About
New Solid Element Types
and a
New Contact Method
in LS-DYNA 971 R4/R5

Infoday "New Methodologies and Developments in LS-DYNA"

Stuttgart, November 24, 2010

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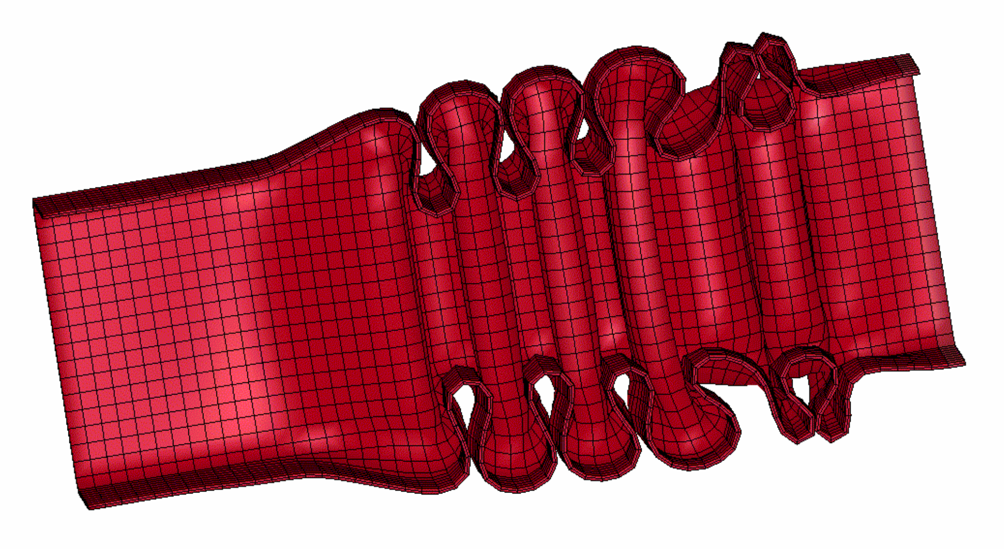
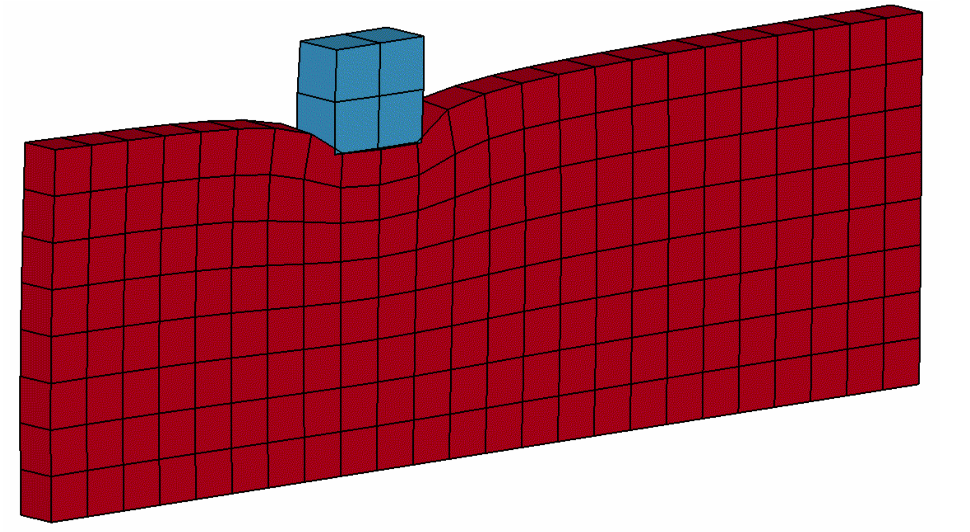
Outline

- **New solid element types**
  - ➡ **Thin walled structures**



- **New contact formulation**
  - ➡ **Implicit analysis**



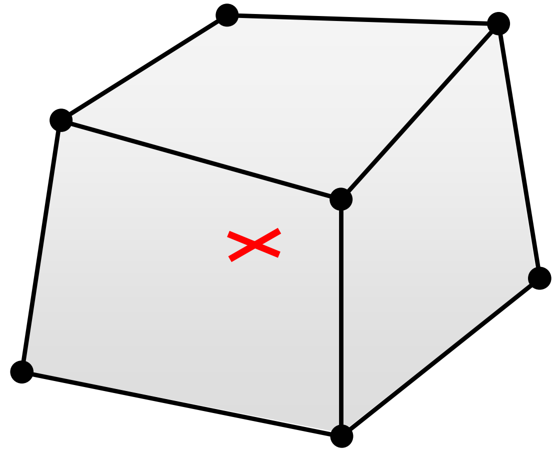
New solid element types -1 and -2

- variants of fully integrated solid type 2
- reduced transverse shear locking
- for hexahedral elements with poor aspect ratio
- available since 971 R4.2.1

Hexahedra element types in LS-DYNA

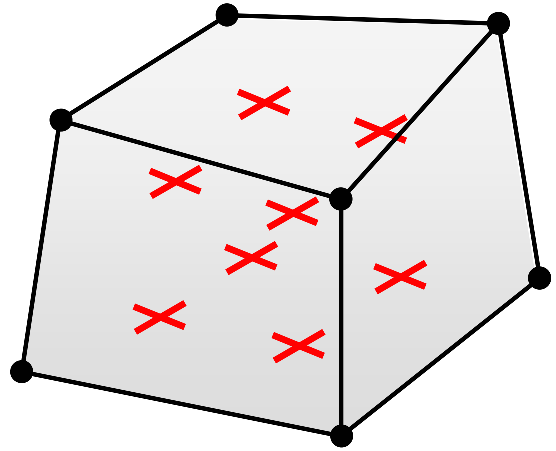
ELFORM = 1

- underintegrated constant stress
- needs hourglass stabilization
- efficient and accurate
- choice of hourglass formulation and values remains an issue



ELFORM = 2

- fully integrated brick element
- no hourglass stabilization needed
- slower
- too stiff in many situations, especially for poor aspect ratios (shear locking)

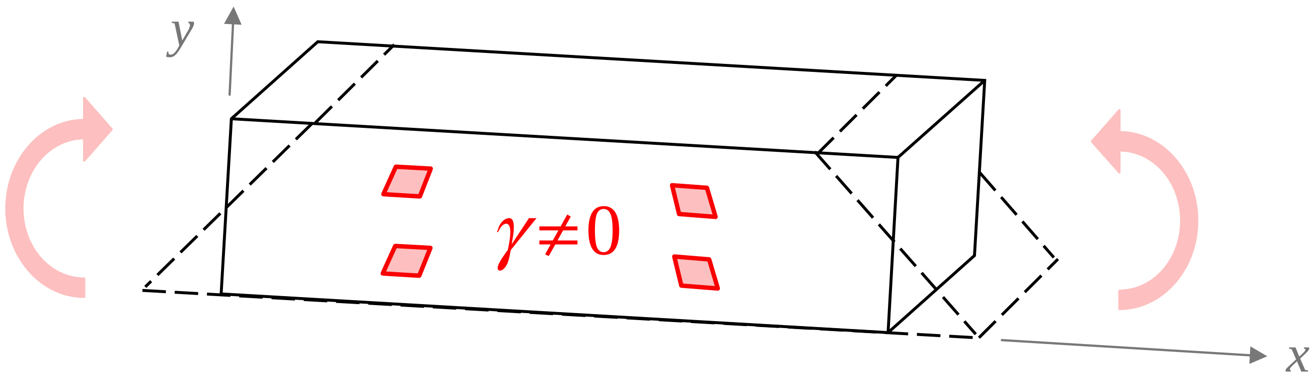


ELFORM = 3 ...

