Using MORTAR contact in explicit simulation
- A potential explicit lifeline

The presentation is based upon the capabilities of LS-DYNA rev. r12.0

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Klas Engstrand, DYNAmore Nordic

Outline of presentation

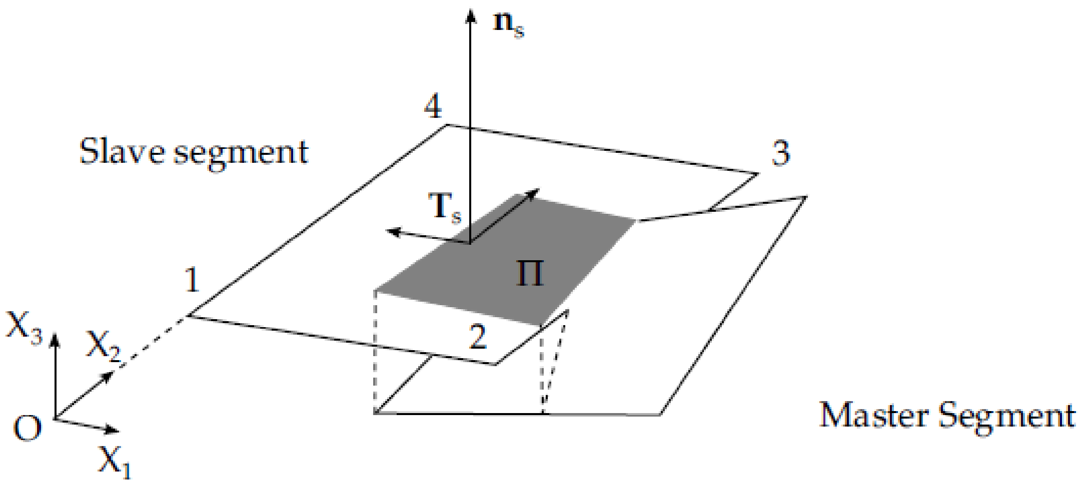
- Introduction
- Available MORTAR contacts
- Recommended explicit settings
- Capabilities
- *CONTACT, *CONTROL_CONTACT
- Contact surface, release depth, stiffness
- Extra output for MORTAR
- Benchmark examples
  - Rubber seal
  - Crash box
- Conclusions

Introduction

- For explicit simulation the main contacts are AUTOMATIC_SINGLE_SURFACE, AUTOMATIC_SURFACE_TO_SURFACE, and the "ERODING" variants, with SOFT=1 or SOFT=2.
  - Fast and robust contacts for crash simulation.

- The main contacts used for implicit simulation are the corresponding MORTAR alternatives.

- MORTAR is a penalty-based segment-to-segment contact.



Introduction

- In recent years MORTAR contacts have been used also for explicit simulation, often to solve tricky contact situations.
- This presentation will focus on the use of MORTAR contact in explicit simulation.
- MORTAR is under continuous development and subject to changes.
  To access all available features a late LS-DYNA release shall be used.
- Execute LS-DYNA with Release=1 to get release notes for MORTAR written to d3hsp.

Available MORTAR contacts

Tied/Tiebreak contacts

- AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_TIED
- AUTOMATIC_SURFACE_TO_SURFACE_MORTAR_TIED_WELD
- AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK_MORTAR
- AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK_USER_MORTAR
  - The tied condition is segment-to-segment based.
  - May induce stresses a bit differently than the usual node-to-segment tied contacts.
  - Mostly used for implicit simulation, but it can be used for explicit simulation as well.

Forming contacts

- FORMING_SURFACE_TO_SURFACE_MORTAR
  - Special forming features such as zero thickness on master side shells.
  - In cases with high pressure the MORTAR alternative can be more accurate (yield smaller penetrations) than corresponding non-Mortar forming alternatives.

Available MORTAR contacts

Sliding contacts

- AUTOMATIC_SINGLE_SURFACE_MORTAR
- AUTOMATIC_SURFACE_TO_SURFACE_MORTAR

This presentation

Force transducer

- CONTACT_FORCE_TRANSDUCER_PENALTY is supported by MORTAR,
  with the requirement that slave-and master sides are define through parts or part sets.

Additional notes

- The groupable algorithm, see CONTROL_MPP_CONTACT_GROUPABLE, is currently not supported by MORTAR.

- For multistage simulations by using the dynain.lsda file the contact state can be transferred between simulations if MORTAR contact is used.

Recommended explicit settings

```
*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID
$#     cid                                                                 title
         1Mortar contact
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         1         0         2         0         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.2       0.2       0.0       0.0      20.0         0       0.01.00000E20
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
       1.0       1.0       0.0       0.0       1.0       1.0       1.0       1.0
$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq
         0       0.1         0     1.025       2.0         2         0         1
$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf
       0.0         0         0         0         0         0       0.0       0.0
$#    igap    ignodprfac/mpadtstif/mpar2    unused    unused    flangl   cid_rcf
         1         0       0.0       0.0                           0.0         0
```

- Our recommended approach is to start with default settings.
- Add contact damping VDC, and contact friction FS/FD/DC as applicable.
- Modelling:
  - Avoid initial penetrations, or at least keep them significantly smaller than penetration depth (at least <75%) .
  - Include only “physical” parts, do not use null shells since solid contact works.

Recommended explicit settings

```
*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID
$#     cid                                                                 title
       1Mortar contact
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         1         0         2         0         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.2       0.2       0.0       0.0      20.0         0       0.01.00000E20
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
       1.0       1.0       0.0       0.0       1.0       1.0       1.0       1.0
$#    soft    sofscl    lcidab    maxpar     sbopt     depth     bsort    frcfrq
         0       0.1         0     1.025       2.0         2         0         1
$#  penmax    thkopt    shlthk     snlog      isym     i2d3d    sldthk    sldstf
       0.0         0         0         0         0         0       0.0       0.0
$#    igap    ignodprfac/mpadtstif/mpar2    unused    unused    flangl   cid_rcf
         1         0       0.0       0.0                           0.0         0
```

```
*PART_CONTACT
$#                                                                         title
Shells
$#     pid     secid       mid     eosid      hgid      grav    adpopt      tmid
         1         1         1         0         0         0         0         0
$#      fs        fd        dc        vc      optt       sft       ssf
       0.0       0.0       0.0       0.0       7.5       0.0       0.0
```

- If contact problems arise such as unacceptable large penetrations the penalty stiffness can be scaled with SFS. Setting the release depth for solids and tshells, with PENMAX, can also help. The magnitude of PENMAX should then be chosen as a typical element thickness in the model.
- Contact thickness for shells and beams can be set by OPTT on *PART_CONTACT, or by SST/MST/SFST/SFMT on *CONTACT, i.e. if the default on *SECTION is not desirable.
- For solids and thick shells the contact surface can be augmented (offset) by SLDTHK on *CONTACT. A negative number is allowed.

