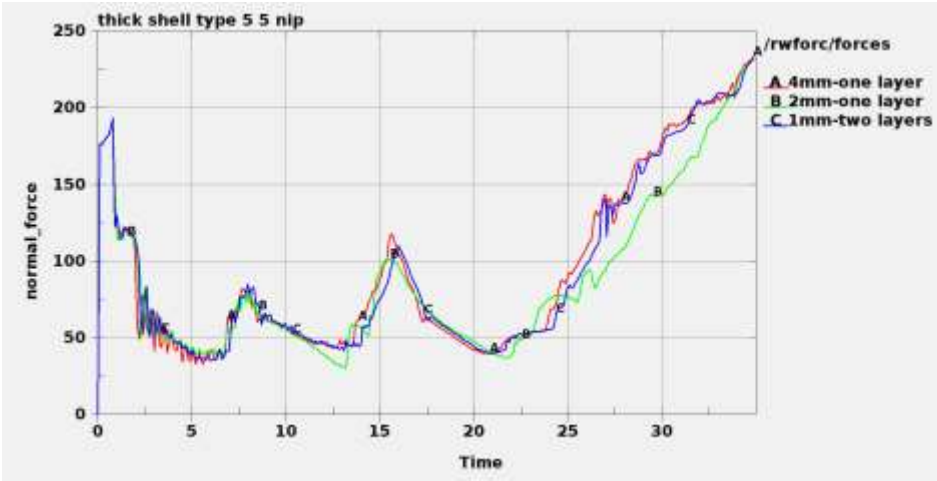
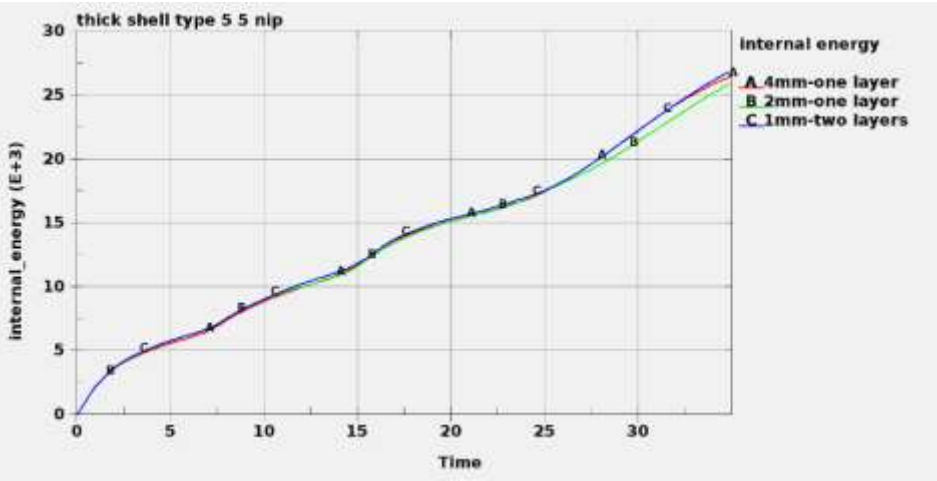
Result