Hexahedra element types in LS-DYNA

SHEAR LOCKING

- pure bending modes trigger spurious shear energy
- getting worse for poor aspect ratios



$$\varepsilon_{xx} = 2\xi_y / l_x,\ \varepsilon_{yy} = 0,\ \gamma_{xy} = \xi_x / l_y$$

- **Alleviation possibility 1:** under-integration → ELFORM = 1
- **Alleviation possibility 2:** enhanced strain formulations/ modified Jacobian matrix

$$\Rightarrow \quad \varepsilon_{xx} = 2\xi_y / l_x,\ \varepsilon_{yy} = 0,\ \gamma_{xy} = \ldots = \xi_x / l_x \quad \Rightarrow$$

ELFORM = -1 / -2

Solid element types -1 and -2

NEW: ELFORM = -1 / -2

- Thomas Borrvall: "*A heuristic attempt to reduce transverse shear locking in fully integrated hexahedra with poor aspect ratio*", Salzburg 2009

- Modification of the Jacobian matrix: reduction of spurious stiffness without affecting the true physical behavior of the element

$$J_{ij}^{\text{orig}} = \frac{\partial x_i}{\partial \xi_j} = x_{Ii} \frac{1}{8}\left(\xi_j^I + \xi_{jk}^I \xi_k + \xi_{jl}^I \xi_l + \xi_{123}^I \xi_k \xi_l \right)$$

aspect ratios between dimensions

$$J_{ij}^{\text{mod}} = x_{Ii} \frac{1}{8}\left(\xi_j^I + \xi_{jk}^I \xi_k \kappa_{jk} + \xi_{jl}^I \xi_l \kappa_{jl} + \xi_{123}^I \xi_k \kappa_{jk} \xi_l \kappa_{jl} \right)$$

- **Type -2:** accurate formulation, but higher computational cost in explicit

- **Type -1:** efficient formulation

- CPU cost compared to type 2: ~1.2 (type -1), ~4 (type -2)

Solid element types -1 and -2

EXAMPLE 1: Implicit elastic bending

- clamped plate of dimensions 10x5x1 mm^3
- subjected to 1 Nm torque at the free end
- E = 210 GPa
- analytical solution for end tip deflection:
  0.57143 mm
- convergence study
  with aspect ratio 5:1 kept constant

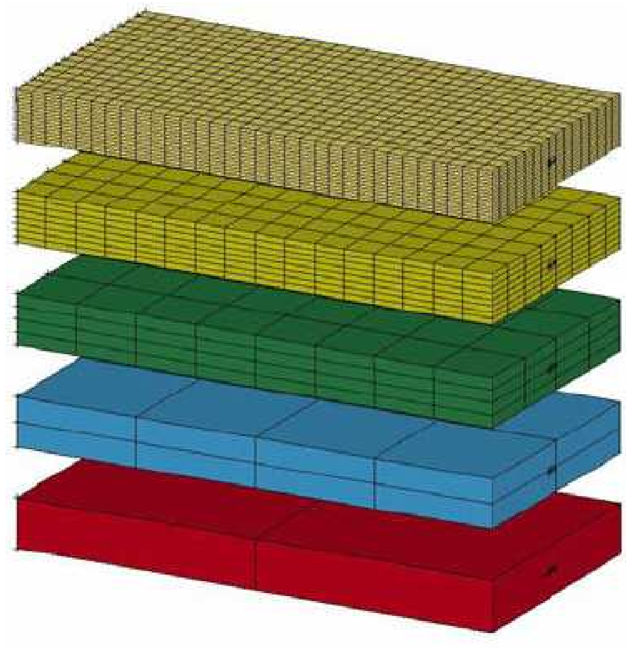


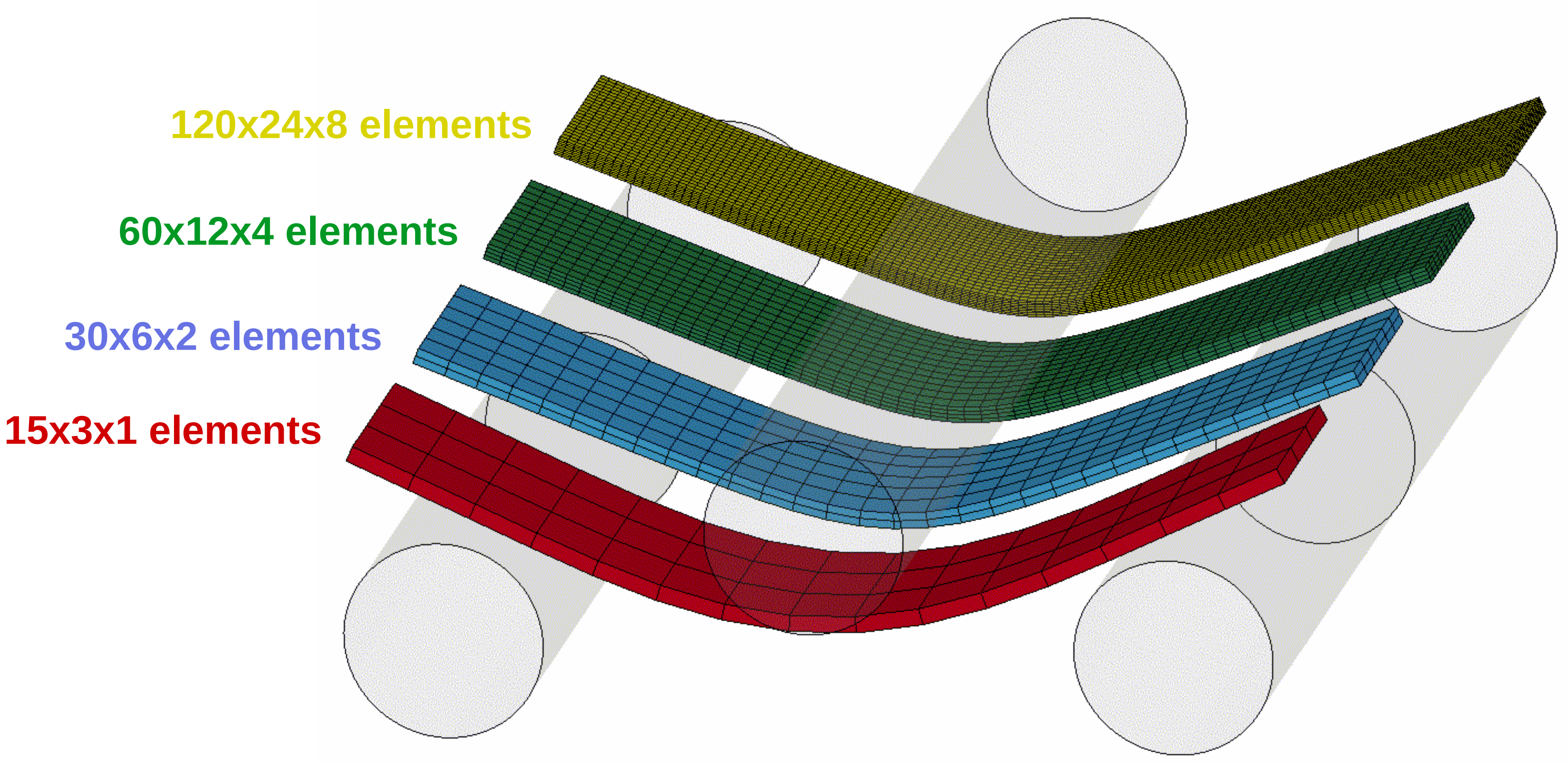
Table 1 End tip deflection for different mesh discretizations and element types, error in parenthesis.