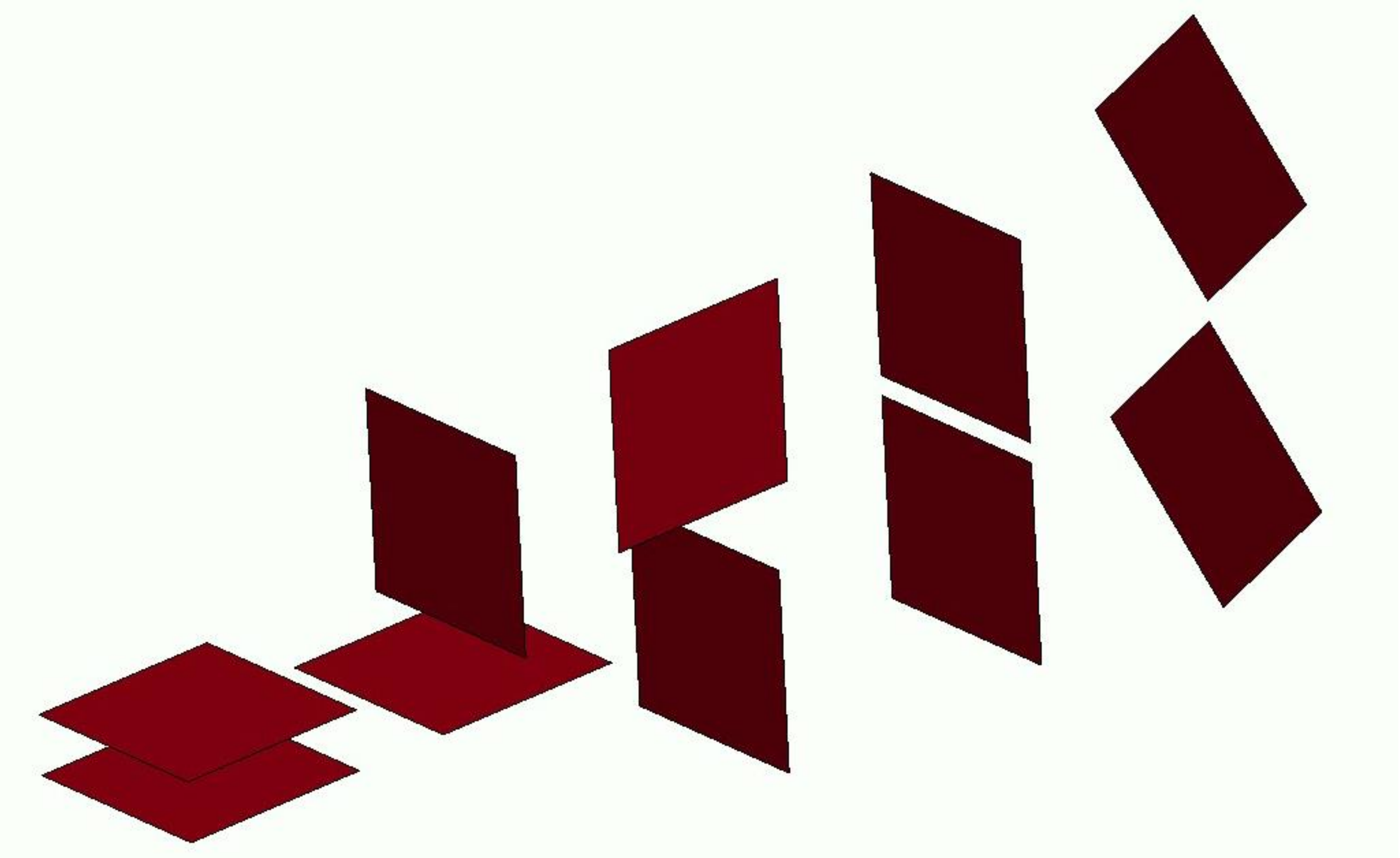
Capabilities

- The intention of MORTAR is to be able to solve most contact situations for shells, solids, tshells and beams with default contact settings.

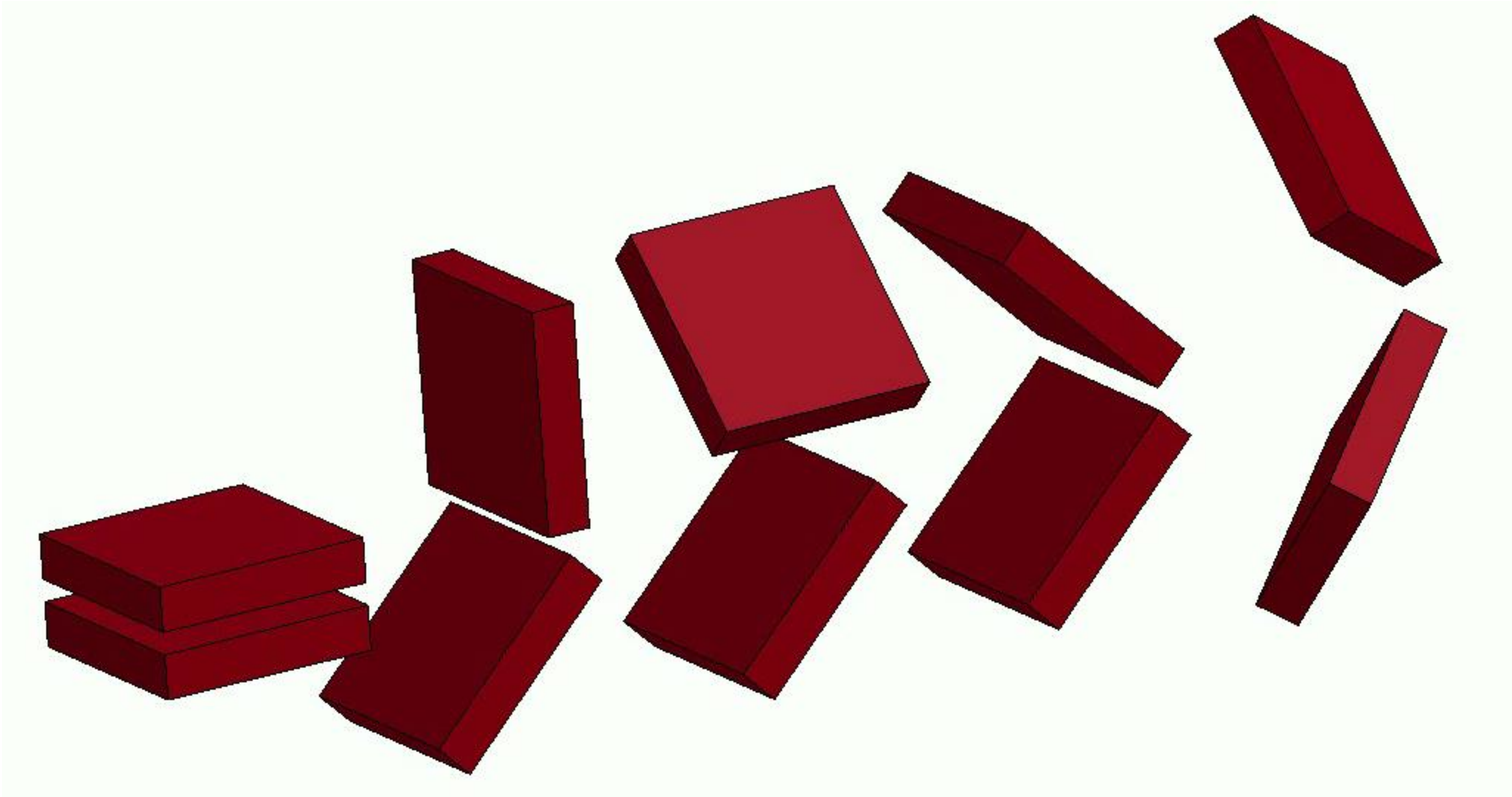
- An always-active approach is applied for many features:
  - Update of contact surface due to element erosion is always active for shells, tshells and solids. Currently not beams.
  - Shell thickness changes are considered if ISTUPD on *CONTROL_SHELL is used.
  - Contact offset for shells as defined by NLOC on *SECTION_SHELL or by *ELEMENT_SHELL_OFFSET is always active.
  - Initial penetrations are ignored (by default IGNORE=2) by translate of the slave contact surface to the level of initial penetrations. The contact surface is not tracked.

    - NOTE: There is an option to use MPAR1 in combination with IGNORE=2 to apply an initial contact pressure. The purpose of this is to eliminate rigid body modes for implicit for better convergence. Not recommended for explicit simulation.

