Segment based contact – soft=2

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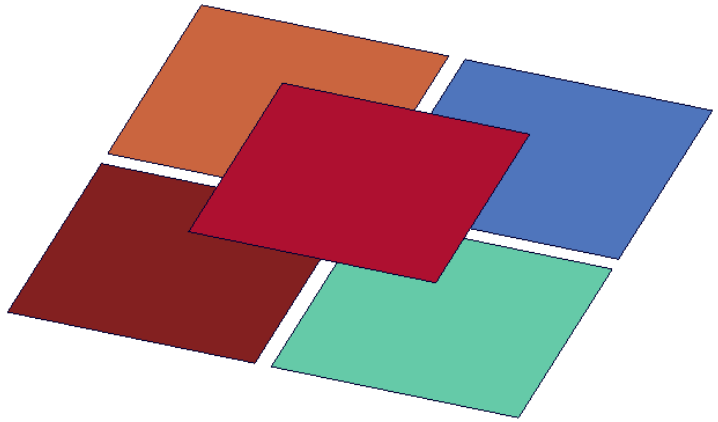
Agenda

- Basic idea
- *CONTACT_’s for soft=2
- Parameters for SOFT=2
- Comparison with other contacts in different situations

Basic idea

- Comes from airbag simulation
  - Robust contact search
  - Speed is crucial
  - Many parameters originates from the airbag folding/deployment.



- Treat interaction between a segment pair once.
- Each segment pair treated individual.
- Default – fast, accuracy can be turned up (compare with _MORTAR).

- Master segment selected internally (ONE_WAY) contacts override this.
- Forces applied in normal direction of master surface (see DEPTH parameter).

Supported elements

- All 3D- analysis elements except beams/springs – need a surface definition.
  - Shells
  - Solids
- Higher ordered element treatment – multiple bilinear segments
  - Shells
  - Tets
  - Hex
- Beam elements are NOT supported

Un-supported options

- *CONTACT_xxx_ORTHO_FRICTION
- *CONTACT_xxx_SMOOTH
- Any constraint based contact
  - TIEBREAK contacts
  - TIED contacts
  - CONSTRAINT contacts

- Beam elements are NOT supported

Parameters affecting soft=2

- _MPP
  The optional card(s) activated by _MPP – read but ignored if soft=2…

Card 1	1	2	3	4	5	6	7	8
Variable	IGNORE	BCKT	LCBCKT	NS2TRK	INITITR	PARMAX		CPARM8
Type	I	I	I	I	I	F		I
Default	0	200	None	3	2	Depends		0
Card 2	1	2	3	4	5	6	7	8
Variable	&	CHKSEGS	PENSF	GRPABLE				
Type		I	F	I				
Default		0	0.0	0				

*CONTACT (1-3)

Card 1	1	2	3	4	5	6	7	8
Variable	SSID	MSID	SSTYP	MSTYP	SBOXID	MBOXID	SPR	MPR
Type	I	I	I	I	I	I	I	I
Card 2	1	2	3	4	5	6	7	8
Variable	FS	FD	DC	VC	VCD	PENCHK	BT	DT
Card 3	1	2	3	4	5	6	7	8
Variable	SFS	SFM	SST	MST	SFST	SFMT	FSF	VSF
Type	F	F	F	F	F	I	F	F
Default	1.0	1.0	Elem. Thick.	Elem. Thick	1.0	1.0	1.0	1.0

- PENCHK does not apply for SOFT=2.
- VSF does not apply for SOFT=2.

*CONTACT - optional cards

Opt. A	1	2	3	4	5	6	7	8
Variable	SOFT	SOFTSCL	LCIDAB	MAXPAR	SBOPT	DEPTH	BSORT	FRCFRQ

Opt. B	1	2	3	4	5	6	7	8
Variable	PENMAX	THKOPT	SHLTHK	SNLOG	ISYM	I2D3D	SLDTHK	SLDSTF

Opt. C	1	2	3	4	5	6	7	8
Variable	IGAP	IGNORE	DPRFAC/	DTSTIF/M			FLANGL	CID_RCF

Opt. D	1	2	3	4	5	6	7	8
Variable	Q2TRI	DPTCHK	SFNBR	FNSCL	DNSCL	TCSO	TIEDID	SHLEDG

Opt. E	1	2	3	4	5	6	7	8
Variable	SHAREC	CPARM8	IPBACK	SRNDE	FRICSF	ICOR	FTORQ	REGION

Opt. F	1	2	3	4	5	6	7	8
Variable	PSTIFF	IGNROFF		FSTOL	2DBINR	SSFTYP		
Type	I	I		F	I			
Default	0	0		2.0	0			

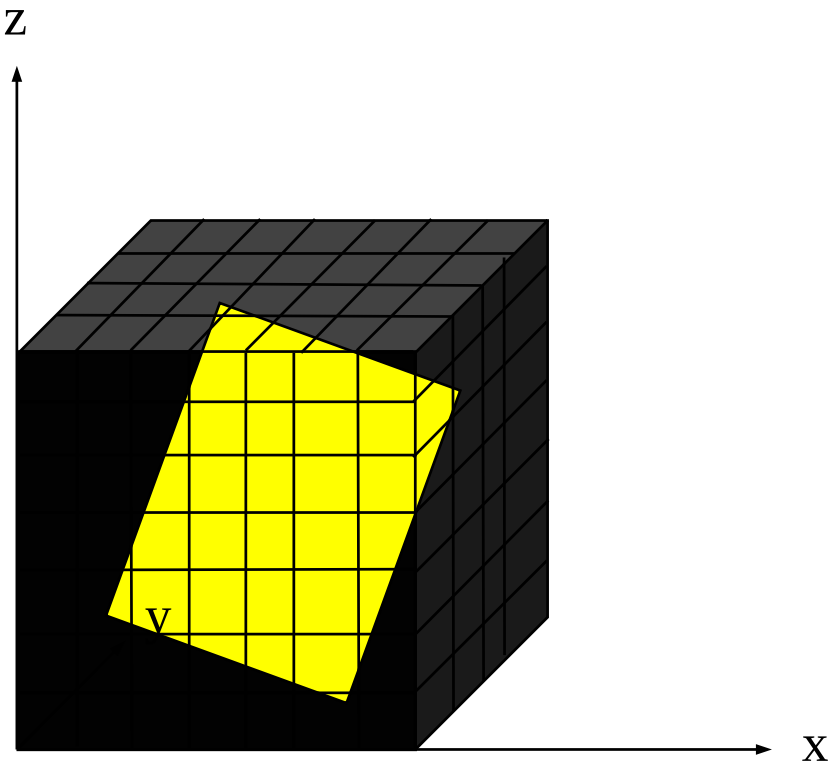
Running through the basic for a contact

- Contact search
- Penalty stiffness in contact
- Frictional behavior of contact
- Contact thickness
- Initial penetration treatment
- Release condition

Contact search for SOFT=2

- Bucket sort
  - BSORT parameter
- Find contact pairs
- Depends on
  - SBOPT
  - DEPTH
- Evaluate segment overlap
- Evaluate contact point
- Apply contact force

- Volume partitioned into buckets
- Find closest buckets to each slave node.
- A list closest nodes are set. Typical 2 for most contacts.
- The segment corresponding to those nodes and their neighbors are then checked for penetration in the subsequent cycles.
- Incremental search each cycle for new closest node of closest segments.
- Execution of bucket sort every 10-200 cycles, implicit every cycle.
- Depending on contact used, modified on _MPP card or Optional card A.

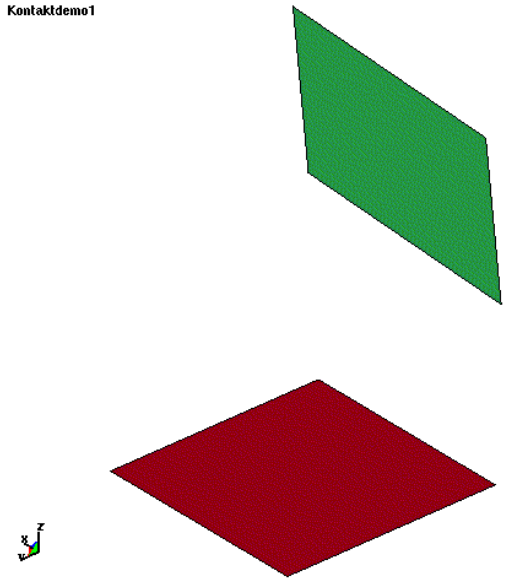


More on contact search

- SBOPT
  - SBOPT=3 → Check for warped segments
  - SBOPT=5 → Check for sliding – primarily solid elements
- DEPTH
  - Many different options exist (1,2,3,4,5,13,23,33,25,35,45)
  - If ending with 3 – no edge2edge checking
  - If ending with 5 – edge2edge checking

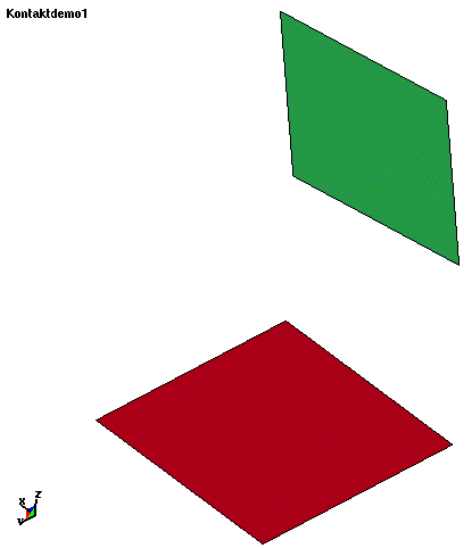
  - Recommended variants: 3/5/35/45.
  - 45 also changes the geometry of the segment interpretation more on that later…

Soft=2, segment based contact



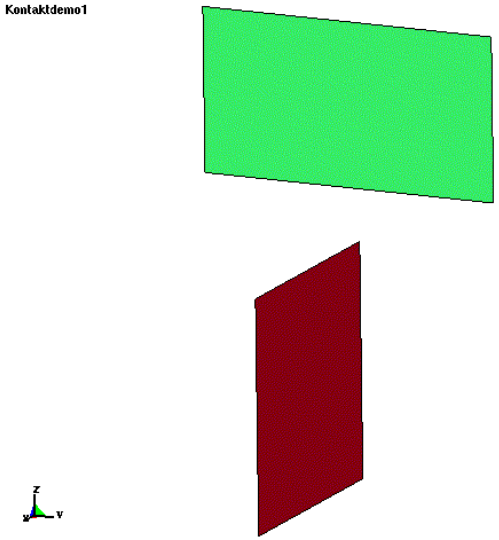
SBOPT = 3, DEPTH =2

Surface Penetration measured at nodes.