Discretization	Solid element type 2	Solid element type -2	Solid element type -1
2x1x1	0.0564 (90.1%)	0.6711 (17.4%)	0.6751 (18.1%)
4x2x2	0.1699 (70.3%)	0.5466 (4.3%)	0.5522 (3.4%)
8x4x4	0.3469 (39.3%)	0.5472 (4.2%)	0.5500 (3.8%)
16x8x8	0.4820 (15.7%)	0.5516 (3.5%)	0.5527 (3.3%)
32x16x16	0.5340 (6.6%)	0.5535 (3.1%)	0.5540 (3.1%)

Solid element types -1 and -2

EXAMPLE 2: Plastic bending

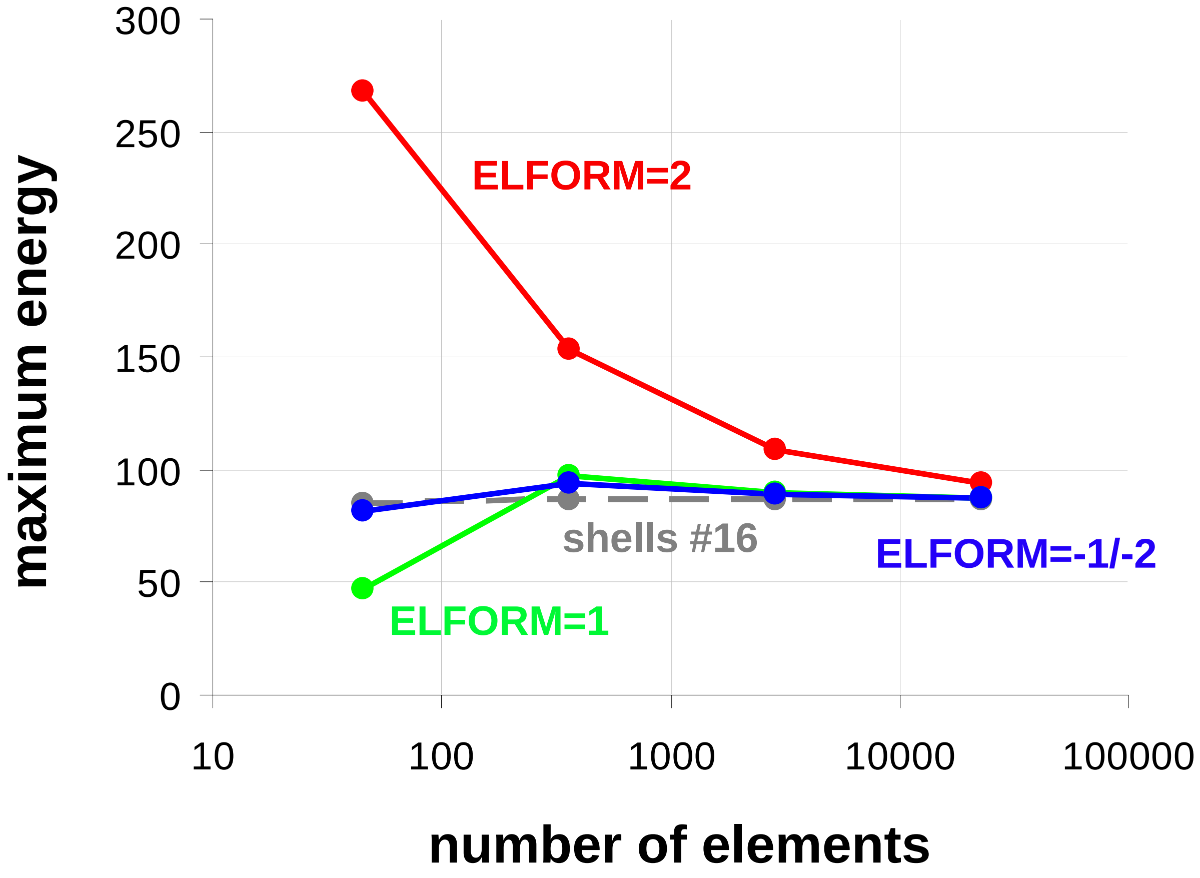
- Explicit plastic 3 point bending (prescribed motion)
- plate of dimensions 300x60x5 mm^3
- *MAT_024 (aluminum)
- convergence study - aspect ratio 4:1 kept constant



Solid element types -1 and -2

EXAMPLE 2: results

- maximum energy (internal + hourglass)



