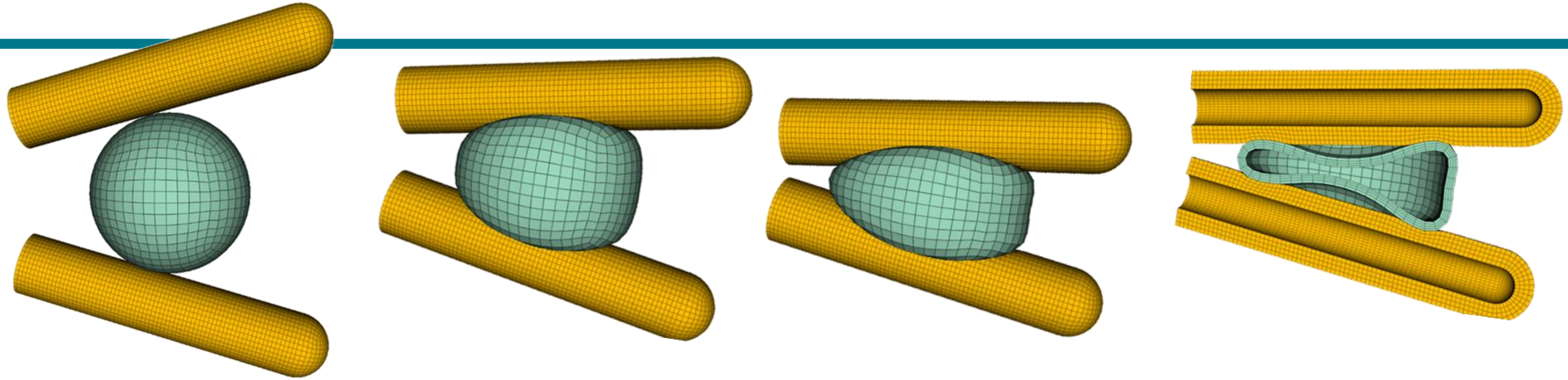
Webinar (2023-04-20)

Contacts for Implicit analyses in LS-DYNA

Anders Jonsson,
DYNAmore Nordic,
an Ansys company



Implicit contacts

Overview

- Introduction
- Sliding contact
  - Mortar contacts
    - Background and overview
    - Handled contact situations
    - IGNORE options
  - Non-mortar contacts
- Press-fit
  - Mortar contacts
  - Interference contact
- Tied contacts
  - (Very briefely)
- Troubleshooting implicit convergence related to contacts
  - The impossible case / Live demo (?)
- Some contact benchmarks
- Summary

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- Some contact benchmarks
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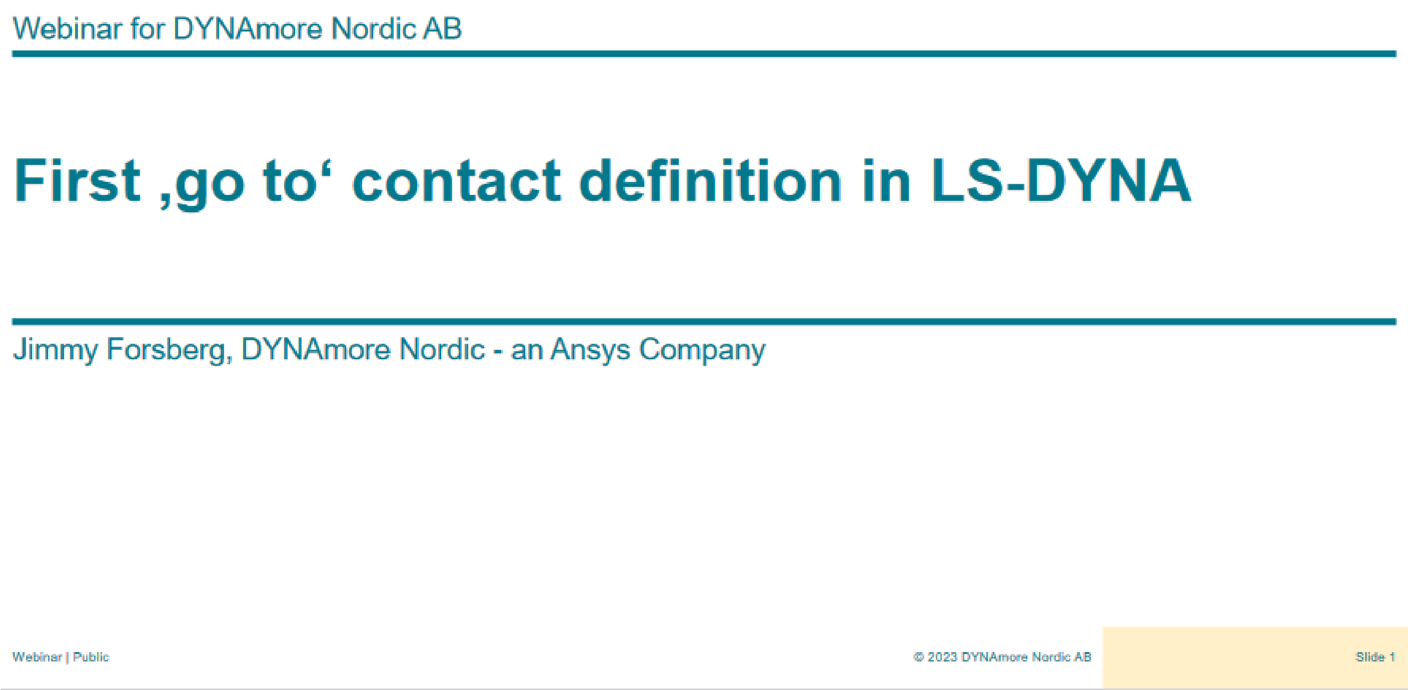
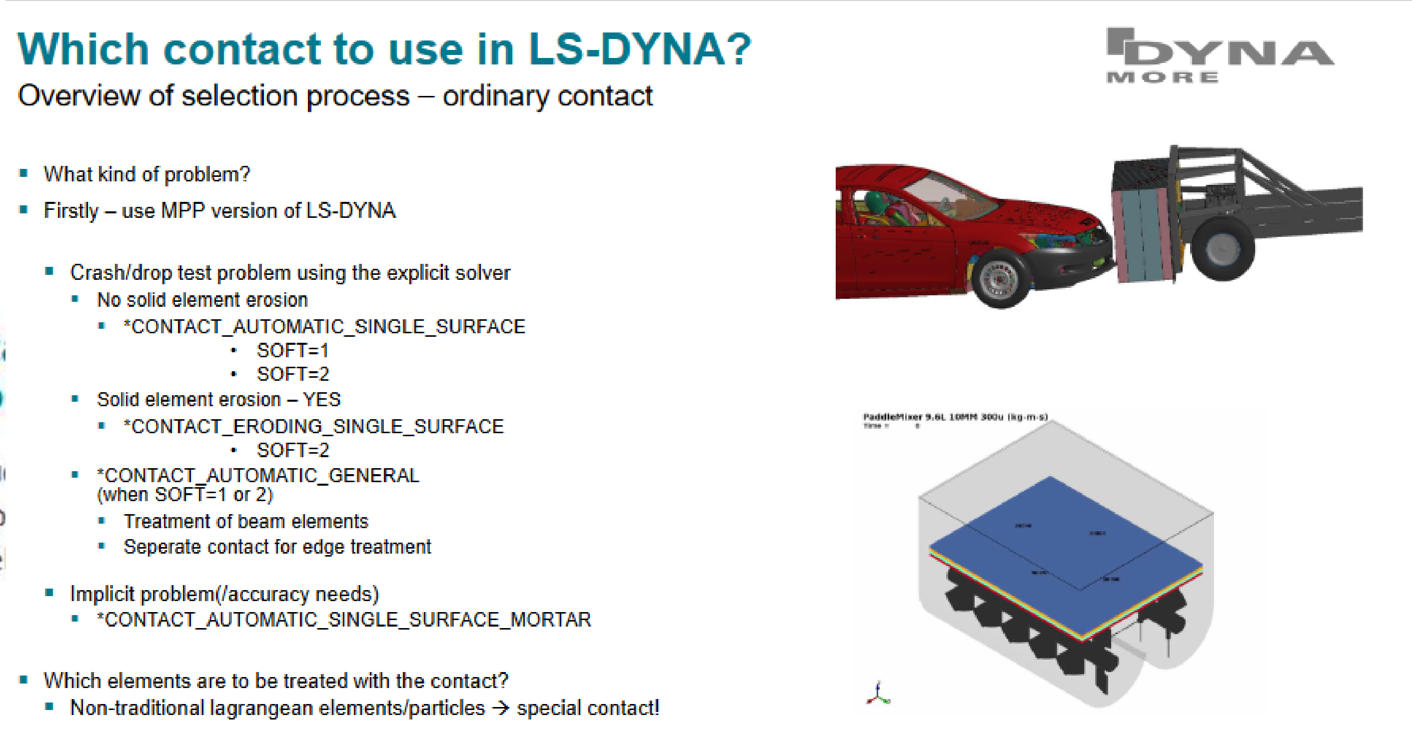
Implicit contacts

Introduction

- Contacts in LS-DYNA is a vast filed
  - Focus on implicit applications
  - Brief overview of possibilities – many more
- Sliding contacts – keeping parts separated
  - Transfer Normal and Tangential forces
  - Heat flux, etc.
- Tied contacts – keeping parts together
  - Transfer all forces
  - Heat flux, etc.
- Tiebreak contacts – a bond that can brea
  - Compare cohesive elements
- Tied weld contacts – creating a bond bas example temperature





Mortar contact

Background

- For sliding contact in implicit analyses, use the Mortar contacts:
  - `*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_ID`
  - `*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID`
- Normally requires a minimum of input:
  - define what is in contact using parts or part sets, and
  - specify coefficient of friction.
  - It is recommended to use the softer part (less stiff material, or coarser mesh) as tracked.
  - Also supports more advanced options, i.e., pressure dependent friction
- Penetration information will be reported in `mes0*` - files.
  - If "too large" penetrations are noted during the simulation, contact stiffness can be increased using the *`SAFS`*- and *`IGAP`*-parameters.
  - Also, in `sleout` and `d3plot` for fringeplotting

Mortar contact

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```
*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID
$#     cid                                                                 title
      1010Global contact all
$#   surfa     surfb  surfatyp  surfbtyp    sboxid    mboxid       spr       mpr
         0         0         5         0         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
      0.15
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
```

`surfayp` = 5 ➔ Include everything in the contact

- Same modelling approach as in an explicit model applies
  - Possible to use one single surface contact definition
  - “All” contact situations will be detected automatically

Mortar contact

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  - *CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID

```
*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID
$#     cid                                                                 title
      1010Global contact all
$#   surfa     surfb  surfatyp  surfbtyp    sboxid    mboxid       spr       mpr
       111         0         2         0         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
      0.15
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
```

surfatyp = 2 ➔ Include a part set

- Same modelling approach as in an explicit model applies
  - Possible to use one single surface contact definition
  - “All” contact situations will be detected automatically
    ➔ Exclude adhesive solids, spotweld solids/beams from contact

Mortar contact

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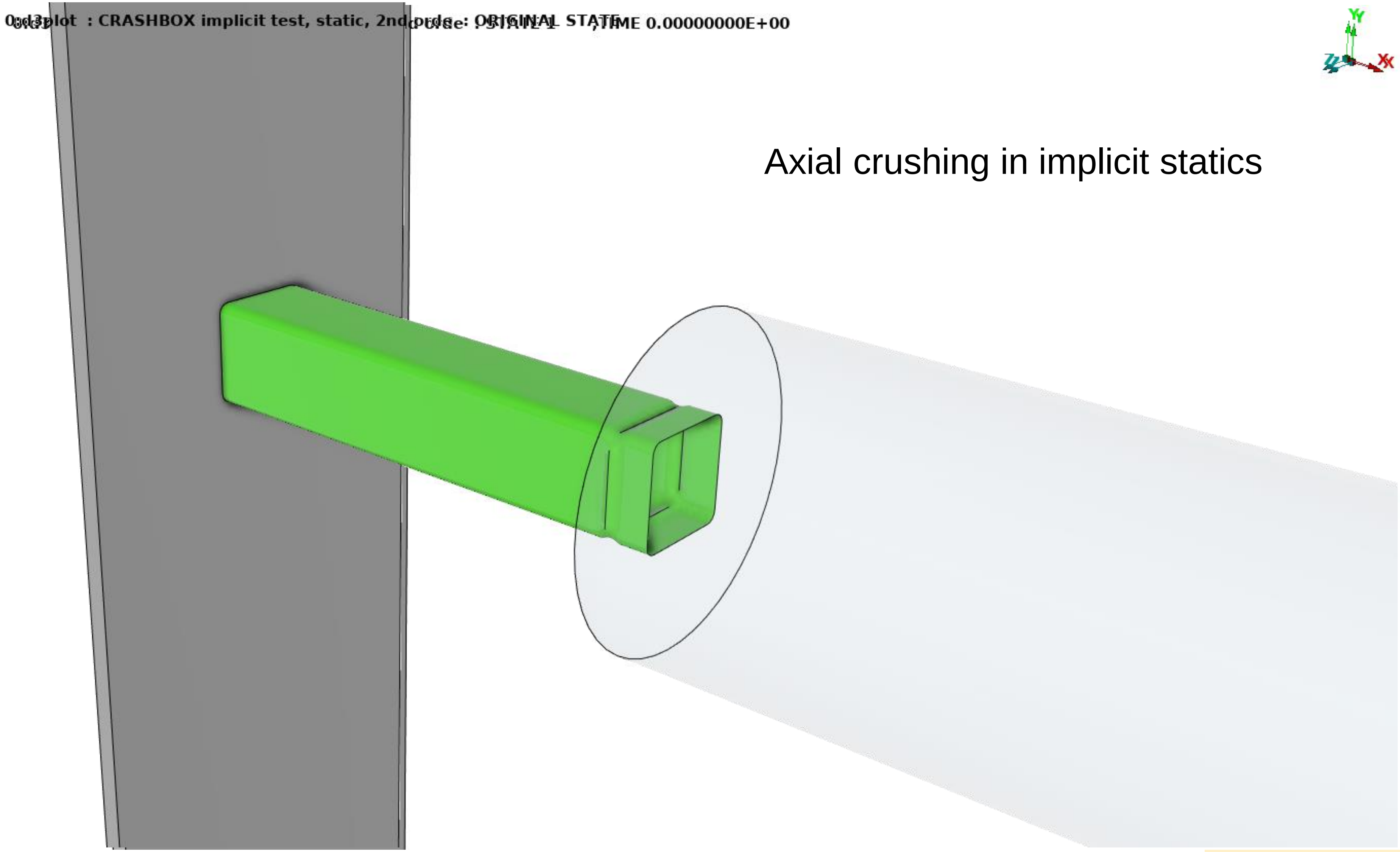
  - *CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID
- Normally requires a minimum of input:
  - define what is in contact using parts or part sets, and
  - specify coefficient of friction.
  - It is recommended to use the softer part (less stiff material, or coarser mesh) as tracked.

