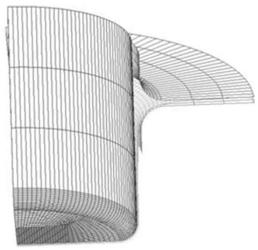
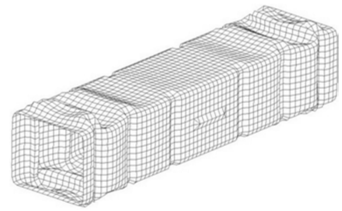
Contact in LS-DYNA

- Introduction
- Method for Calculation of Contact Forces/ Penalty Stiffness
- General Overview of Penalty Contact Types
  - SURFACE_TO_SURFACE Contacts
  - Non-AUTOMATIC versus AUTOMATIC Contacts
  - ONE-WAY Contacts
  - SINGLE_SURFACE Contacts
- General Contact Options
  - Contact Thickness
  - Contact Damping
  - Contact Friction
  - Contact Related Output Files
  - Contact Energy
- Contact with Soft Materials
  - Soft Constraint Contact (SOFT=1)
  - Segment Based Contact (SOFT=2)

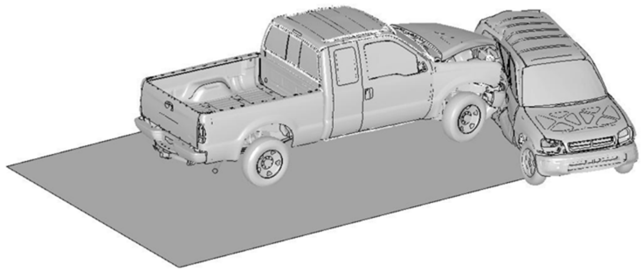
Contact in LS-DYNA (cont'd)

- Special Feature Contacts
  - Eroding Contact
  - Contact in Sheet Metal Forming
  - Airbag Contact
  - Interior Contact
  - Inteference Contact
- 2D Contact
- Tied Contact
- MPP Contact (skip)
- Rigid Walls
- Difficult or Unusual Contact Situations
- Practical Guidelines





Introduction



Introduction

- Purpose of Contact
  - Allows unmerged Lagrangian elements to interact with each other
    - Parts that impact/push/slide/rub against each other
    - Parts that should be tied together
- Contact surfaces can be selected in a variety of ways on Card 1 of *CONTACT
  - By part ID(s) (include or exclude)
  - By node sets, shell sets, segment sets
  - Pare selection using *DEFINE_BOX or *DEFINE_CONTACT_VOLUME
- Currently (LS-971) there are over 35 different contact algorithms in LS-DYNA®

Introduction

- **Two primary ways to distinguish contact algorithms**
  - Method of searching for penetration
  - Method of applying contact forces after penetration is found

- **Methods are chosen by …**
  - Contact 'type' (*CONTACT_<type>)
  - Flags and parameters chosen in…
    - *CONTROL_CONTACT
    - *CONTACT

Introduction

- **A table in the User's Manual lists the "structured input" contact type corresponding to each keyword contact type. It's not terribly important that you know this.**

[redacted]

Introduction

- **There are 3 (sometimes 4) mandatory cards for *CONTACT**

What portion of model to consider for contact

Flags for add'l output

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

Friction

Damping

Birth/death time

Penetration check

Card 2	1	2	3	4	5	6	7	8
Variable	FS	FD	DC	VC	VDC	PENCHK	BT	DT
Type	F	F	F	F	F	I	F	F

Scale factors for penalty stiffness

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	F	F	F

Friction scaling

Contact thickness

Introduction

- **And up to 5 optional cards (A,B,C,D,E) for *CONTACT**

Thickness vs. time (airbags)

SOFT choice

Segment extension

SOFT=2 options

Bucket Sorting interval

Optional card A

Variable	SOFT	SOFSCL	LCIDAB	MAXPAR	SBOPT	DEPTH	BSORT	FRCFRQ
Type	I	F	I	F	F	I	I	I
Default	0	.1	0	1.025.	0.	2	10-100	1

Scale for soft=1

Force update interval

Max penetration

Thickness

Shooting node logic

Symmetry

Search order

Solid thickness

Solid stiffness

Optional card B

Variable	PENMAX	THKOPT	SHLTHK	SNLOG	ISYM	I2D3D	SLDTHK	SLDSTF
Type	F	I	I	I	I	I	F	F
Remarks		Old types 3, 5, 10	Old types 3, 5, 10					

Note:
Contact notation
See next slide

Ignore initial penetration

Gradually reduce penetration

Timestep used for SOFT2

SMOOTH option

Optional card C

Variable	IGAP	IGNORE	DPRFAC	DTSTIF			FLANGL	CID_RCF
Type	I	I	F	F			F	I

CID for force output

Sticky contact for implicit

*CONTROL_CONTACT

- Used to modify default values for parameters governing various aspects of contact behavior
- If used, first two cards are mandatory; subsequent cards are optional.
- Modified default values apply to all contacts but know that contact parameters given in each individual *CONTACT_... command will always take precedence over those defaults for that particular contact.