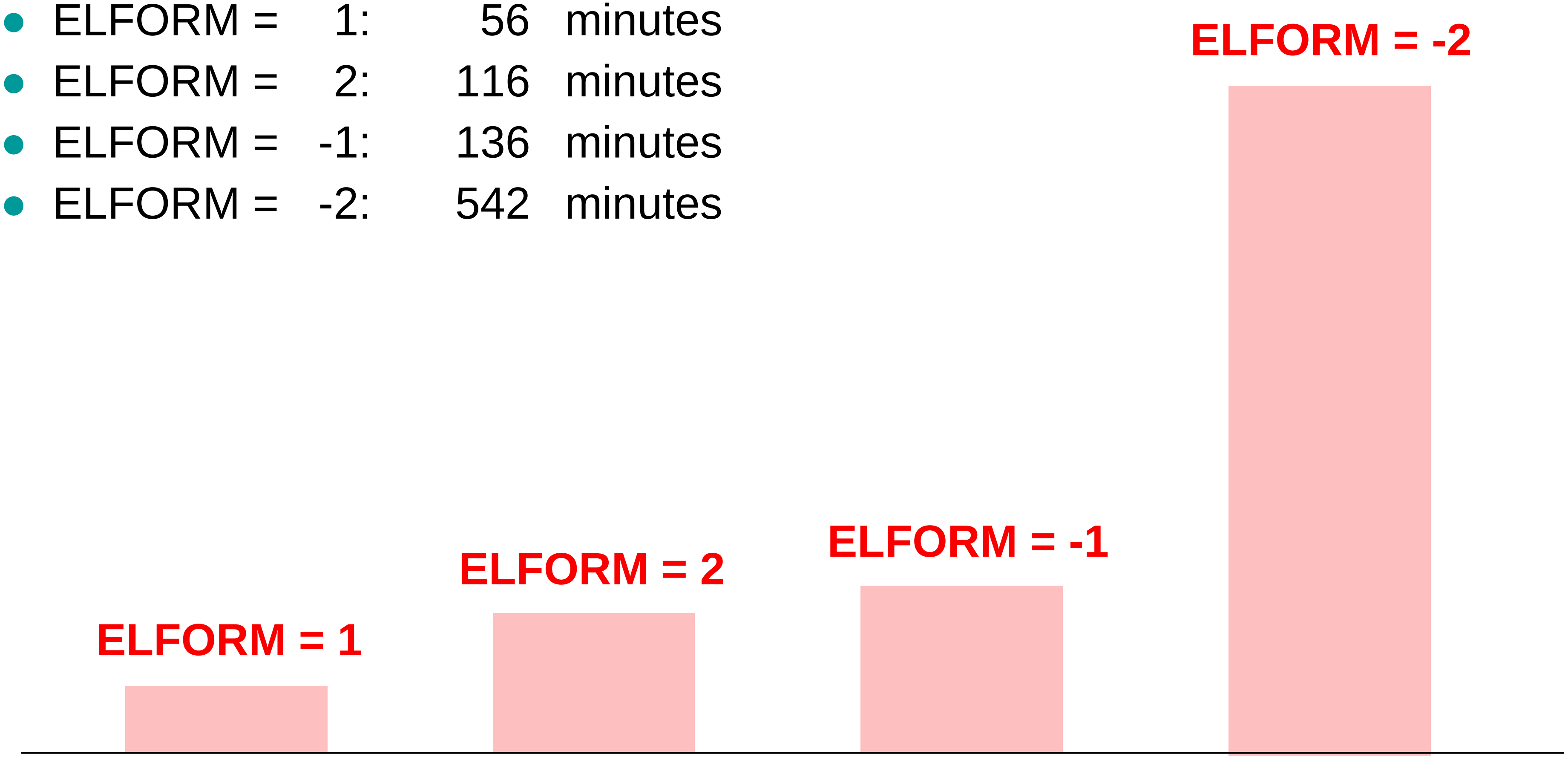
bad convergence of type 2 (stiff behavior)

good convergence with types 1, -1, -2

Solid element types -1 and -2

EXAMPLE 2: CPU times

- ELFORM = 1: 56 minutes
- ELFORM = 2: 116 minutes
- ELFORM = -1: 136 minutes
- ELFORM = -2: 542 minutes