SBOPT = 3, DEPTH =3

Surface Penetration measured at edges at nodes and edges

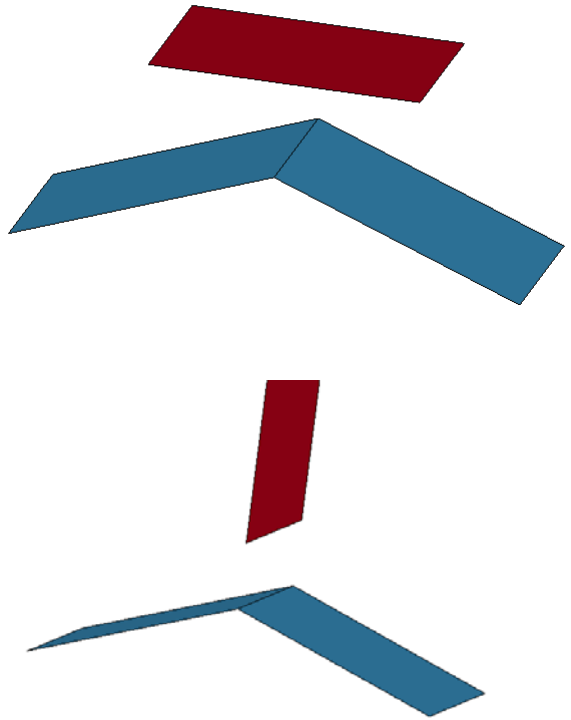


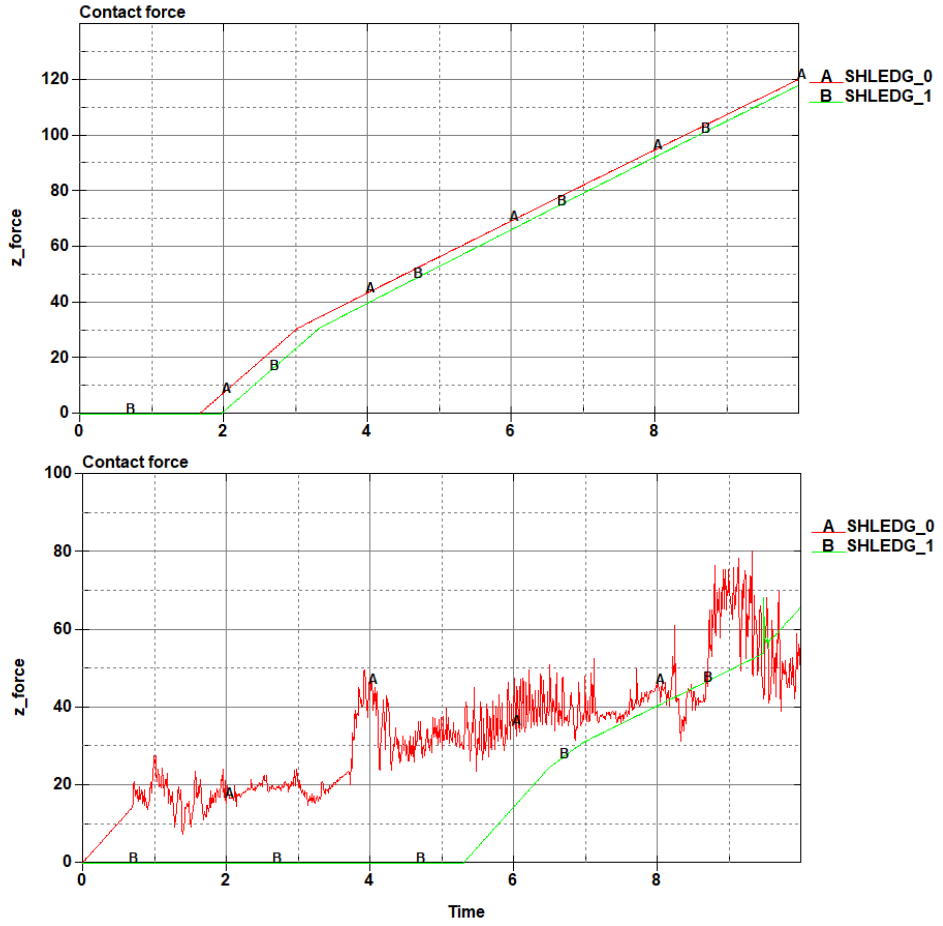
SBOPT = 3, DEPTH =5

Surface Penetration and Edge-to-Edge Penetration checked

Soft=2 – SHLEDG parameter

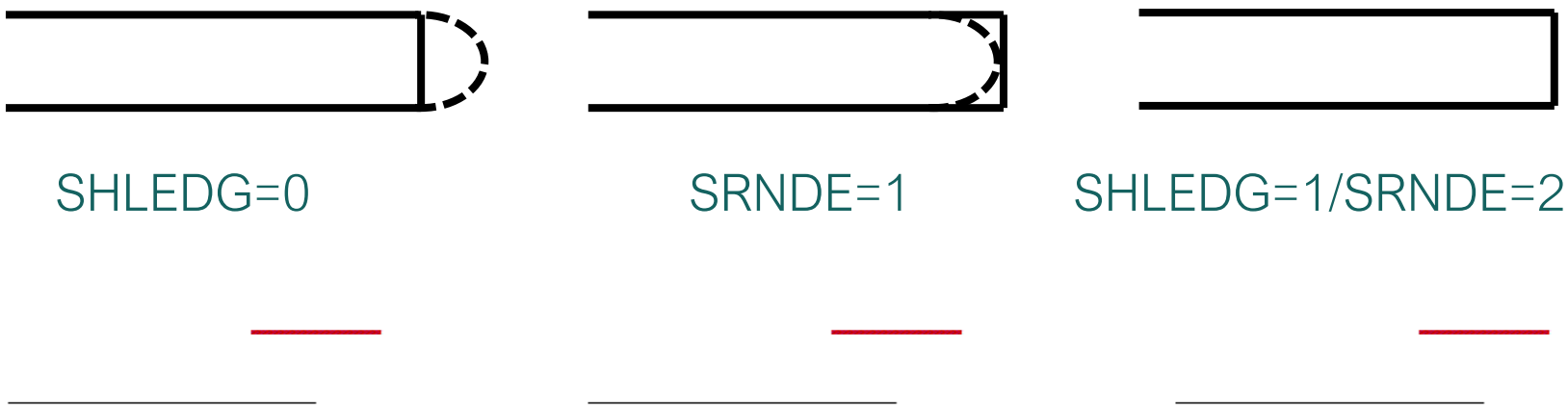
- Affects ALL segment edges – also internal edges between shells.
  - Simple flat surface coming into contact with an internal shell edge.
  - SBOPT=3, DEPTH=5, SHLEDG=0/1
  - Rotate





Edge geometry

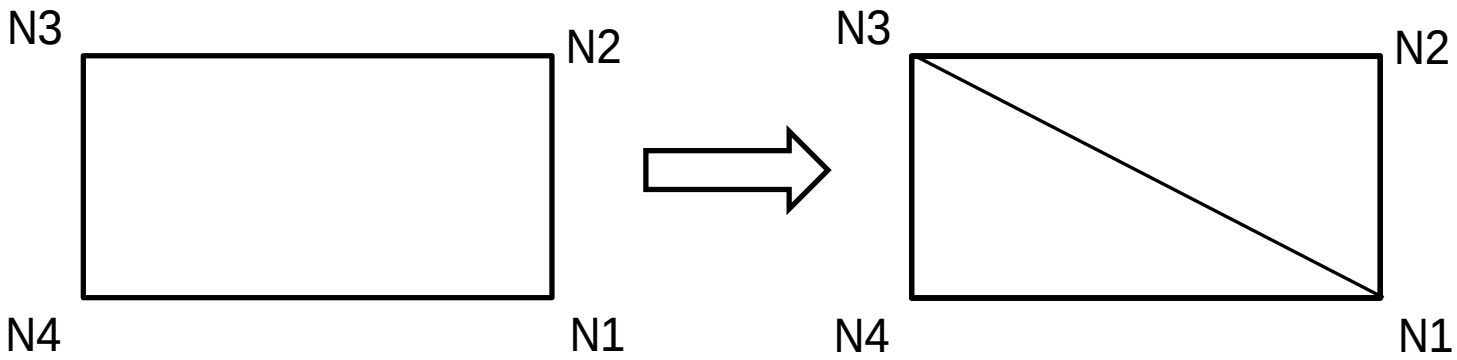
- SOFT=2
  - Normal use is SHLEDG parameter
  - SRNDE=2
    - Optional card E, position 4.
  - Changes the extension of the cylindrical edges for soft=2 contacts
  - No extension when DEPTH=35.