```
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_ID
$#     cid                        Rigid impactor as reference
 10000004PLATEN to BiW
$#   surfa     surfb  surfatyp  surfbtyp    sboxid    mboxid       spr       mpr
     10001  50000001         2         3                             1         1
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.2
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
```

Mortar contact

Example: `*CONTACT_AUATOMATIC_SINGLE_SURFACE_MORTAR`

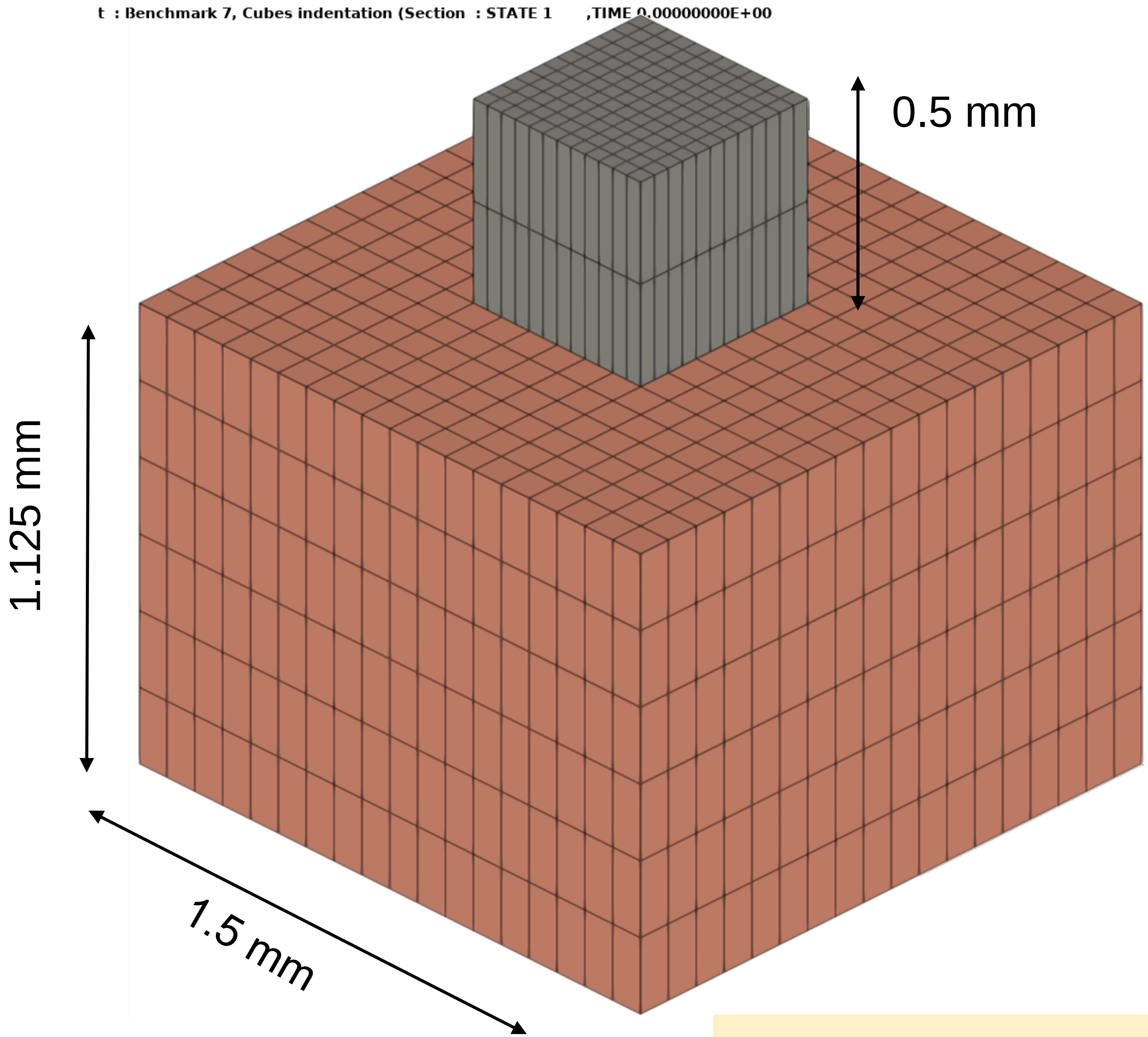


Axial crushing in implicit statics

Mortar contact

Example: `*CONTACT_AUATOMATIC_SURFACE_TO_SURFACE_MORTAR`

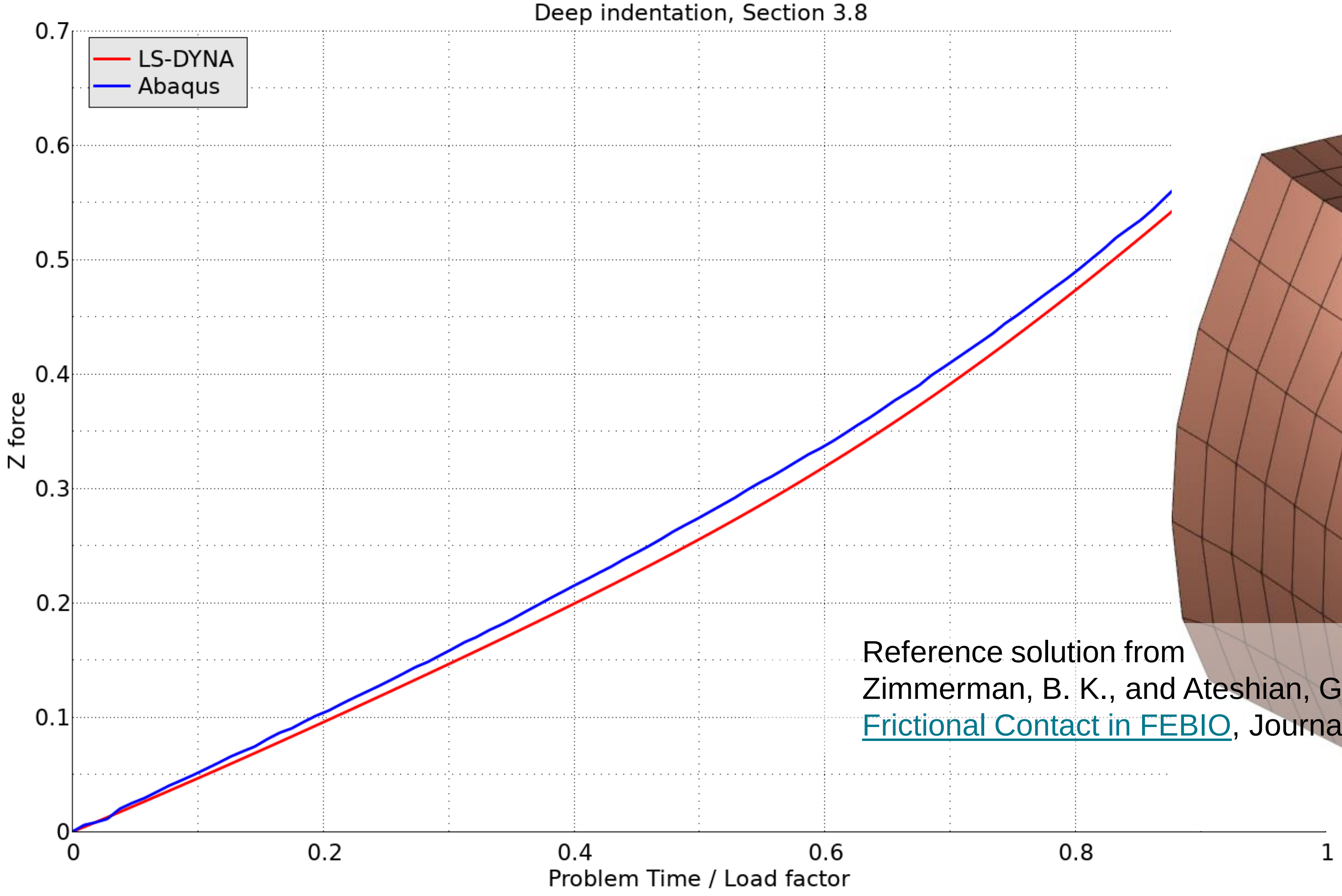
- A small stiff block is pressed into a larger, softer body
- Hyperelastic materials
  - Top block: E=100 MPa, ν = 0.3
  - Bottom block: E=1 MPa, ν = 0.3
- Target motion is 0.6 mm (53 % of thickness)
- A quarter slice removed from visualization for clarity

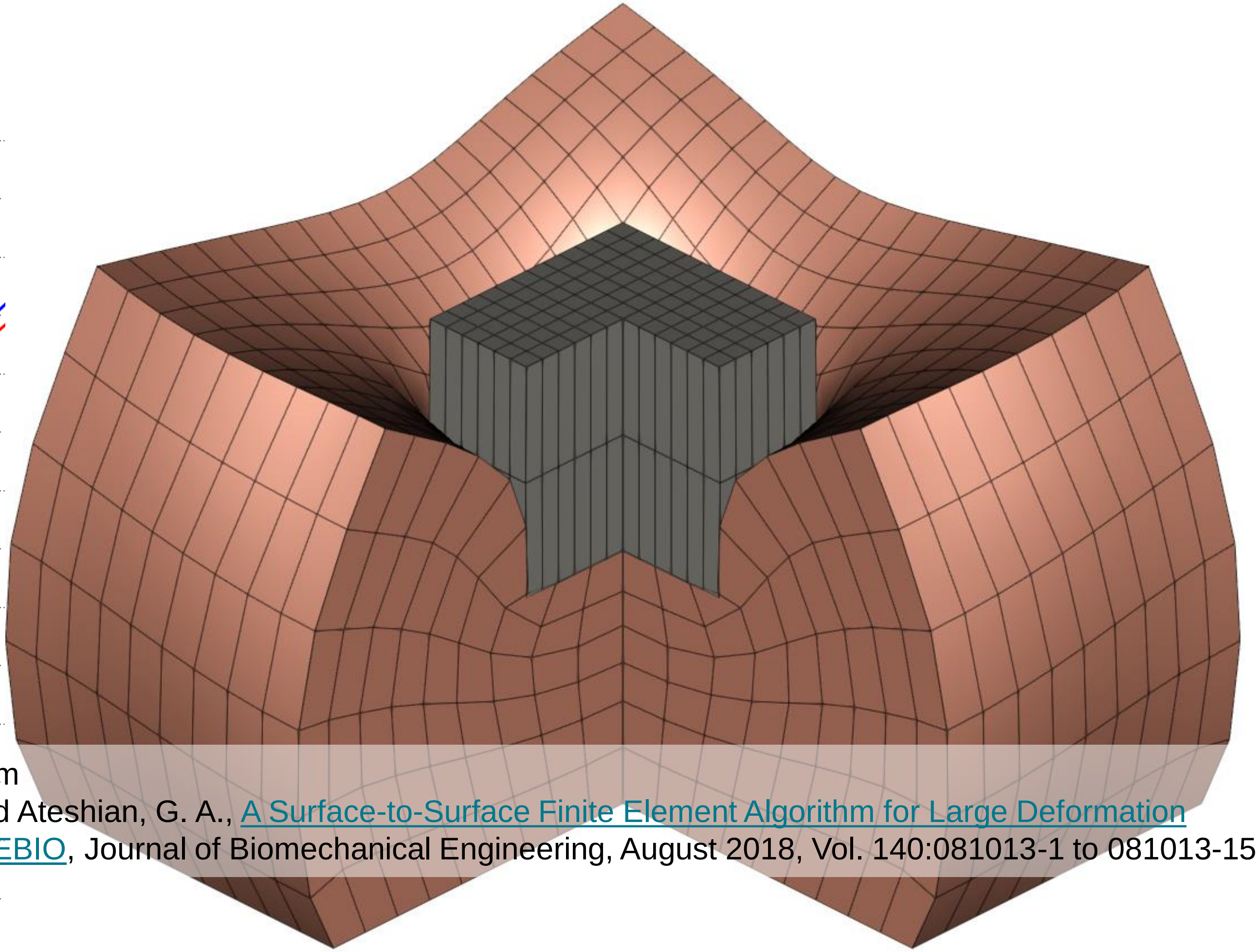


Mortar contact

Example: *CONTACT_AUATOMATIC_SURFACE_TO_SURFACE_MORTAR

- Force vs. displacement comparison

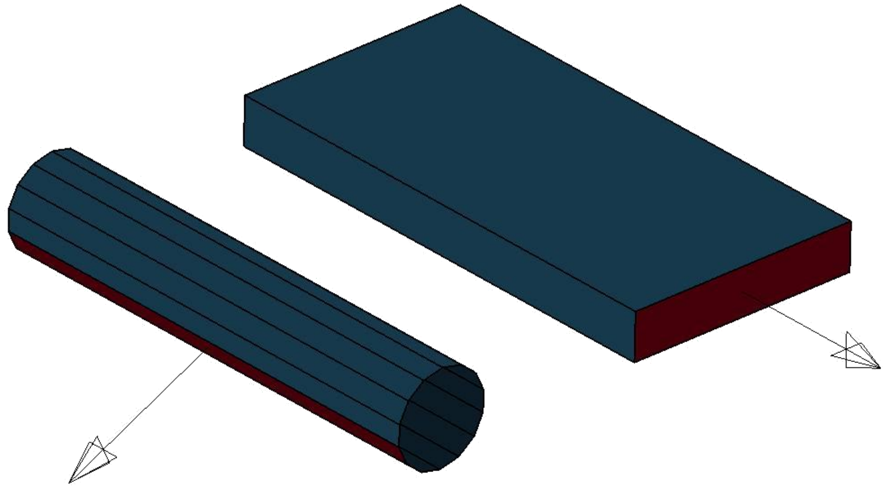


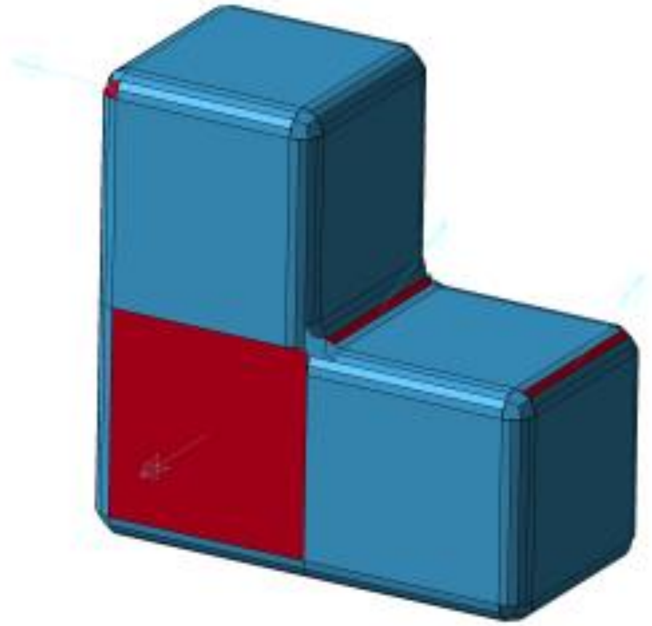


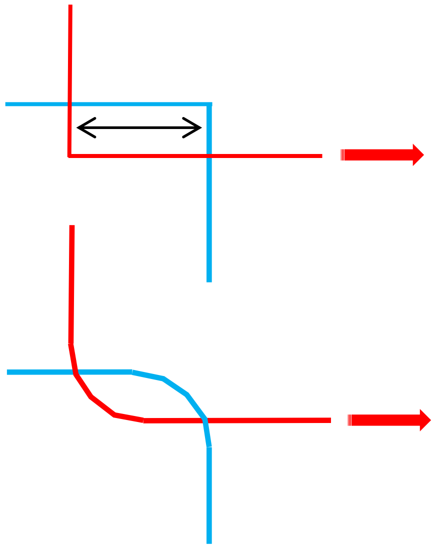
Reference solution from
Zimmerman, B. K., and Ateshian, G. A., [A Surface-to-Surface Finite Element Algorithm for Large Deformation Frictional Contact in FEBIO](), Journal of Biomechanical Engineering, August 2018, Vol. 140:081013-1 to 081013-15

Mortar contact

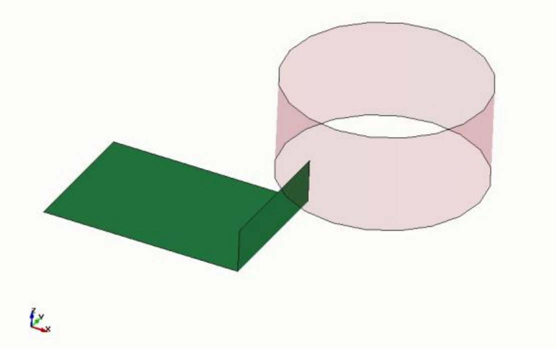
Contact situations

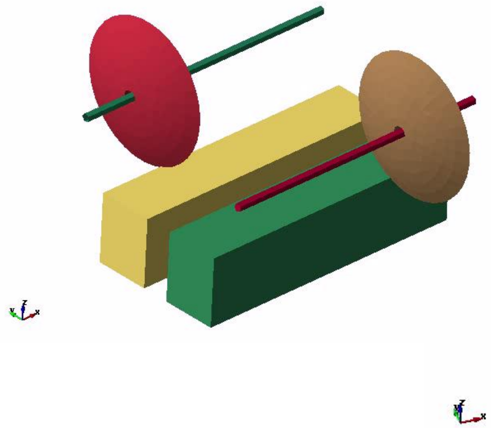


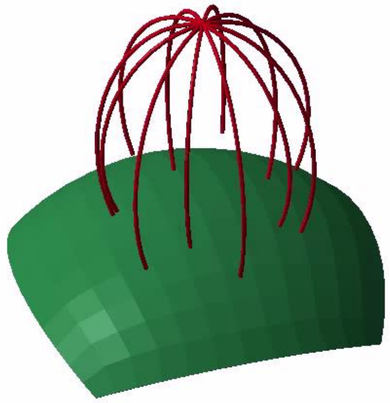




- Edge contact with shells
  - Flat surfaces
- Faceted surface on beams
  - Including end point
- Smoothed edges on solid elements
  - Avoids spurious contact situation when sliding off edges



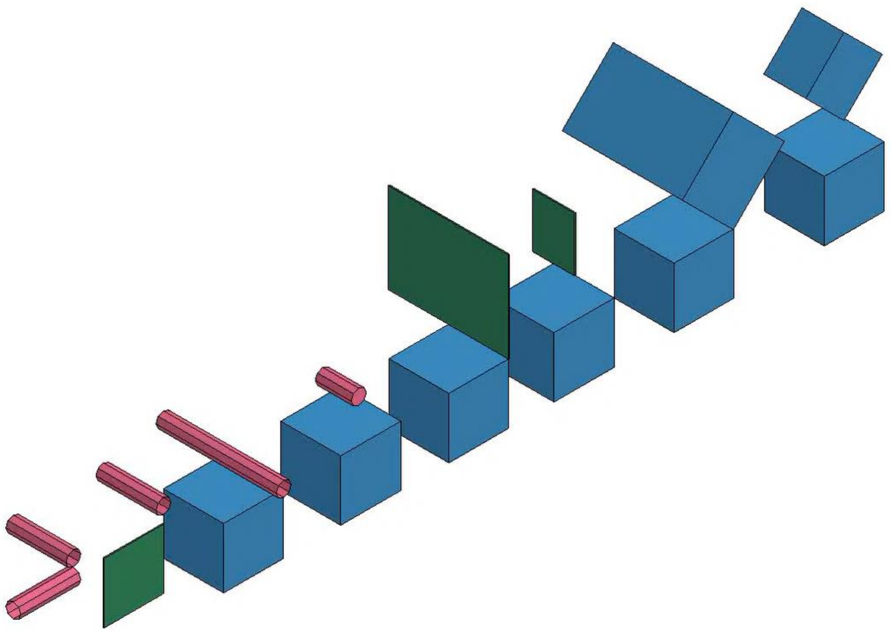




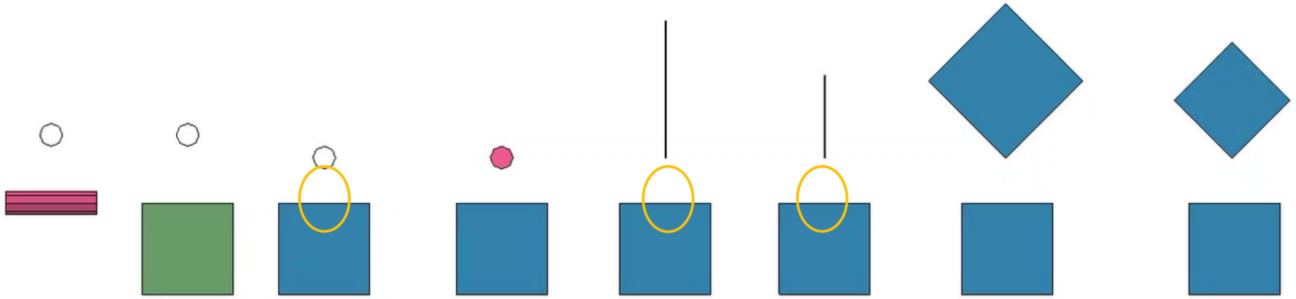
Mortar contact

Contact situations

- Segment-based penetration check



- Captured contact situations
  - Segments not allowed to penetrate segments
    - Shell edge to segment of shell and solid
    - Solid edge to segment of shell and solid
  - Beam to beam
  - Beam to shell edge (NO segment extension!)
  - Beam to segment of shell and solid
- Including element erosion



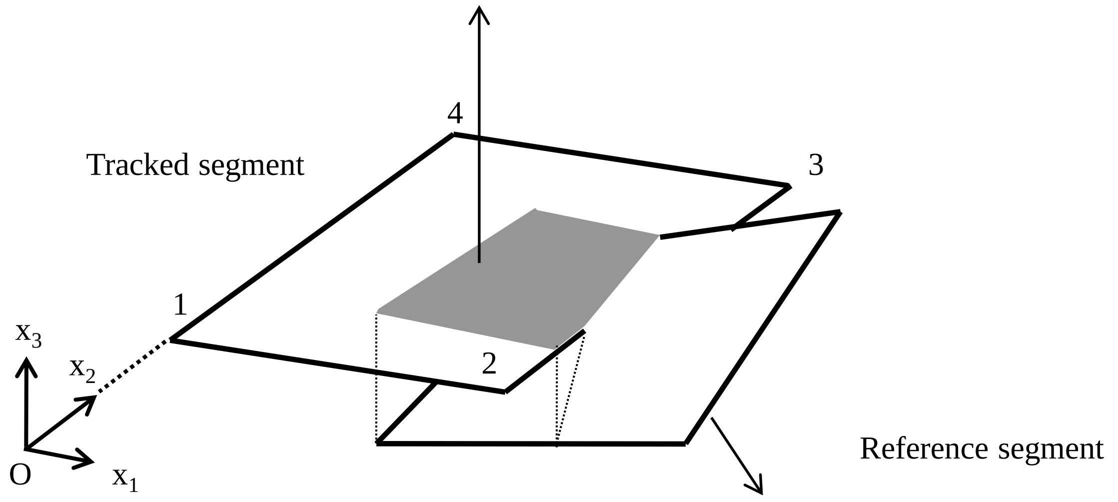
Mortar contact

- Segment-to-segment based contact intended for implicit analysis. Based on consistent FE theory.
- Smooth force transition for penetration and segment to segment sliding
- Contact stress consistent with element shape functions
- Expensive but accurate
- Most contact situations detected automatically
  - Including element erosion
- Long term goal is to make it universal with few parameters
- Also, Mortar options for `*CONTACT_`
  - `2D`,
  - `THERMAL`,
  - `TIED`, `TIEBREAK`, `TIED_WELD` and `FORMING`

Most common are

`*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR`

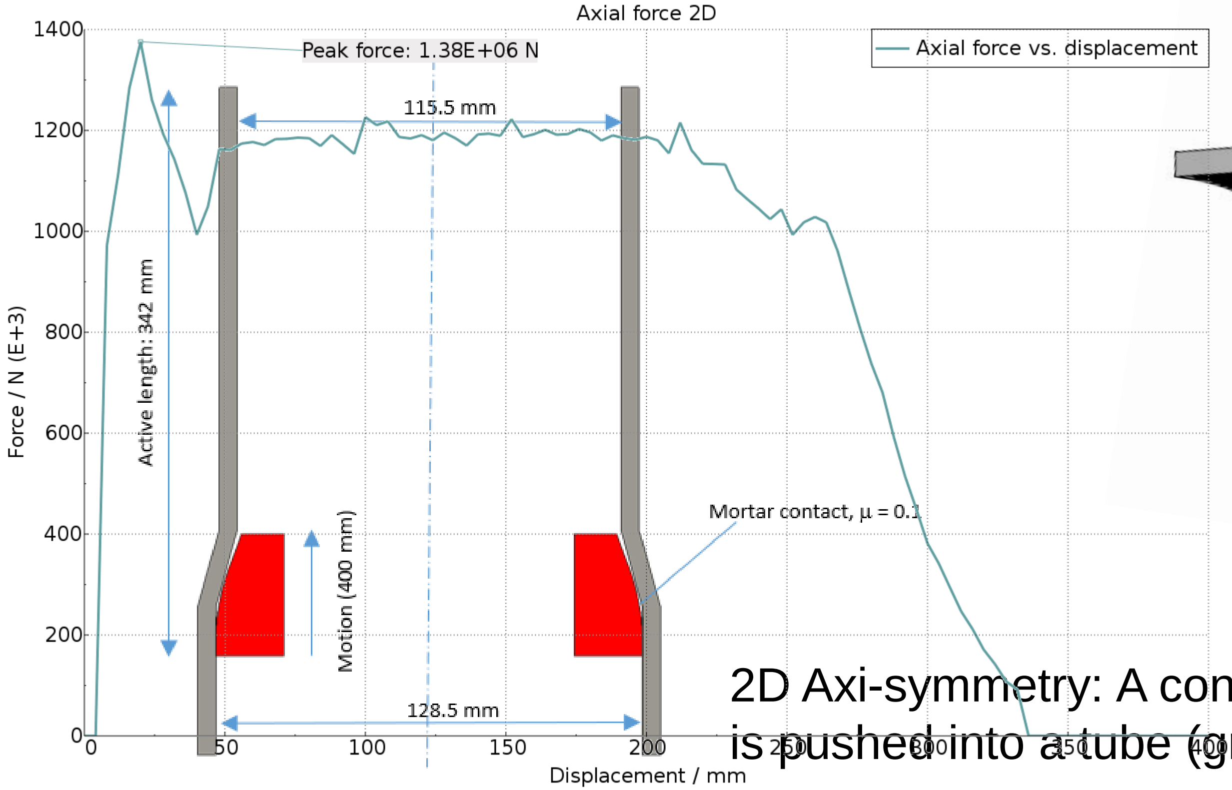
`*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR`

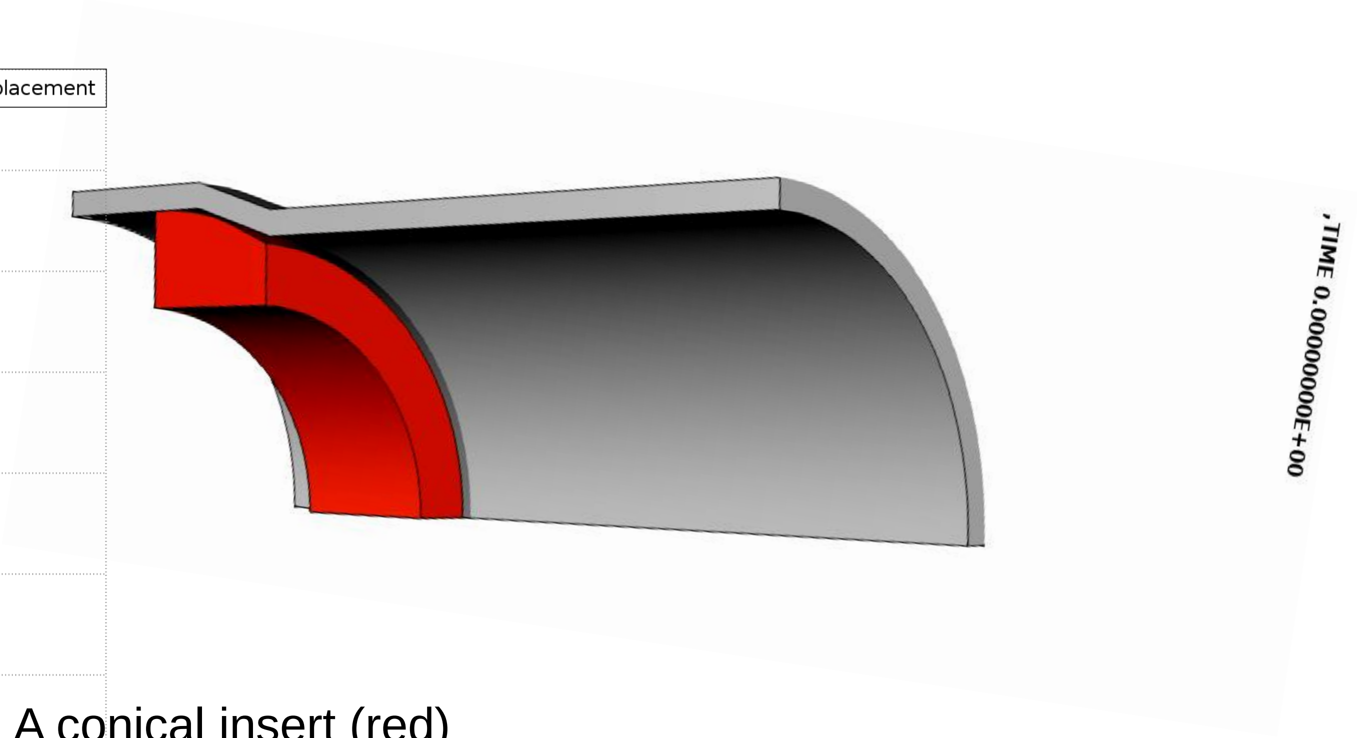


Mortar contact

2D Example

- *CONTACT_2D_AUTOMATIC_SINGLE_SURFACE_MORTAR