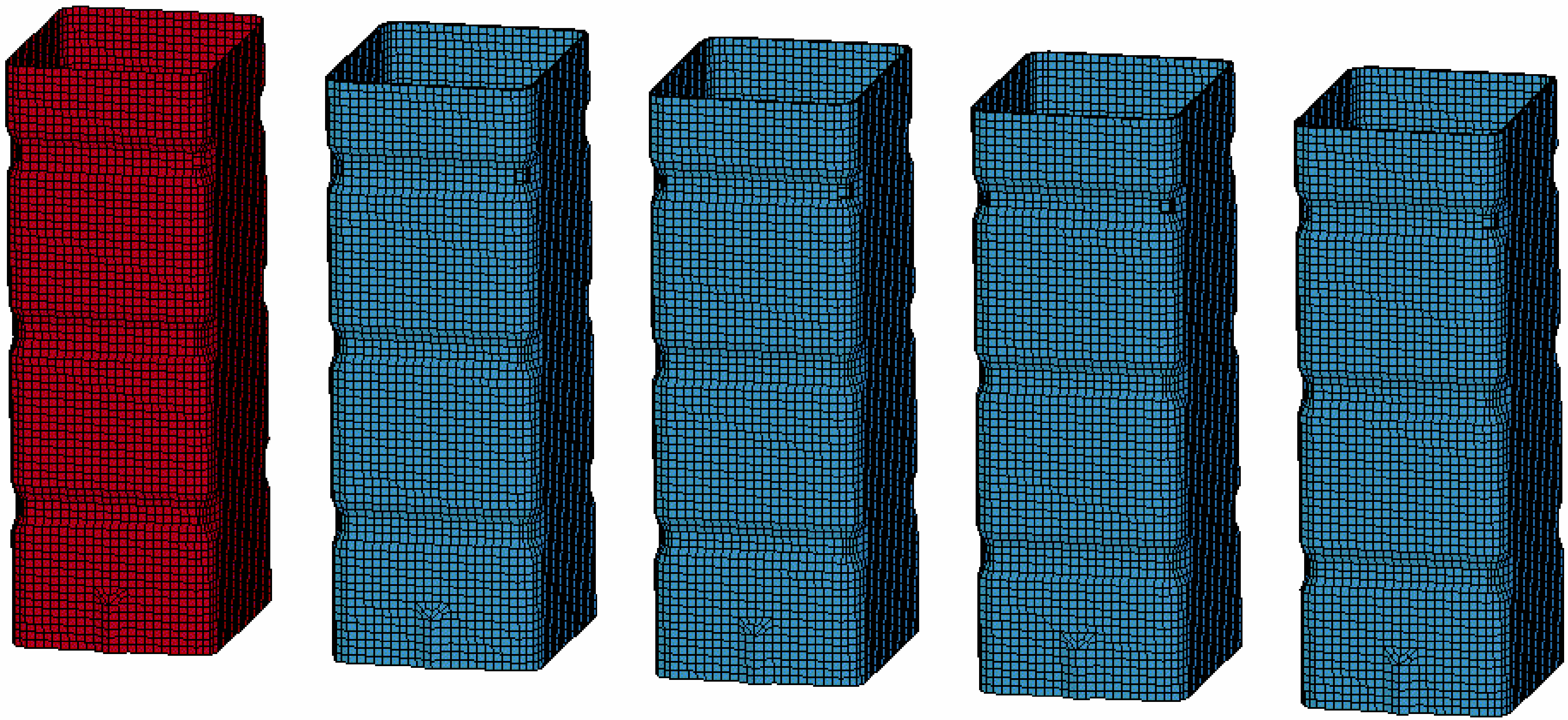


ELFORM = -2 not efficient, ELFORM = -1 comparable to 2

Solid element types -1 and -2

EXAMPLE 3: Tube crash problem

element size: 3.5 mm
thickness: 2 mm



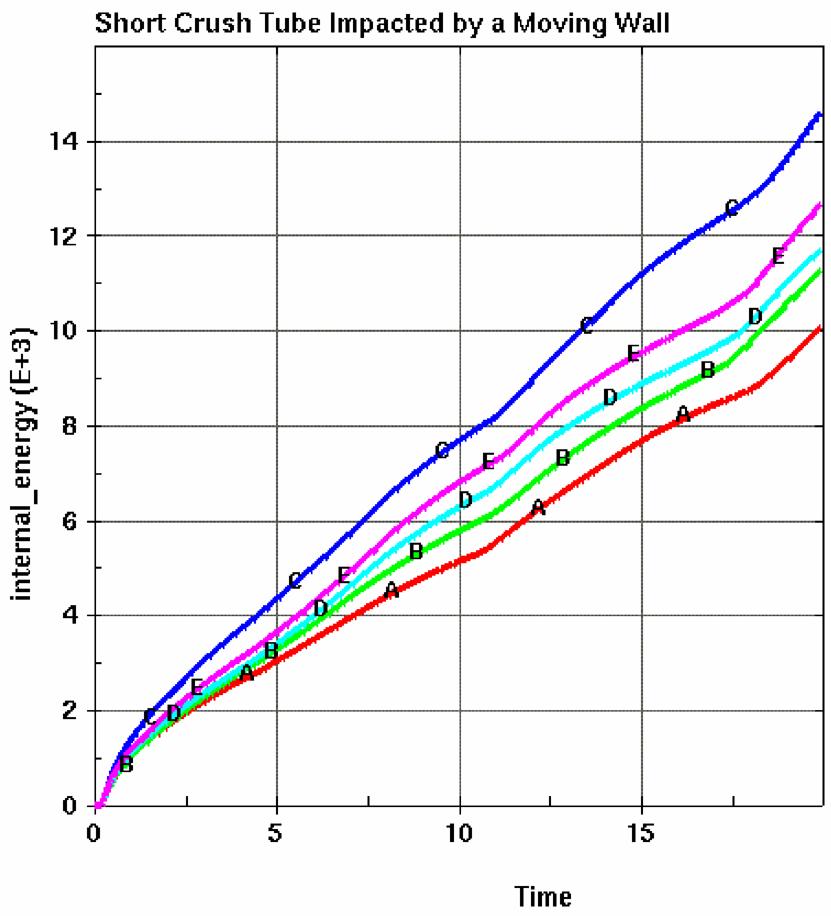
shells type 16	solids type 1 (t_{CPU}=1.0)	solids type 2 (t_{CPU}=5.5)	solids type -1 (t_{CPU}=5.2)	solids type -2 (t_{CPU}=8.3)

Solid element types -1 and -2

EXAMPLE 3: Tube crash problem

contact force

internal energy



Solid element types -1 and -2

CONCLUSIONS

- two new alternatives to solid element type 2: ELFORM = -1 / -2
- well suited for thin walled structures
- convergence behavior of -1 / -2 much better than 2
- accuracy of -1 and -2 is nearly equal
- efficiency of -1 is much better

➡ **for fully integrated brick elements with poor aspect ratio, use ELFORM = -1 instead of ELFORM = 2 !**

```
*SECTION_SOLID
$     secid    elform
$         1         2
          1        -1
```

Mortar contact

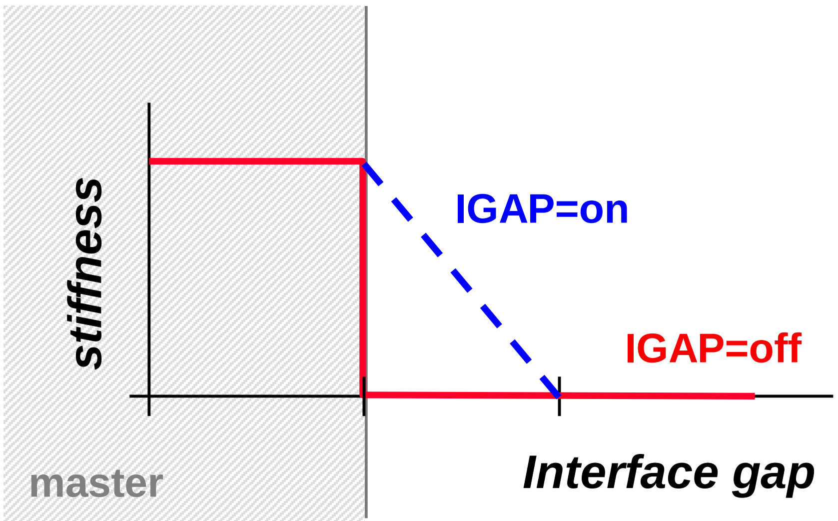
- segment-to-segment penalty based contact
- smooth properties: robust and accurate
- intended for implicit, but also available for explicit
- available since 971 R5.0

Contact mechanics

Standard contact algorithms in LS-DYNA

- penalty based, double sided node-to-surface contacts
- in implicit, nodes tend to oscillate in and out of the contact
- often leads to convergence problems
- stiffness smoothing (IGAP=on) can help but accuracy suffers

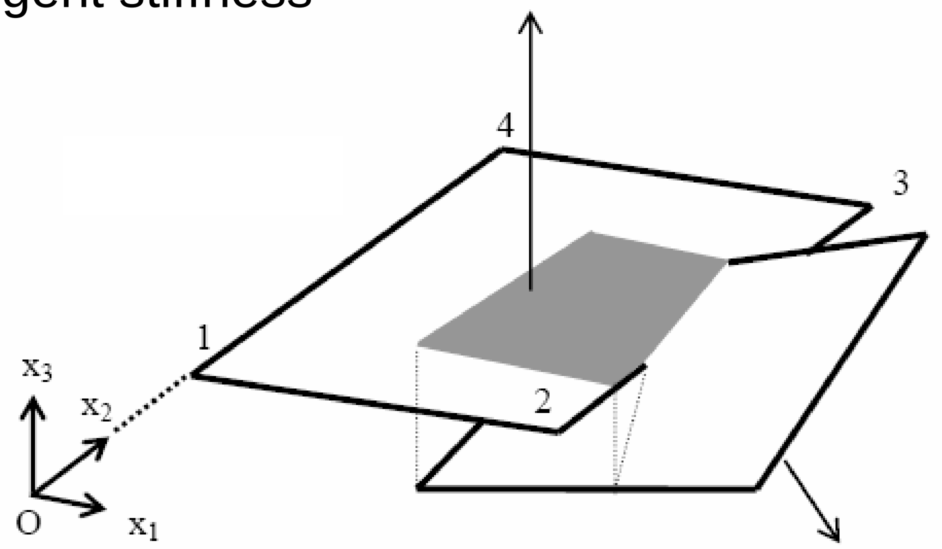
The IGAP option can significantly improve the convergence behavior but can also produce a "sticky" contact, that will resist opening of the contact gap



Contact mechanics

New method: segment-to-segment MORTAR contact

- penalty based segment-to-segment contact
- contact tractions are proportional to both the penetration and the overlapped area of segments in contact
- continuous transition of forces when a slave segment slides across adjacent master segments
- weak satisfaction of the contact conditions
- well suited for implicit: continuous tangent stiffness



Mortar contact

Available contact types (971 R5.0)

- append optional suffix to contact keyword: *CONTACT_..._MORTAR
- *CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR
- *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR
- *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_TIED
- *CONTACT_FORMING_SURFACE_TO_SURFACE_MORTAR
- SMP and MPP

Promising performance ...