Segment geometry

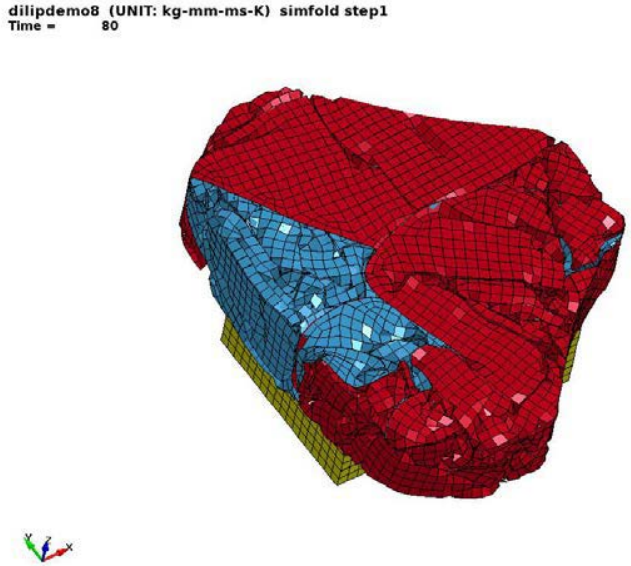
- There are a couple of flags that will change the geometry of the segment:
  - QUAD2TRIA
  - DEPTH=45

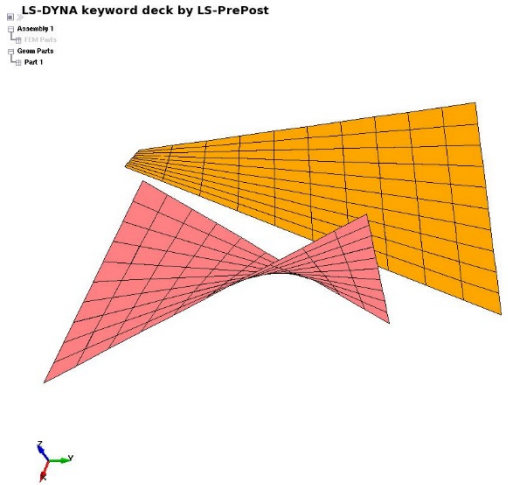
- QUAD2TRIA
  - Split each 4 noded segment into 2 quads based on their nodal topology. Same nodal topology will always give the same split.

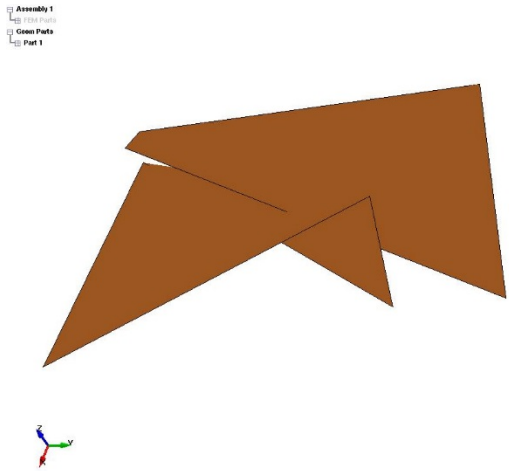


From airbag application – folding/inflating

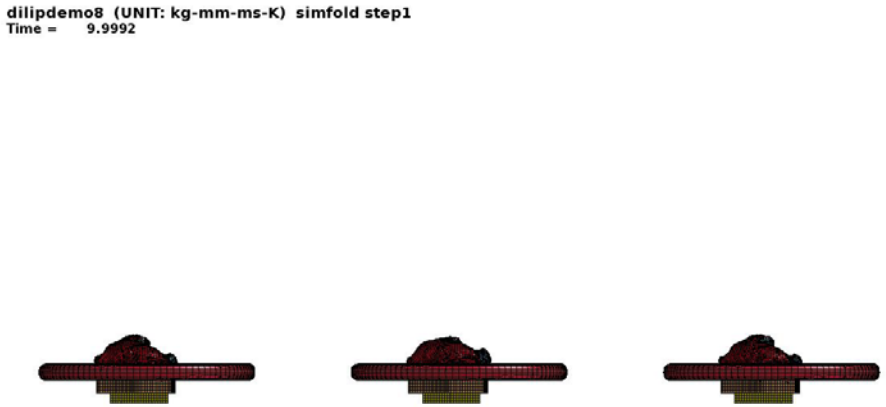
- DEPTH=45
  - Q2TRI=0 recommended

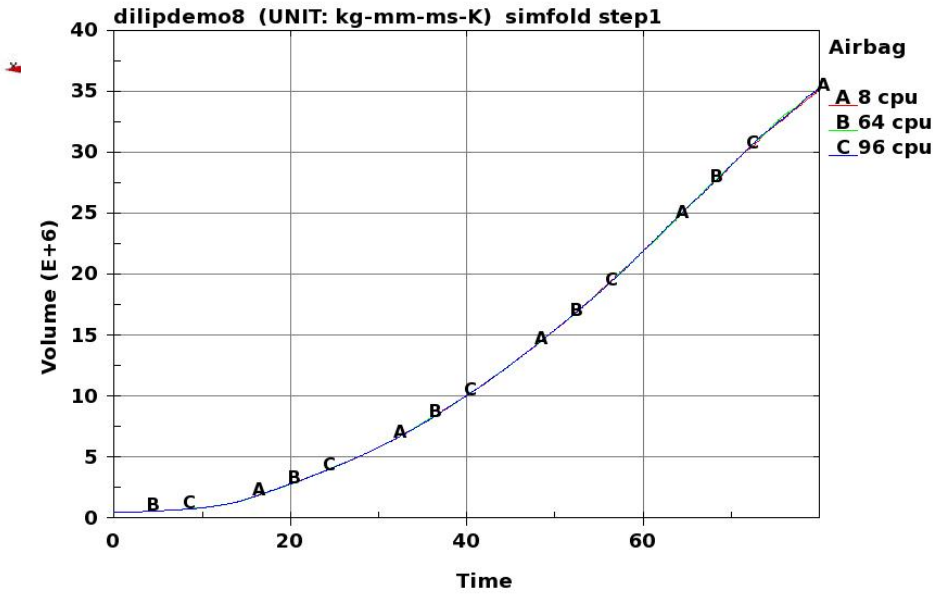






Soft=2, Depth=45





Penalty Scale Factor

- Soft = 2 Segment Based Contact (Optional Card A, Flag 1 on *CONTACT…)

$$k_{SOFT=2} = 0.5 * SLSFAC \begin{Bmatrix} SFS \\ or \\ SFM \end{Bmatrix} \left(\frac{m_1 m_2}{m_1 + m_2} \right) \left(\frac{1}{\Delta t} \right)^2$$

- Where:
  - m1,m2 = segment mass of contact partners.
    - shells: mass of element.
    - solids: half the mass of the element.
  - Δt = initial global time step (or larger).

Parameters affecting penalty scale factor

- SFS/MSF on Card 3 of contact definition

$$k_{SOFT=2} = 0.5 * SLSFAC \begin{Bmatrix} SFS \\ or \\ SFM \end{Bmatrix} \left(\frac{m_1 m_2}{m_1 + m_2} \right) \left(\frac{1}{\Delta t} \right)^2$$

- DTSTIFF
  - Set the timestep size used for calculation for the penalty stiffness.
- PSTIFF
  - Default segment volume times density gives segment mass.
  - PSTIFF=1, sum nodal masses and divide with a number giving the ‘normal’ amount of elements attached to a node.
    - Added mass due to mass-scaling/*ELEMENT_MASS can increase the stiffness.
    - Edge nodes mass underestimated – probably attached to fewer elements.
- SSFTYP on Optional card F
  - If contact used with *PART_CONTACT and SSF parameter use

Parameters affecting penalty scale factor – nonlinear scaling

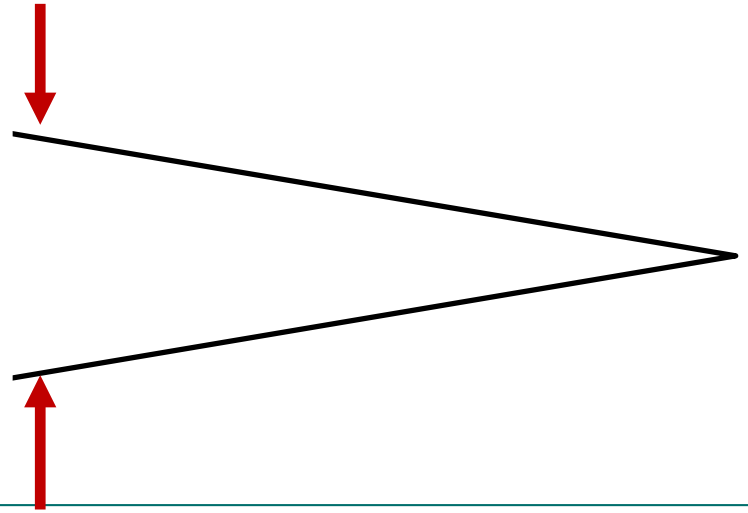
Opt. D	1	2	3	4	5	6	7	8
Variable	Q2TRI	DPTCHK	SFNBR	FNSCL	DNSCL	TCSO	TIEDID	SHLEDG
Type	I	F	F	F	F	I	I	I
Default	0	0.0	0.0	0.0	0.0	0	0	0