- *CONTACT_2D_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR
  - Supported in mpp from R13



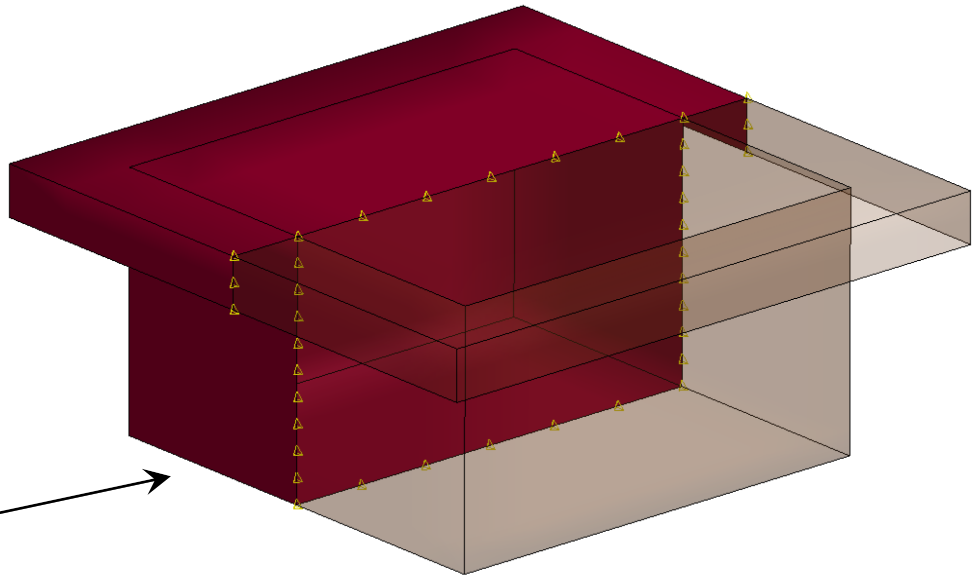


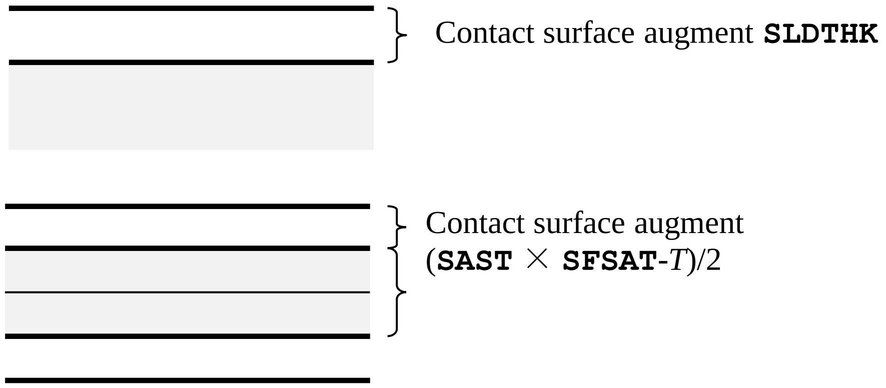
2D Axi-symmetry: A conical insert (red) is pushed into a tube (gray).

Mortar Contact

Parameters

- **`FS, FD, DC`**
  - Dynamic friction supported in dynamic or explicit
- **`VDC`**
  - Damping only in dynamic or explicit (not recommended in implicit)
- **`VC`**
  - Cap for the tangential surface stress (`VC` $\approx \sigma_Y/\sqrt{3}$)
- **`SFSA`**
  - Scale factor on penalty stiffness
- **`ISYM`** *on* **`*CONTROL_CONTACT`**
  - Set to negative to define a node set on symmetry plane
- **`PENMAX, SLDTHK`**
  - Used to offset contact surface for solids
  - `PENMAX` is maximum penetration depth
- **`SAST, SFSAT`**
  - Used to set/offset contact surface for shells





Mortar Contact

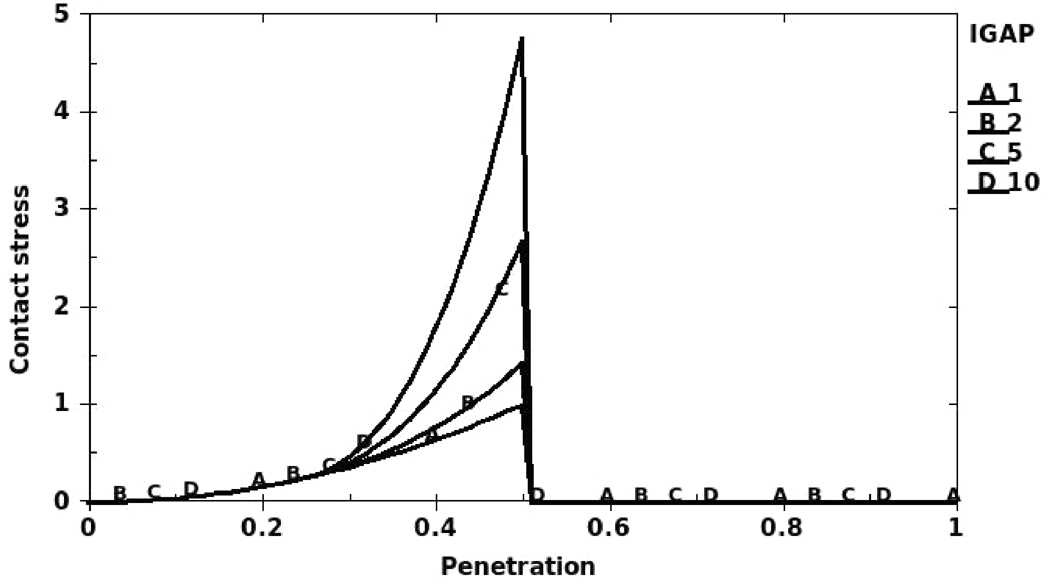
Parameters

MPP 1	IGNORE	BCKT	LCBCKT	NS2TRK	INITITR	PARMAX		CPARM8
MPP 2	&	CHKSEGS	PENSF	GRPABLE				
Card 1	SURFA	SURFB	SURFATYP	SURFBTUB	SABOXID	SBBOXID	SAPR	SBPR
Card 2	FS	FD	DC	VC	VDC	PENCHCK	BT	DT
Card 3	SFSA	SFSB	SAST	SBST	SFSAT	SFSBT	FSF	VSF
Card A	SOFT	SOFSCL	LCIDAB	MAXPAR	SBOPT	DEPTH	BSORT	FRCFRQ
Card B	PENMAX	THKOPT	SHLTHK	SNLOG	ISYM	I2D3D	SLDTHK	SLDSTF
Card C	IGAP	IGNORE	DPRFAC/ MPAR1	DTSTIF/ MPAR2	EDGEK		FLANGL	CID_RCF
Card D	Q2TRI	DTPCHK	SFNBR	FNLSCL	DNLSCL	TCSO	TIEDID	SHLEDG
Card E	SHAREC	CPARM8	IPBACK	SRNDE	FRCSF	ICOR	FTORQ	REGION
Card F	PSTIFF	IGNROFF		FSTOL	2DBINR	SSFTYP		

Mortar contact

Contact stiffness

- The $SFSA$ – parameter scales the contact stiffness
  - Typically increase by orders of magnitude to get noticeable reduction of penetrations, for example $SFSA$ = 5, 10, 100, ... etc.
- The $IGAP$ - parameter controls the progressive contact stiffness increase
  - On optional card C



$$\sigma_\mathrm{n} = \alpha\beta_s\varepsilon K_\mathrm{s} f\left(\frac{d}{\varepsilon d_c^s}\right),$$

α = stiffness scaling factor (**SFS**$*$**SLSFAC**)
K_s = stiffness modulus of *tracked* side
$\varepsilon = 0.03$
d = penetration distance
d_c^s = characteristic length of *tracked* side
β_s = stiffness scale factor of tracked side

Mortar contact

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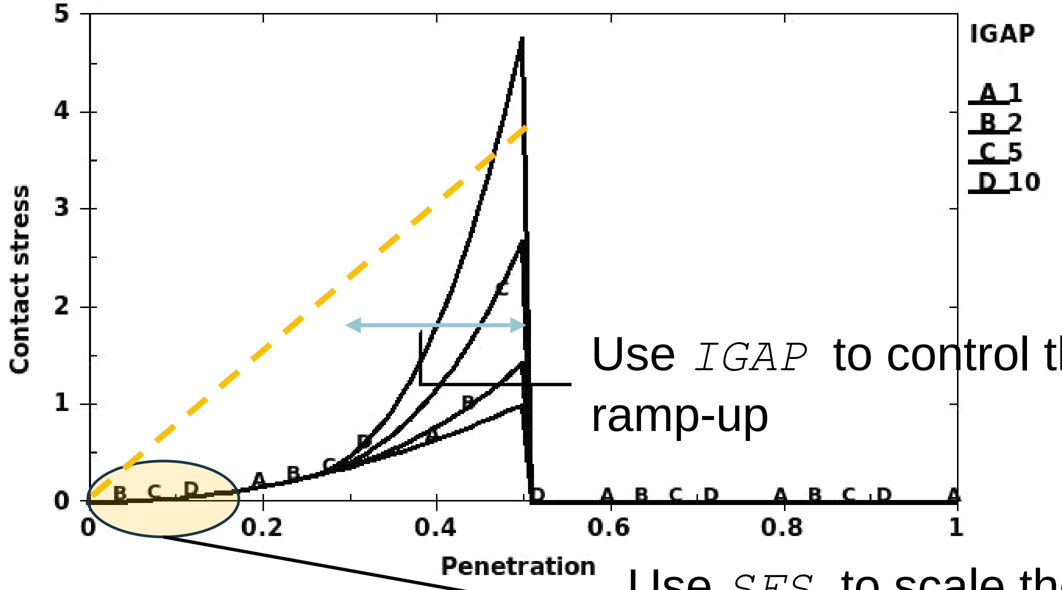


Use *IGAP* to control the ramp-up

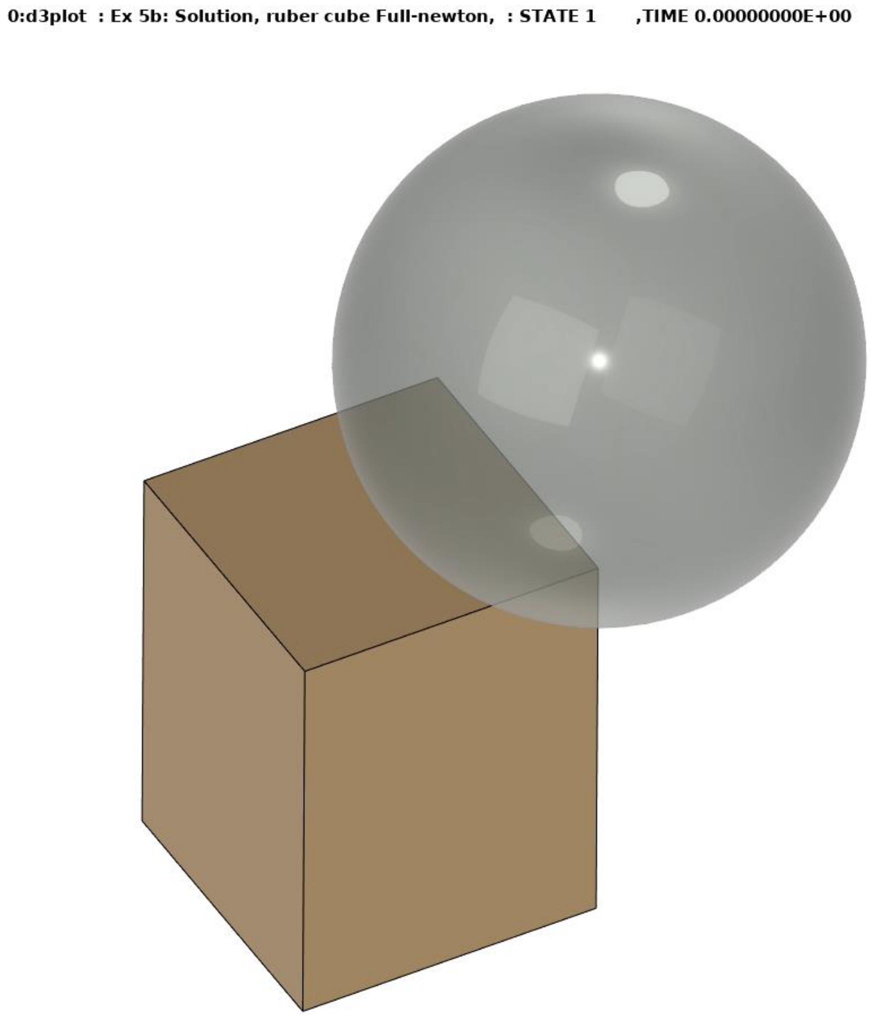
Use *SFS* to scale the initial slope

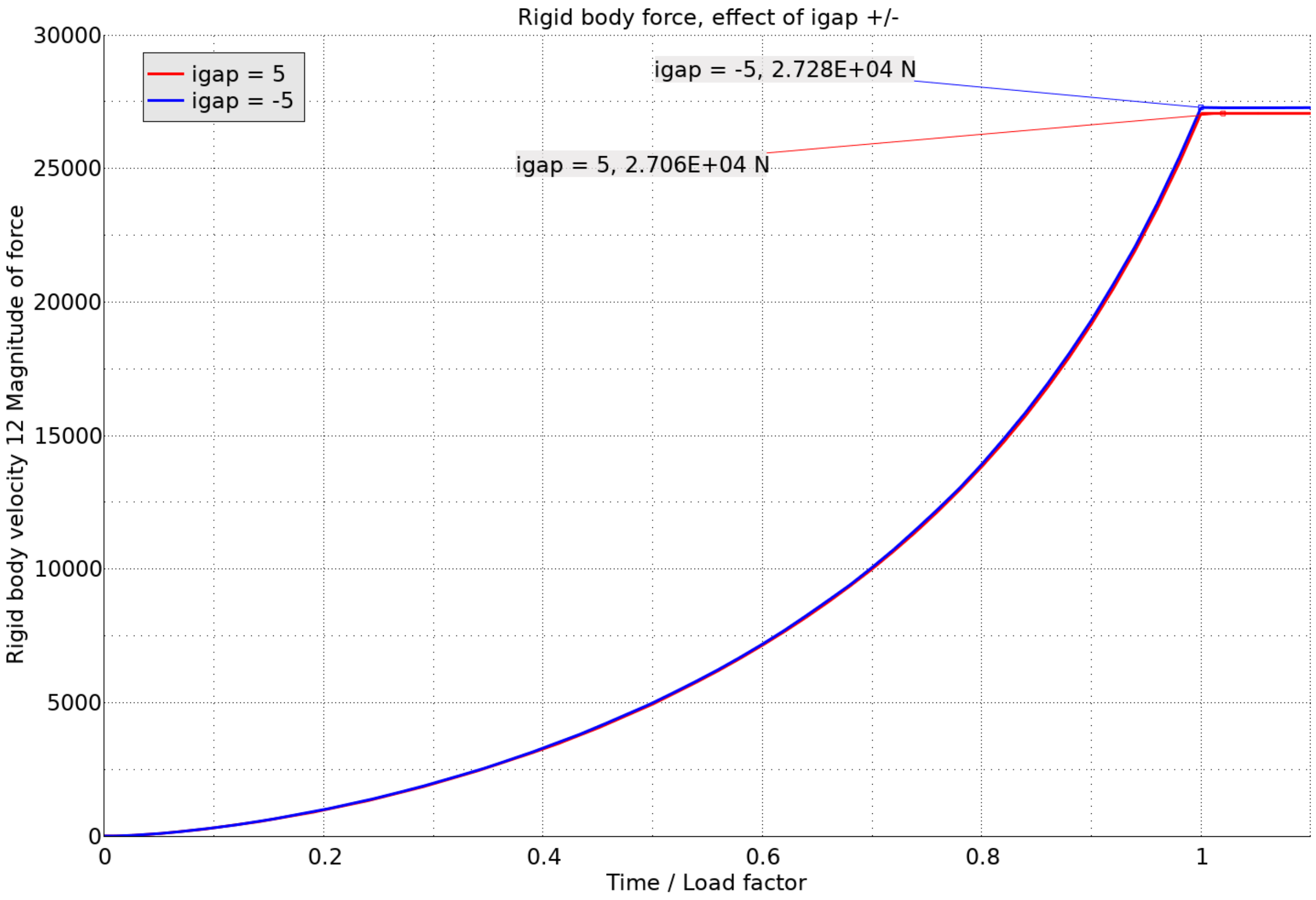
- Increase the *SFSA* - parameter to reduce contact penetrations and obtain a stiffer contact.
- Increase the *IGAP* - parameter to avoid contact release

IGAP < 0 ➔ Linear relation for Contact stress vs. Penetration

Mortar contact

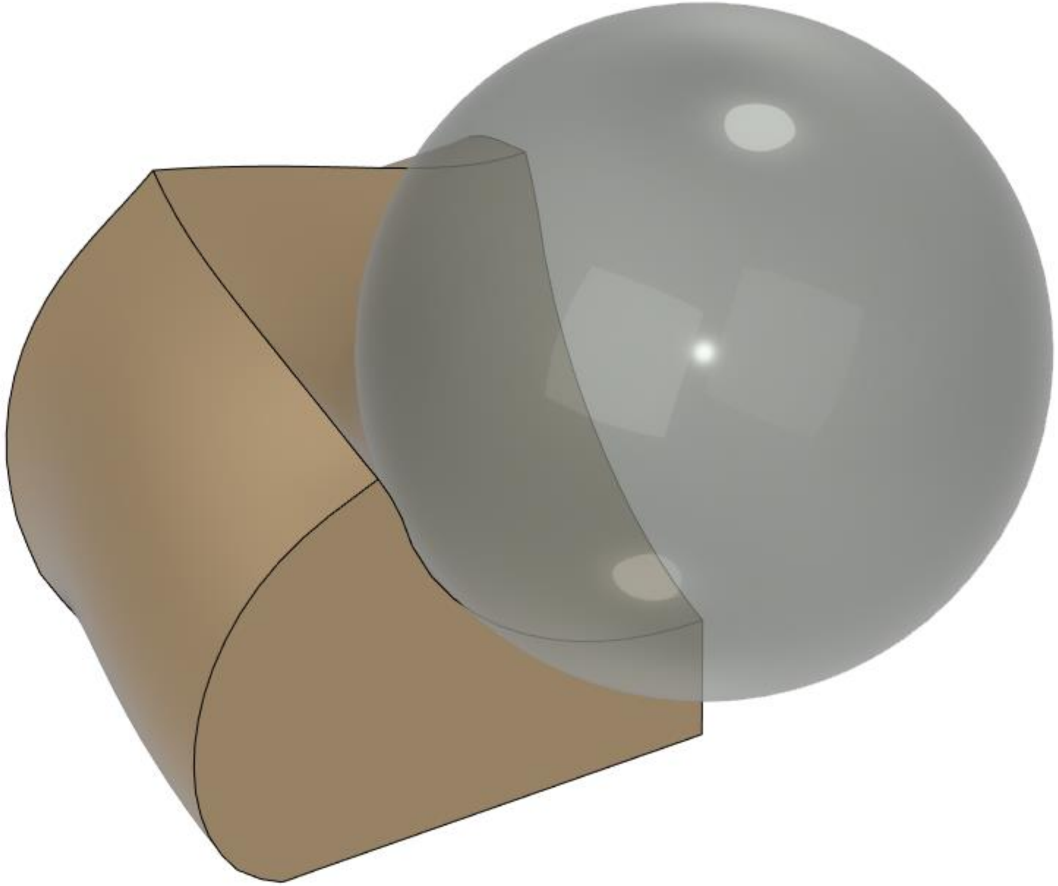
Contact stiffness: IGAP < 0

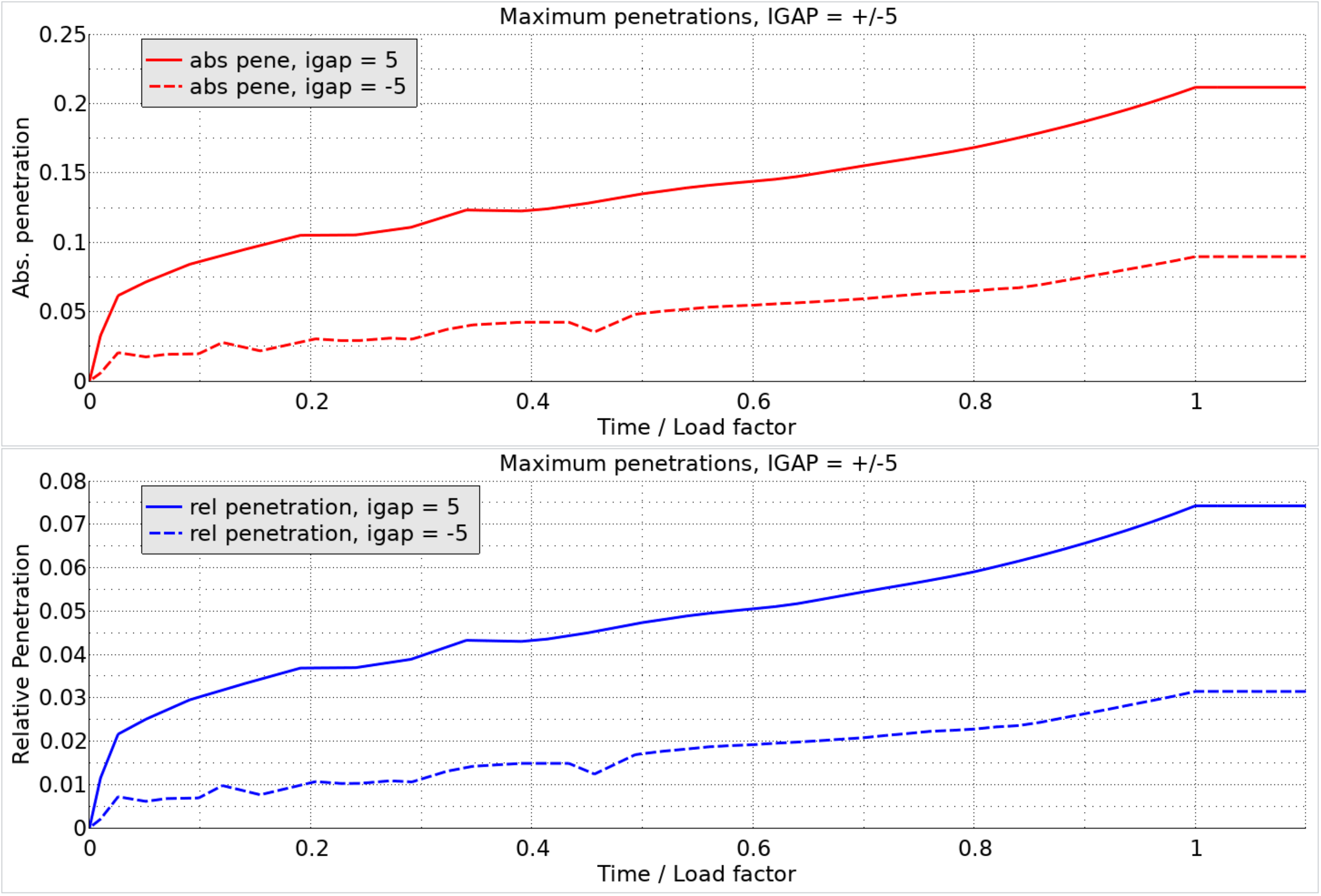




Mortar contact

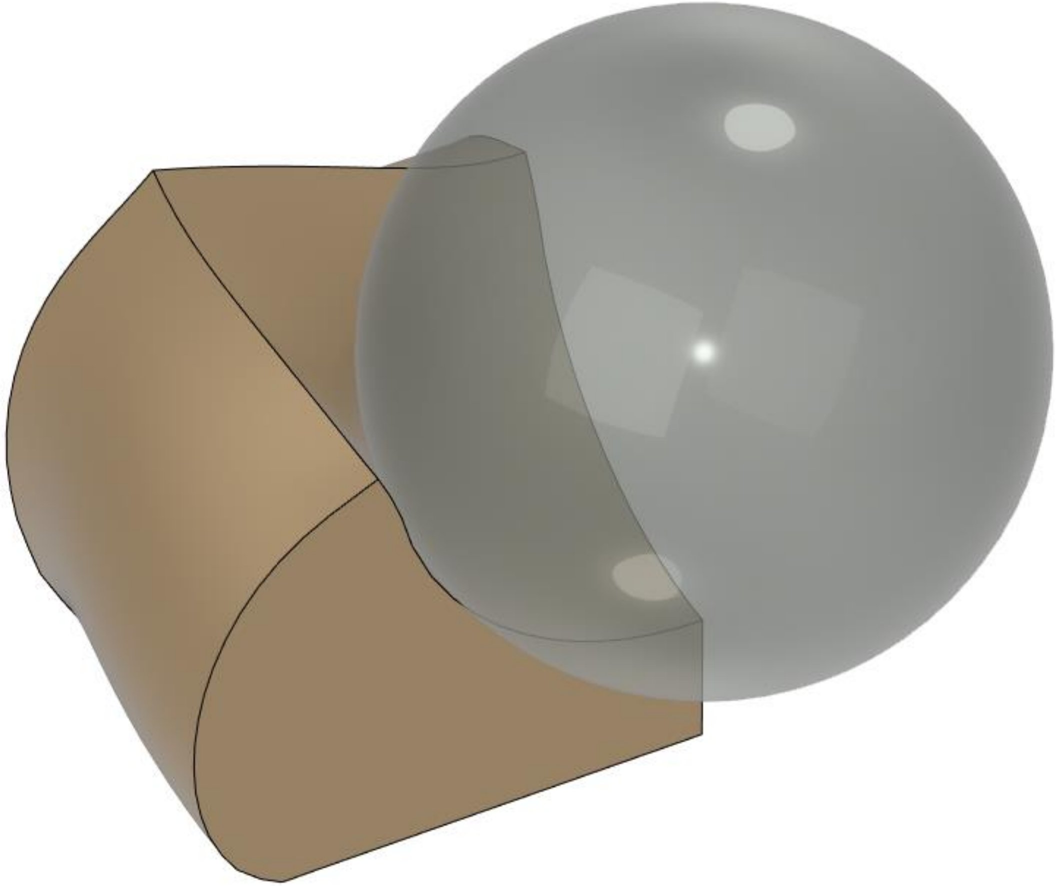
Contact stiffness: IGAP < 0

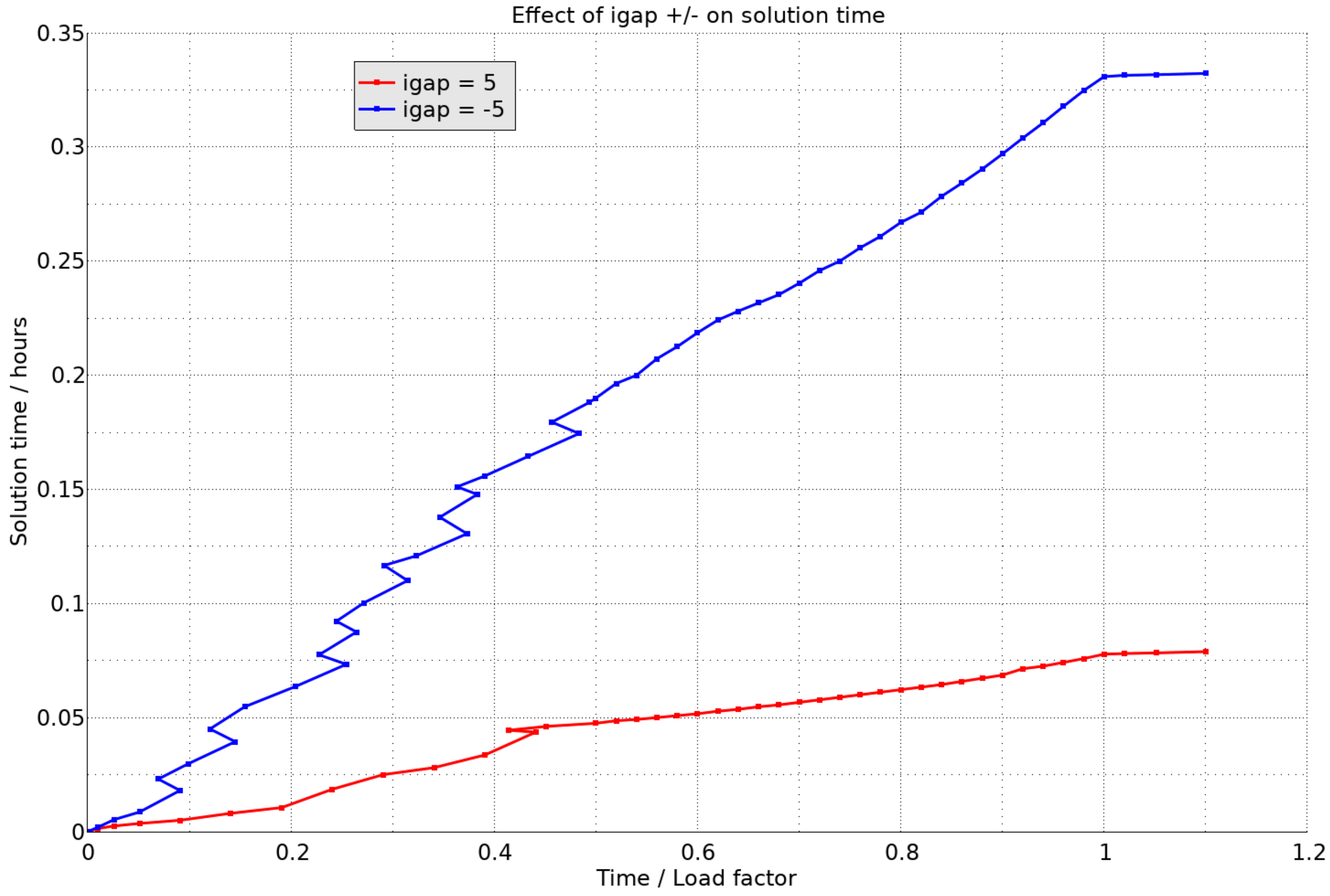




Mortar contact

Contact stiffness: IGAP < 0





Mortar contact recommendations

- Use part or part set based tracked and reference sides
  - Avoid possible false edges in the interior of a component