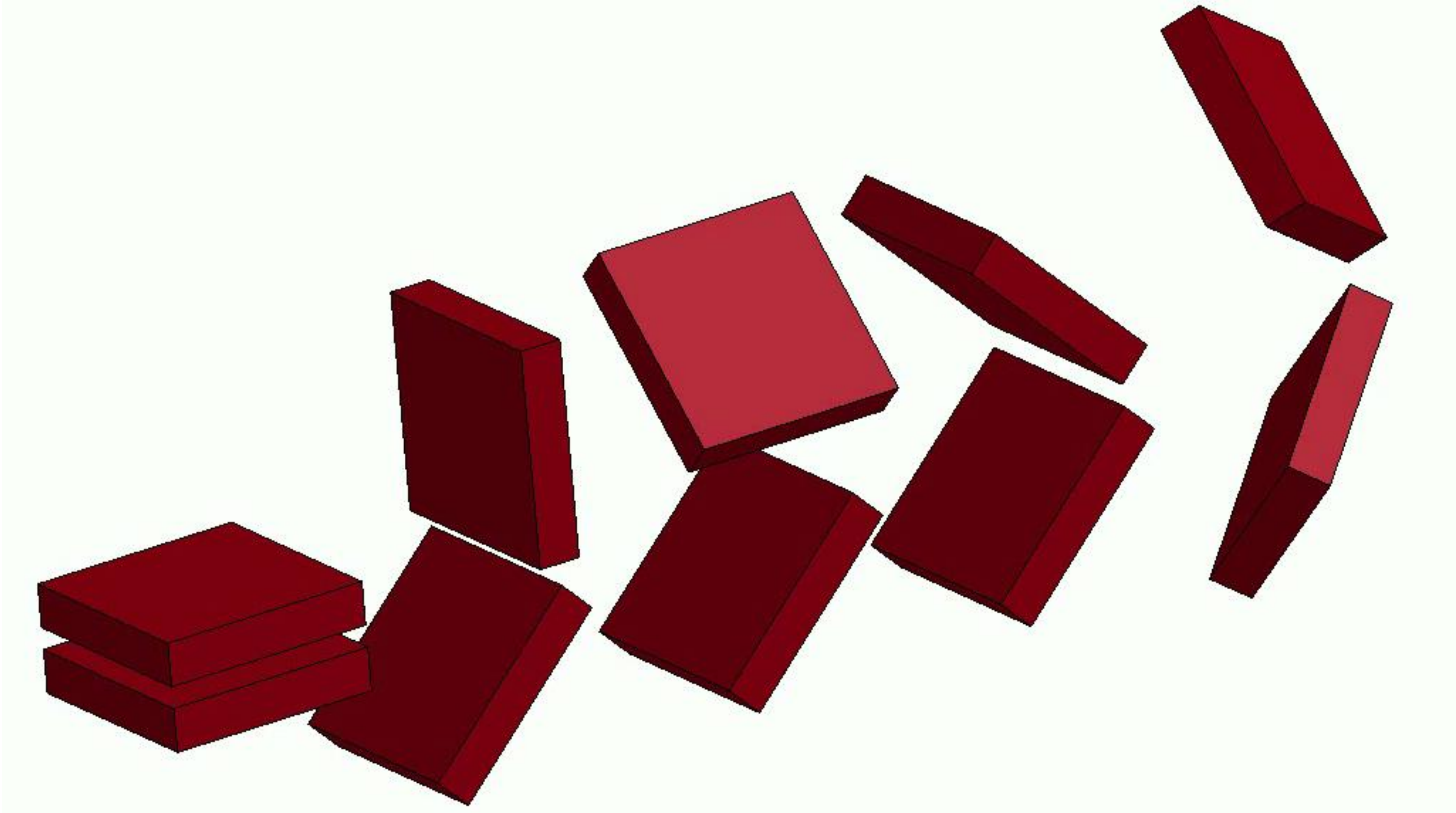
Capabilities - Shells



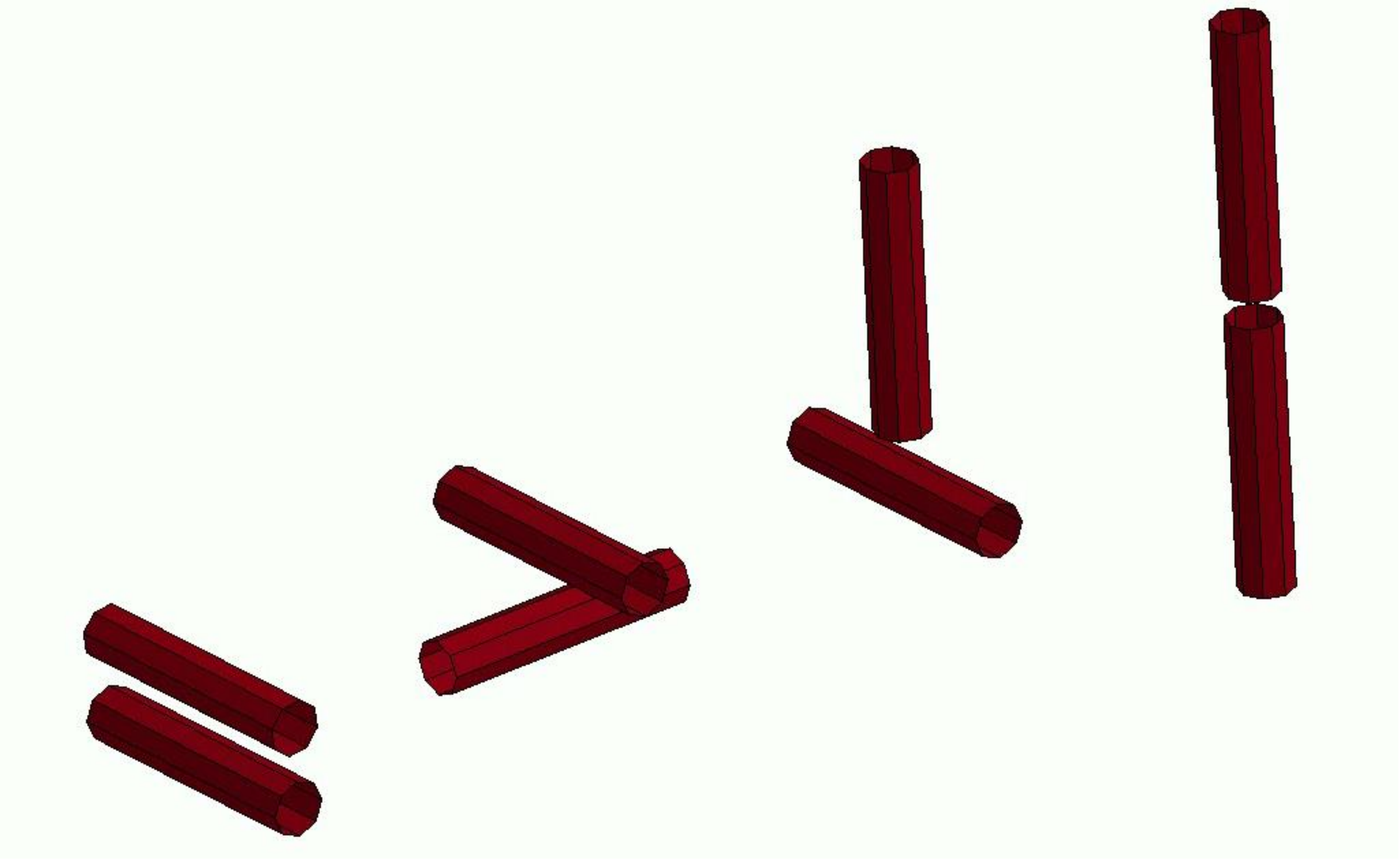
Capabilities - Solids



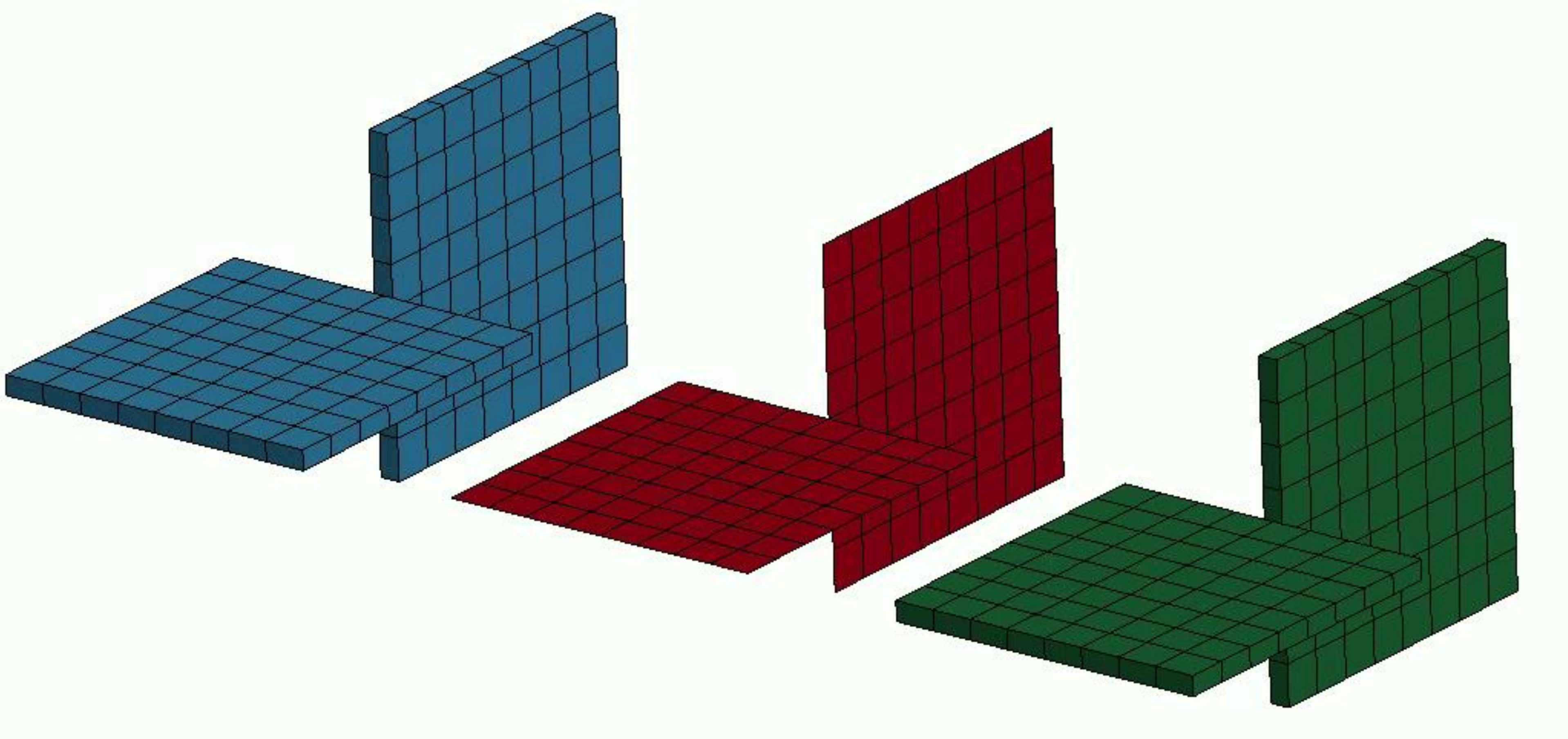
Capabilities - Tshells



Capabilities - Beams



Element erosion



Solids Shells Tshells

*CONTACT (parameters marked red do not apply to MORTAR)