- Using combination of FNSCL (f) and DNSCL (d)
  - FNSCL<0; DNSCL>0: $k \rightarrow k\left[\frac{0.01 f A_0}{d(d-\delta)}\right]$ $Ao = overlap$ area of segment in contact.
  - FNSCL>0; DNSCL>0: $k \rightarrow kf\sqrt{\frac{\delta}{d}}$
  - FNSCL>0; DNSCL=0: $k \rightarrow kf\left(\frac{A_0}{A_m}\right)$ $Am = mean\ area\ of\ all\ segment\ in\ contact.$

Final parameter for stiffness scaling

Opt. D	1	2	3	4	5	6	7	8
Variable	Q2TRI	DPTCHK	SFNBR	FNSCL	DNSCL	TCSO	TIEDID	SHLEDG
Type	I	F	F	F	F	I	I	I
Default	0	0.0	0.0	0.0	0.0	0	0	0

- SFNBR: originates from folding simulations of airbags. Neighbor segments contact reduced possibility to make tight folded bags.
  - <0: (recommended -0.5 to -1.0) →improve energy balance
  - >0: scale the contact stiffness: $k \rightarrow SFNBR * k$
  - Only shell elements are checked.



Frictional behavior in CONTACT

Card 2	1	2	3	4	5	6	7	8
Variable	FS	FD	DC	VC	VCD	PENCHK	BT	DT
Card 3	1	2	3	4	5	6	7	8
Variable	SFS	SFM	SST	MST	SFST	SFMT	FSF	VSF
Type	F	F	F	F	F	I	F	F
Default	1.0	1.0	Elem. Thick.	Elem. Thick	1.0	1.0	1.0	1.0

- FS: static frictioncoefficient
- DC: exponential decay coefficient
- FD: dynamic friction coefficient
- VC: coefficient for viscous friction

$$\mu_C = FD + (FS - FD)e^{DC|v_{rel}|}$$

- FSF: coulomb friction scale factor $\longrightarrow \mu_{SC} = FSF \cdot \mu_S \longrightarrow F_{Limit} = VC \cdot VSF \cdot A_{Cont}$

Frictional behavior from *PART_CONTACT

Extra	1	2	3	4	5	6	7	8
Variable	FS	FD	DC	VC	OPTT	SFT	SSF	CPARM8
Type	F	F	F	F	F	F	F	
Default	0.0	0.0	0.0	0.0	0.0	0.0	0.0	

- The average between friction for master and slave segment is used.
  - The master segment is selected by contact (least penetrated segment) and normally the frictional behavior is picked up from master segment).

- FS=-1 on *CONTACT definition

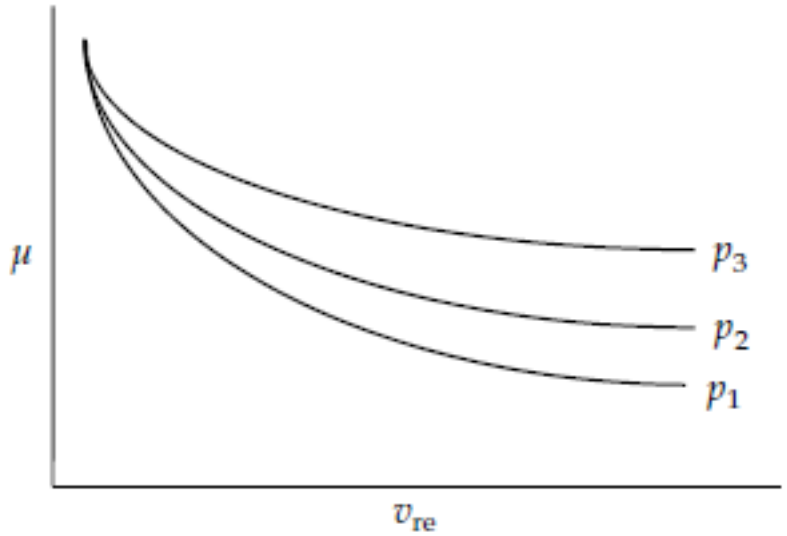
Frictional behavior using *DEFINE_FRICTION

Card 1	1	2	3	4	5	6	7	8
Variable	ID	FS_D	FD_D	DC_D	VC_D			
Type	I	F	F	F	F			
Default	0	0.0	0.0	0.0	0.0			
Card 2	1	2	3	4	5	6	7	8
Variable	PIDi	PIDj	FSij	FDij	Dcij	VCij	PTYPEi	PTYPEj
Type	I	I	F	F	F	F	A	A
Default			0.0	0.0	0.0	0.0		

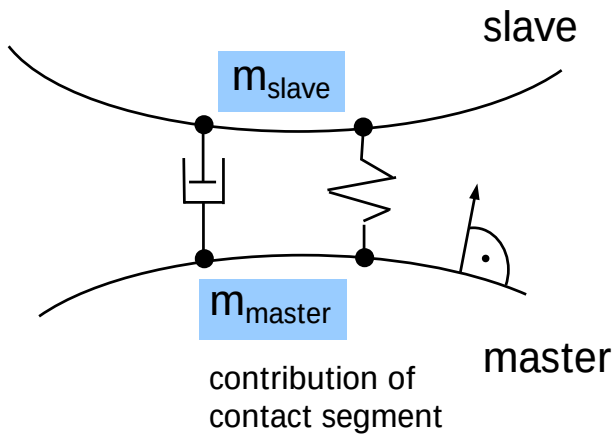
- *DEFINE_FRICTION superseeds *PART_CONTACT
- Definition in *contact_xxx using FS=-2 (-2 and FD gives table ID if multiple tables used).

Having a pressure/velocity dependent friction behavior

- Implemented for all contacts for SOFT=2.
  - Recommended when SOFT=2, FS=2 (FD gives table id):
    - FNLSCL=-1
    - DNLSCL=1/10:th of element thickness.
    - (DPRFAC=0.01 if significant sliding).



Contact damping – viscous damping

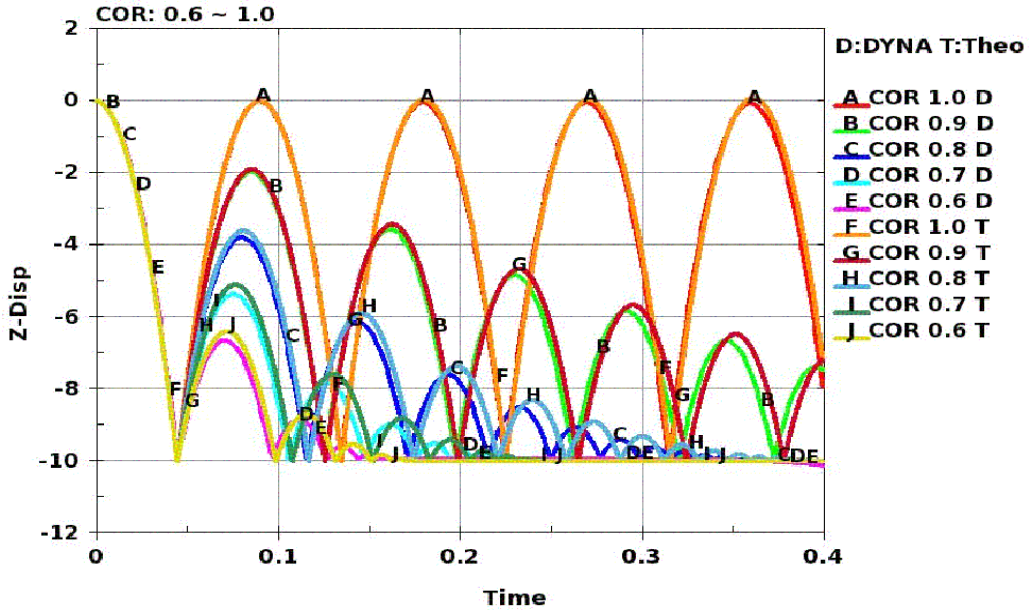


$$\xi = 2m\omega$$

$$\omega = \sqrt{\frac{k\left(m_{slave} + m_{master}\right)}{m_{slave} \cdot m_{master}}}$$

- Parameter: VDC (*CONTACT, card 2)
- Contact damping is often beneficial in reducing high frequency oscillations
  - VDC=20 (corresponding to 20% of critical damping) is recommended
  - VDC=40-60 has been used for contacts with soft material
- Energies dissipated by viscous damping in contact is not reported seperatly.

Contact damping – ICOR



- Parameter: ICOR (*CONTACT, Optional card E)
- Applies to all soft=2 contacts and soft=0/1 when contact is one of:
  - AUTOMATIC_NODES_TO_SURFACE
  - AUTOMATIC_SURFACE_TO_SURFACE
  - AUTOMATIC_SINGLE_SURFACE
- Coefficient of Restitution set using VDC parameter
  - 0.0 (plastic collision) ≤ VDC (COR) ≤ 100.0 (elastic collision).

Parameters for thickness definition of segments

- PART_CONTACT: OPTT

Extra	1	2	3	4	5	6	7	8
Variable	FS	FD	DC	VC	OPTT	SFT	SSF	CPARM8

  - Solid elements → gives the segment of the solid a thickness.
  - Shells → normal behavior.