```
*** Warning 30397 (INI+397)
    Mortar contact master side is detected as softer
    than slave side, might suggest a recommendation of switch
    between master and slave
```

- Use weak part as tracked
  - Leads in general to the best possible implicit convergence behavior
  - Automatically taken care of in a single surface contact

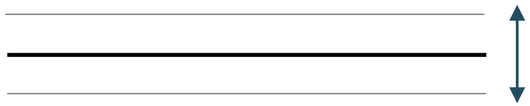
- Contact thickness
  - All parts have real thickness in Mortar contacts
  - Always including effect of `nloc` for shells
  - Rigid shell parts have no thickness in forming contacts

NLOC	Location of reference surface (shell mid-thickness) for three-dimensional shell elements.
	EQ.1.0: Nodes are located at top surface of shell.
	EQ.0.0: Nodes are located at mid-thickness of shell (default).
	EQ.-1.0: Nodes are located at bottom surface of shell.

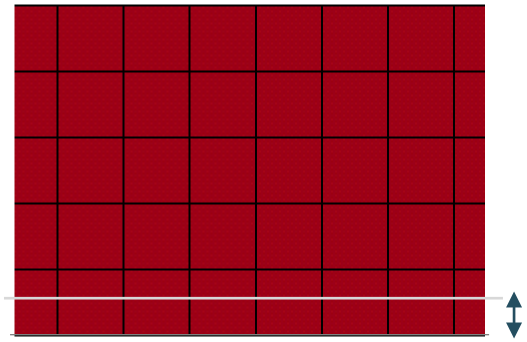
Mortar contact

Contact thickness

- For shells, the contact thickness is directly related to the physical thickness
  - Separate contact thickness may be specified using `*PART_CONTACT` and *OPTT*
- For solids, the “contact search depth” may be specified using
  - *PENMAX* (Optional card B of the `*CONTACT_` definition) in R10 and later
  - The “default value” – based on tracked side mesh size - is often OK



Contact thickness for shell elements directly related to physical thickness



`PENMAX` (R10 and later)
`SAST` (before R10)
for solids

Contact search depth for solids

Mortar contacts

Contact thickness

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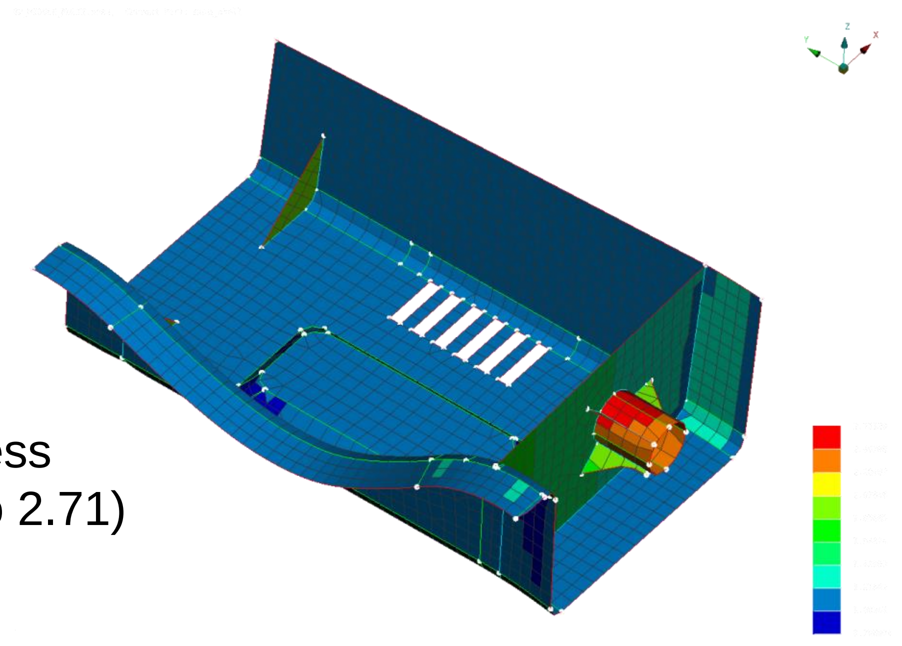
  - Separate contact thickness may be specified using `*PART_CONTACT` and *OPTT*
  - For Mortar contacts, physical parts with varying thickness are beneficial to represent as one part also in LS-DYNA, with the thickness variation defined using `*ELEMENT_SHELL_THICKNESS`.

Shell thickness
(from 0.79 to 2.71)



Mortar contacts

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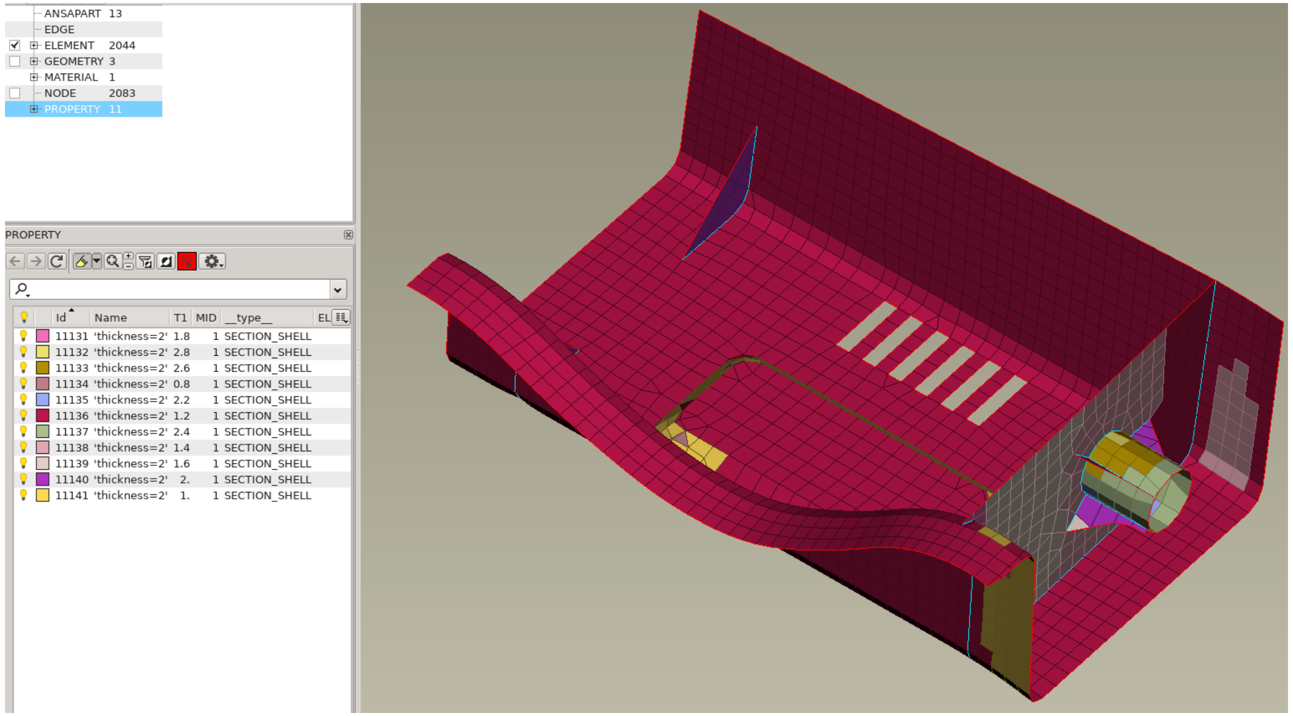

Output as `*PART`s (in this case 11)
Works OK in most cases

Mortar contacts

Contact thickness

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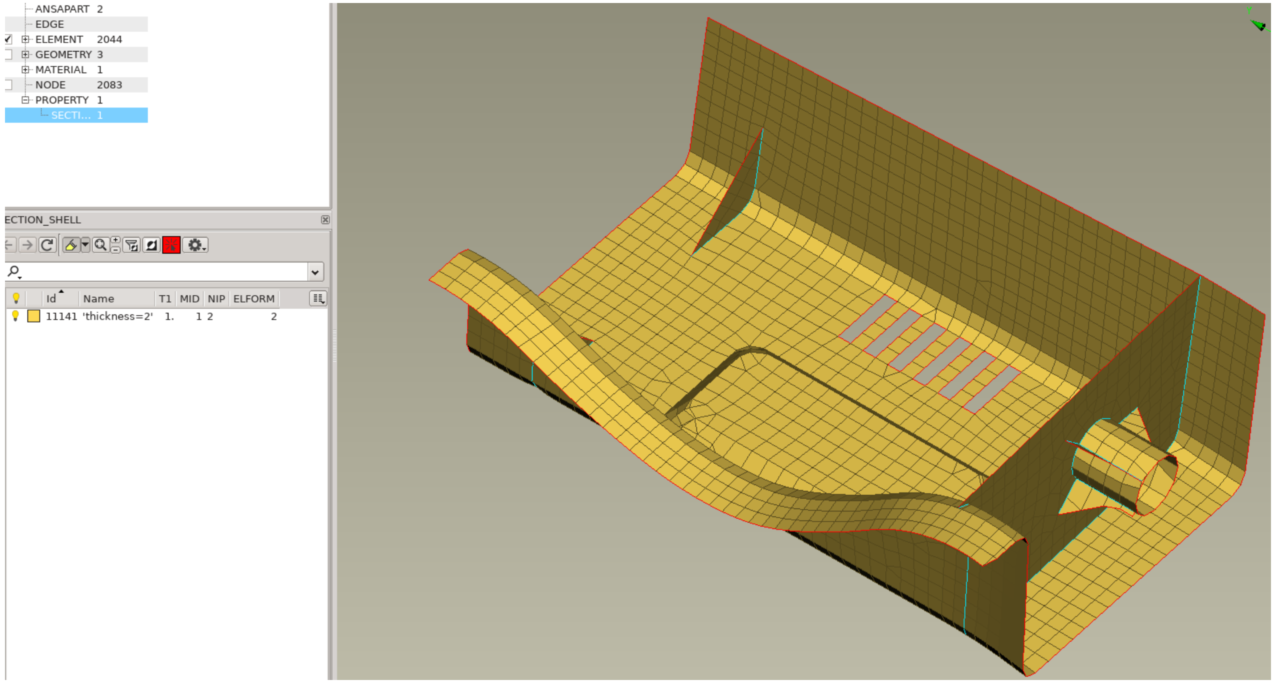
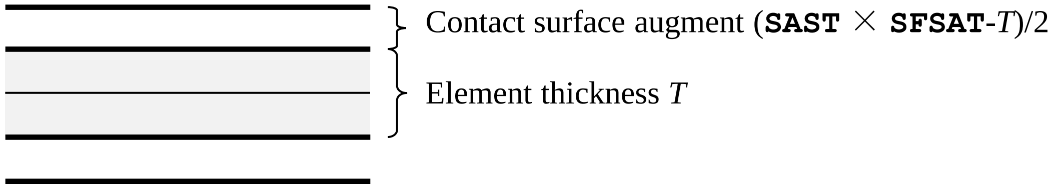


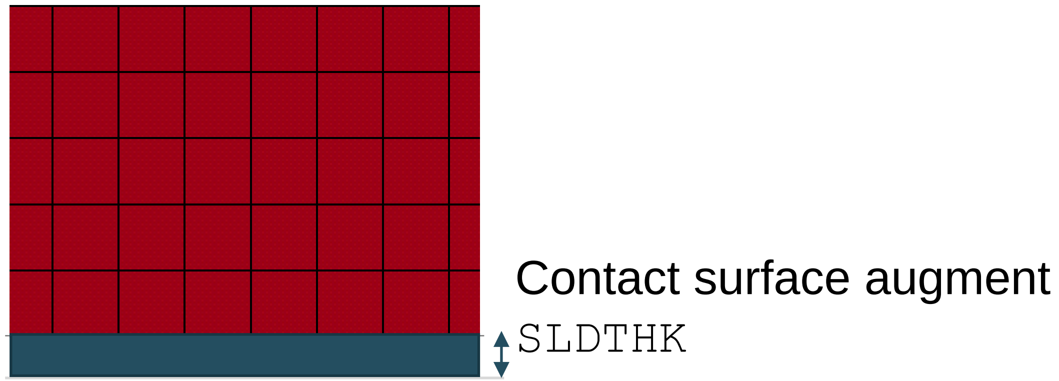
Output as one `*PART` and
`*ELEMENT_SHELL_THICKNESS`
Preferred for Mortar contact

Mortar contact

Modifying contact thickness

- May be useful in for example press-fit analyses
- For shells, the contact thickness may be modified using *SAST* and *SFSAT*
- For solids, the contact thickness may be augmented by
  - *SLDTHK* (Optional card B of the *CONTACT_ definition) may also be negative ...
- Separate contact thickness for shells may be specified using *PART_CONTACT and *OPTT*



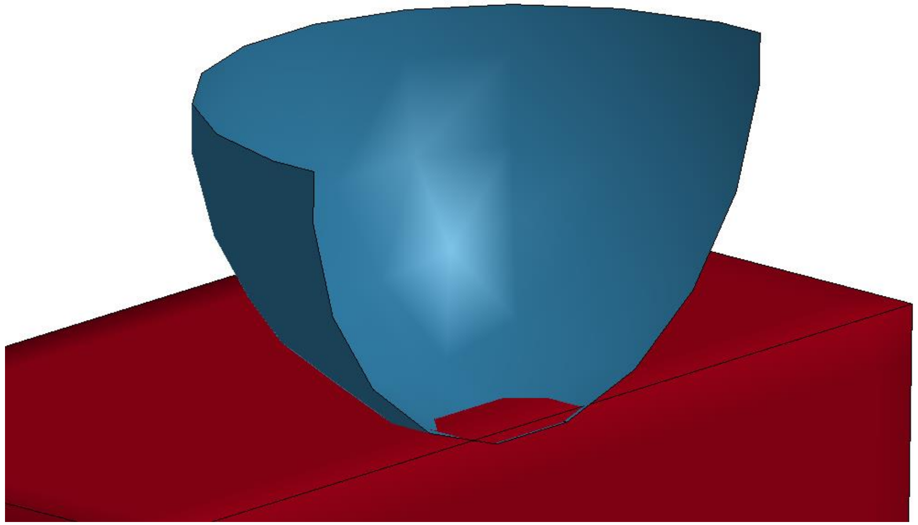


Contact thickness for shell elements may be augmented using SAST and SFSAT

Contact thickness for solids can be augmented using SLDTHK (may also be < 0).

Mortar contact

Initial penetrations



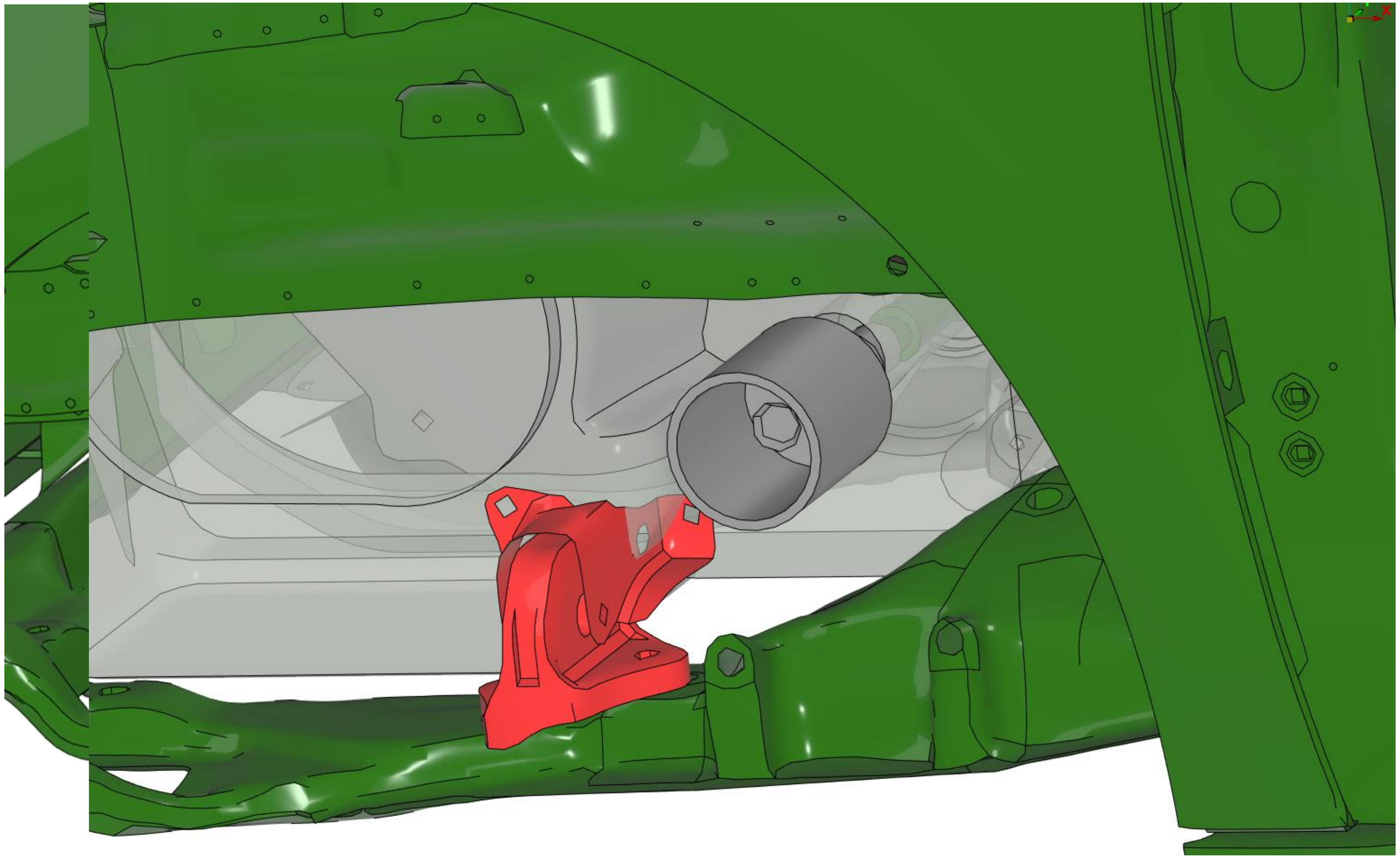
- Mortar contact always output initial penetrations in mes* file(s) and how they are treated
- **`IGNORE`** will handle initial penetrations