~~MPP 1~~	~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~
~~MPP 2~~	~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~
Card 1	1	2	3	4	5	6	7	8
Variable	SSID	MSID	SSTYP	MSTYP	SBOXID	MBOXID	SPR	MPR
Card 2	1	2	3	4	5	6	7	8
Variable	FS	FD	DC	VC	VDC	~~PENCHK~~	BT	DT
Card 3	1	2	3	4	5	6	7	8
Variable	SFS	~~SFM~~	SST	MST	SFST	SFMT	~~FSF~~	~~VSF~~
Card A	1	2	3	4	5	6	7	8
Variable	~~SOFT~~	~~SOFSCL~~	~~LCIDAB~~	~~MAXPAR~~	~~SBOPT~~	~~DEPTH~~	BSORT	~~FRCFRQ~~
Card B	1	2	3	4	5	6	7	8
Variable	PENMAX	~~THKOPT~~	~~SHLTHK~~	~~SNLOG~~	~~ISYM~~	~~I2D3D~~	SLDTHK	~~SLDSTF~~
Card C	1	2	3	4	5	6	7	8
Variable	IGAP	IGNORE	DPRFAC / MPAR1	DTSTIF / MPAR2			~~FLANGL~~	~~CID_RCF~~
~~Card D~~	~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~
~~Card E~~	~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~
~~Card F~~	~~1~~	~~2~~	~~3~~	~~4~~	~~5~~	~~6~~	~~7~~	~~8~~

SSID/MSID, node sets are not supported.

FS=-1 and FS=-2 is supported. I.e. frictional coefficients are then taken from *PART_CONTACT or *DEFINE_FRICTION.

FS=2 is also supported. I.e. frictional coefficients as function pressure and relative velocity.

IGNORE=-3/3 and IGNORE=-4/4 can be used for interference fit simulations.

BSORT default is 100. BSORT applies to both SMP and MPP for MORTAR.

*CONTROL_CONTACT (parameters marked red do not apply to MORTAR)

Card 1	1	2	3	4	5	6	7	8
Variable	SLSFAC	~~RWPNAL~~	~~ISLCHK~~	~~SHLTHK~~	~~PENOPT~~	~~THKCHG~~	~~ORIEN~~	~~ENMASS~~
Card 2	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Variable	~~USRSTR~~	USRFRC	NSBCS	~~INTERM~~	~~XPENE~~	~~SSTHK~~	~~ECDT~~	~~TIEDPRJ~~
Card 3	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Variable	SFRIC	DFRIC	EDC	VFC	TH	TH_SF	PEN_SF	PTSCL
Card 4	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Variable	IGNORE	FRCENG	~~SKIPRWG~~	~~OUTSEG~~	~~SPOTSTP~~	~~SPOTDEL~~	~~SPOTHIN~~	
Card 5	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Variable	ISYM	~~NSEROD~~	~~RWGAPS~~	~~RWGDTH~~	~~RWKSF~~	~~ICOV~~	~~SWRADF~~	~~ITHOFF~~
Card 6	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Variable	~~SHLEDG~~	~~PSTIFF~~	~~ITHCNT~~	~~TDCNOF~~	~~FTALL~~		~~SHLTRW~~	~~IGACTC~~

Our recommendation is to set parameters on *CONTACT if possible, rather than on *CONTROL_CONTACT.
(ISYM is an exception for MORTAR)

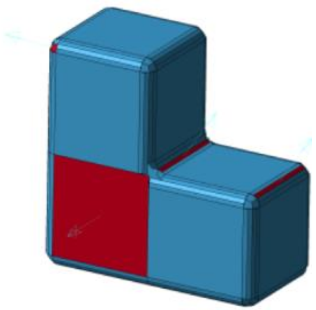
Contact surface

- Contact thicknesses are considered for both rigid and deformable parts.

- The contact surface for shells essentially follows the FE-geometry.
  I.e. shell edges are square, with a little edge smoothing,
  and flush with the nodes.
  - For shells the contact thickness can be set by OPTT (*PART_CONTACT), or by SST/MST/SFST/SFMT (*CONTACT).

- The contact surface for solids and tshells essentially follows the FE-geometry, but again with a little edge smoothing for “sharp” edges.
  - For solids and thick shells the contact surface can be augmented (offset) by SLDTHK (*CONTACT). A negative number is allowed.

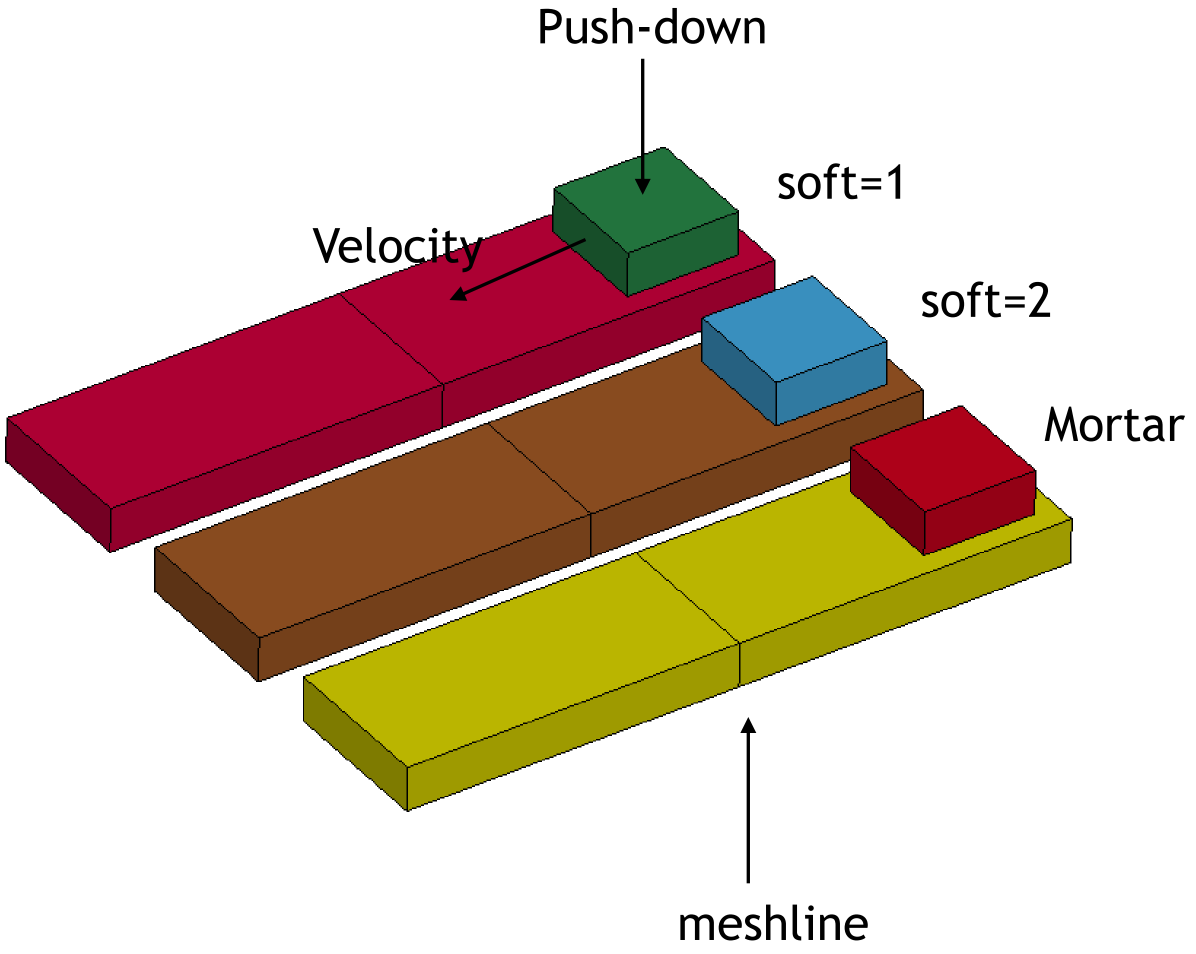
- Beams are always represented as cylindrical with a cross sectional area coincident with that of the underlying beam element.
  - For beams the contact thickness can be set on OPTT (*PART_CONTACT), or by SST/MST/SFST/SFMT (*CONTACT).