... but further testing is needed (new method)

Reference

T. Borrvall: "Mortar contact algorithm for implicit stamping analyses
in LS-DYNA", Proc. 10th International LS-DYNA Users Conference, 2008.

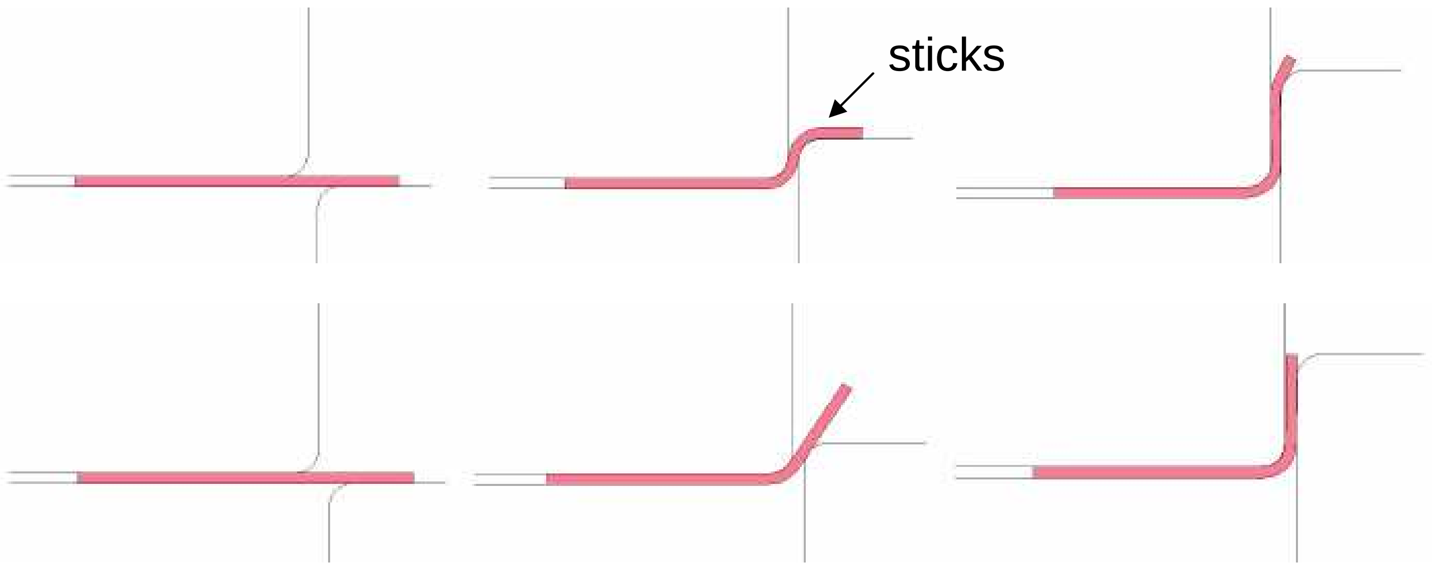
Mortar contact: example 1

Flanging problem: IGAP method vs. mortar contact

- Standard contact + IGAP=off: accurate, but difficult convergence
- Standard contact + IGAP=on: improved convergence, but loss of accuracy
- mortar contact: accurate and good convergence behavior

IGAP=on:

IGAP=off and Mortar:



Normalized CPU times

IGAP=on: **1.0**, IGAP=off: **5.7**, Mortar: **1.6**

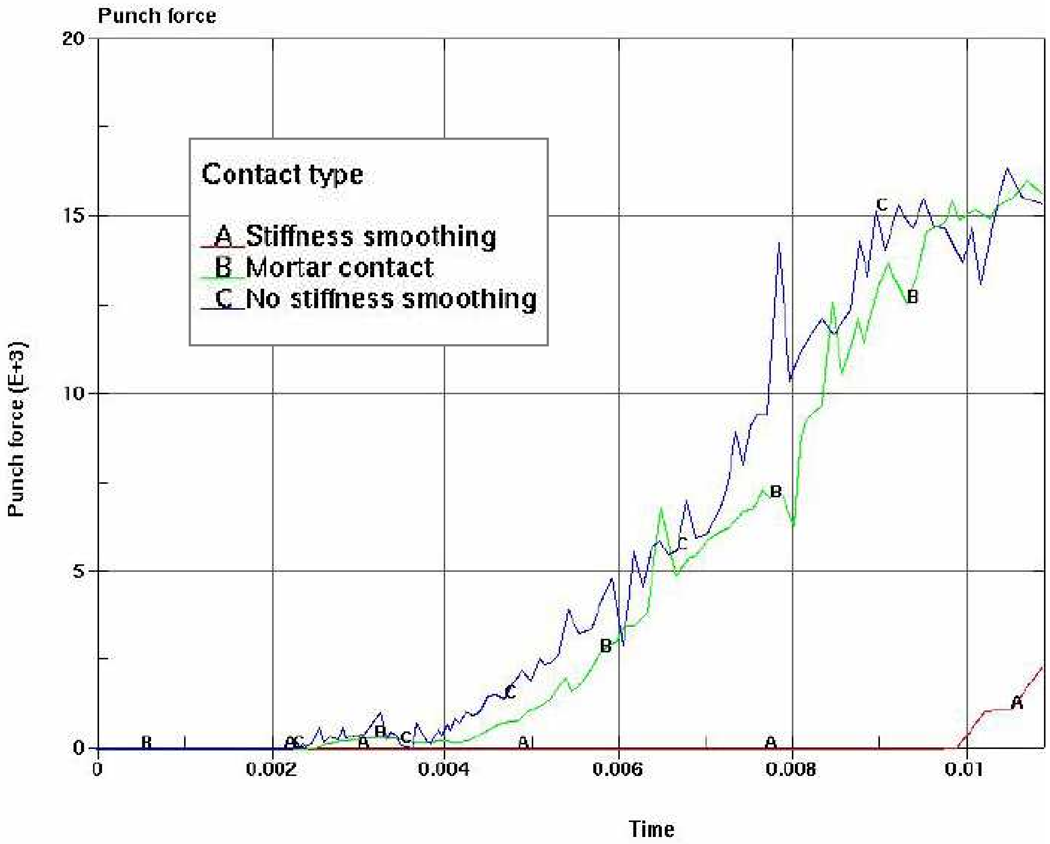
Mortar contact: example 2

Forming problem: Circular blank, spherical punch

IGAP=on

IGAP=off

and Mortar

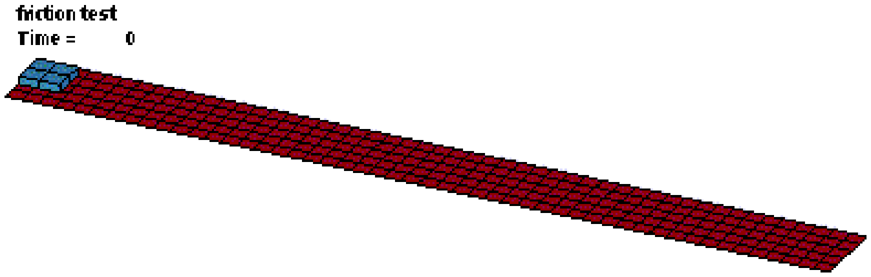


Normalized CPU times: IGAP=on: **1.0**, IGAP=off: **3.1**, Mortar: **2.2**

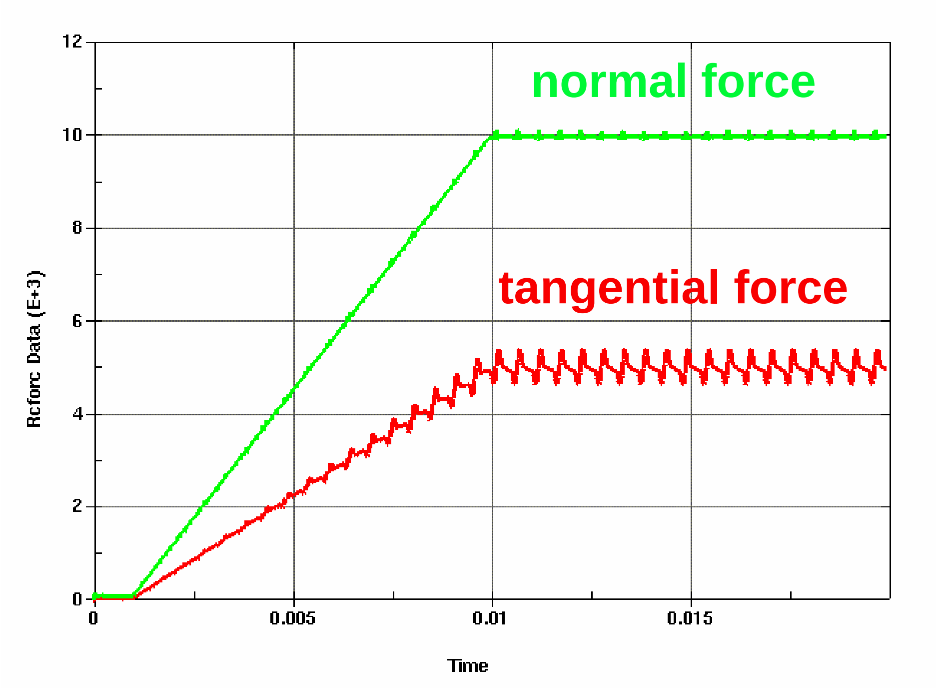
Mortar contact: example 3

Explicit friction test

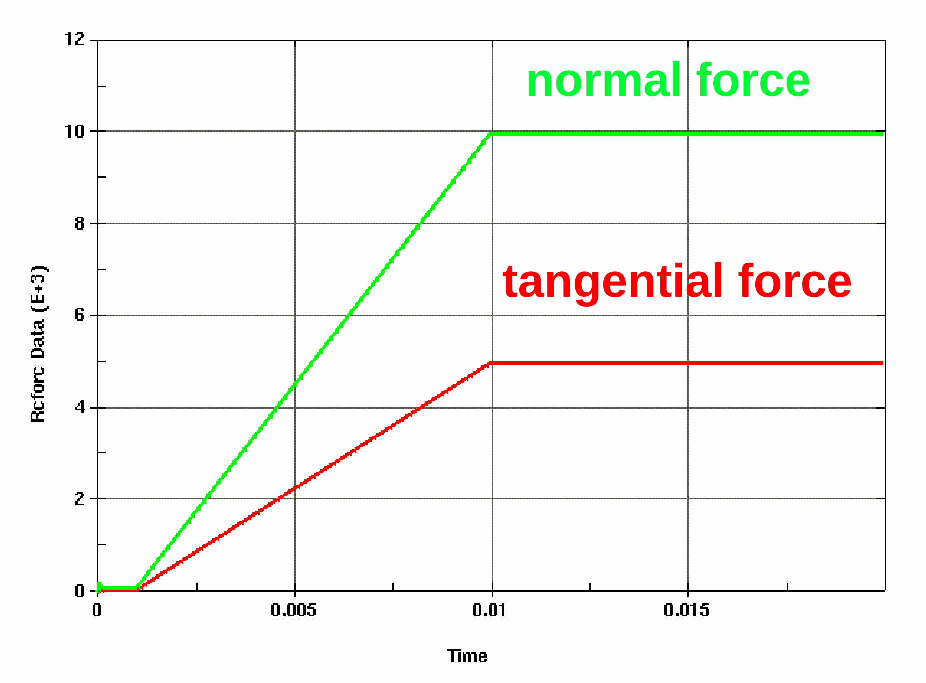
- normal pressure on small part
- prescribed motion
- observation of contact forces