```
Mortar contact information for contact ID      1

Number of slave segments..............      360
Number of slave segments
connected to rigid shells.............        0
etc
.
Number of master segments.............      270
etc
.
*** Warning      19 number of initial penetrations

List of penetrated pairs to follow

Face of shell element 301 is penetrating
face of solid element 401 by 0.8919116E-02
etc
.

Maximum penetration is 0.9999999E-02 between
Elements 360 and 450

These penetrations will be tracked
```

Mortar contact

Initial penetrations

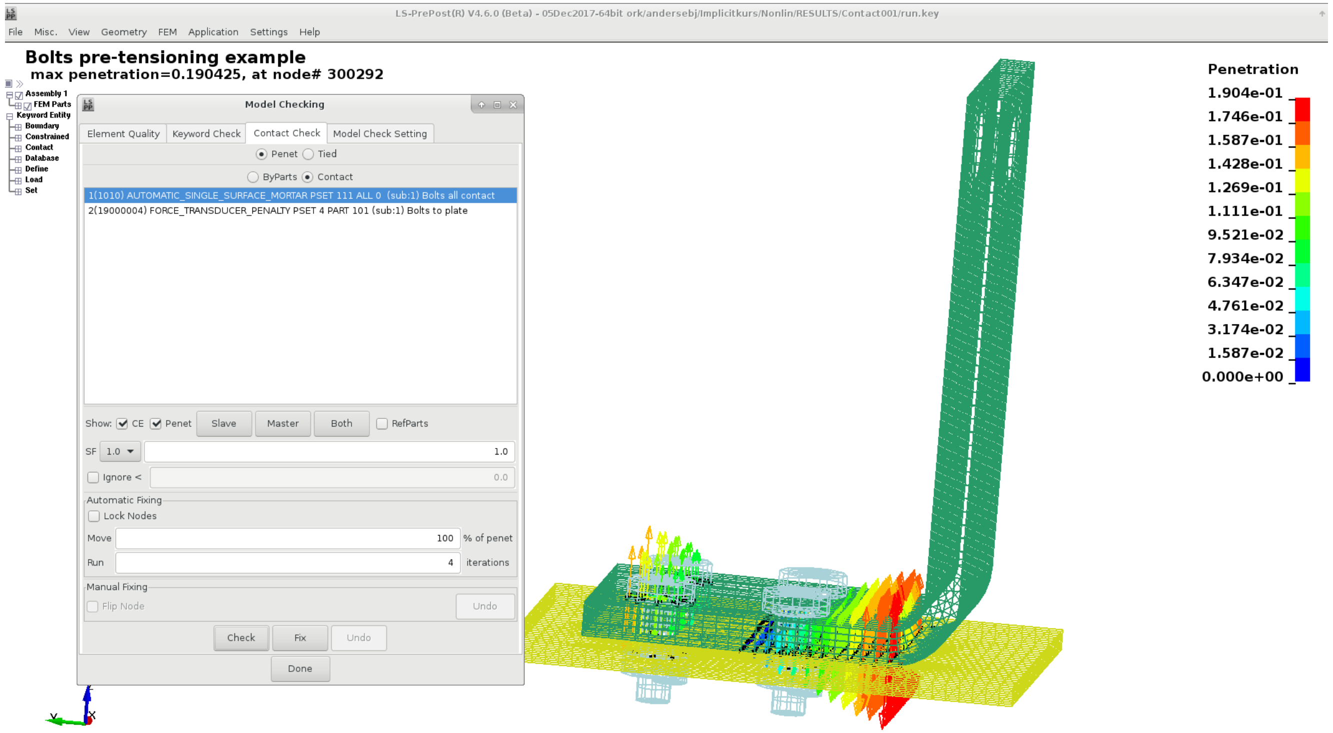
- Avoid unintended initial penetrations



Mortar contact

Initial penetrations

- Avoid unintended initial penetrations
  - Use LS-PrePost (or ANSA, or other pre-processor) to check and fix initial penetrations

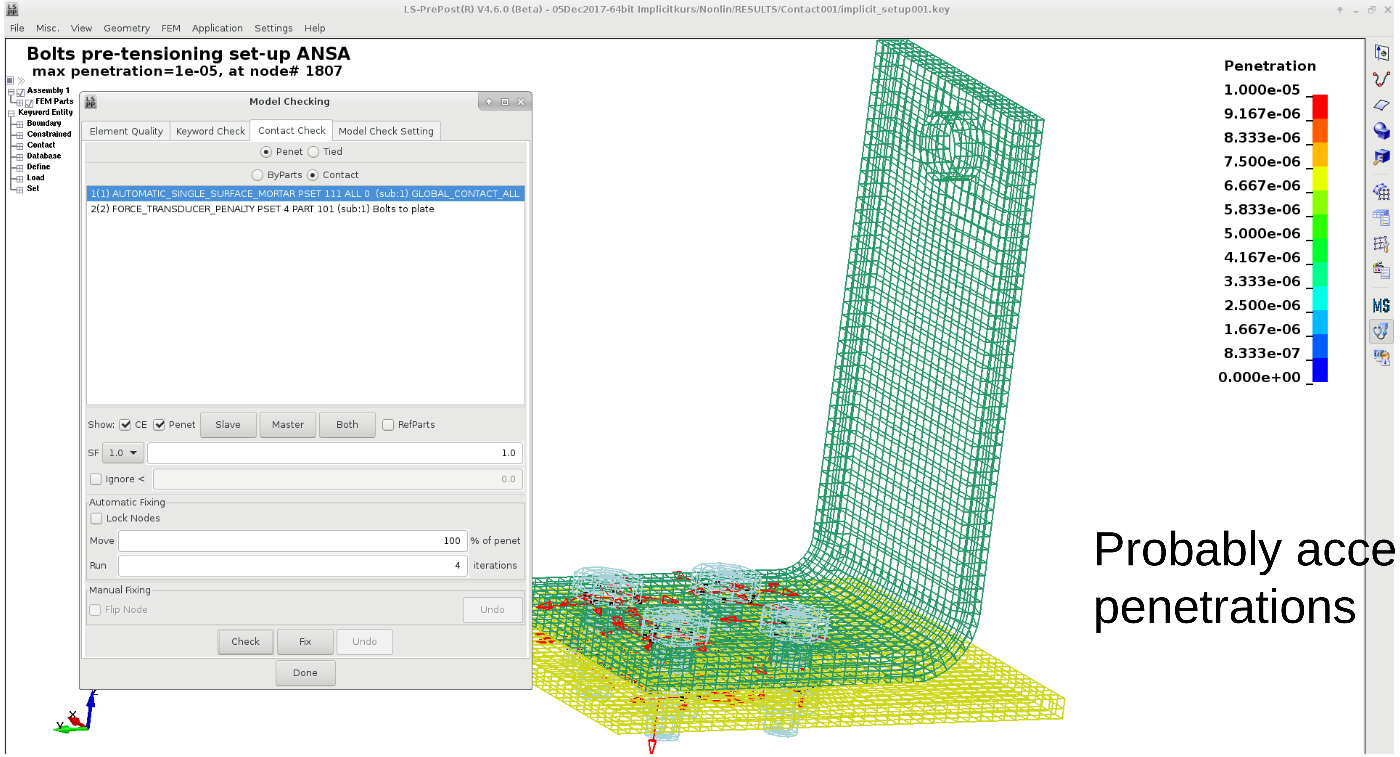


In LS-PrePost: Application>Model Checking>Contact Check

Mortar contact

Initial penetrations

- Avoid unintended initial penetrations
  - Use LS-PrePost (or ANSA, or other pre-processor) to check and fix initial penetrations



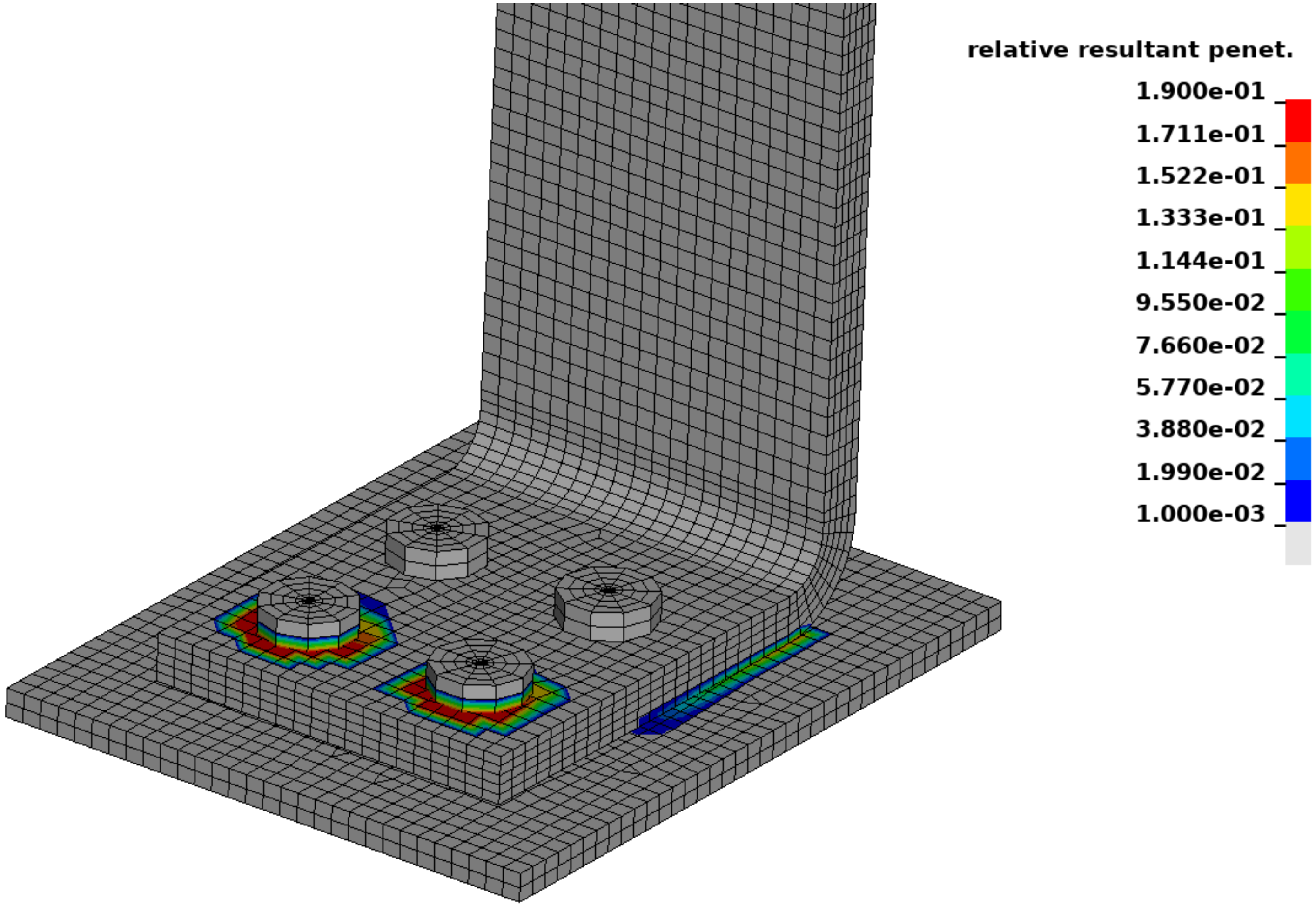
Probably acceptable penetrations

In LS-PrePost: Application>Model Checking>Contact Check

Mortar contact

(Initial) penetrations

- From R12, it is possible to visualize penetrations reported from the Mortar from d3plot/intfor and binout (sleout)
  - Set *PENOUT* = 2 on `*CONTROL_OUTPUT`



Mortar contact

Initial penetrations

Contact Optional Card C	IGAP	IGNORE	DPRFAC/ MPAR1	DTSTIF/ MPAR2	EDGEK		FLANGL	CID_RCF
Default	1	0	0.0	0.0	0.0		0.0	0

Ignored by Mortar contact

- IGNORE flag has partially *modified* meaning for Mortar contacts
  - IGNORE=1 initial penetrations ignored and tracked
  - IGNORE=2 initial penetrations ignored and tracked

    MPAR1 corresponds to initial contact pressure

    See next slide
  - IGNORE=3 initial moderate penetrations will be removed over time, e.g. for rubber press-fitting

    MPAR1 time of closure from time zero

    MPAR1<0 curve ID |MPAR1| defines relative penetration reduction over time

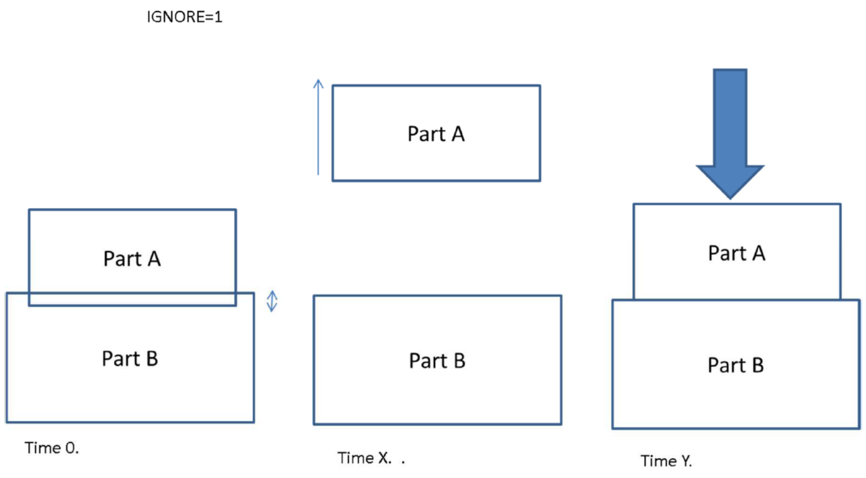
    may be used as alternative to interference contacts
  - IGNORE=4 same as 3, but for large penetrations

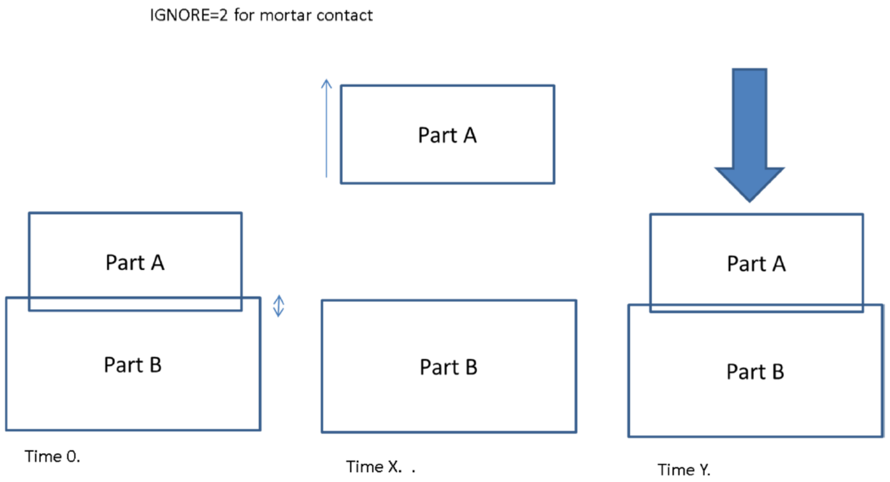
    MPAR2 Maximum initial penetration to resolve (at least the one occurring in the contact interface). Can only be used if the SURFA side consists of solid elements
  - IGNORE<0 same as |IGNORE| but ignore contact between segments belonging to same part, Main purpose are single surface contacts when eliminating initial penetrations by interference

Mortar contact

Initial penetrations

- This is controlled by the *IGNORE* option on *CONTROL_CONTACT or Optional card C of the contact.
  - *IGNORE* = 1, 2 ➔ No contact stress is applied, the "contact surface" (see figure) is modified





For *IGNORE* = 2, the contact surface is fixed at its initial location

Mortar contacts

Ignore options: IGNORE = -2

- A global single surface contact using part set
  - A case where self-contact within parts is neglected (which is OK in many quasi-static load cases)
  - All contacts between segments belonging to different Parts are still detected automatically

```
*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID
$#     cid                                                                 title
         2vehicle self contact
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
       100         0         2
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.2
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf

$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq

$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf

$#    igap    ignore     mpar1     mpar2    unused    unused    flangl   cid_rcf
                  -2
```

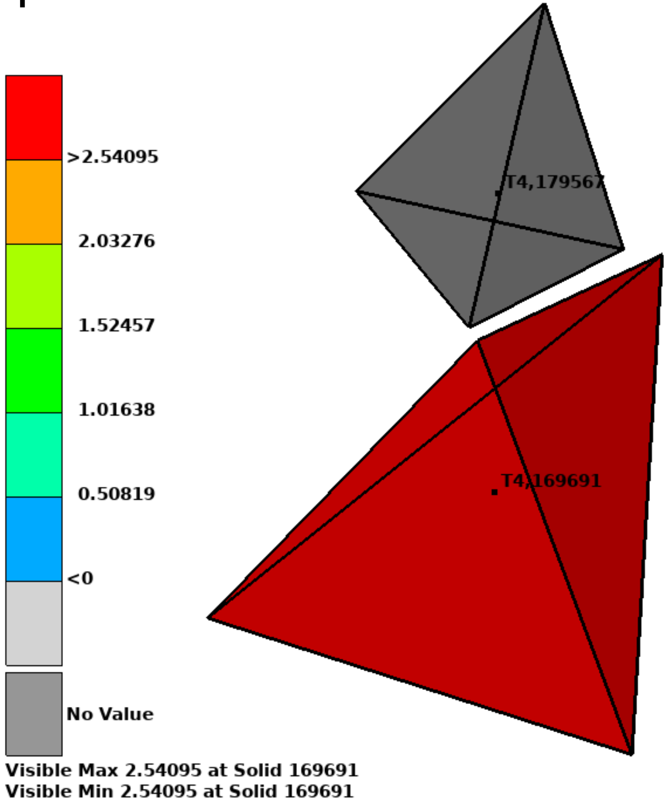
IGNORE < 0

Mortar contact

Initial penetrations

- In some cases, typically with coarse solid mesh of surfaces close to each other, the default search depth of the Mortar contact may be too large.
- This can typically be noted by that spurious penetrations are reported in the mes0* - files.
- In these cases, either
  - Give a reasonable search depth using `PENMAX`,
  - and/or change mesh size on the surfaces