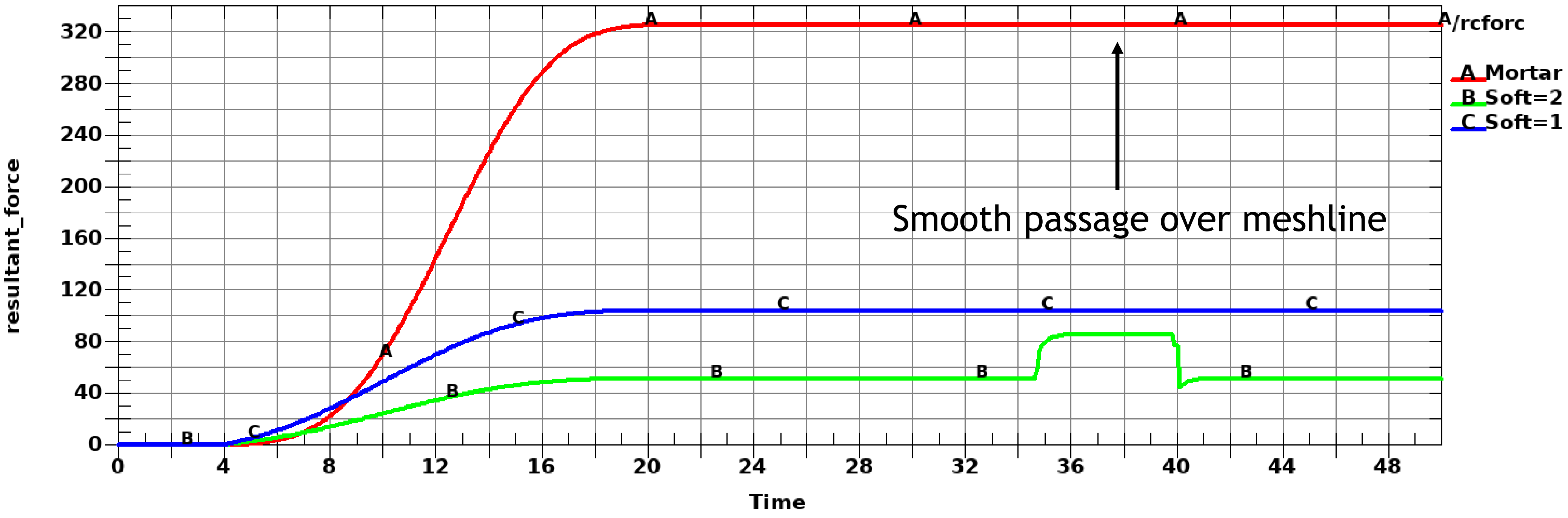
The concept of edge smoothing. (exaggerated for demonstrative purpose)

Contact surface

- Example of sliding with mortar, soft=2 and soft=1 contact.
- One element per block.
- First prescribed motion applied in z-direction of top block, then prescribed velocity in forward direction.
- Default contact settings, except dprfac=0.001 for soft=2.
- The contact force is measured with rcforc.
- Element size 5x5x2 mm.
- Solid element model.



Contact surface



Contact release depth

- The maximum allowed penetration
  (release depth) is defined as 95% of the contact thickness.

$$d_{\max} = 0.95\frac{d_c^s + d_c^m}{2}$$

- The contact thickness is calculated from the characteristic lengths, which is by default, for shells, the shell element thicknesses and, for solids, carefully selected minimum element edge lengths of the part(s) on each side.

- For solids and tshells the characteristic lengths can be set with PENMAX (*CONTACT).

- Similarly, for shells and beams the characteristic lengths can be set with OPTT, SST/MST/SFST/SFMT.

Contact stiffness

- The contact stress is based on the slave side material stiffness.
- The characteristic length is based on the slave side segment.
- It is recommended to define slave and master with parts or part sets.

$$\sigma_c = \alpha \varepsilon K_s f\left(\frac{d}{\varepsilon d_c}\right)$$

where

*CONTACT *CONTROL_CONTACT

α = stiffness scaling factor (SFS * SLSFAC)

K_s = stiffness modulus of slave segment

d = penetration distance

$\varepsilon = 0.03$

d_c = characteristic length

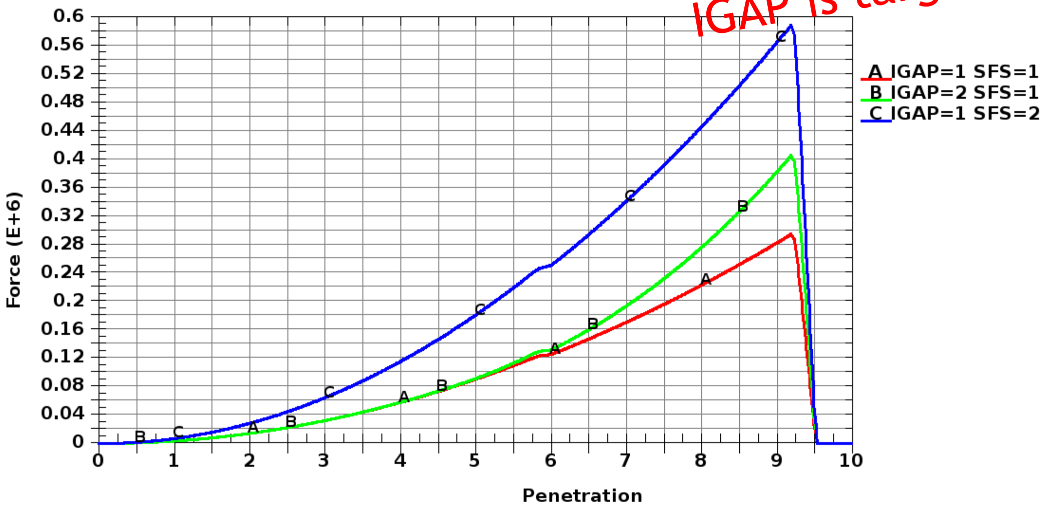
Contact stiffness

- Scaling the stiffness using SFS (*CONTACT) will affect the entire penetration and not only large penetrations. Good if penetrations globally are unacceptable.

- f(x) depends on IGAP (*CONTACT).

- If locally the penetrations become larger than the release depth, the contact stiffness can be increased for these large penetrations (>50% of max d) using IGAP.

IGAP is targeted for implicit



$$\sigma_c = \alpha \varepsilon K_s f\left(\frac{d}{\varepsilon d_c}\right)$$

*CONTACT *CONTROL_CONTACT

where

α = stiffness scaling factor (SFS * SLSFAC)