- CONTROL_SHELL → not affected by THEORY → First node gives segment thickness If *ELEMENT_SHELL_THICKNESS is used

Card 1	1	2	3	4	5	6	7	8
Variable	WRPANG	ESORT	IRNXX	ISTUPD	~~THEORY~~	BWC	MITER	PROJ

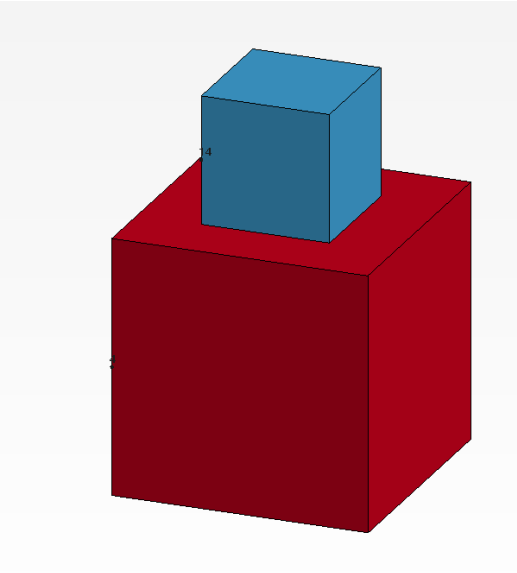
Difference with large thickness elements

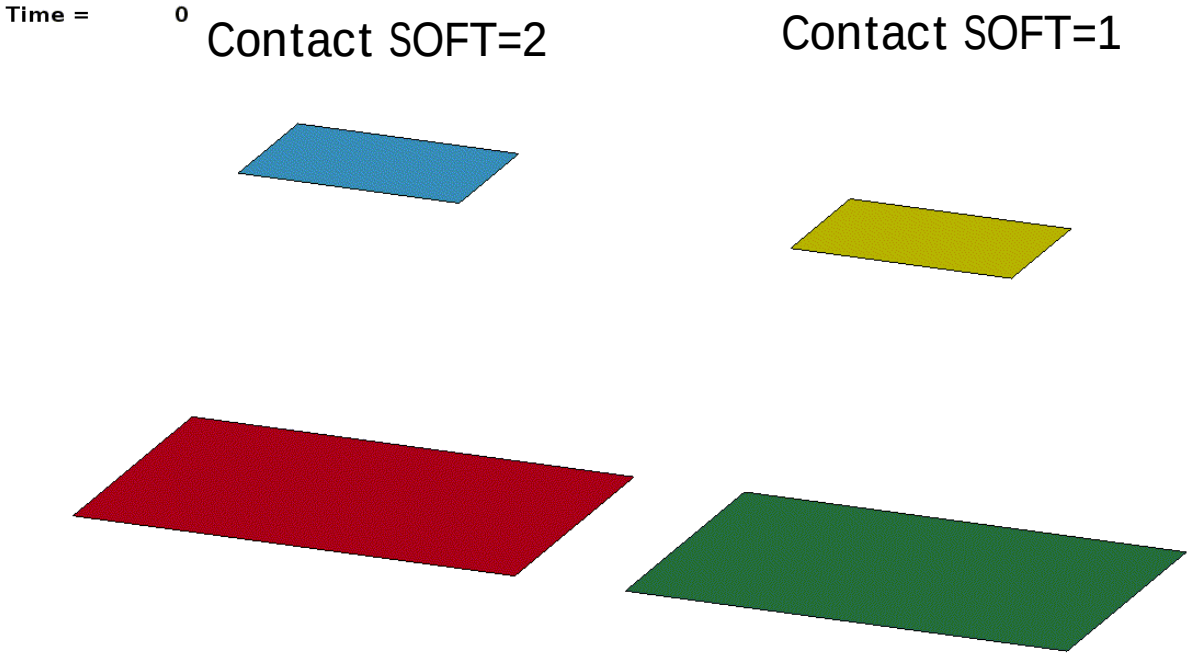
- CONTROL_CONTACT → do not use SSTHK → True element thickness used.

Card 2

	1	2	3	4	5	6	7	8
Variable	USRSTR	USRFRC	NSBCS	INTERM	XPENE	SSTHK	ECDT	TIEDPRJ

Structural geometry





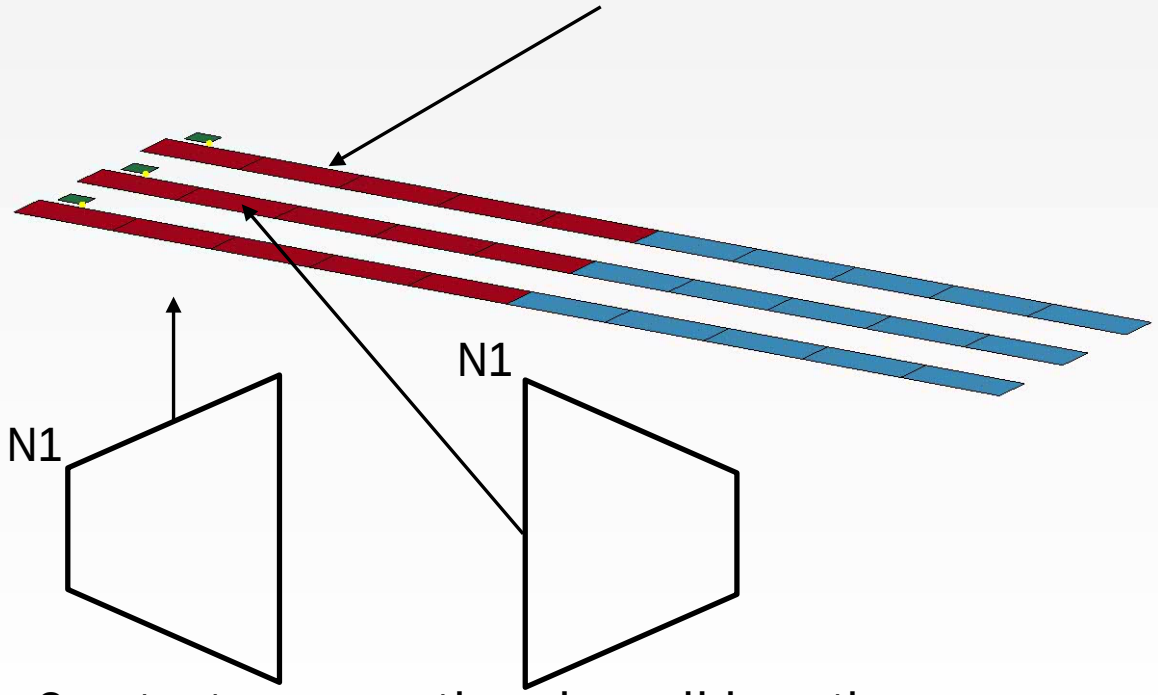
Segment thickness – tapered element

- Mechanical behavior of shells elform=2/16 – constant thickness!
  - ELEMENT_SHELL_THICKNESS_BETA → average nodal thickness value.
- Contact thickness behavior
  - Soft=2 → constant thickness using first nodal thickness
  - Soft=0/1 constant thickness using first nodal thickness
    - However segment thicknesses averaged on nodes and then inerpolated over surface.
  - Soft=0/1 + THEORY=1 on *CONTROL_SHELL
    - Actual nodal thickness used and then interpolated over surface.