```
Face of solid  element 169691 is penetrating
 face of solid element 179567 by 0.2540949E+01

 Face of solid element 169691 is penetrating
 edge of solid element 179567 by 0.2512578E+01
```



Mortar contact

Initial penetrations

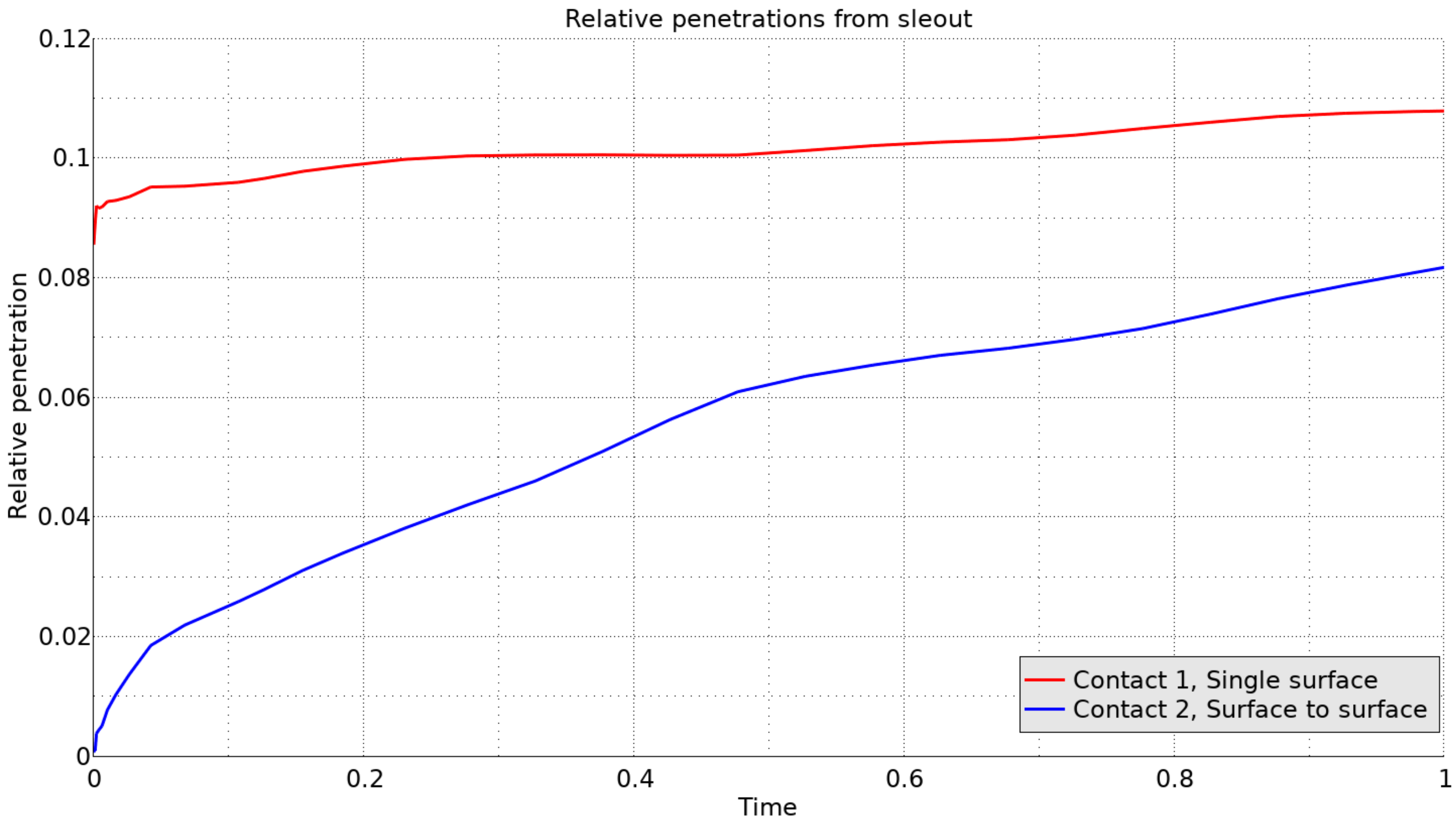
- It is good practice to inspect the `mes00*` - files and check for penetration messages once the simulation gets started.
  - For example:

```
 Contact sliding interface        151
 Number of contact pairs        80179

 Maximum penetration is  0.1686677E-17 between
 elements     515944 and     493946 on this processor

 Maximum relative penetration is  0.6337536E+00 % between
 elements     515944 and     493946 on this processor

BEGIN implicit dynamics step      1 t= 1.0000E-02            02/04/20 21:15:17
============================================================
```

Mortar contact

Initial penetrations

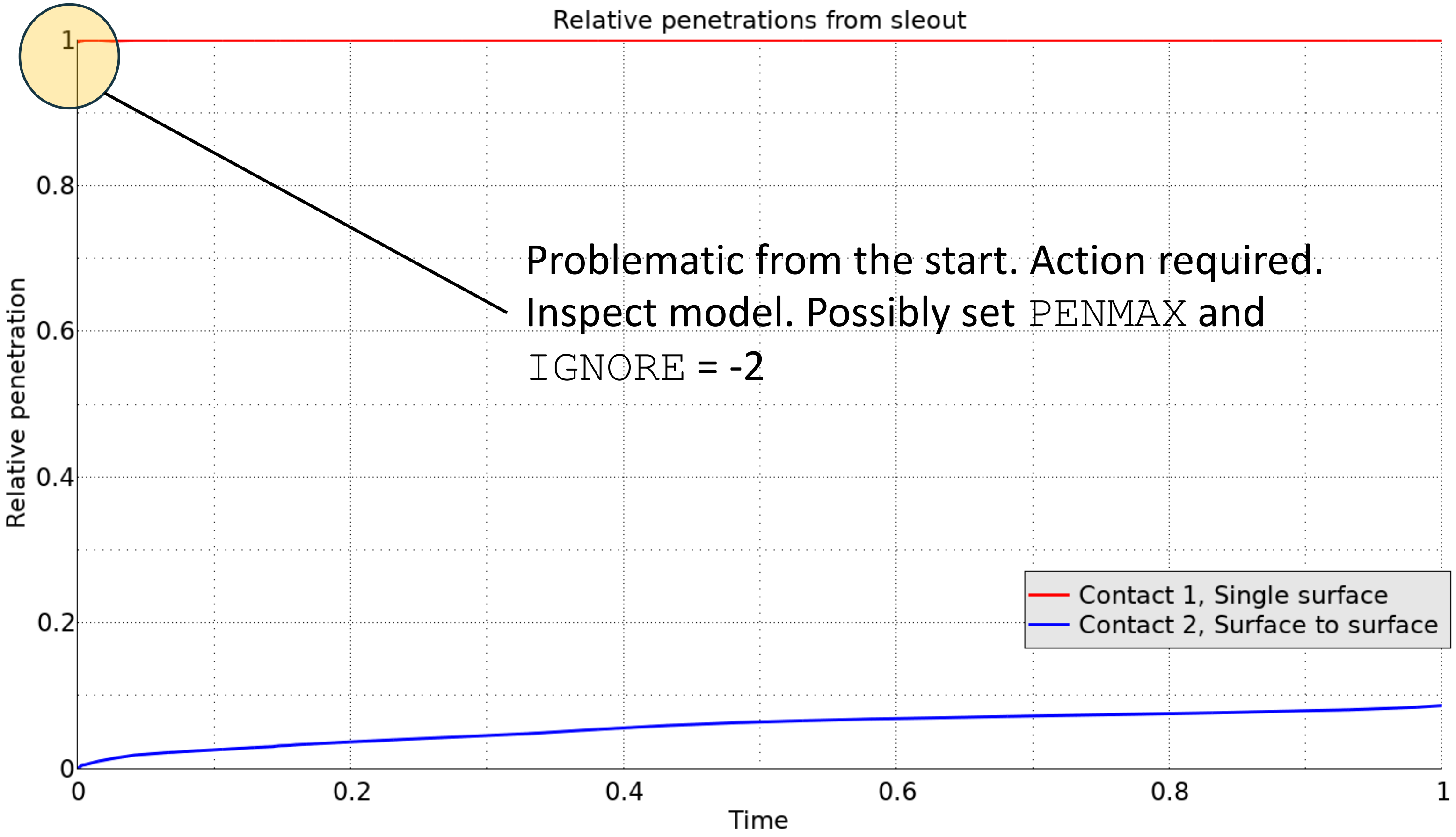
- It is convenient to track the evolution of penetrations if the *PENOUT* – option is active on `*CONTROL_OUTPUT`
  - History plot from `sleout`
  - For example:



Mortar contact

Initial penetrations

- It is convenient to track the evolution of penetrations if the *PENOUT* – option is active on `*CONTROL_OUTPUT`
  - For example:



Mortar contact

Penetration information in mes* file(s)

- Number of contact pairs
- Maximum penetration, absolute and relative, and elements where this penetration occurs
- Warning if contact is about to release

Number of pairs

```
    Contact sliding interface          1
    Number of contact pairs        16209

    Maximum penetration is  0.5027372E+00 between
    elements     219492 and      94935 on this processor

    Maximum relative penetration is  0.1005474E+03 % between
    elements     219492 and      94935 on this processor
*** Warning Penetration is close to maximum before release

    Contact sliding interface          2
    Number of contact pairs        11932

    Maximum penetration is  0.5007380E+00 and occurs
    on some other processor

    Maximum relative penetration is  0.1001476E+03 % and occurs
    on some other processor
*** Warning Penetration is close to maximum before release

    Contact sliding interface          3
    Number of contact pairs            0

    Contact sliding interface          4
    Number of contact pairs          776

    Maximum penetration is  0.3886436E+00 between
    elements     205048 and     224238 on this processor

    Maximum relative penetration is  0.7772871E+02 % between
    elements     205048 and     224238 on this processor
```

```
Contact sliding interface          5
Number of contact pairs          981

Maximum penetration is  0.3835662E+00 and occurs
on some other processor

Maximum relative penetration is  0.7671323E+02 % and occurs
on some other processor

Contact sliding interface          7
Number of contact pairs           62

Maximum penetration is  0.1375767E+00 and occurs
on some other processor

Maximum relative penetration is  0.2751534E+02 % and occurs
on some other processor

Contact sliding interface          8
Number of contact pairs           24

Maximum penetration is  0.5608894E-01 and occurs
on some other processor

Maximum relative penetration is  0.1121779E+02 % and occurs
on some other processor
```

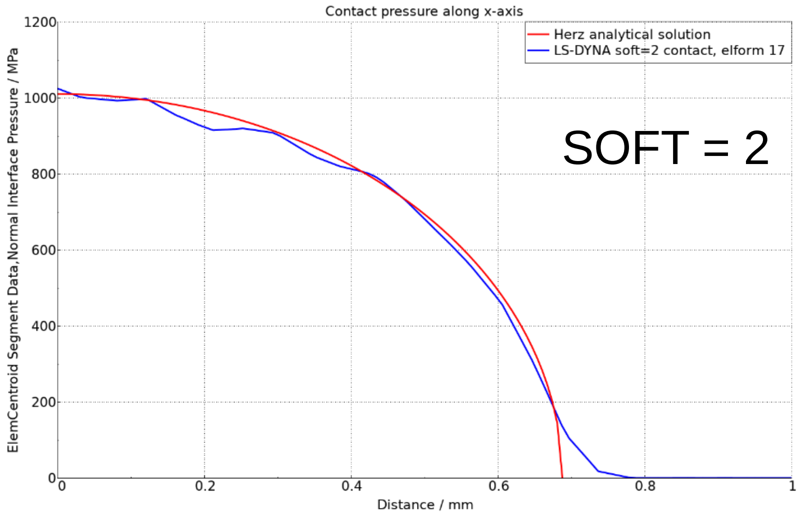
Warnings

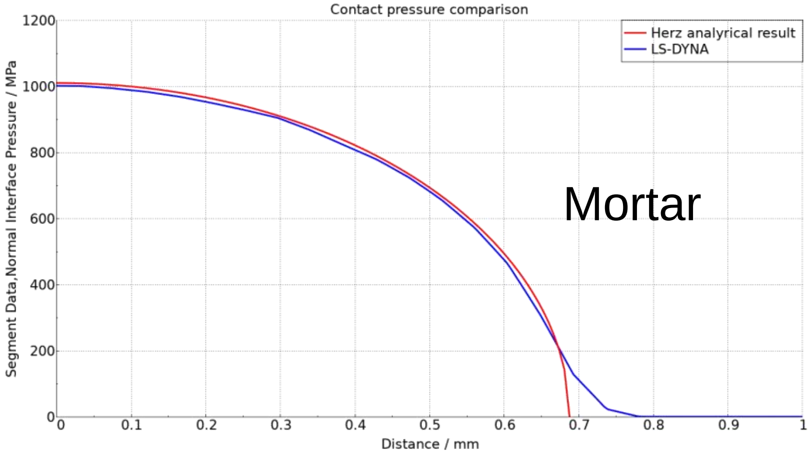
Penetrations

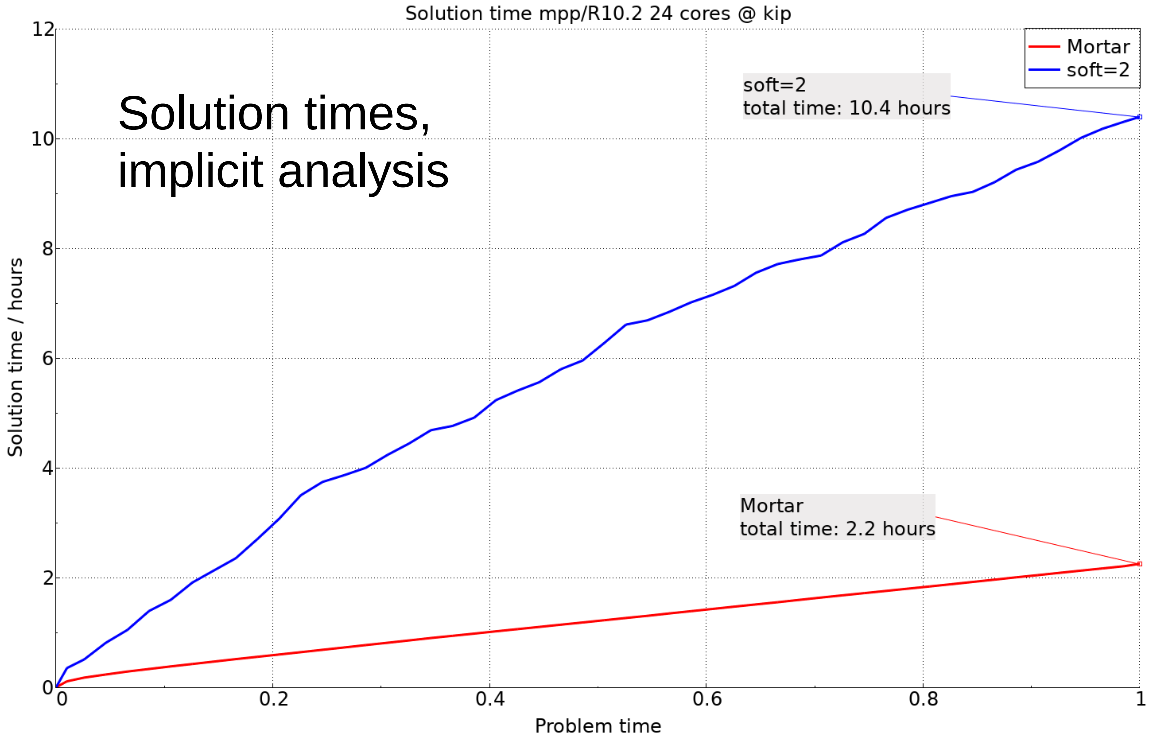
Mortar contact

Motivation (for implicit)

- Comparison to analytical (Herz) solution and “explicit” SOFT=2 contact







Non-Mortar contacts

Other contact types

Sliding contacts

Using non-Mortar contacts

- All contact types are available for explicit and implicit analysis, e.g.

```
*CONTACT_SURFACE_TO_SURFACE
*CONTACT_NODES_TO_SURFACE
*CONTACT_ONE_WAY_SURFACE_TO_SURFACE
```

family of **three**

`*CONTACT_FORMING_…` — **three** variations

`*CONTACT_AUTOMATIC_…` — **three** variations

```
*CONTACT_AUTOMATIC_SINGLE_SURFACE
*CONTACT_AUTOMATIC_BEAMS_TO_SURFACE
*CONTACT_AUTOMATIC_GENERAL
*CONTACT_2D_AUTOMATIC_…
```

`*CONTACT_…_THERMAL` — for coupled **thermal-mechanical** analysis

`*CONTACT_…_INTERFERENCE` — **interference** fit between parts

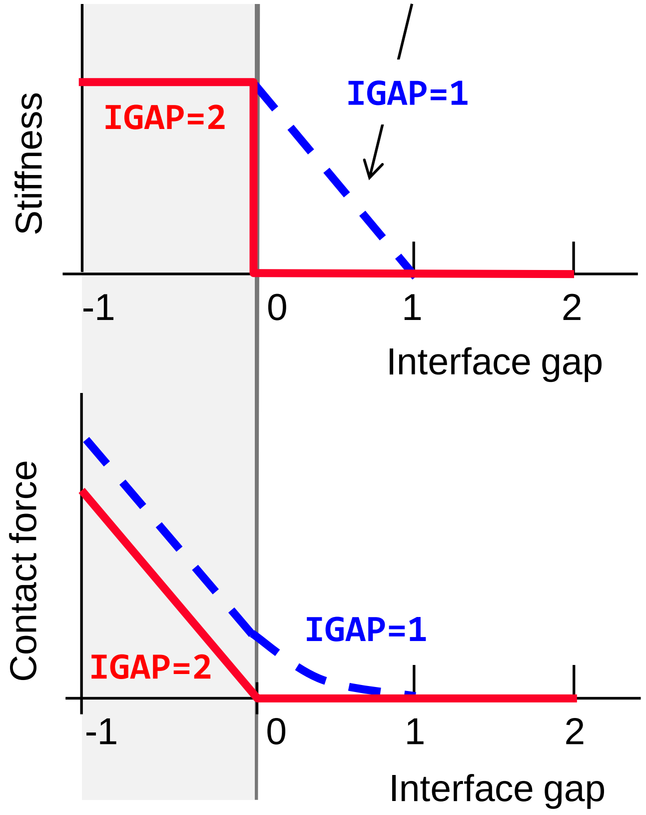
`*CONTACT_DRAWBEAD` — metal stamping

IGAP

- `IGAP` controls treatment of nodes which are *close*
  - `IGAP<0` Like `IGAP=1`, except distance between interfaces for sticky contact is scaled by `|IGAP|/10`
  - `IGAP=1` Apply method to improve convergence default in implicit
  - `IGAP=2` No sticky contact
  - `IGAP>2` Set `IGAP=1` for first `IGAP-2` steps, then set `IGAP=2`

- `IGAP` can improve convergence at the expense of
  - producing a *sticky* contact, that will resist opening of the contact gap
  - possibly under-reporting the contact force magnitude

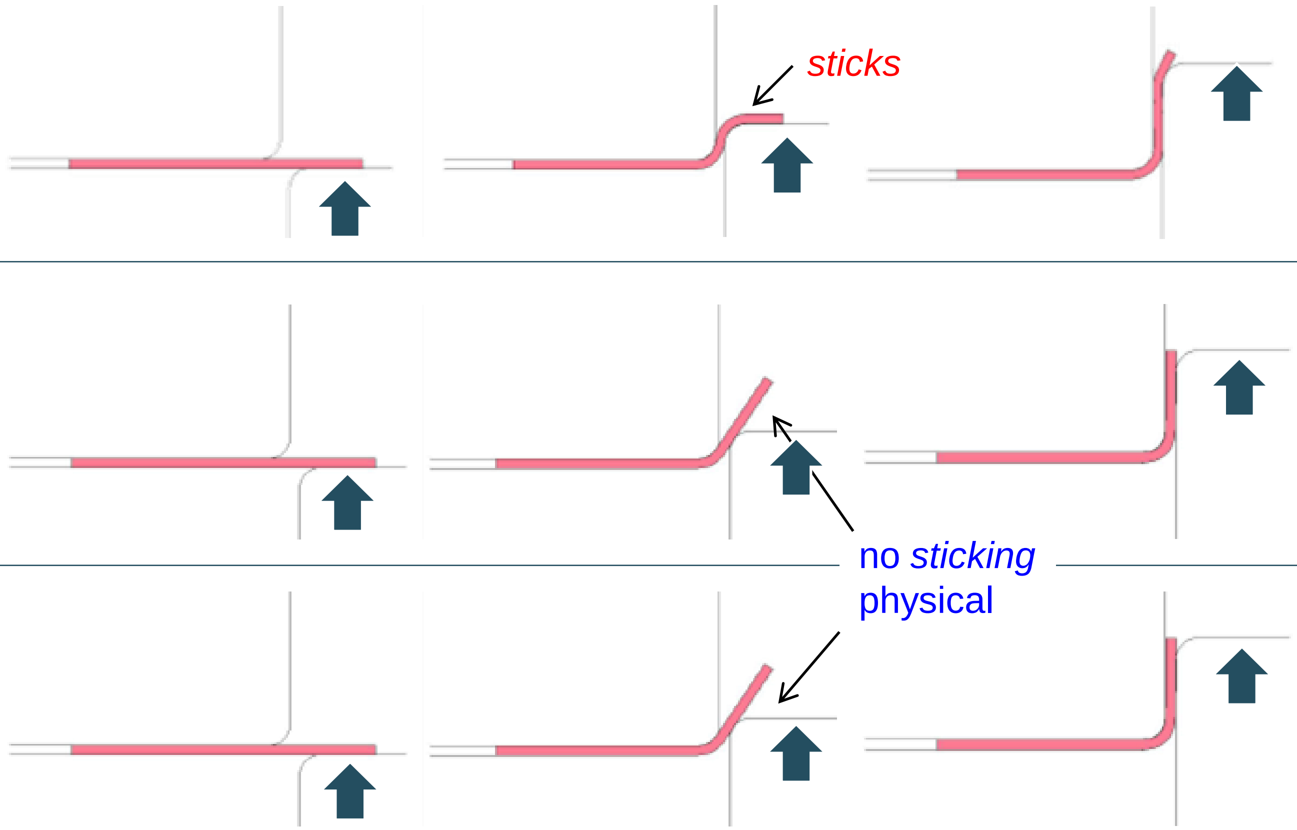
Stiffness terms are added before there actually is contact. When contact is established the stiffness is 100%.




```
*** Warning 60303 (IMP+303)
    Using IGAP=1 may result in zero contact forces.
    If this occurs set IGAP=2.
```

Flanging problem example

“Standard” explicit contact vs. Mortar



	Normalized runtime	
Standard contact with `IGAP=1`	1.0	Improved convergence but loss of accuracy
Standard contact with `IGAP=2`	5.7	Accurate but difficult convergence
Mortar contact	1.6	Accurate and good convergence

Pressfit

Resolving intended penetrations

Press-fit

Mortar contact, *IGNORE* = 3 and 4

- Intended initial penetration corresponding to the grip between the parts
  - Possible to parametrize using *OPTT*, *SAST*, *SFSAT*, *SLDTHK*
- Two options for Mortar contact
  - *IGNORE* = 3
    - Resolve a press fit based on the standard contact search parameters
      - For moderate penetrations
    - Time when penetration should be resolved (using a linear ramp) is given by *MPAR1*
      - For a user-specified curve, set *MPAR1 = -1*LCID*
    - Only option if both *SURFA* and *SURFB* are shell parts
  - *IGNORE* = 4
    - Specify a custom search depth for finding the penetrations using *MPAR2*
      - *Since the default search depth will not find penetrations below PENMAX/2*
    - Requires *SURFA* to be a solid part

Press-fit

Mortar contact, *IGNORE* = 3

- Mortar example for small penetration / press-fit

```
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_ID
$#     cid                                                                 title
      1010Pressfit
$#   surfa     surfb  surfatyp  surfbtyp   saboxid   sbboxid      sapr      sbpr
         5         4         3         3         0         0         1         1
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.1
$#    sfsa      sfsb      sast      sbst     sfsat     sfsbt       fsf       vsf

$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq

$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf

$#    igap    ignore     mpar1     mpar2     edgek    unused    flangl   cid_rcf
                   3       1.0
```

MPAR1 is the time when the press-fit should be resolved using a linear ramp.
Or *MPAR1=-1*LCID* for user-specified curve.

Set *IGNORE* = 3 for "small" interference

Press-fit

Mortar contact, *IGNORE* = 4

- Mortar example for large penetration / press-fit

```
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_ID
$#     cid                                                                 title
      1010Pressfit
$#   surfa     surfb  surfatyp  surfbtyp   saboxid   sbboxid      sapr      sbpr
         5         4         3         3         0         0         1         1
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.1
$#    sfsa      sfsb      sast      sbst     sfsat     sfsbt       fsf       vsf