K_s = stiffness modulus of slave segment

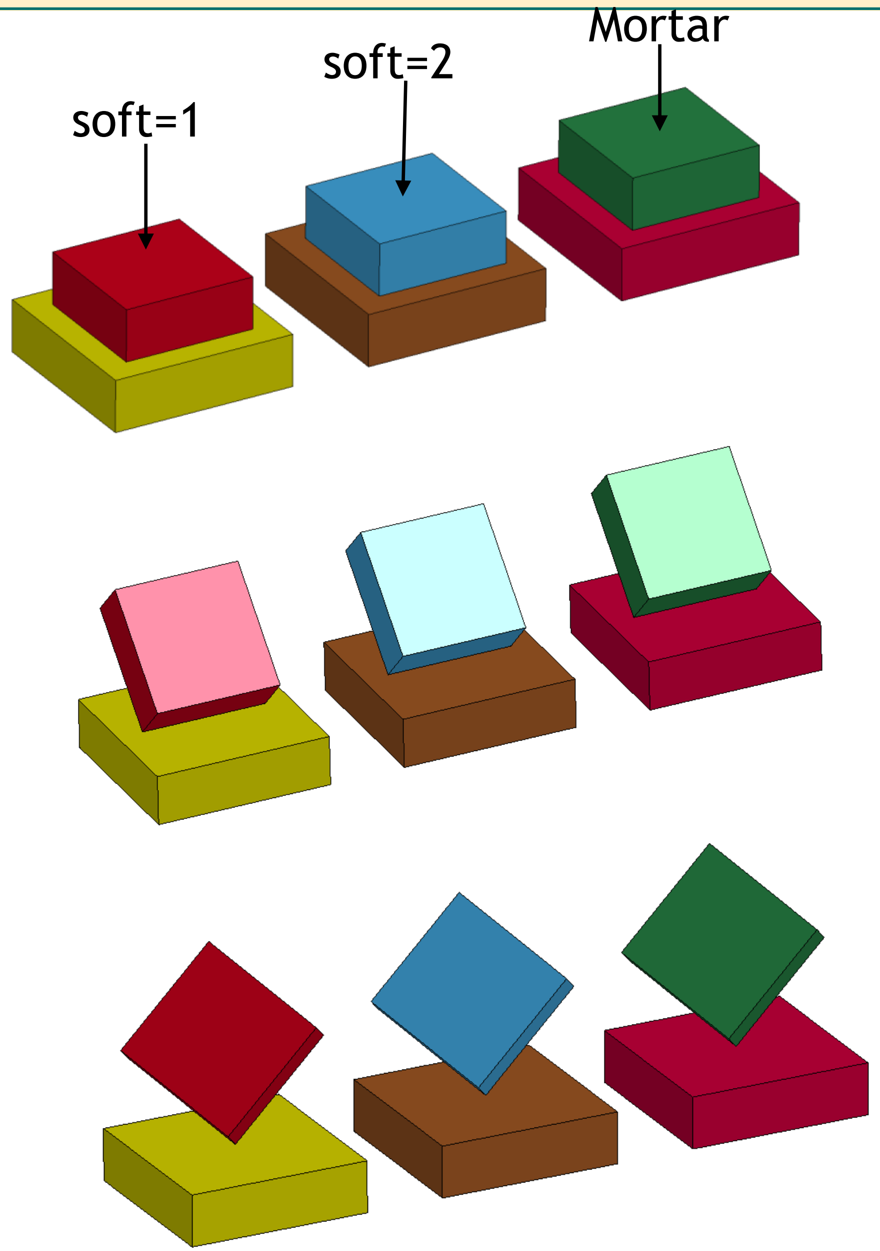
d = penetration distance

$\varepsilon = 0.03$

d_c = characteristic length

Contact stiffness

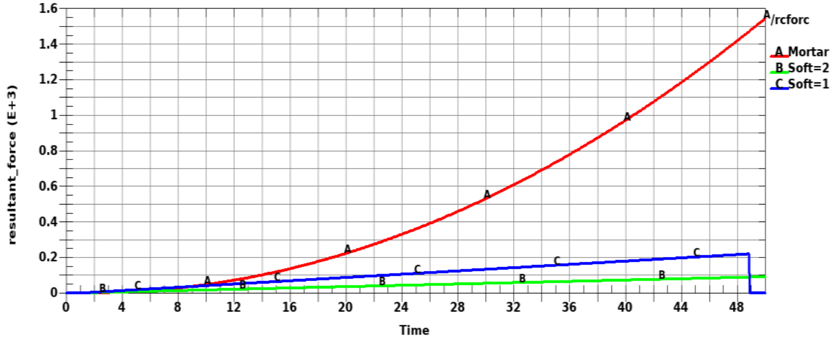
- Example with mortar, soft=2 and soft=1 contact.
- One element in each block.
- Prescribed motion applied in z-direction of top block.
- Default contact settings, except shledg=1 for soft=2.
- The contact force is measured with rcforc.
- Surface-surface, edge-surface, corner-surface tested.
- Element size 5x5x2 mm.
- Solid model and shell model.
- Simulated until the soft=1 contact was pushed through and released.

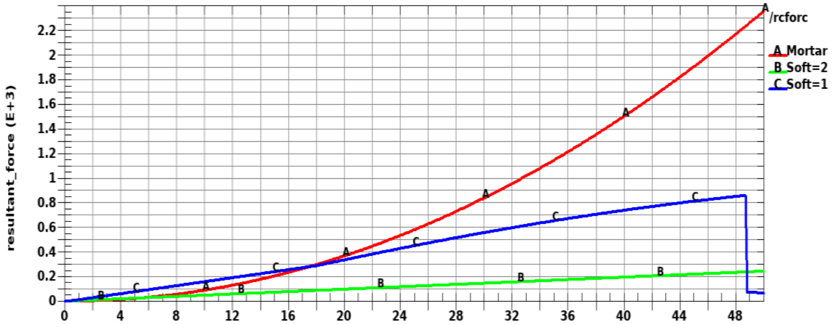


Contact stiffness

surface-surface

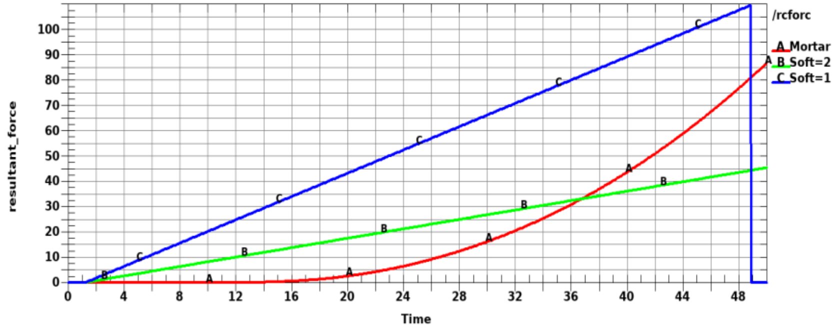
Strong

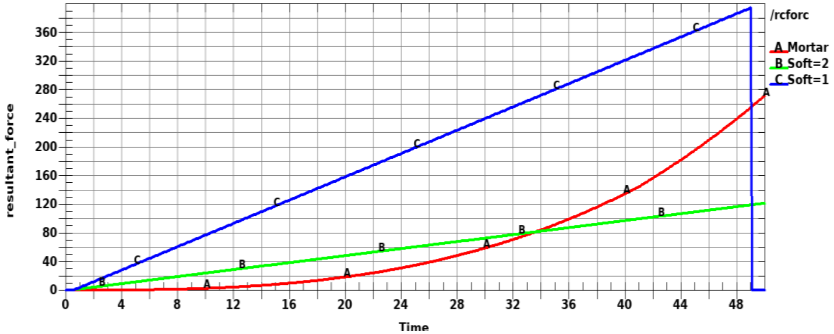




edge-surface

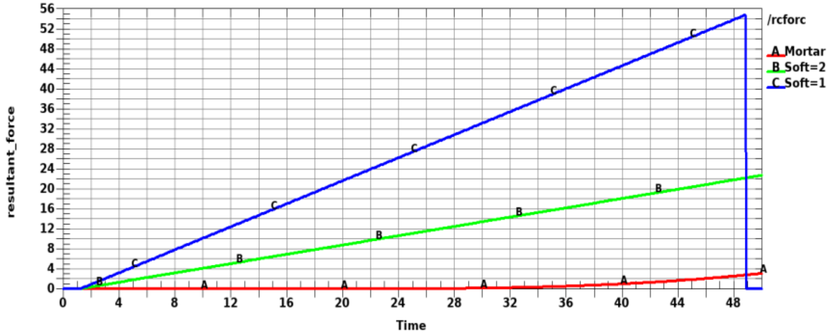
Mid-range

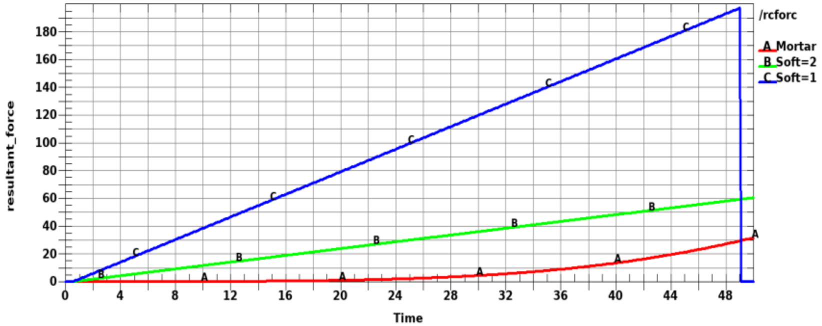




corner-surface

Weak





Solids

Shells

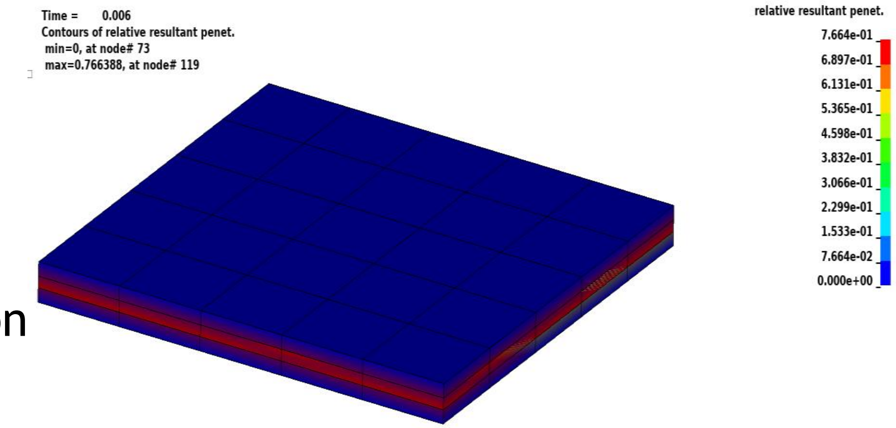
Extra output for MORTAR

Output MORTAR-contact sliding energy density to d3plot and intfor

- CONTROL_OUTPUT, ENGOUT=1
- DATABASE_EXTENT_INTFOR, NENG=1

Output MORTAR-contact penetration to d3plot and sleout (binary format), and intfor

- CONTROL_OUTPUT, PENOUT
- DATABASE_EXTENT_INTFOR, NPEN
  - PENOUT/NPEN=0 -> Do not output
  - PENOUT/NPEN=1 -> Output absolute penetration
  - PENOUT/NPEN=2 -> Output absolute and relative penetration



Relative penetration is output as a percentage of the penetration at which the contact is released.