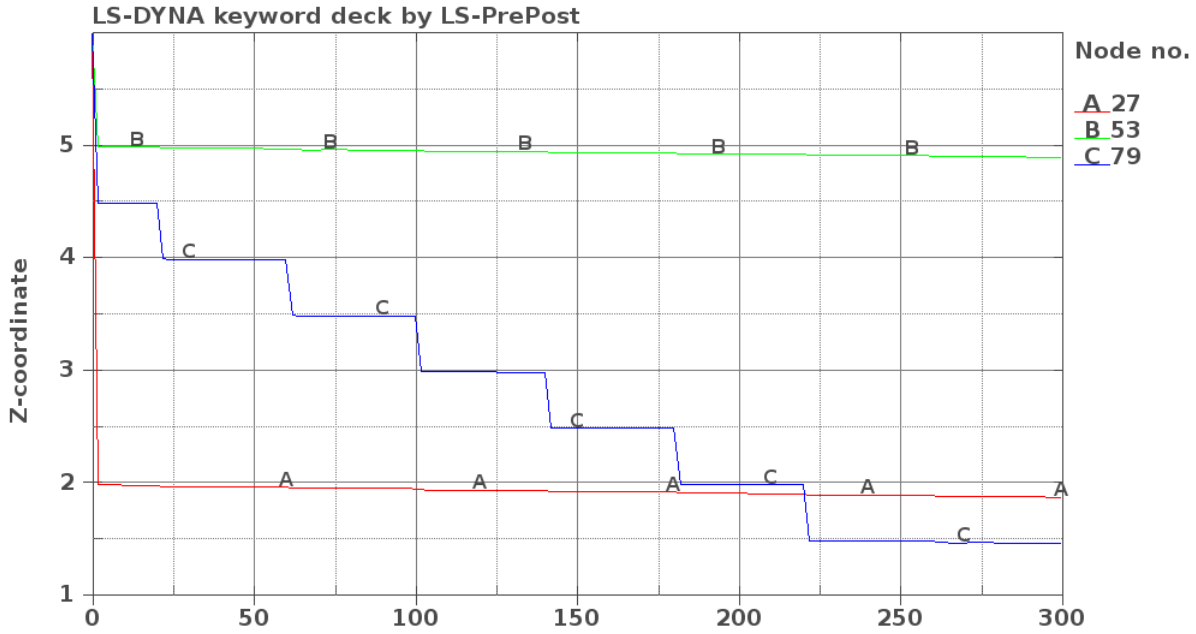
Simple test

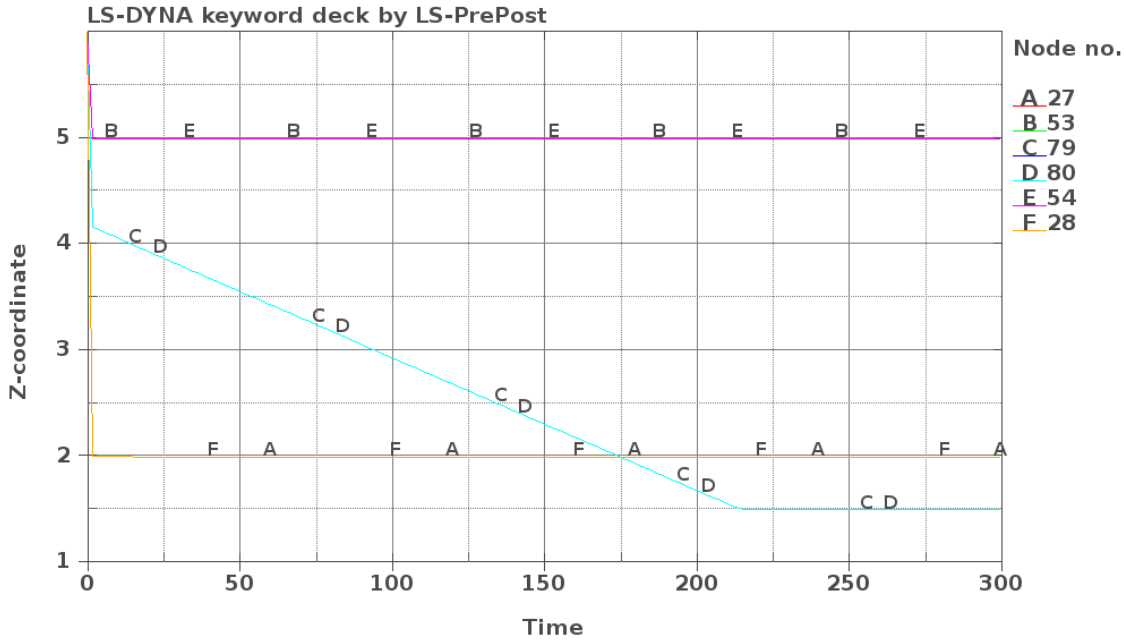
- Sliding with *ELEMENT_SHELL_THICK

Strip with deceasing nodal thickness along slide path



Constant cross-section along slide path





Initial penetrations

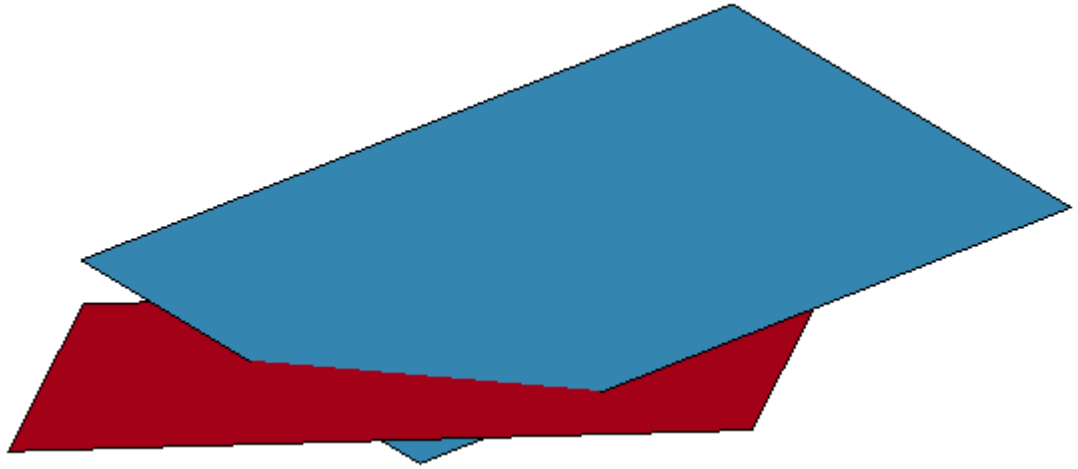
- IGNORE is always on.
  - Penetration found during first cycle between new contact pairs is treated with ignore → do not produce any contact forces.
- DPRFAC
  - Factor to reduce initial penetrations found after t=0.
  - Typical a factor of the initial penetration (which do not cause any contact force) is transformed into penetration which gives contact force:

$$\delta_i^{t+1} = \delta_i^t (1 - DPRFAC)$$

Hence a factor of 0.001 will approximately transform the initial penetration to contact pressure over 1000 cycles.

Possibility to check contact status

- The parameter DTPCHK gives a time interval for writing status between contact segments.
  - If a node of a segment cross the midsurface of another segment that node is reported into the d3hsp and message files.



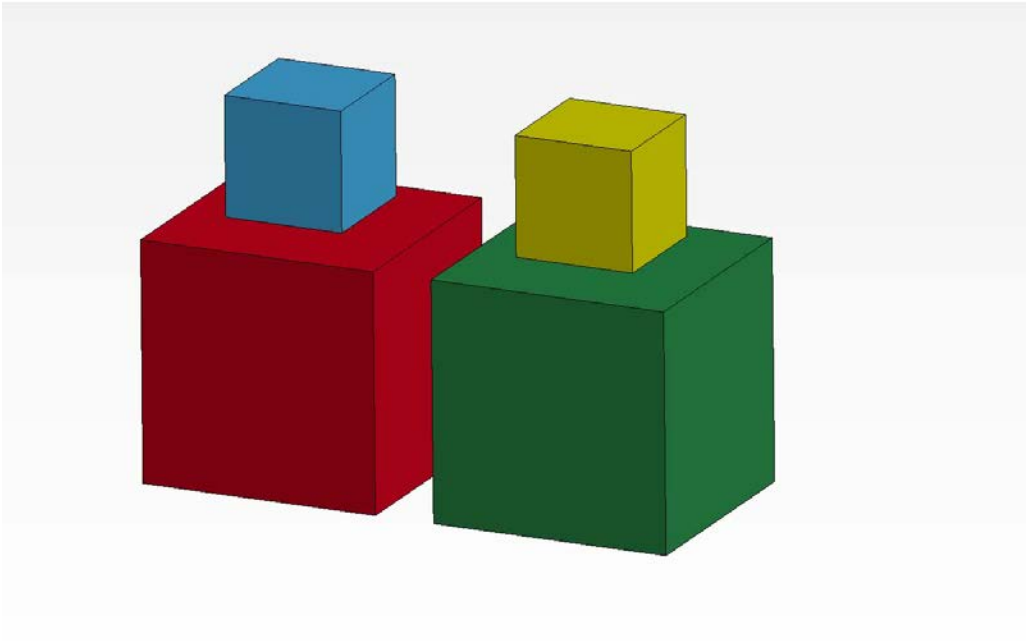
  - In an airbag deployment this is likely to happen. If reported once – no problem. If the same segment is reported several times in a row – slow down of unfolding should be expected.

*SECTION_SHELL

- NLOC parameter – which surface is meshed
- Similar functionality as _OFFSET on some element definitions.

- Requires CNTCO to be set on *CONTROL_SHELL to be honored in contact routines.

Soft=2 (NLOC/CNTCO)

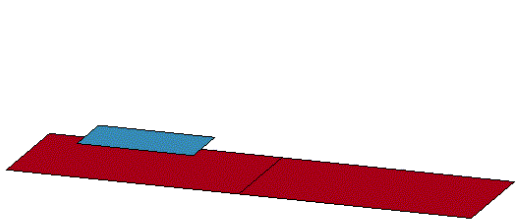


Soft=0/1 (NLOC/CNTCO)