Contact Force

Internal energy

- Relative coarse mesh can get converged results

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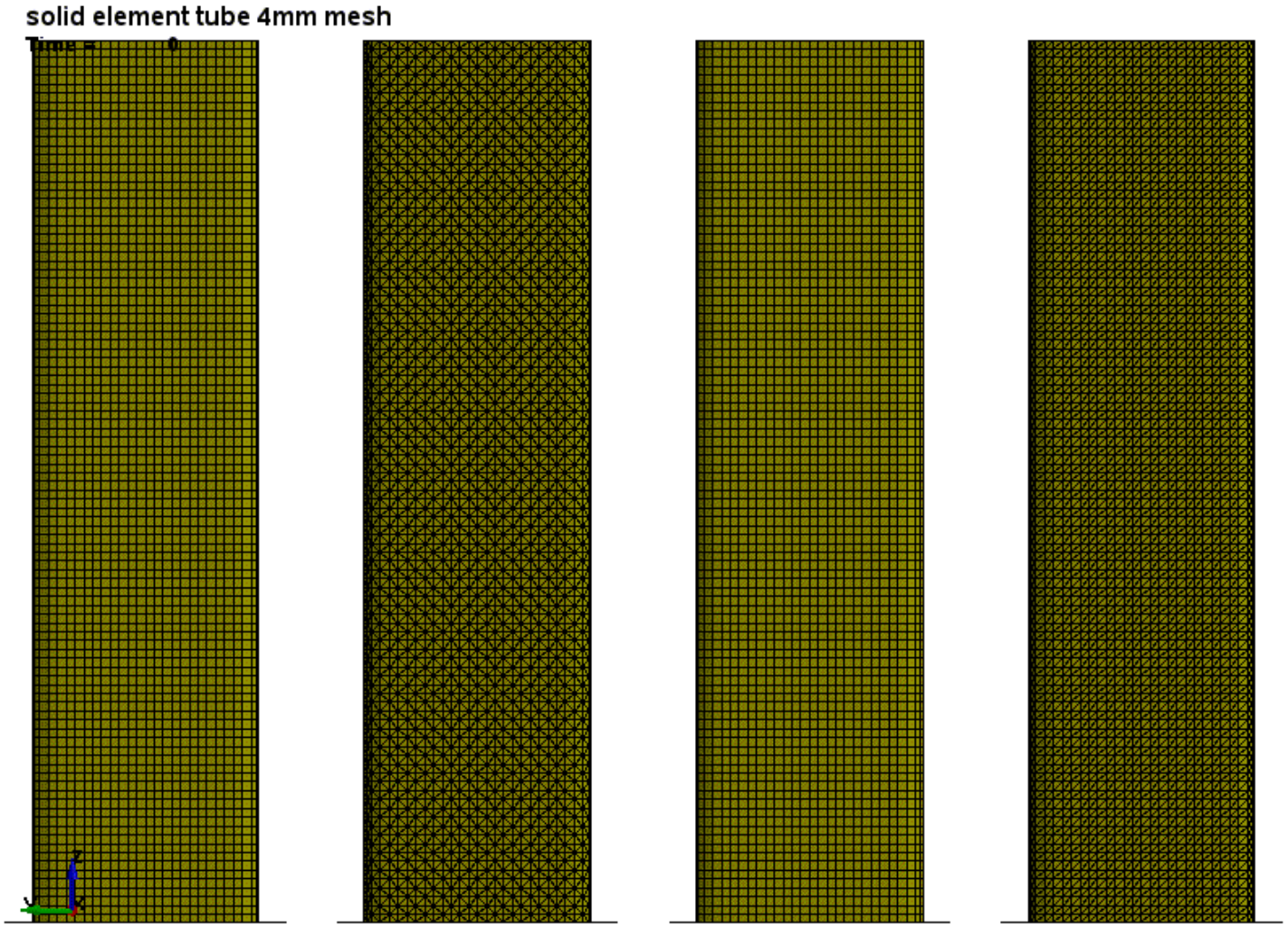

Hexahedron *Tetrahedral* *Pentahedron* *Pentahedron*

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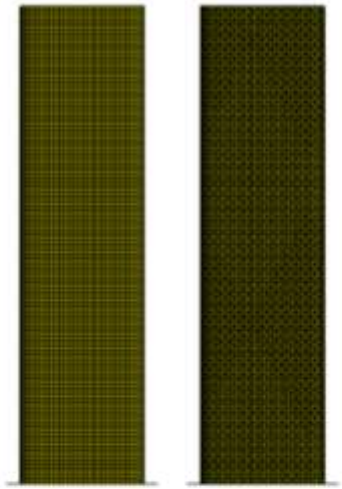