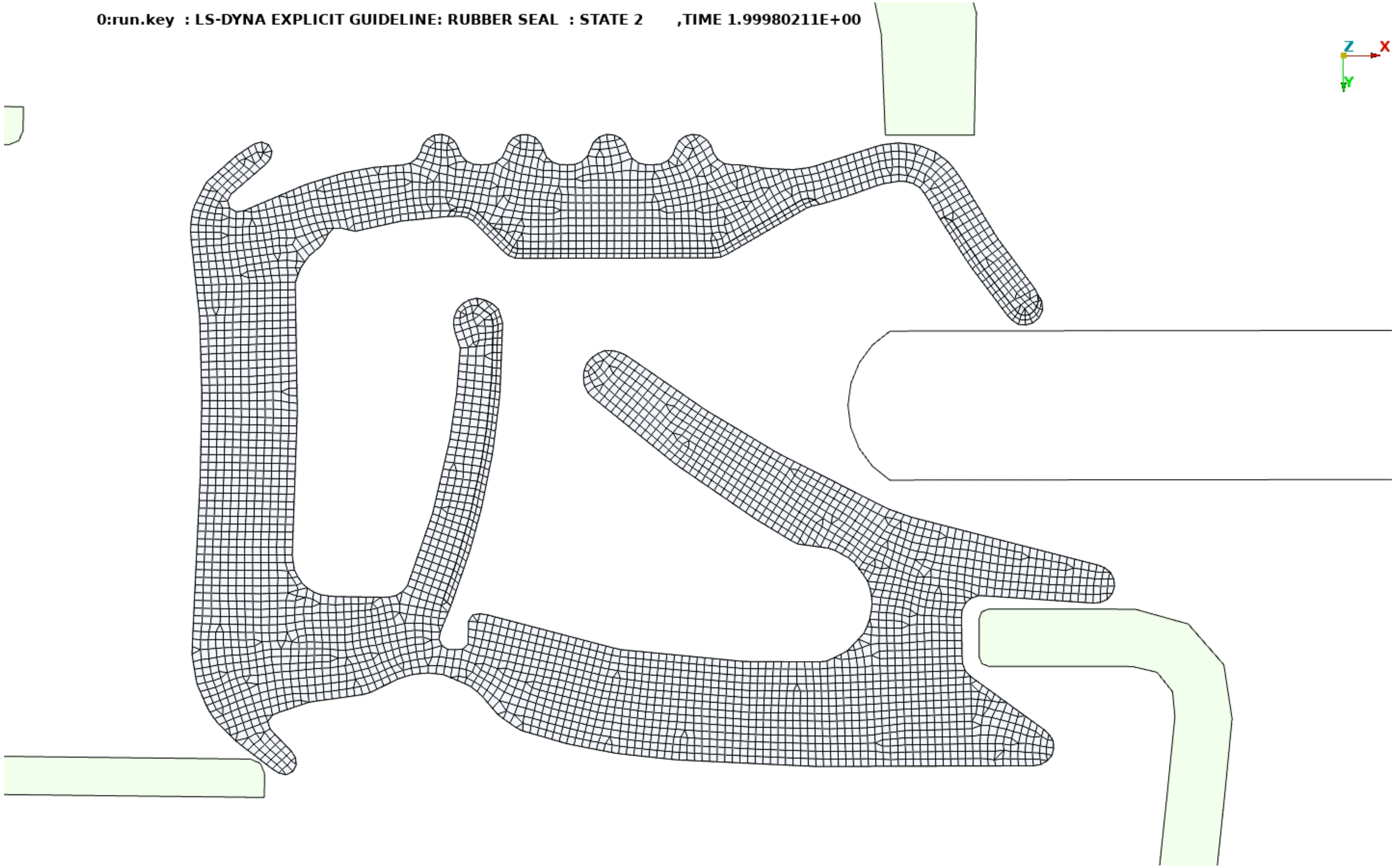
Benchmark – Rubber seal

- Model collected from our Explicit guideline.
- 3D solid model (elform 1) of a rubber seal between a door frame and the side window of a car.
- 23k elements. Element size 0.2 mm.
- Contact parameters set to default except contact friction and damping.

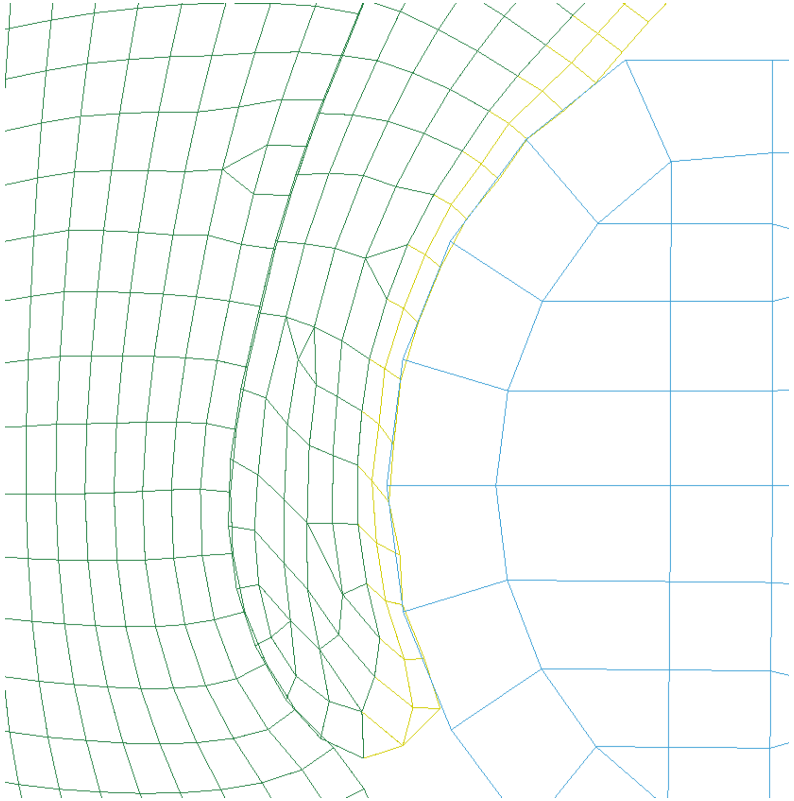
```
*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID
$#     cid                                                                 title
         1General contact
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         1         0         2         0         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
      -2.0       0.0       0.0       0.0      40.0         0       0.01.00000E20
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
       1.0       1.0       0.0       0.0       1.0       1.0       1.0       1.0
```

- The contact situation involves large deformation and high pressures.