$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq

$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf
       3.0
$#    igap    ignore     mpar1     mpar2     edgek    unused    flangl   cid_rcf
                   4       1.0       3.0
```

PENMAX may require modification

MPAR2 is the search distance

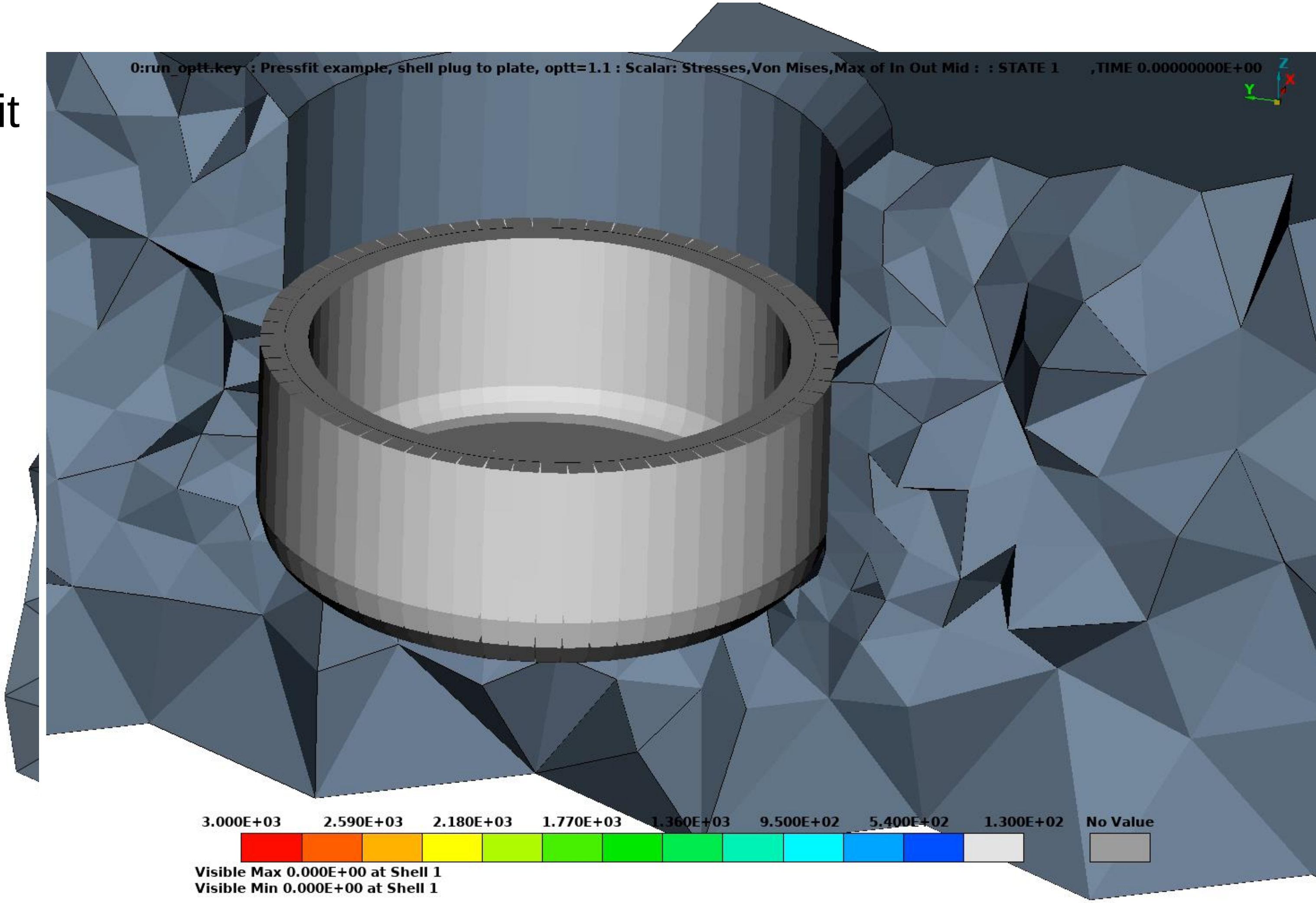
MPAR1 is the time when the press-fit should be resolved

Set *IGNORE* = 4 for “finite” interference

Press-fit

Mortar contact, $IGNORE = 3$

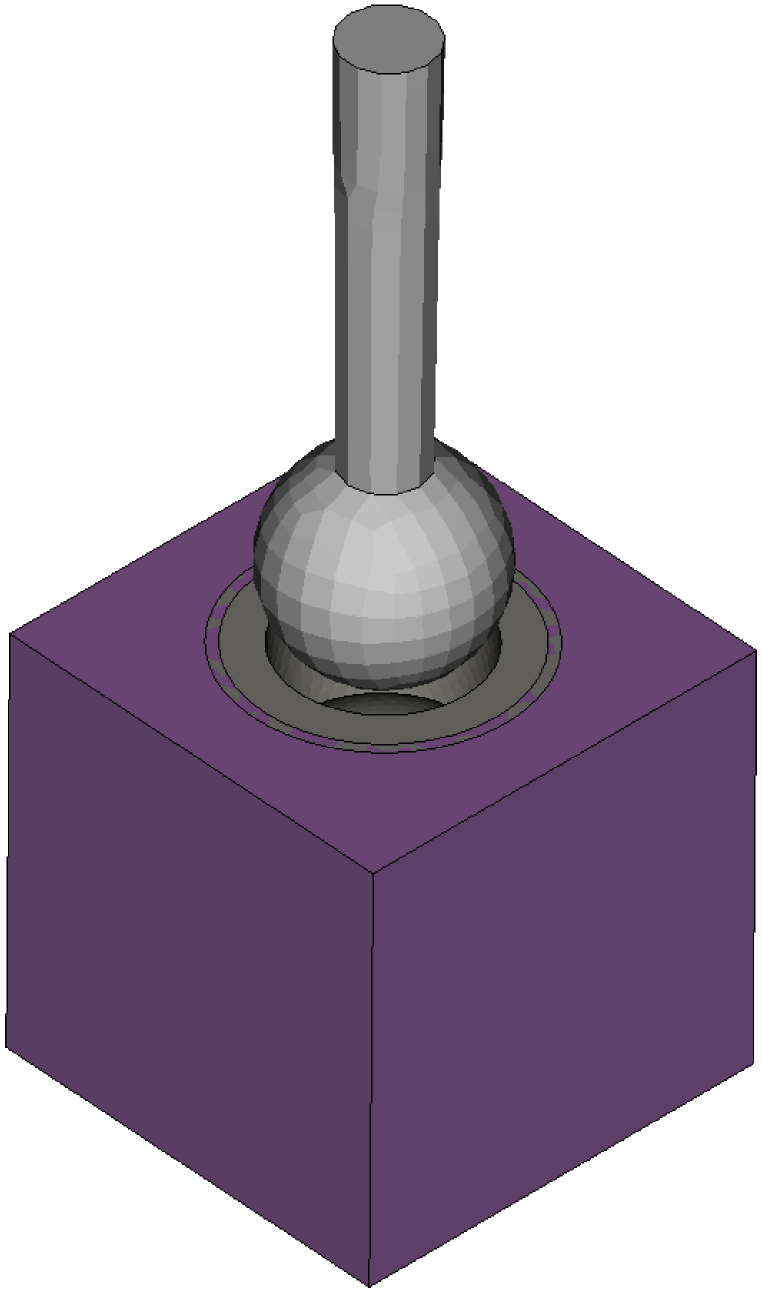
- Mortar example for ($IGNORE = 3$) press-fit
- Shell element plug, $\varnothing \approx 12$ mm.
  Radial grip 0.1 mm
- Thickness 1.1 mm



Press-fit

Mortar contact, *IGNORE* = 4

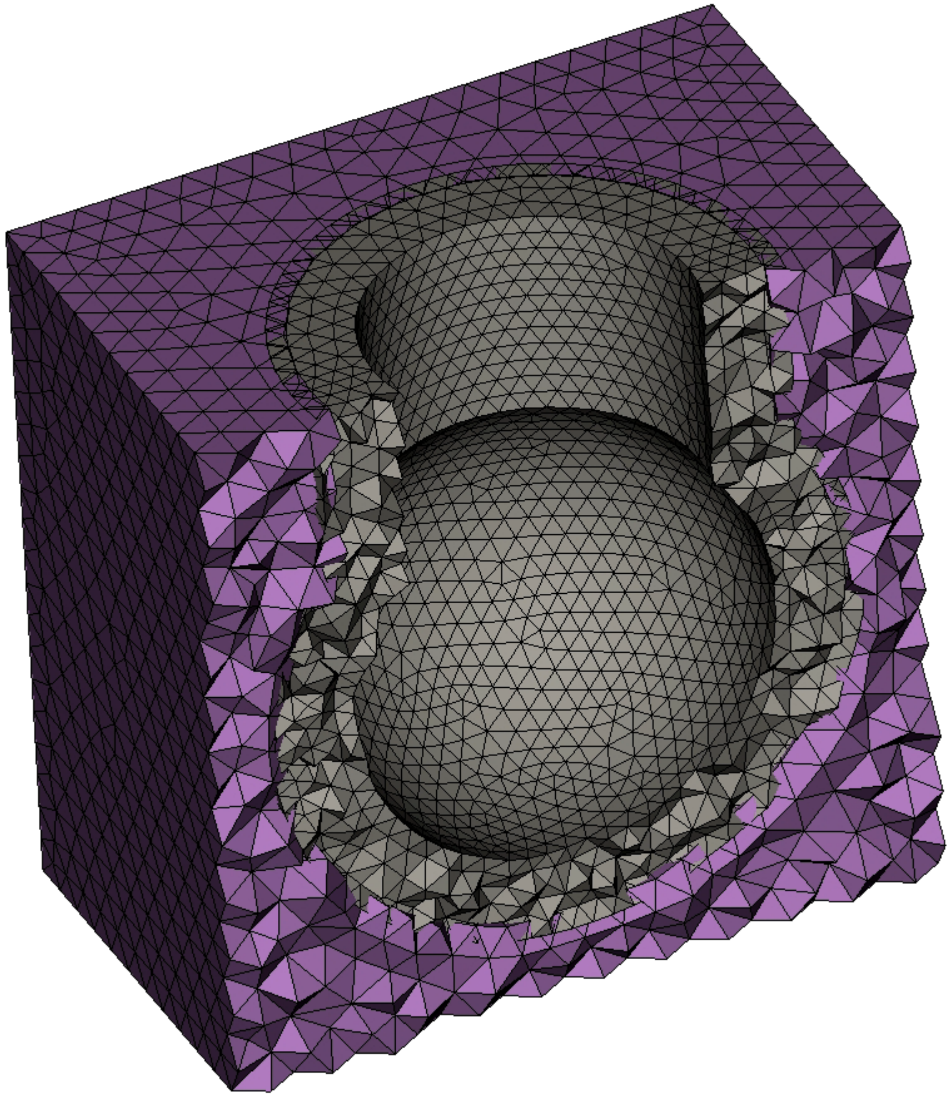
- Mortar example for large penetration (*IGNORE* = 4) press-fit
  - ~2.7 mm penetration, vs. mesh size 3 mm



Press-fit

Mortar contact, *IGNORE* = 4

- Mortar example for large penetration (*IGNORE* = 4) press-fit
  - Purple part = Rigid
  - Gray = Rubber `(MAT_77)`



Press fit

*CONTACT_SURFACE_TO_SURFACE_INTERFERENCE

- In some cases, for press-fit (often "large" penetrations, *IGNORE* = 4) analyses using the Mortar contact may run into (convergence) problems.
- An option to try out is then

```
*CONTACT_SURFACE_TO_SURFACE_INTERFERENCE_ID
$#     cid                                                                 title
      1010Pressfit
$#   surfa     surfb  surfatyp  surfbtyp   saboxid   sbboxid      sapr      sbpr
         5         4         3         3         0         0         1         1
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.1
$#    sfsa      sfsb      sast      sbst     sfsat     sfsbt       fsf       vsf

$#   lcid1     lcid2
         0      1014
$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq

$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf
       1.0         1         2
$#    igap   ignodprfac/mpadtstif/mpar2   unused    unused    flangl   cid_rcf
         2
```

Curve for scaling penalty stiffness. Start at (0., 0.) end at (t, 1.)

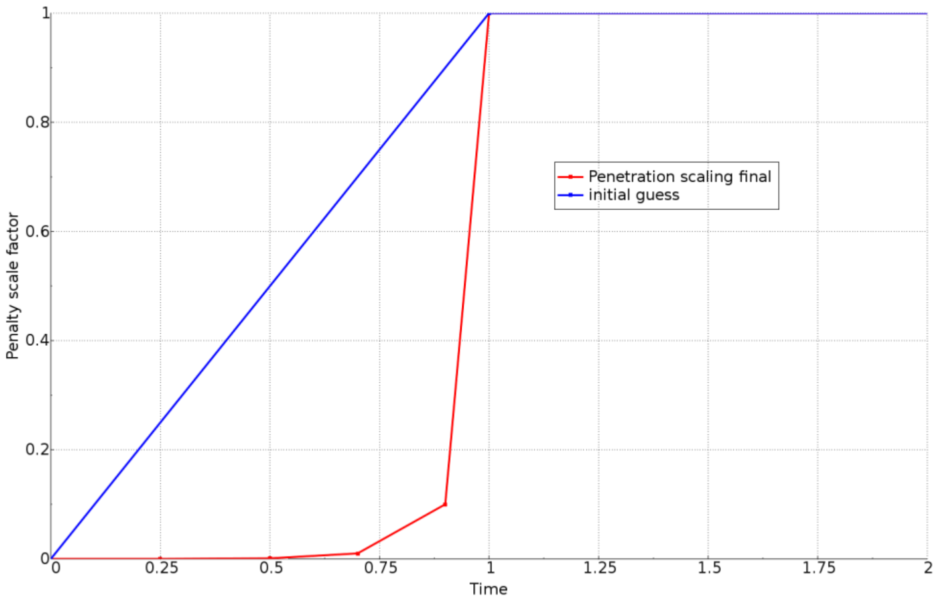
Activate shell thickness

Set *IGAP* = 2 to disable "sticky" contact

Press-fit

*CONTACT_SURFACE_TO_SURFACE_INTERFERENCE

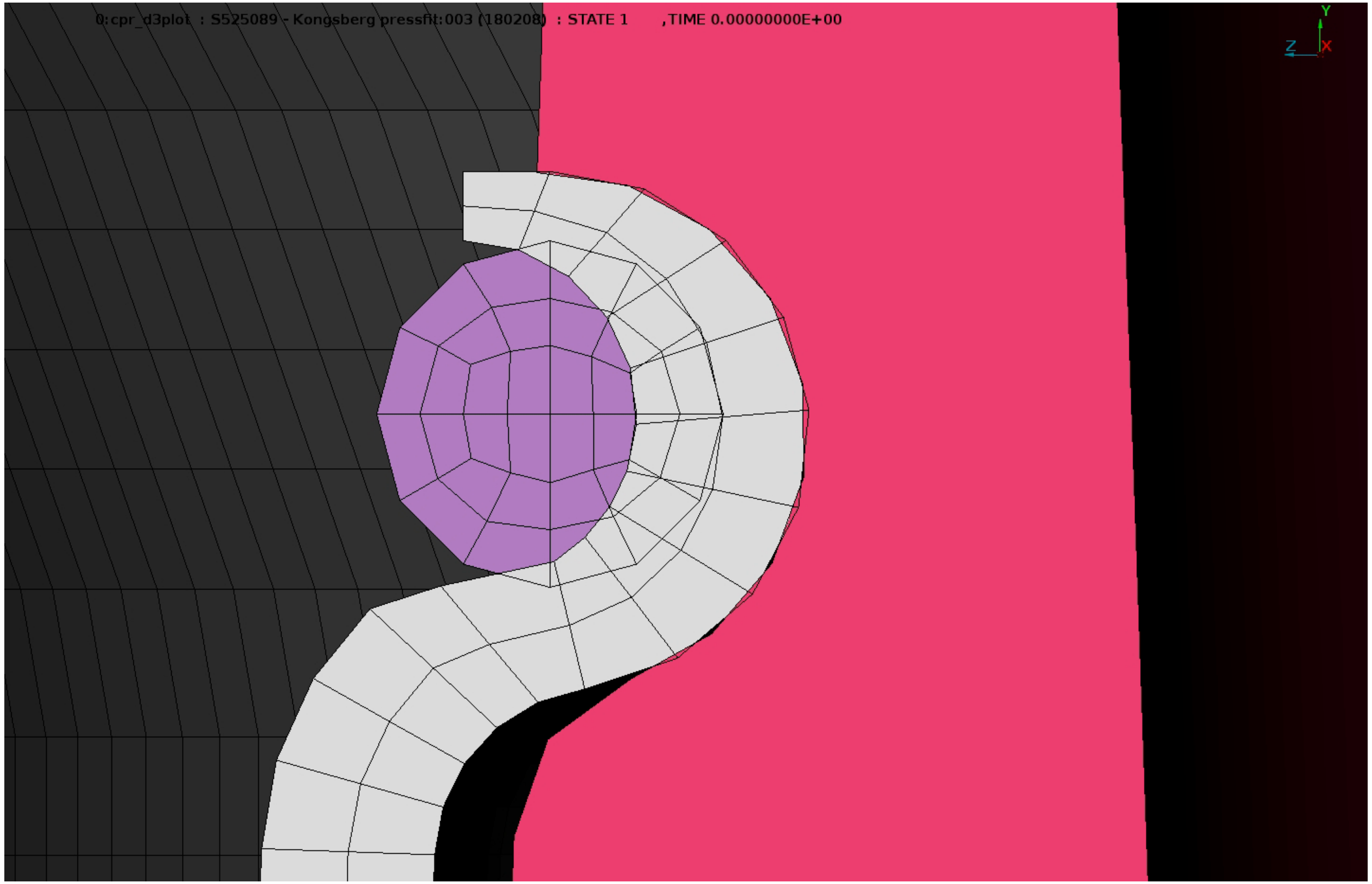
- A curve - starting at (0., 0.) – should be provided for scaling the penalty stiffness up to 1.
  - May need some iterations to find the “right” curve. Start with linear ramp



- This contact has the “sticky” option on by default. Set *IGAP* = 2 to disable.
  - Non-Automatic, requires activation of shell thickness

Press-fit

*CONTACT_SURFACE_TO_SURFACE_INTERFERENCE example



Tied contacts

Tied contacts

Recommendations

*CONTACT_TIED_	Constraint formulation	DOFs	Move nodes[1]	Moment transferred[2]
NODES_TO_SURFACE	Kinematic	1 – 3	Yes	
NODES_TO_SURFACE_OFFSET	Penalty	1 – 3	No	No
NODES_TO_SURFACE_CONSTRAINED_OFFSET	Kinematic	1 - 3	No	Yes
SHELL_EDGE_TO_SURFACE	Kinematic	All	Yes	
SHELL_EDGE_TO_SURFACE_OFFSET	Penalty	All	No	No
SHELL_EDGE_TO_SURFACE_BEAM_OFFSET	Penalty	All	No	Yes
SHELL_EDGE_TO_SURFACE_CONSTRAINED_OFFSET	Kinematic	All	No	Yes

- For contacts involving structural elements / 6 DOFs, use
  - `*CONTACT_TIED_SHELL_EDGE_TO_SURFACE_ID`
  - `*CONTACT_TIED_SHELL_EDGE_TO_SURFACE_BEAM_OFFSET_ID`
- For maximum control, use a node set as `SURFA` (`SURFATYP` = 4)
  - Carefully check which nodes get tied, using for example LS-PrePost (Check > Contacts > From solver in ANSA)
- Main application of `*CONTACT_..._MORTAR_TIED` is troubleshooting convergence issues
- Setting *IPBACK* = 1 may be beneficial for avoiding loose parts ...

Tied contacts

IPBACK = 1

- Setting *IPBACK* = 1 may be beneficial for avoiding loose parts ...

```
*CONTACT_TIED_SHELL_EDGE_TO_SURFACE_ID
$#     cid                                                                 title
          1SPOTWELD CONTACT with ipbak
$#   surfa     surfb  surfatyp  surfbtyp   saboxid   sbboxid      sapr      sbpr
         3         9         2         2
$#      fs        fd        dc        vc       vdc    penchk        bt        dt

$#    sfsa      sfsb      sast      sbst     sfsat     sfsbt       fsf       vsf
       0.0       0.0      -0.9      -0.9       0.0       0.0       0.0       0.0
$# 4

$# A

$# B

$# C

$# D                     ipbak
                           100
```

LS-DYNA will auto-create a penalty based tied contact for the nodes that fail to get tied due to conflicting constraints

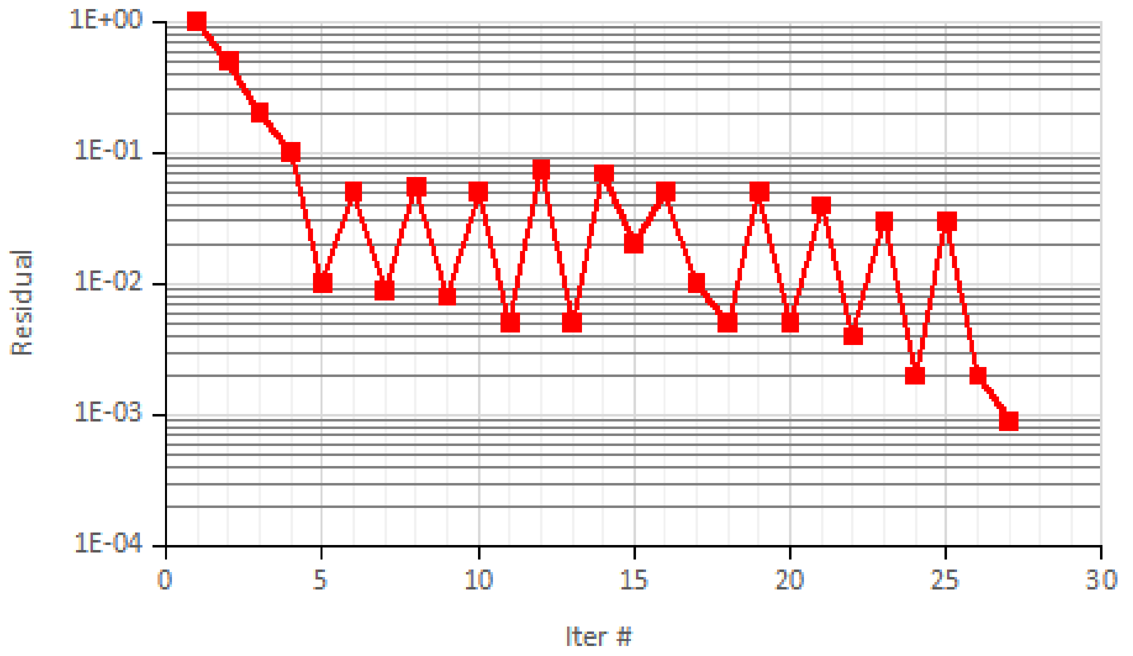
Troubleshooting convergence

Related to contact

Troubleshooting convergence

Related to contacts

- An oscillating residual norm may be an indication of a convergence problem caused by contacts
  - One iteration close to converge, the next norms are orders of magnitude higher, and then close to converge again, and so on
  - Check d3hsp / mes0* files
- RETRY due to contact problems




```
Contact algorithm rejected current iterate,
list of element pairs affected follows (at most 10):

    Element #          47052 vs          58986

------------------------------------------------------------
     automatic time step size DECREASE, RETRY step:
```

Problematic element IDs listed: inspect model, check d3iter and d3plot files

Troubleshooting convergence

Related to contacts

- Avoid unintended initial penetrations
  - Check and fix penetrations in for example LS-PrePost
  - Check reported initial penetrations in mes0* - file(s)
- Spurious initial penetrations
  - Adjust `PENMAX`
  - Set `IGNORE` = -2 on `*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR`
- If you <u>suspect</u> that problems with the contacts is causing convergence issues, you can try
  - switching to tied contacts. Just add `_TIED` to `*CONTACT_AUTOMATIC_..._MORTAR`
  - reduce contact stiffness (`SFSA`)
  - Note! Only a step in the troubleshooting process, not a permanent fix!

Troubleshooting convergence

Related to contacts

- If the assembly is only connected via pre-tension and sliding contacts, it will contain rigid body modes
  - Check for

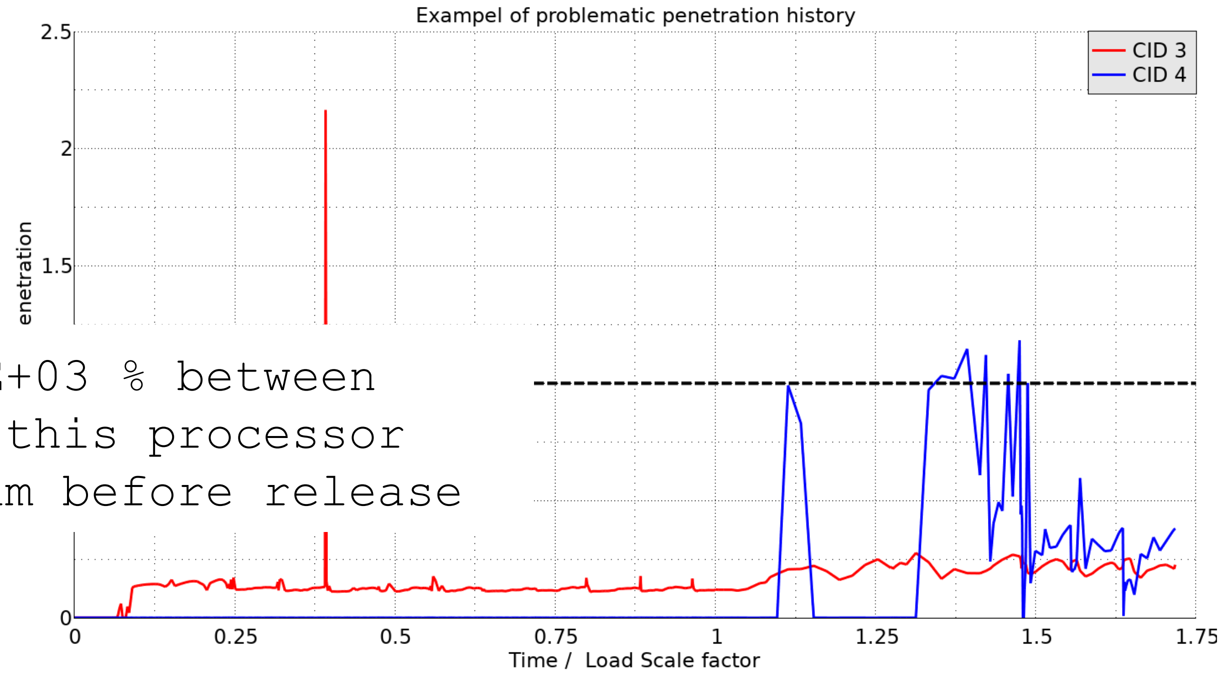
```
*** Warning 60124 (IMP+124)
      2 negative eigenvalues detected
     36 t 2.0000E-03 dt 2.00E-03 write d3iter file            02/02/18 21:12:51
```

- To overcome this, activate implicit dynamics (initially)
  - Set `IMASS` = 1 on `*CONTROL_IMPLICIT_DYNAMICS`
  - Ramp down dynamic effects using `TDYBUR` and `TDYDTH`
  - Note! For implicit dynamics, use a physical time scale for load application
    - For example 1000 ms or 10 s

Troubleshooting convergence

Related to contacts

- Contact release can cause severe convergence problems
  - Look for relative penetrations > 1
  - in `mes0*` files:




```
Maximum relative penetration is  0.1268843E+03 % between
     elements     162548 and     162861 on this processor
 *** Warning Penetration is close to maximum before release
```

  - Try increase IGAP to avoid contact release

Troubleshooting convergence

Related to Mortar single surface contacts

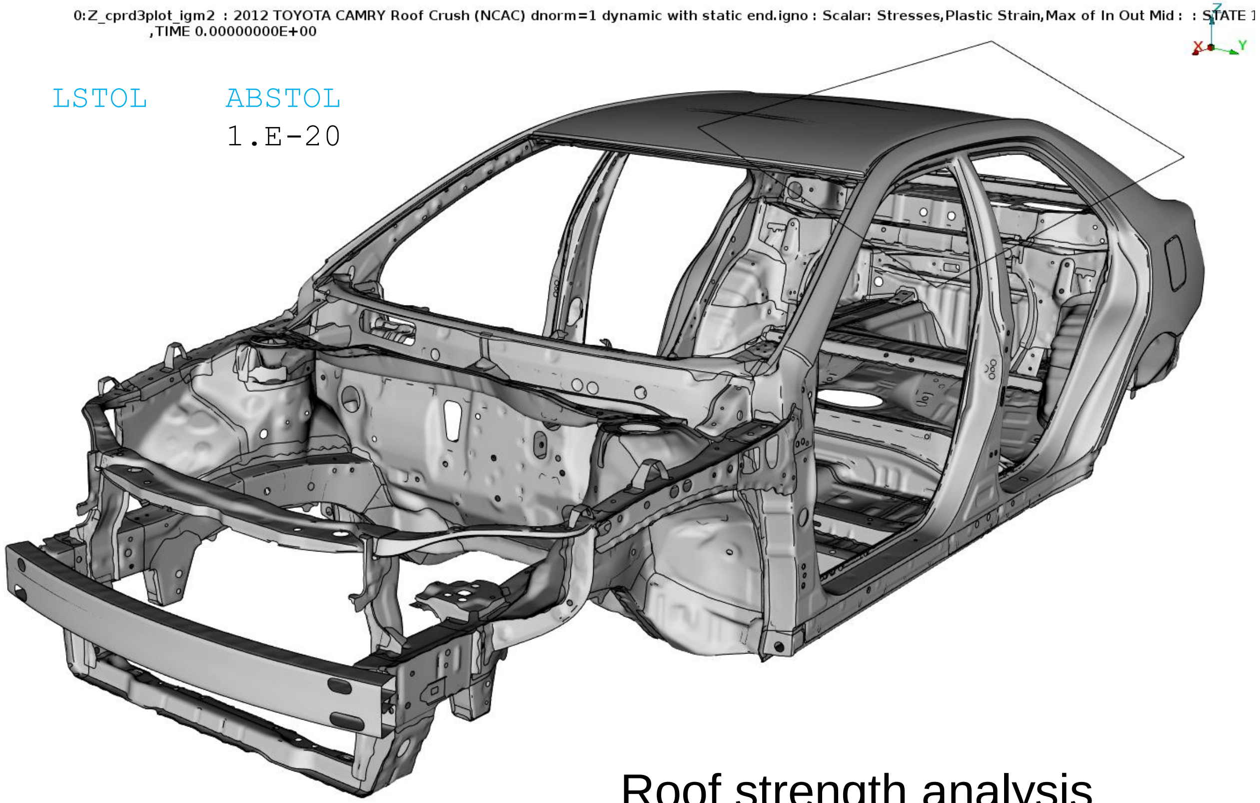
- If self-contact within the same part can be neglected, set *IGNORE* = -2 on `*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR`
- It may speed up the simulation to use a box to limit the contact search domain
  - `*DEFINE_BOX`
  - `...`*BOXID* on Card 1 of `*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR`

Troubleshooting convergence

Related to contacts

- For simulations with big changes in contact state in each iteration, switching to full-Newton may be beneficial for convergence