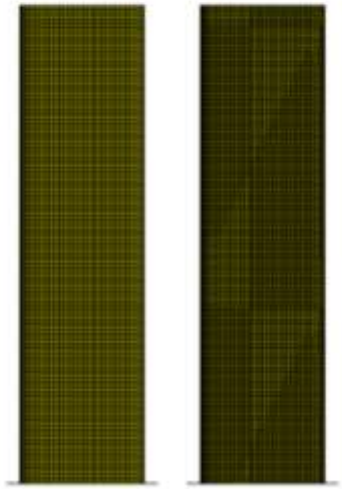

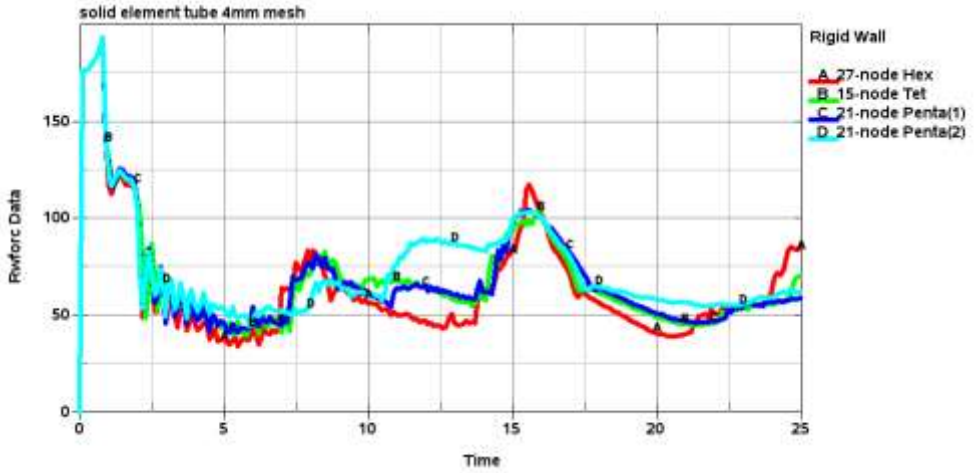

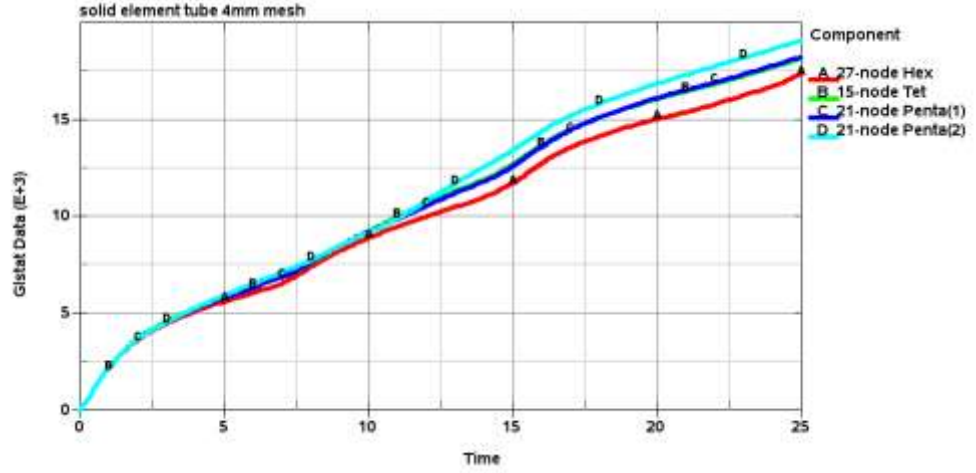

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Summary

- Accurate for large deformation, severe distortion
- Non-uniform row summation mass lumping
- Selective reduced integration to alleviate volumetric locking
- No hourglass stabilization needed
- Excellent behavior in bending, one element is used over plate thickness
- The corresponding Tet and Wedge element are 15-node and 21-node element
- If the structure undergoes significant bending, the structure should be modeled with higher-order elements, 27-node brick elements or 64-node element

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