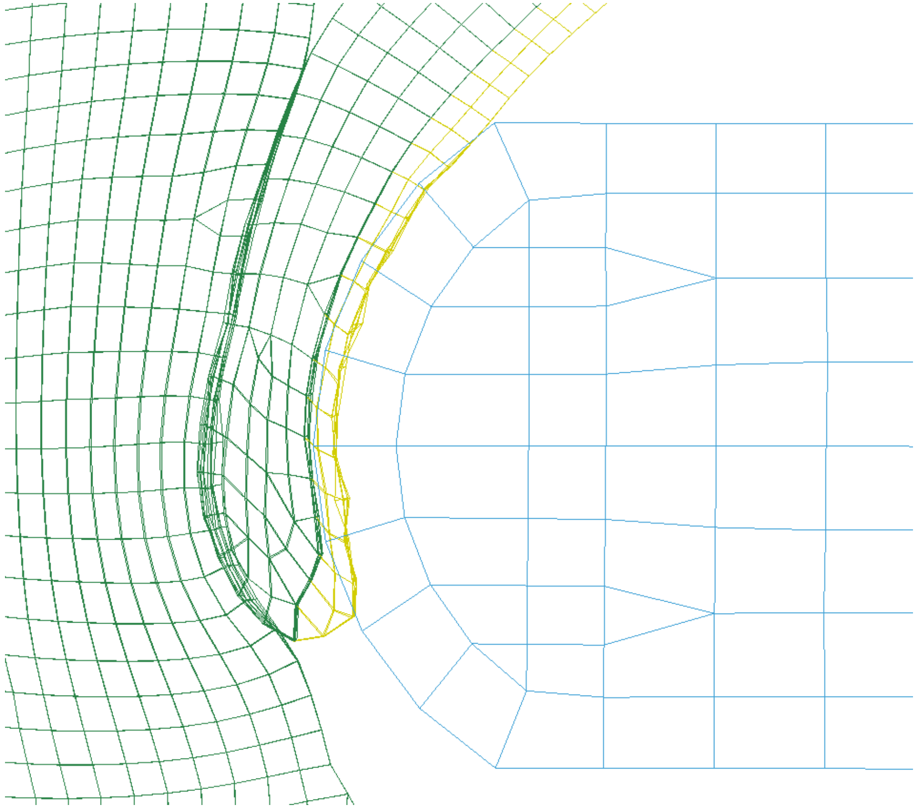
Benchmark – Rubber seal



Benchmark – Rubber seal



Mortar



SOFT=2

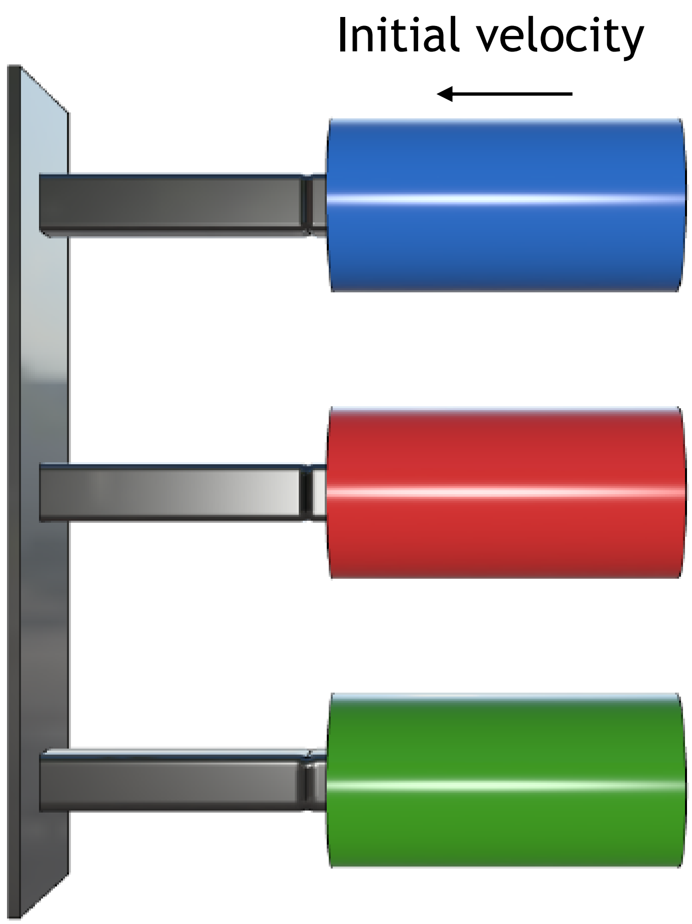
Benchmark – Rubber seal

- The simulation was run on 4 cores on a linux machine equipped with dual Xeon SP 6148 CPU's (2.40 GHz).
- A constant timestep 0.311e-6 s.
- Elapsed time using MORTAR contact was 130 minutes.
- Elapsed time using SOFT=2 contact was 143 minutes.
- The MORTAR-contact was actually faster and performed very well at first try. No need for tweaking parameters, which was the case of the SOFT=2 contact.
- In this comparison the MORTAR contact yield smaller penetrations compared to the SOFT=2 contact.

Benchmark – Crash box

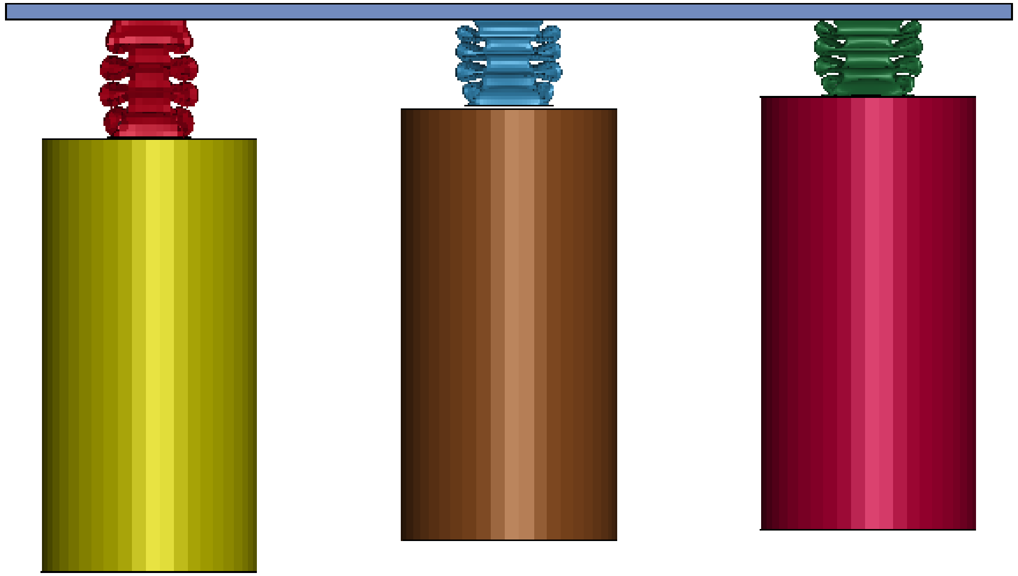
- Model collected from our Explicit guideline.
- Shell model (elform -16) of beam crush.
- Element sizes, 2.5 mm, 5.0 mm and 10.0 mm.
- 72k elements.
- Contact parameters set to default except contact friction and damping.

```
*CONTACT_AUTOMATIC_SINGLE_SURFACE_MORTAR_ID
$#     cid                                                                 title
         1General contact
$#    ssid      msid     sstyp     mstyp    sboxid    mboxid       spr       mpr
         1         0         2         0         0         0         0         0
$#      fs        fd        dc        vc       vdc    penchk        bt        dt
       0.2       0.2       0.0       0.0      40.0         0       0.01.00000E20
$#     sfs       sfm       sst       mst      sfst      sfmt       fsf       vsf
       1.0       1.0       0.0       0.0       1.0       1.0       1.0       1.0
```



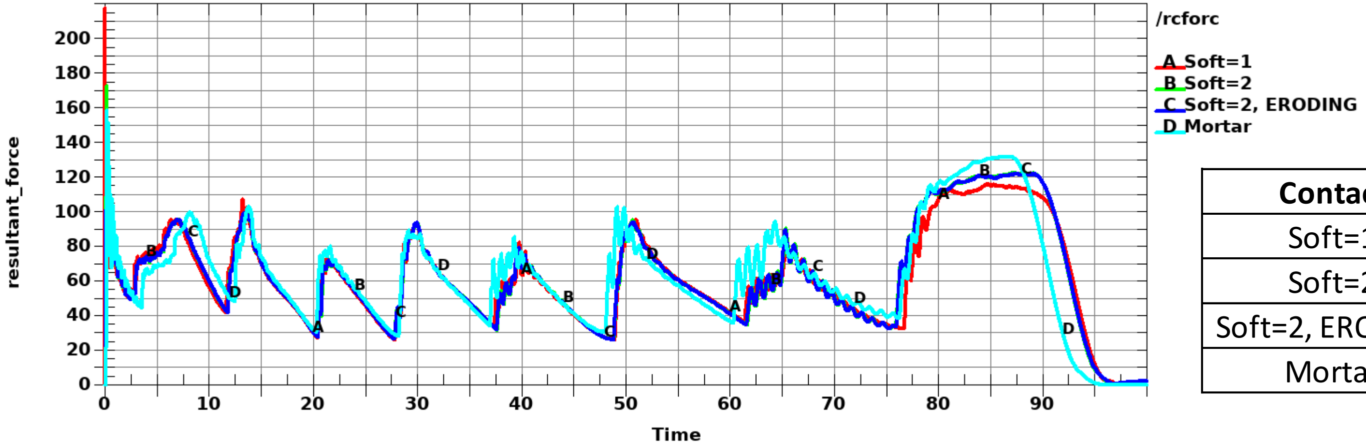
Benchmark – Crash box

- The simulation was run on 20 cores on a linux machine equipped with dual Xeon SP 6148 CPU’s (2.40 GHz).
- A constant timestep 0.361e-6 s.
- The simulation was run with soft=1, soft=2, soft=2 “ERODING” and MORTAR.
- All contacts gave similar results.



MORTAR

Benchmark – Crash box



Contact	Wall clock run time (seconds)	Ratio (%)	Contact CPU(%)
Soft=1	1450	100	14
Soft=2	2204	152	28
Soft=2, ERODING	2300	159	35
Mortar	4168	287	66

- MORTAR is the most expensive contact as expected.
- Regarding capabilities CONTACT_ERODING_SINGLE_SURFACE is the most similar.
- Compared to “ERODING” mortar is 1.8 times more expensive in this example.

Conclusions

- The Mortar contact can be a good complement to traditional explicit contacts.
- For instance for solving tricky contact situations involving large deformations and high stresses.
- Also, it can be used for interference fit (IGNORE=-3/3,-4/4), as well as multistage simulations using dynain.lsda.
- Often no tweaking of contact parameters is necessary.
- The contact can handle element erosion natively.
- The contact is more expensive than other contacts, but when in trouble it can be worth it!