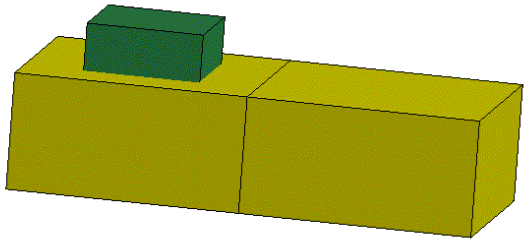
SSTHK flag operates first

Simple sliding behavior of SOFT=2

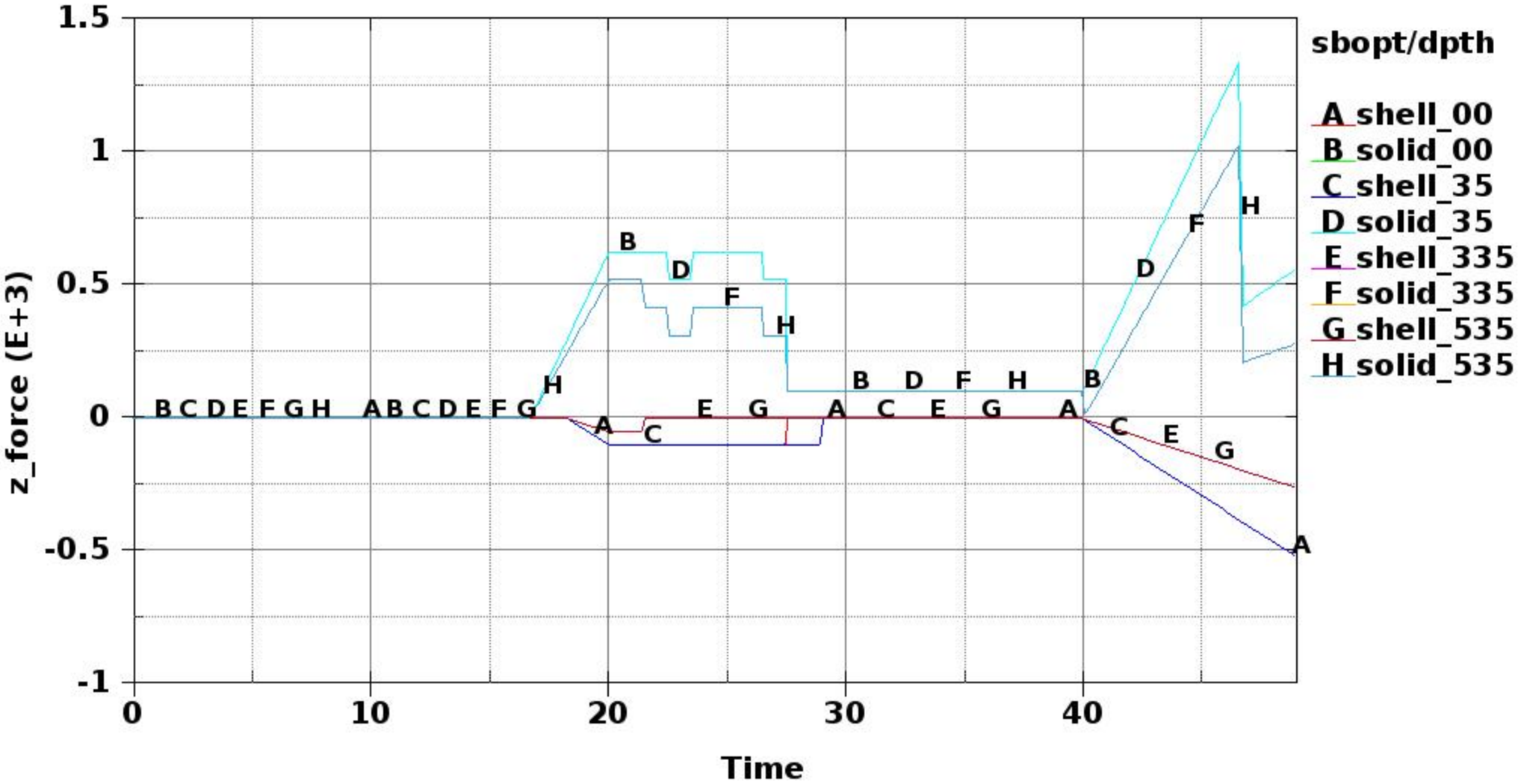
- Simple model
  - Shell in initial penetration goes out of initial penetration and back again and slides to adjacent shell.



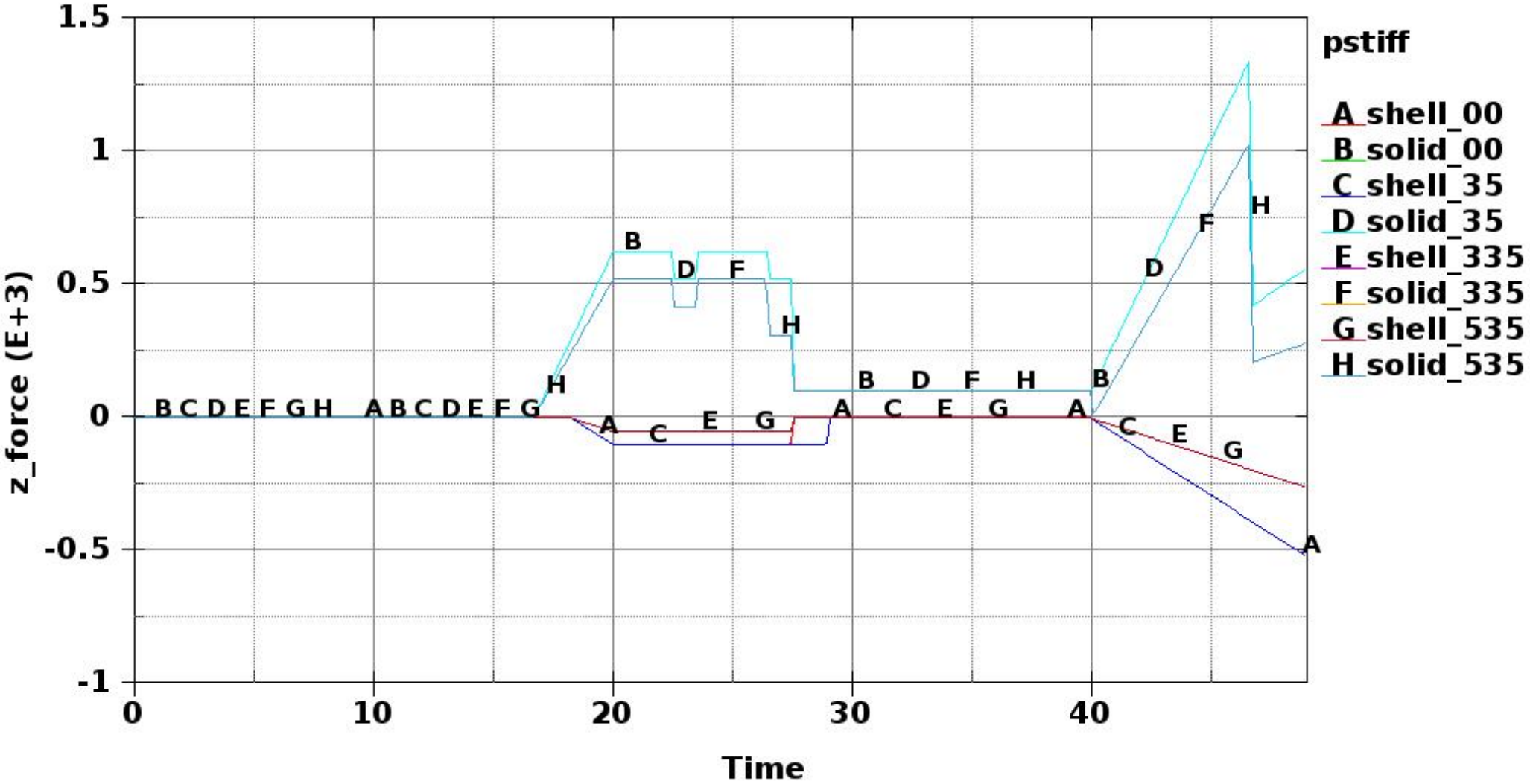
  - Solid in initial penetration penetration goes out of initial penetration and back again and slides to adjacent solid.



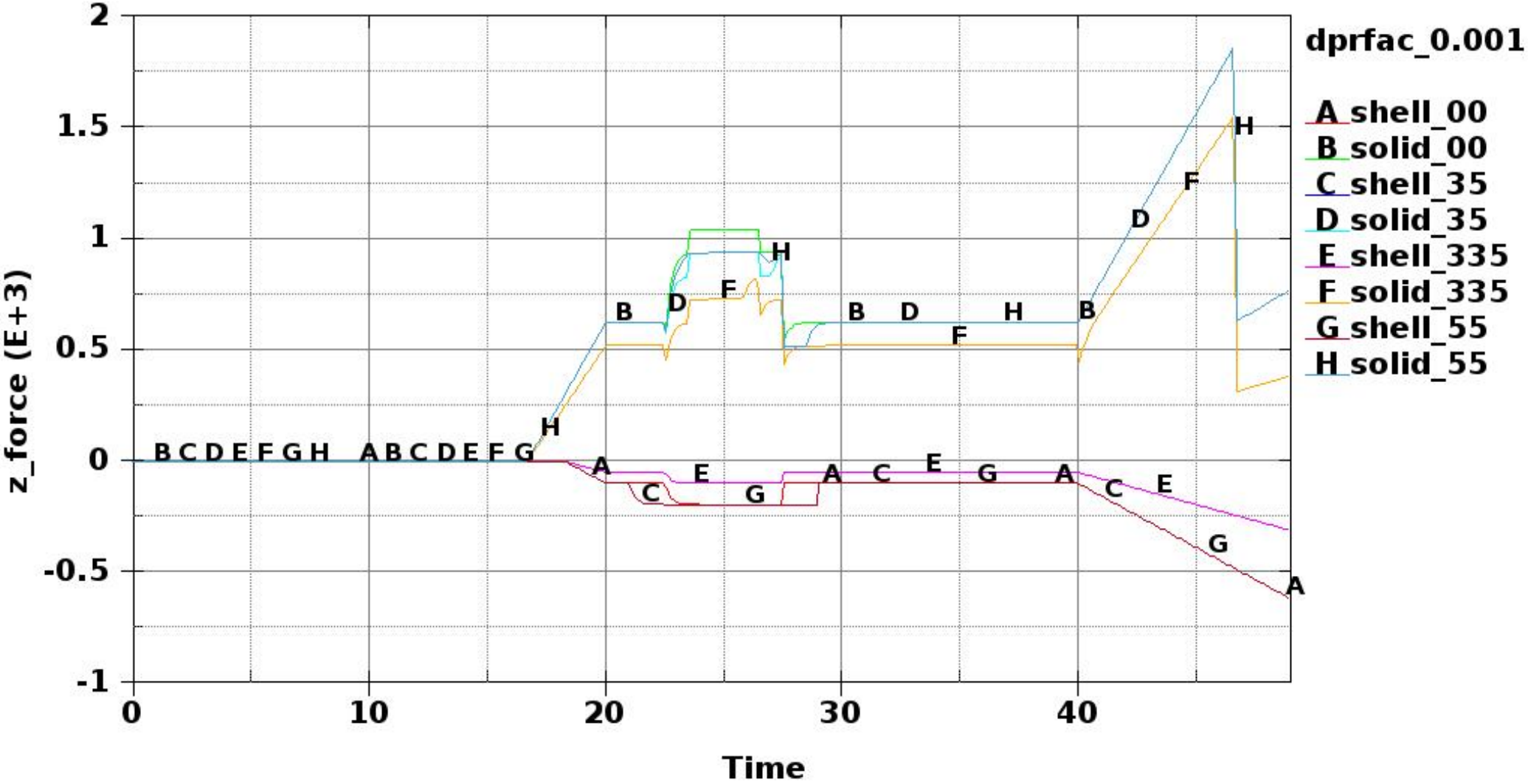
Sliding contact force with different settings SBOPT/DEPTH