***CONTACT_AUTOMATIC_...**



***CONTACT_AUTOMATIC_..._MORTAR**



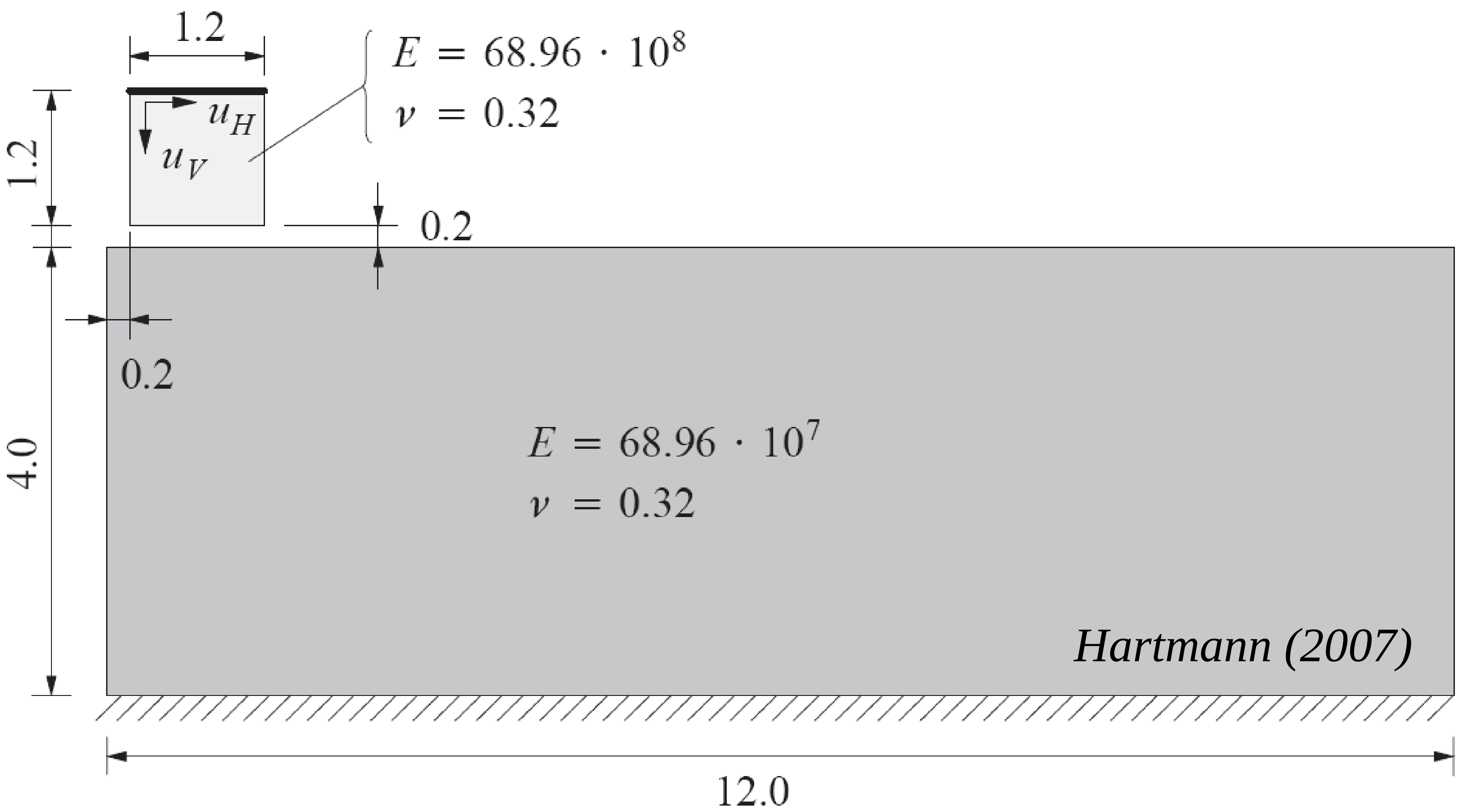
deficiency of node-to-surface

much smoother

Mortar contact: example 4

Ironing problem

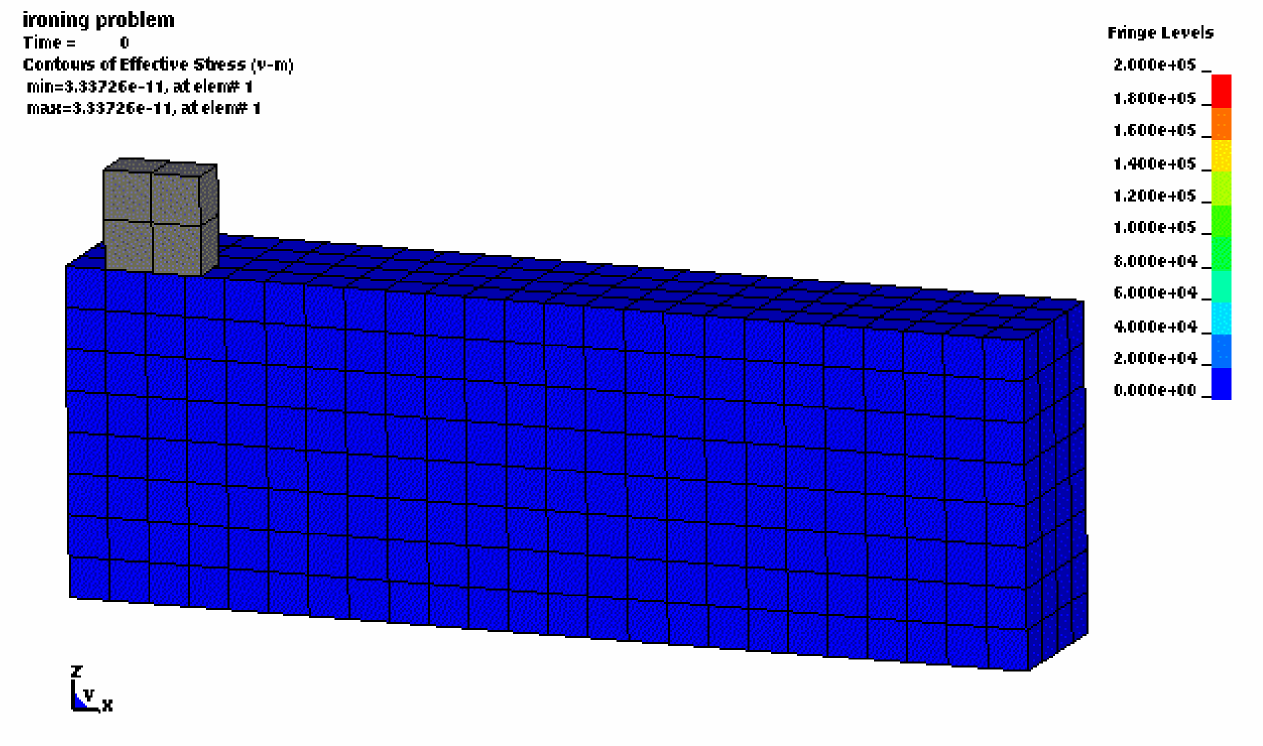
- contact benchmark problem (Yang et al., 2005)
- stiff elastic block is pressed into soft elastic block and then pulled over
- very difficult task for standard node-to-segment contact

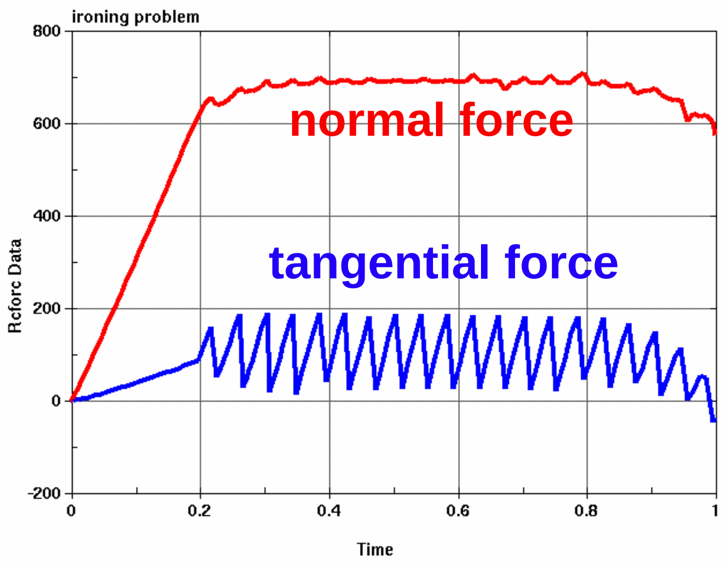


Mortar contact: example 4

Results

- **explicit:** nonsmooth contact, penetrations, no solution
- **implicit with standard contacts:** no convergence at all
- **static implicit with mortar contact:** ~ 3 minutes, 3-20 iterations per step





Mortar contact

Conclusions

- new contact formulation for smoother results
- very promising for implicit analyses: efficient and accurate
- usefullness for explicit remains to be seen

try the new contact types with 971 R5.0
by adding "_MORTAR" to the contact card

```
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR
...
```