```
*CONTROL_IMPLICIT_SOLUTION
$#  NSOLVR    ILIMIT    MAXREF     DCTOL     ECTOL     RCTOL     LSTOL    ABSTOL
                   1        55                                           1.E-20
$#   DNORM    DIVERG     ISTIF   NLPRINT    NLNORM   D3ITCTL
         1                             3         4         1
$#  ARCCTL    ARCDIR    ARCLEN    ARCMTH    ARCDMP

$#   LSMTD
         5
*CONTROL_IMPLICIT_AUTO
$    IAUTO    ITEOPT    ITEWIN     DTMIN     DTMAX     DTEXP
         1        30         5      1.E-5     -700.
```



Roof strength analysis

Troubleshooting convergence

Related to tied contacts

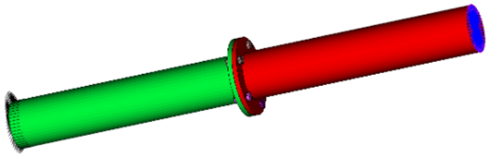
- Carefully check which nodes get tied
  - Using for example LS-PrePost, or Check > Contacts > From solver in ANSA
- Inspect d3hsp/mes0* files to confirm check results from pre-processors.
- Define a tracked node set (`SURFATYP`=4) if full control is desired
- Check for mesh distortion due to nodal projections `*** Warning 41240 (SOL+1240)`
  - Tied contacts causing zero-volume hexas, for example spotwelds or adhesives
- Activate `IPBACK` if a constraint-based tied contact is used

Troubleshooting convergence

General

- See previous Webinar
  - Troubleshooting convergence problems in LS-DYNA implicit, 2021-12-16
- Appendix C of the Guideline for implicit analyses in LS-DYNA

Guideline for implicit analyses using LS-DYNA



2022-09-16 LS-DYNA / LS-PrePost

16 Appendix C: Troubleshooting convergence problems

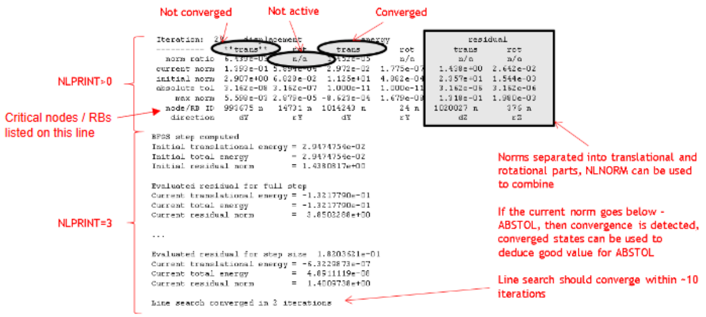


Figure 58. Tracking convergence information in the mes0* - files. If the norms in the table header are surrounded by "***" this means that the norm is not converged.

If the solution converges well, typically the norms decrease with almost each iteration (see the left image of Figure 59), line search converges in less than 10 iterations, and convergence of a time step is achieved within less than 50 iterations, and the penetrations reported from the Mortar contacts stays within reasonable limits.

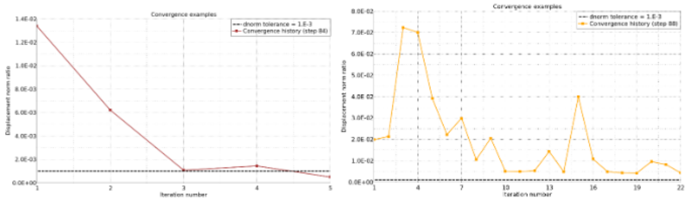


Figure 59. Examples of convergence histories. The left image shows rapid decrease of the displacement norm, and the required tolerance is met in 5 iterations. The right image shows problematic convergence, and the step is abandoned after 21 iterations.

Troubleshooting convergence

Related to Mortar contact

- Interesting example
- Live demo!

Contact benchmarks

Comparisons to analytical solution, comparisons to FEBIO and Abaqus

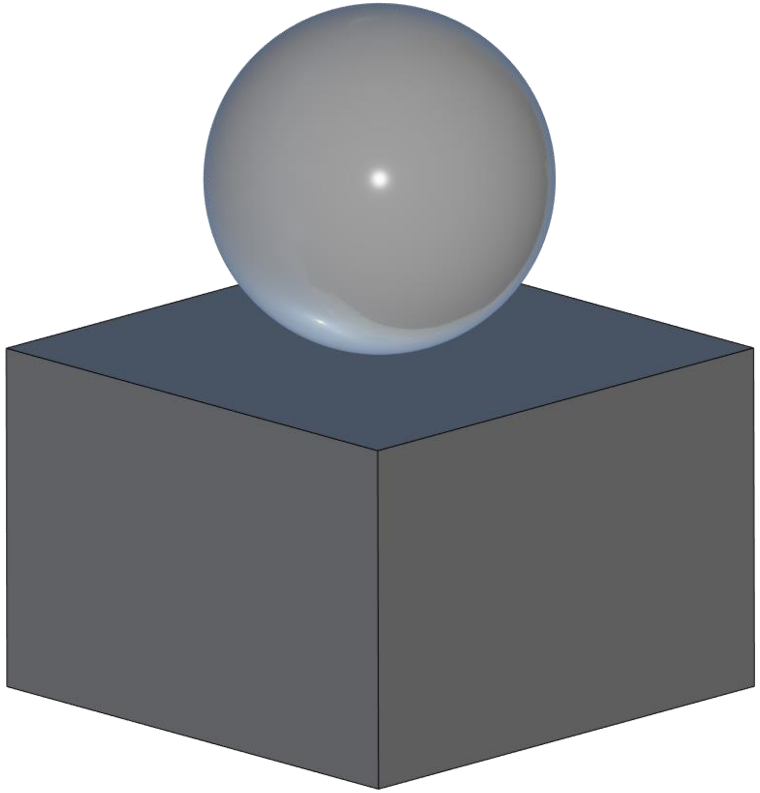
LS-DYNA implicit and Mortar contacts

Contact benchmarks

- Highly accurate and efficient contacts are important
- Here, some benchmark results are presented
  - Herz' contact
  - Comparisons to some of the cases presented in the paper
    - Zimmerman, B. K., and Ateshian, G. A., A Surface-to-Surface Finite Element Algorithm for Large Deformation Frictional Contact in FEBIO, Journal of Biomechanical Engineering, August 2018, Vol. 140:081013-1 to 081013-15
    - Some of these were reproduced using LS-DYNA R13.1
      1. Pinching of a hollow ball
      2. Deep indentation
      3. Compression of concentric spheres
      4. Twisting contact between hemisphere and box

Herz contact, LS-DYNA vs. analytical

- Compare stress, displacements and contact pressures from LS-DYNA to results Herz' theory
  - Herz results from *Johnson, K.L.,* Contact mechanics, Cambridge university press, 1985
- A steel (E=210 GPa, ν = 0.3) sphere, R = 50 mm, is pushed into a flat ”infinite” steel plate by a force of 1 kN.
- Meshed using 2nd order tets
  0.1 – 5 mm size. 550E3 elements
  - A ¼ model with 245E3 elements was also studied

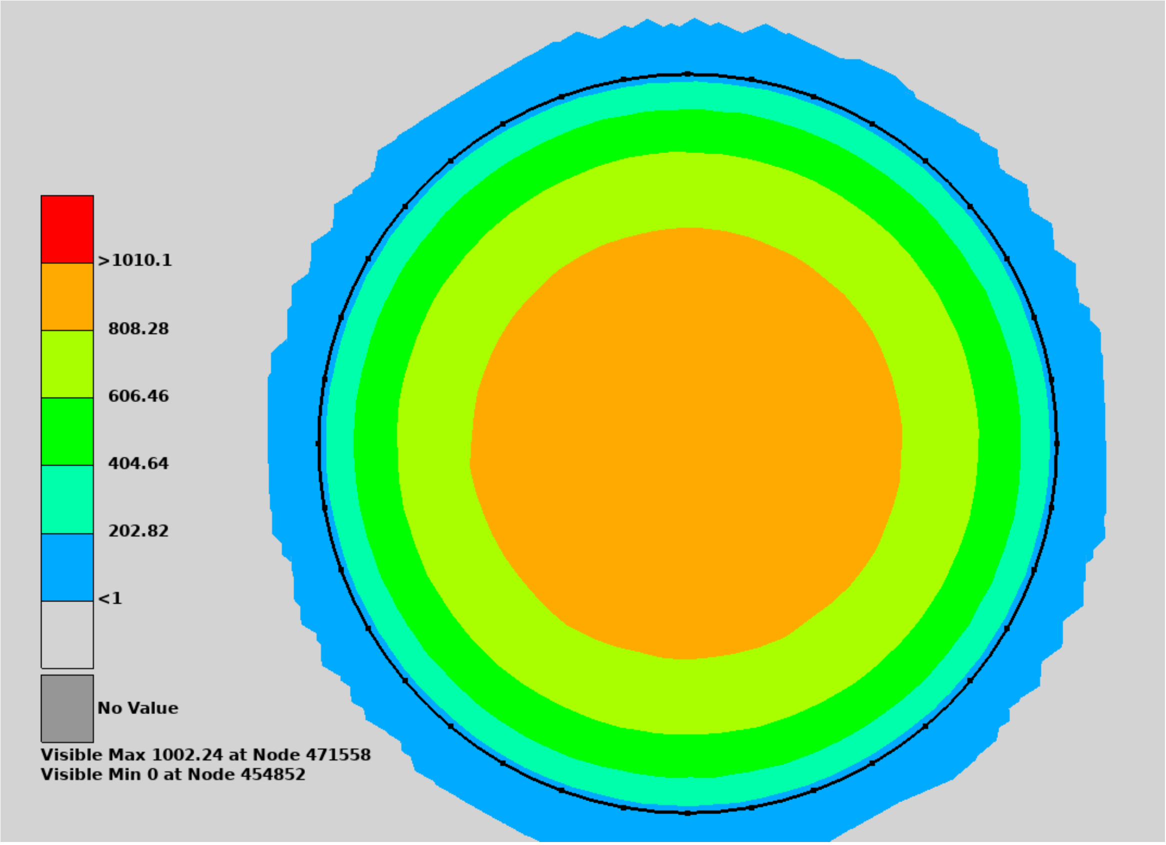


Results

Contact area (a) and peak contact pressure (p_0)

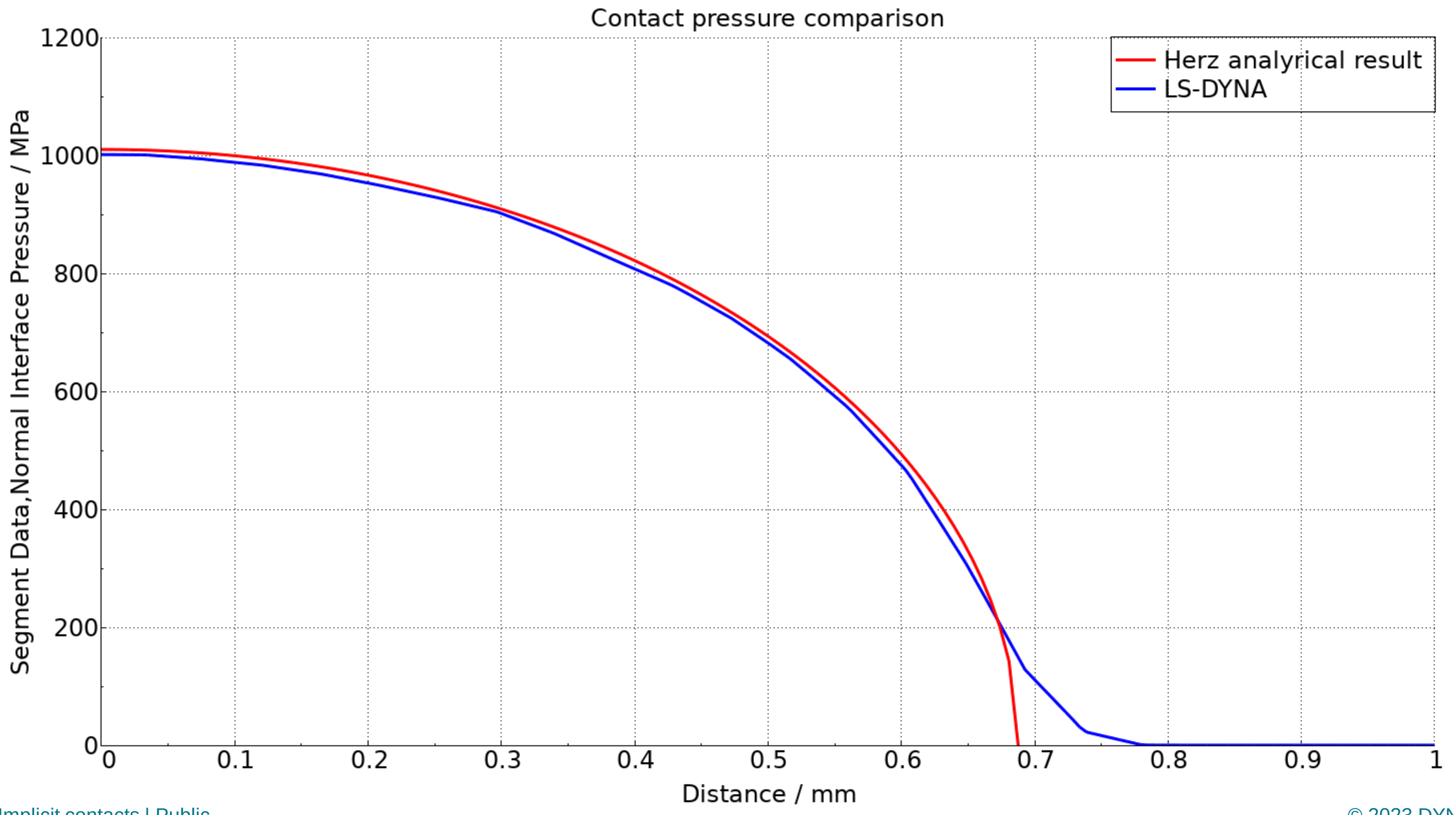
- $a = \left(\frac{3PR}{4E^*}\right)^{1/3} \approx 0.68753$ mm, with $E^* = \frac{E}{2(1-\nu^2)}$ in this case
- $p_0 = \frac{3P}{2\pi a^2} \approx 1010.1$ MPa.

Fringe plot of the contact pressure from LS-DYNA. The black line shows the contact circle according to Herz theory. The peak contact pressure from LS-DYNA is 1002.2 MPa, which is 0.8 % lower than the analytical solution.



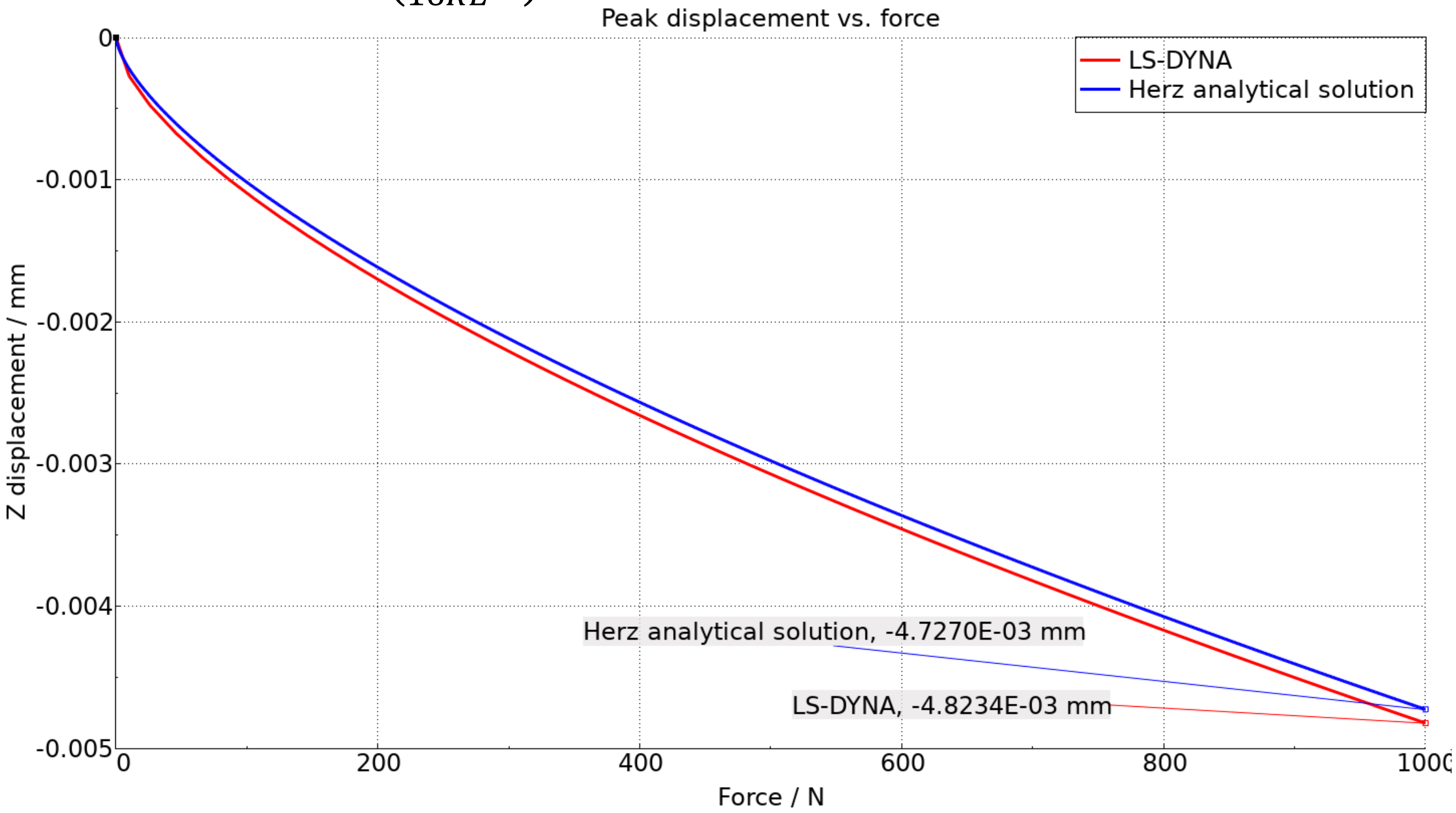
Herz contact, LS-DYNA vs. analytical

- Contact pressure distribution: $p = p_0\sqrt{1-\left({}^{r}/_{a}\right)^2}$



Peak deformation of the sphere vs. applied force

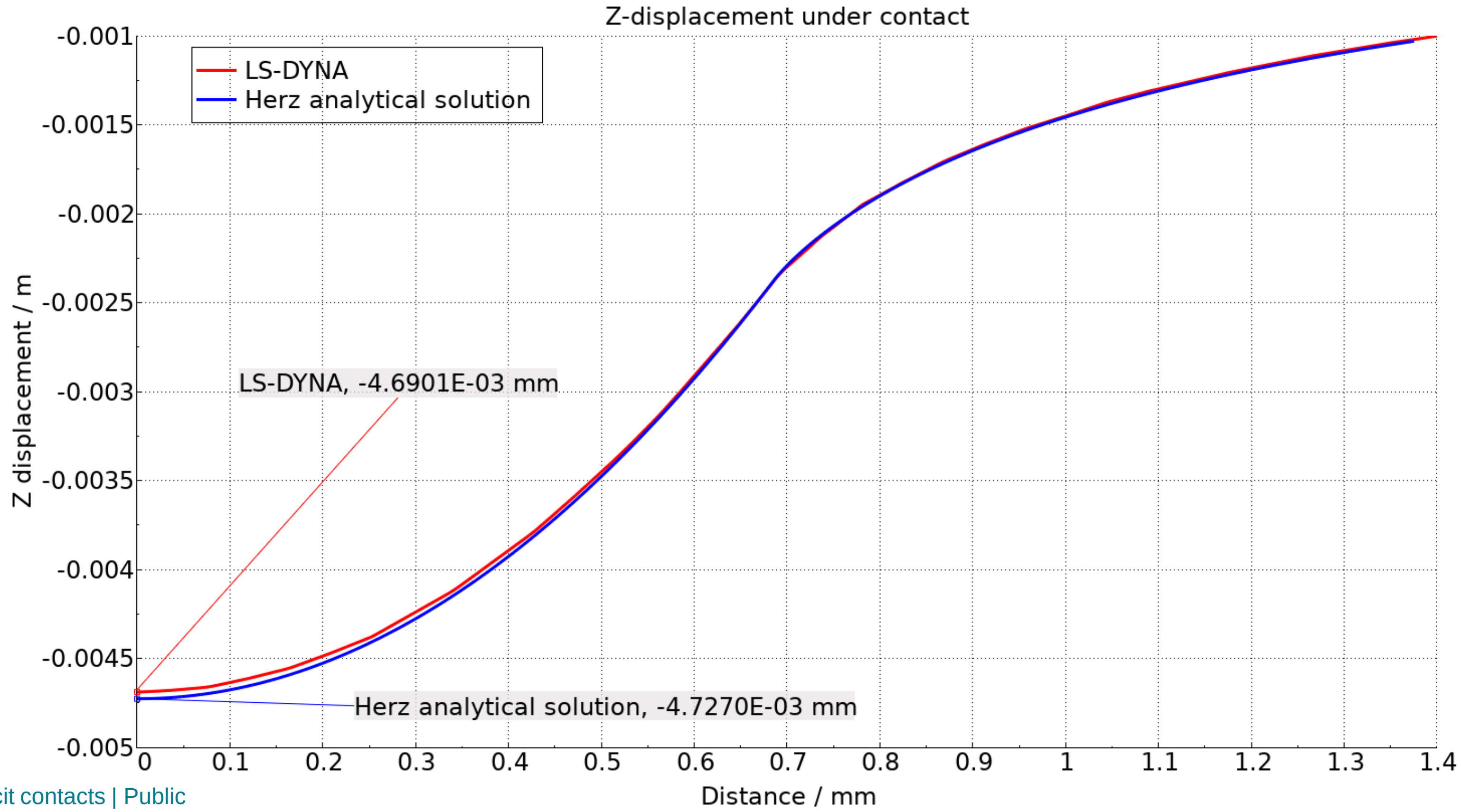
- Herz theory: $\delta = \left(\frac{9P^2}{16RE^{*2}}\right)^{1/3}$



The peak deformation from LS-DYNA is -4.8234E-3, or about 2 % above the Herz theory

Z-deformation of plate under the contact

- Herz theory: $u_z(r) = \frac{\pi p_0}{4aE^*}(2a^2 - r^2), r \leq a$
- $u_z(r) = \frac{p_0}{2aE^*}(2a^2 - r^2)\sin^{-1}\frac{a}{r} + ar\sqrt{1 - {a^2}/{r^2}}, r > a$

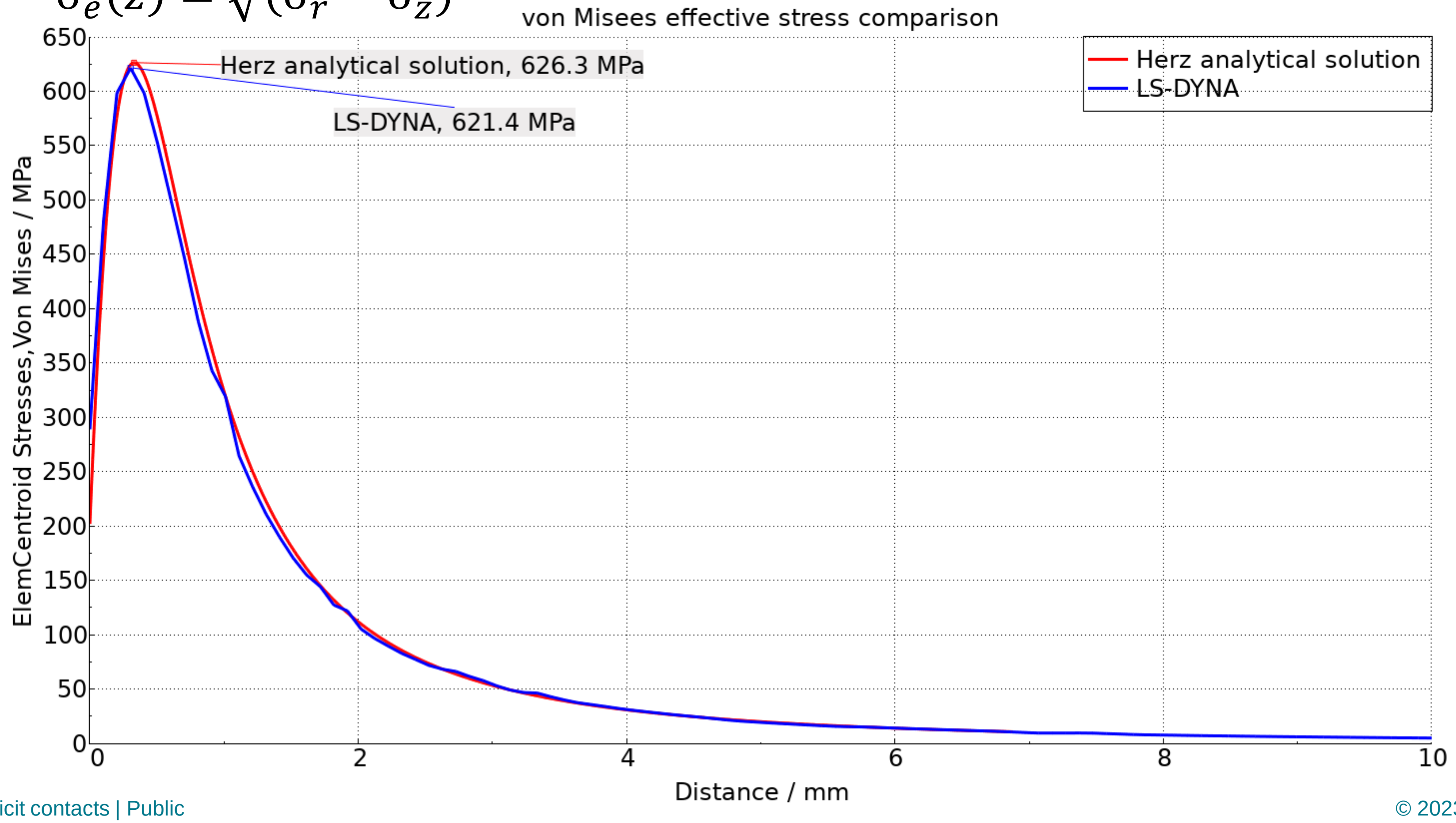


The peak deformation from LS-DYNA is -4.6901E-3, or about 0.8 % above the Herz theory

Von Mises effective stress vs. Z, at r = 0

From ¼ model

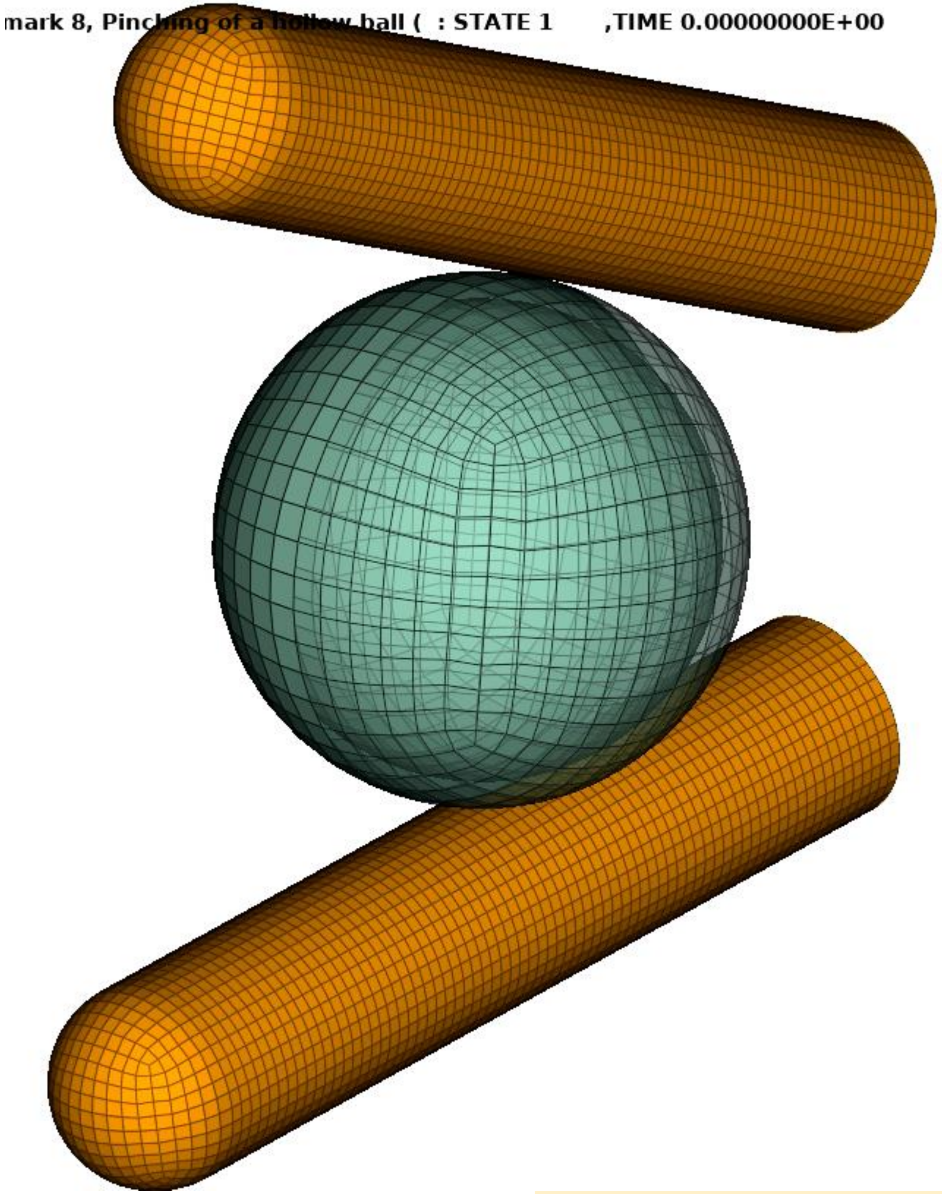
- Herz theory: $\sigma_z(z) = \frac{-p_0}{(1+z^2/a^2)}$, $\sigma_r(z) = -p_0(1+\nu)\left(1 - z/a \cdot \tan^{-1}\frac{a}{z}\right) + \frac{p_0}{2(1+z^2/a^2)}$
- $\sigma_e(z) = \sqrt{(\sigma_r - \sigma_z)^2}$



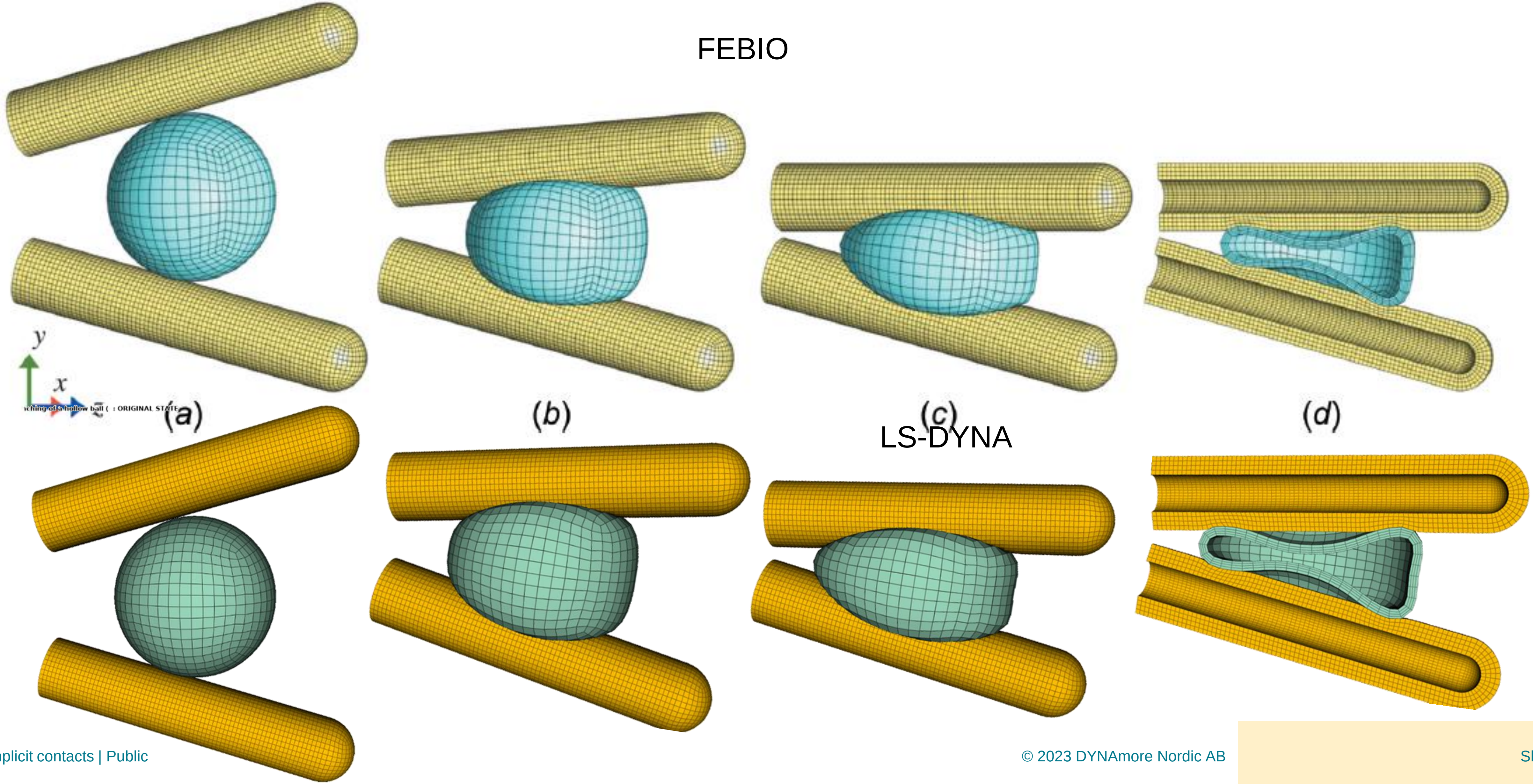
The peak effective stress from LS-DYNA is 621.4 MPa, or about 0.8 % below the Herz theory

Pinching of a hollow ball

- Simulate compression of a hollow ball between two fingers
- Fingers idealized as hollow tubes (L= 10 cm, r_y = 1 cm, r_i =0.5 mm)
  - Hemispherical cap
  - Elastic, E=1 MPa, ν = 0.3
- Hollow ball, r_y=2.5 cm, r_i = 2.25
  - Hyperelastic material, Mooney-Rivlin, C10 = 1.25 MPa, C01=0, k = 1250 MPa
- Coefficient if friction: μ = 0.9.

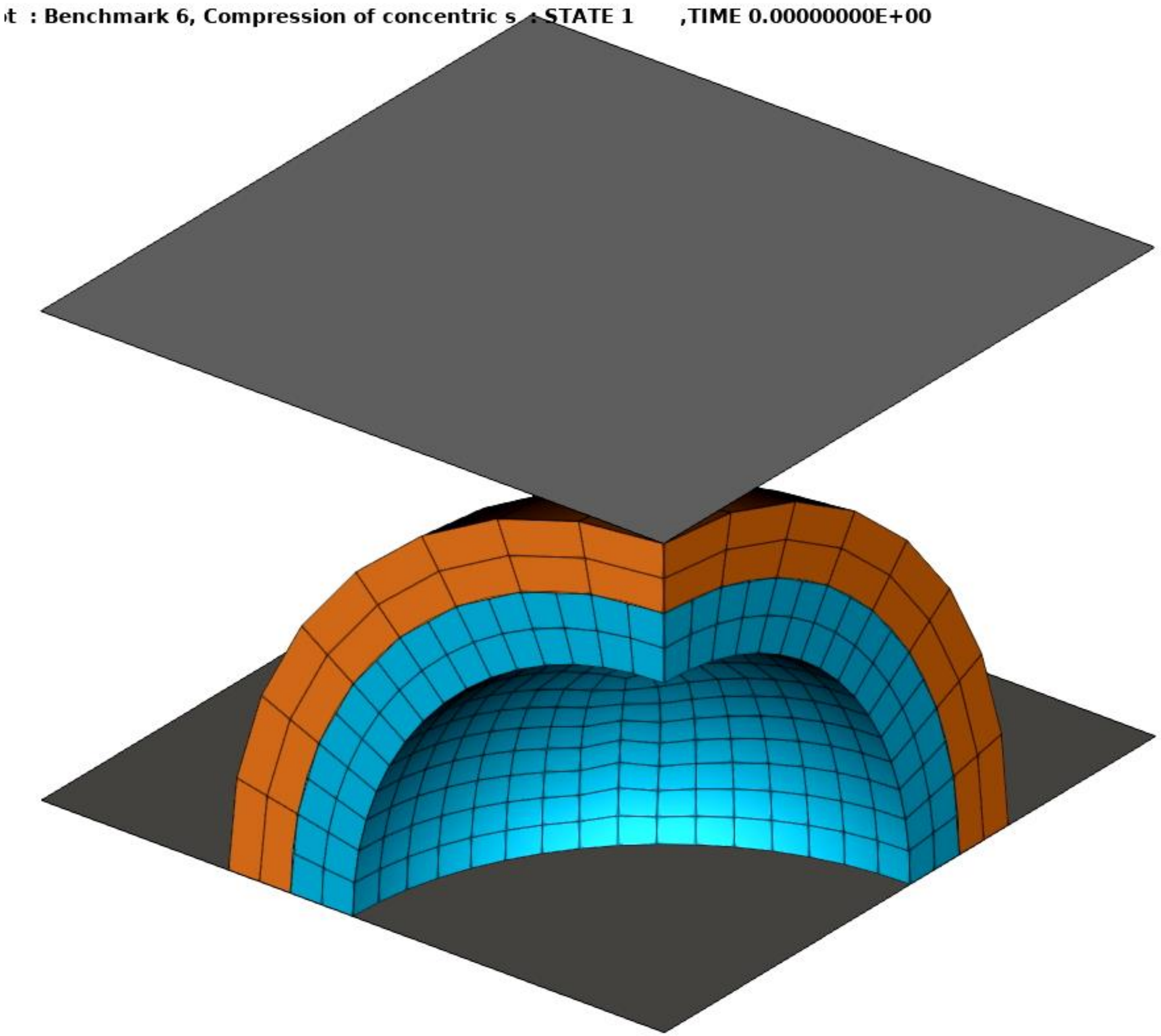


Deformation comparison



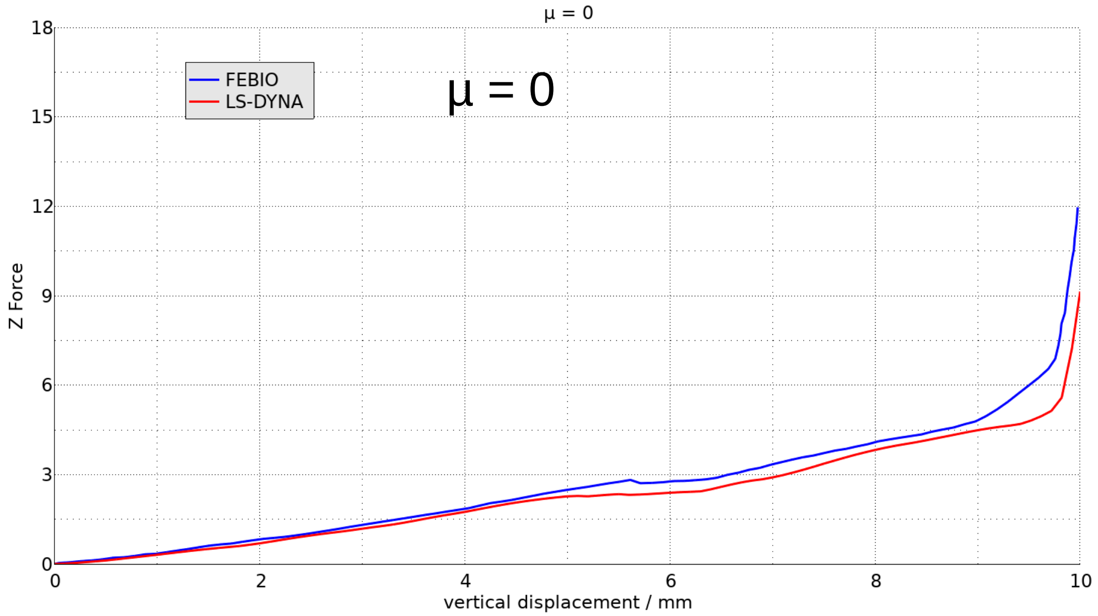
Compression of concentric spheres

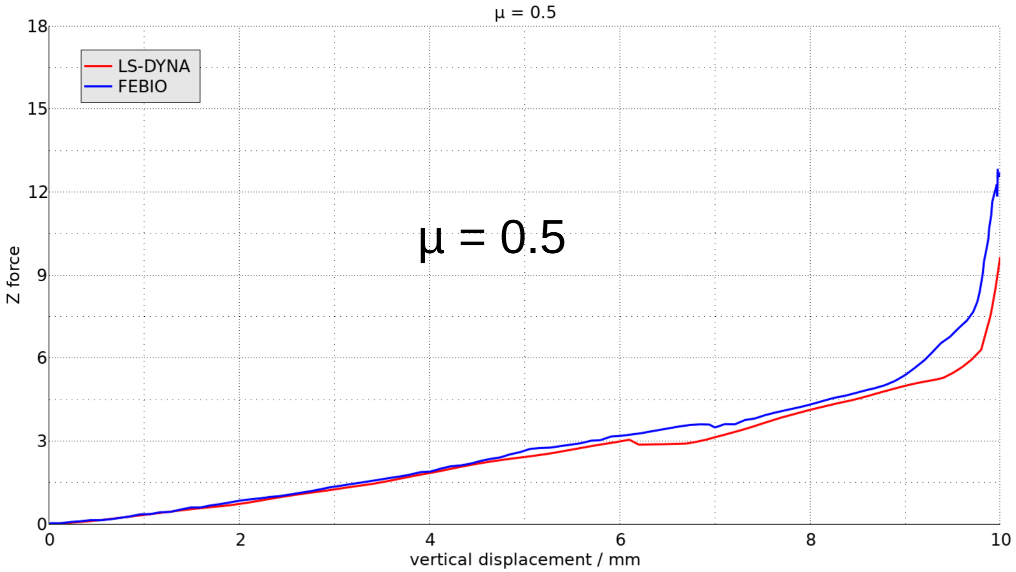
- Elastic spheres, outer radius 14mm, innermost radius 10 mm
  - E=1, $\nu = 0.3$
  - ¼ model (symmetry)
- Upper plate is pushed 10 mm downwards
- Studied frictions
  - $\mu = 0$, $\mu = 0.5$, $\mu \approx 2$

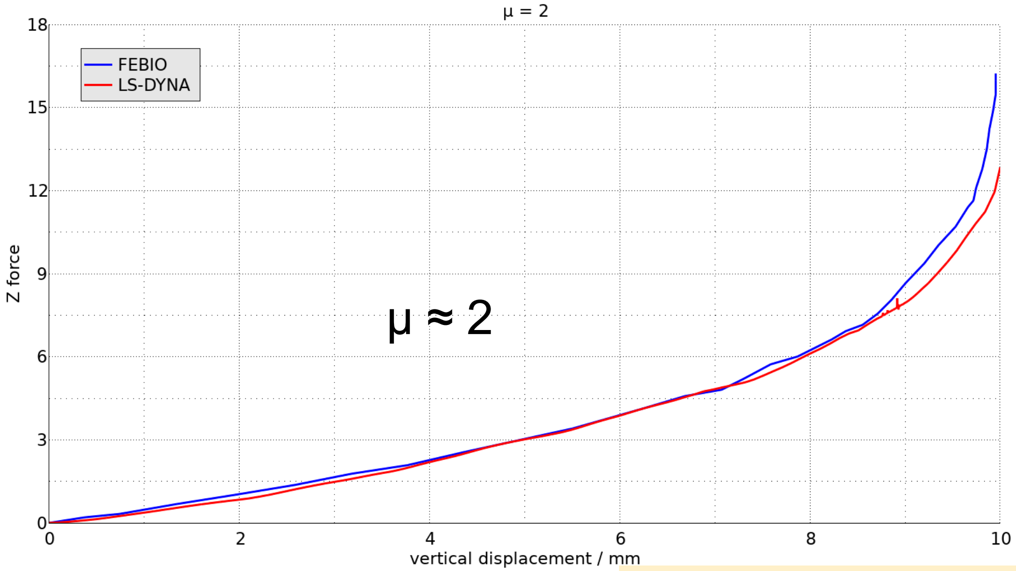


Compression of concentric speres

- Force vs. displacement comparisons

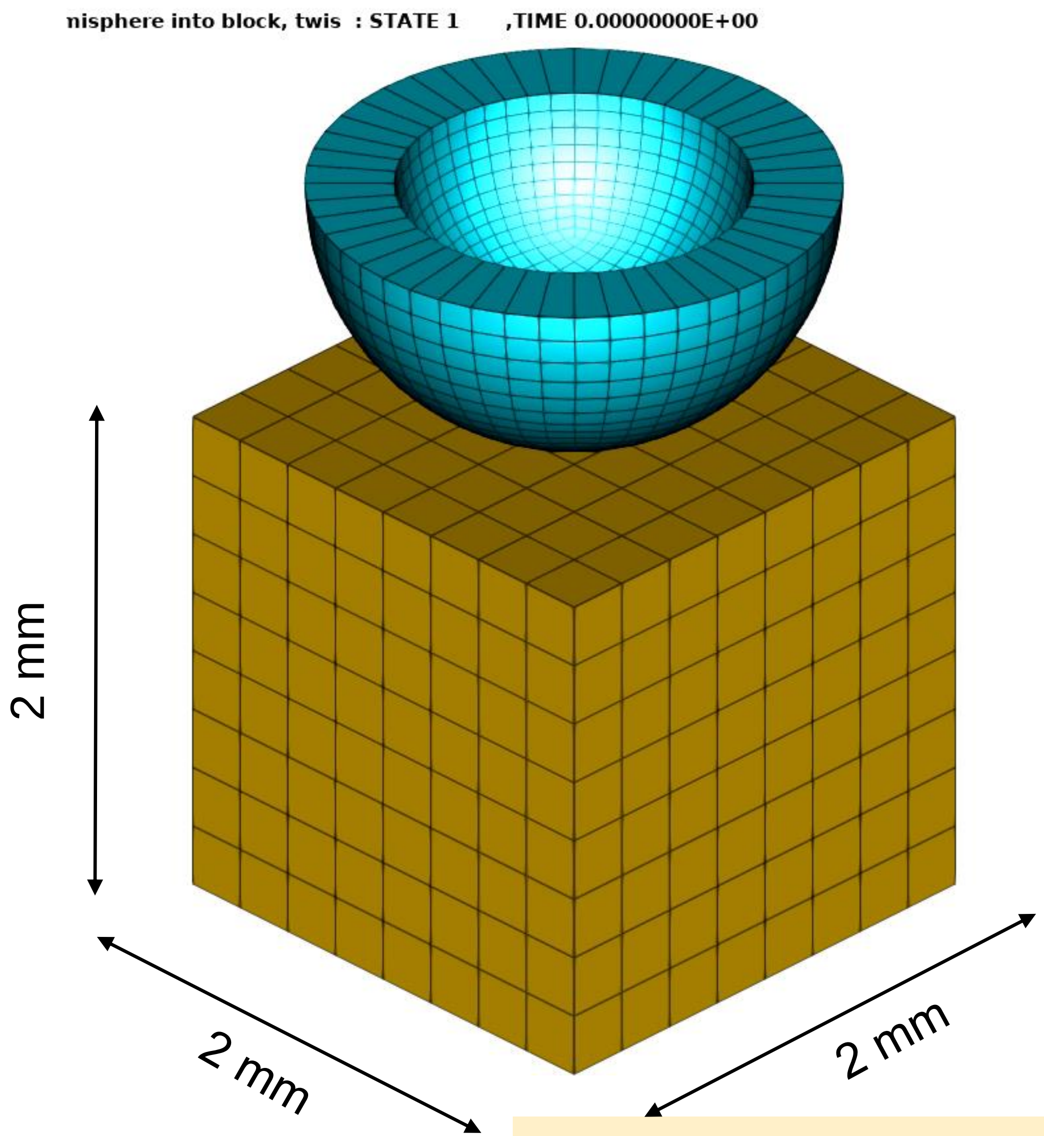






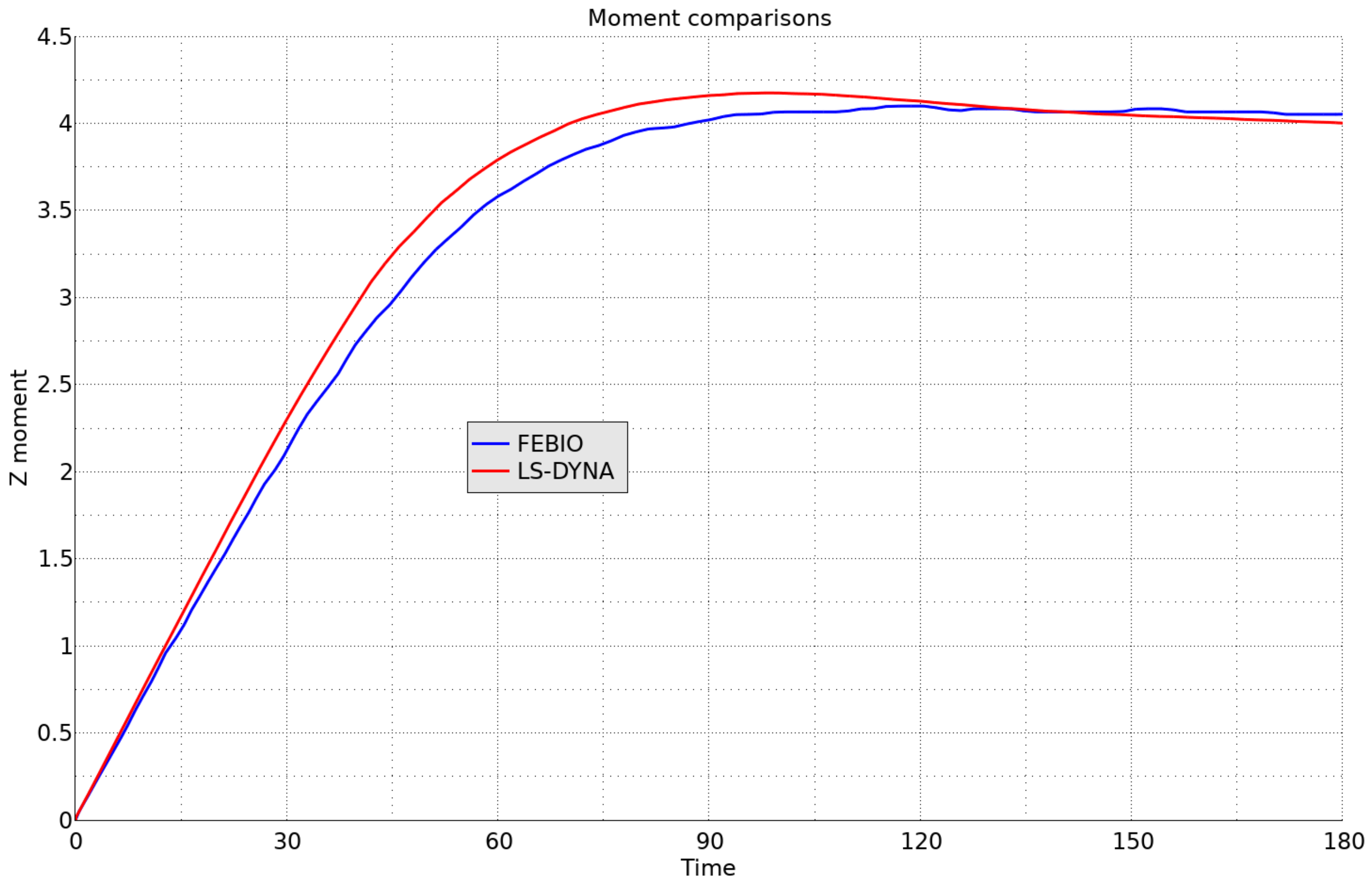
Twisting contact between a hemisphere and a box

- A hemisphere is pushed into a box and twisted 180°
- Elastic materials
  - For hempisphere: E = 50 MPa, ν = 0.3
  - For box : E = 10 MPa, ν = 0.3
- Friction: μ = 0.5
- Initial displacement of (-)1 mm of the hemisphere, followed by
- rotation by 180°



Twisting contact between a hemisphere and a box

- Moment vs. rotation comparison

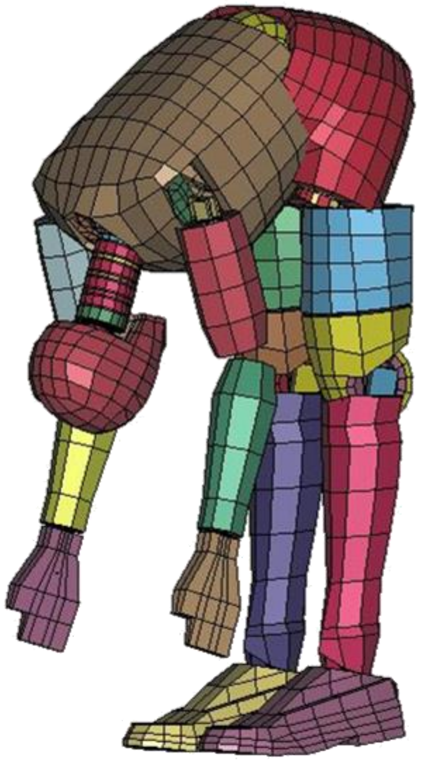


Contacts in LS-DYNA implicit

Summary

- The Mortar contacts are recommended for implicit analyses
  - `*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_ID`
  - `*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID`
- Handles most possible contact situations, including element erosion
- Efficient and accurate
- Similar modelling approach as in explicit, using single surface contact definition, can also be applied in implicit
  - Use `IGNORE` = -2 if no self-contact within the same part is expected
- Use `IGNORE` = 3 or 4 to resolve press fit

Thank You



DYNAMore Nordic AB
Brigadgatan 5
587 58 Linköping, Sweden

Tel.: +46 - (0)13 23 66 80
info@dynamore.se

www.dynamore.se
www.dynaexamples.com
www.dynasupport.com
www.dynalook.com

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