Sliding contact force with different settings PSTIFF=1

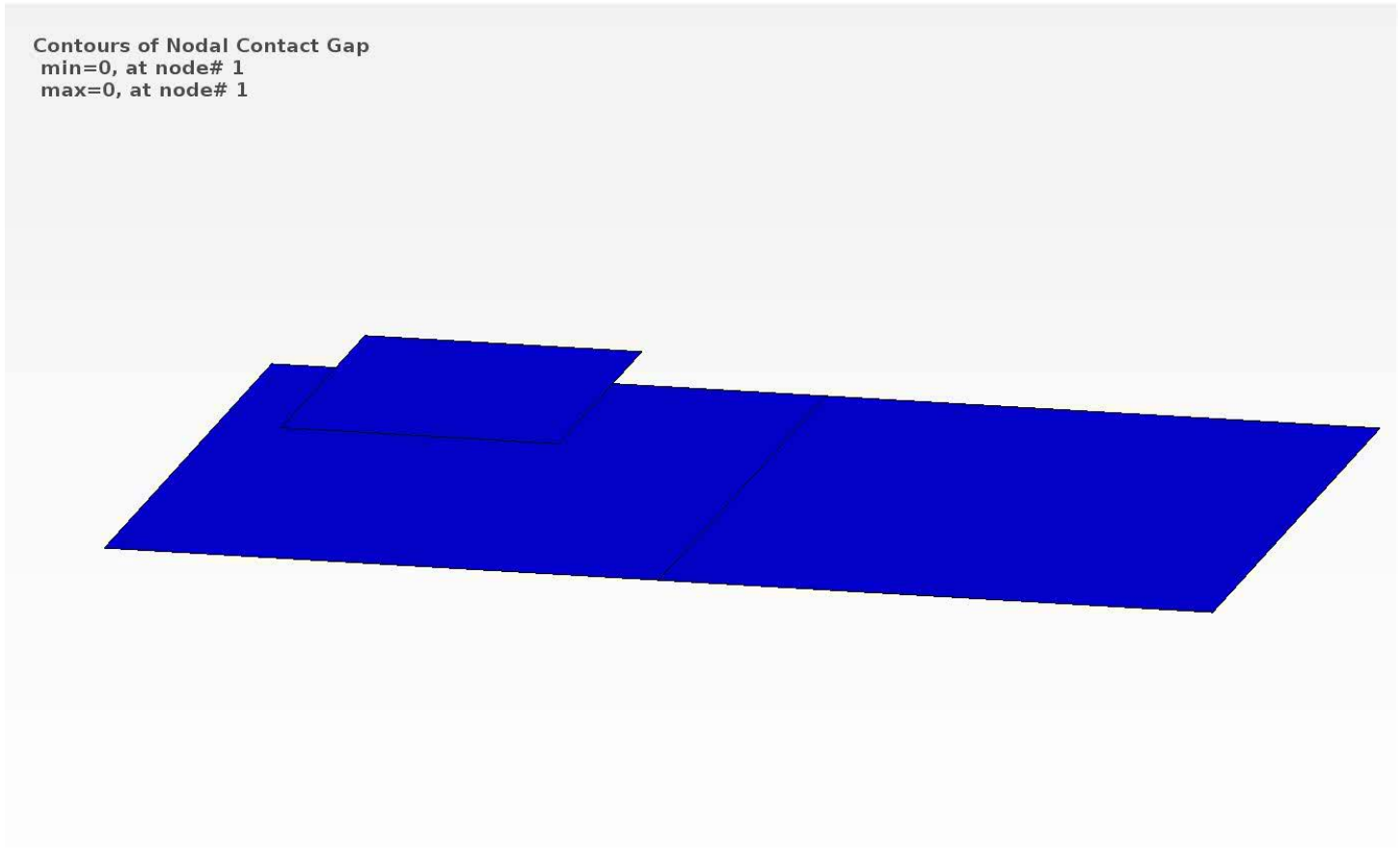


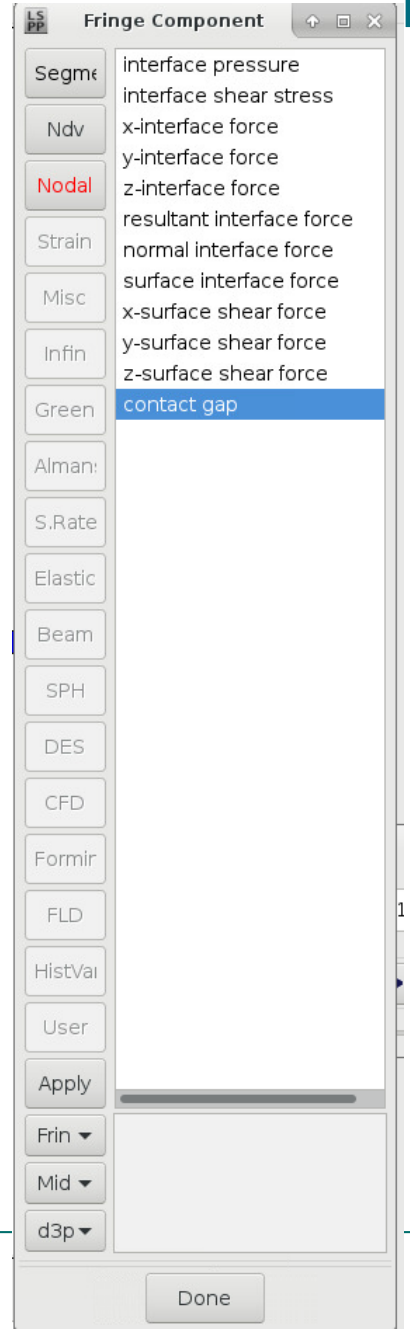
Sliding contact force with different settings DPRFAC=0.01



Special output for SOFT=2 in intfor

- Gap parameter for definition of gap/penetration fringe plots





Conclusions & Recommendations

- Major problem of contact failure today:
  - Contact search!
  - High loading on single node – rare today (decreased use of rigid material and finer meshes)
  - Searching for segment2segment overlap rather than a vector feels more robust.
  - SOFT=2 best way to handle solid contact (and also a possibility to get edge treatment of the solid in a good way).
  - SOFT=2 and eroding solid elements seems to be the future.

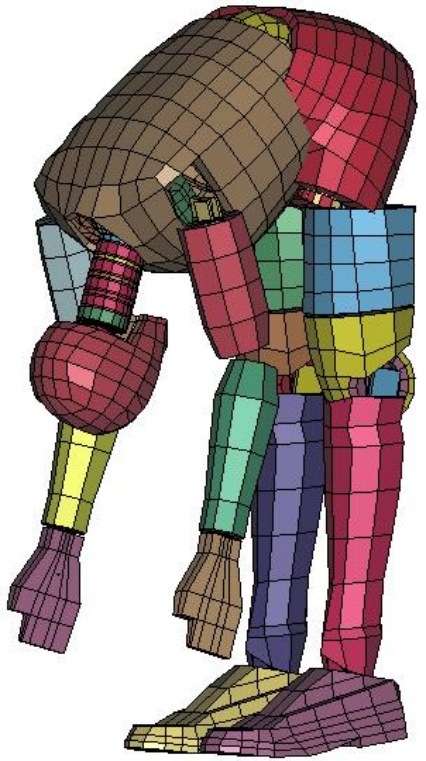
Final recommendations

- Use friction.
- VDC=20-40%
- SBOPT=3/5
- DEPTH=5 or 35 (45)
- SHLEDG=1
- PSTIFF=0/1
- SFNBR=0/0.5/-1.0
- DTSTIFF=initial timestep used

Thank you!

DYNA MORE

Your LS-DYNA distributor and more



*DEFINE_FRICTION

Card 1	1	2	3	4	5	6	7	8
Variable	ID	FS_D	FD_D	DC_D	VC_D			
Type	I	F	F	F	F			
Default	0	0.0	0.0	0.0	0.0			
Card 2	1	2	3	4	5	6	7	8
Variable	PIDi	PIDj	FSij	FDij	DCij	VCij	PTYPEi	PTYPEj
Type	I	I	F	F	F	F	A	A
Default			0.0	0.0	0.0	0.0		

*DEFINE_FRICTION_ORIENTATION

Card 1

Variable	PID	LCID	LCIDP	V1	V2	V3		
Type	I	I	I	F	F	F		
Default	none	0	0	0.0	0.0	0.0		