LSTC

*CONTROL_CONTACT

Cards 1,2,3

Scale factor, Rigidwall, Initial penetration, Thickness, Stiffness, Actual thickness, Normals, Mass eroding contact

Variable	SLSFAC	RWPNAL	ISLCHK	SHLTHK	PENOPT	THKCHG	ORIEN	ENMASS
Type	F	F	I	I	I	I	I	I
Default	.1	none	1	0	1	0	1	0

User defined, Bucket, Penetration search, Thickness, Eroding, Tied

Variable	USRSTR	USRFRC	NSBCS	INTERM	XPENE	SSTHK	ECDT	TIEDPRJ
Type	I	I	I	I	F	I	I	I
Default	0	0	10-100	0	4.0	0	0	0

Friction, Thickness, Penalty

Variable	SFRIC	DFRIC	EDC	VFC	TH	TH_SF	PEN_SF	
Type	F	F	F	F	F	F	F	

LSTC

*CONTROL_CONTACT

Cards 4,5,6

Initial penetration · Friction energy · Rigidwall · Spotweld

Variable	IGNORE	FRCENG	SKIPRWG	OUTSEG	SPOTSTP	SPOTDEL	SPOTHIN	
Type	I	I	I	I	I	I	F	
Default	0	0	0	0	0	0	inactive	

Symmetry · One way/two way · Rigidwall · Forming contact · Spotweld · Thermal

Variable	ISYM	NSEROD	RWGAPS	RWGDTH	RWKSF	ICOV	SWRADF	ITHOFF
Type	I	I	I	F	F	I	F	I

Shell edge

Variable	SHLEDG							
Type	I							

Penetration Search Methods

- ‘Old’ Node-based search

(Sect. 26.6 in LS-DYNA Theory Manual [2006])

  - Used by non-automatic contacts
  - Not good for disjoint or irregular meshes
  - Requires correct orientation of segments
  - Shell thickness is optional

- Bucket Sort Approach

(Sects. 26.8.1 and 26.11 in LS-DYNA Theory Manual [2006])

  - Used by automatic contacts with SOFT=0 or 1
  - Bucket sorting approach works for non-continuous surfaces
  - Bucket sorting: Periodically dividing spatial domain into buckets (or volumes) to make contact searching very efficient.
  - Orientation of segments doesn’t matter (searches for contact from either side of a shell)
  - Shell thickness offsets are always considered

- SOFT=2 Segment-based contact
  - Searches for segments penetrating segments (not nodes penetrating segments)

Methods for Calculation of Contact Forces/Penalty Stiffness

Methods of Calculating Contact Forces

- Penalty-based
  - By far, most common approach
  - Uses a finite contact stiffness
- Tied (with or without failure)
  - Tied usually constraint-based
  - Tiebreaks, i.e., tied with failure, usually penalty-based
- Others - very seldom, if ever, used
  - Constraint by forces (*CONTACT_CONSTRAINT)
  - Constraint by displacement (*CONTACT_SLIDING_ONLY)
    - Developed for high explosive gas-to-structure interaction

Penalty-Based Contact

- Elastic, compression-only springs in normal direction to resist penetration
  - SOFT on Optional Card A affects method of computing stiffness of contact springs
- Tangential interface springs for friction
  - Coulomb friction coefficient is function of relative velocity and also, optionally of interface pressure
  - Can specify an upper limit for friction stress (function of yield stress)
- Very stable and tends NOT to excite mesh hourglassing (good!)
- Applicable to deformable bodies and to rigid bodies
- Ref: Sects. 26.3 and 26.7 in the LS-DYNA Theory Manual [2006]

Penalty Stiffness: SOFT=0

- Default contact stiffness k is prescribed as follows for a solid element:

$$k = \frac{\alpha KA^2}{V}$$

K is the material bulk modulus
α is the penalty scale factor
A is the segment area
V is the element volume

- For a shell element:

$$k = \frac{\alpha KA}{Max(\,shell\,diagonal)}$$

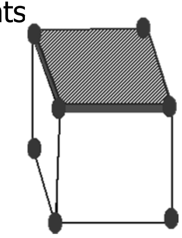
PENALTY STIFFNESS VALUE

- PENOPT (discussed below) is rarely used, rather the generally superior SOFT=1 or SOFT=2 contact options (discussed later) are used when contact stiffness is an issue.

- SOFT=0 penalty stiffness is affected by PENOPT in *CONTROL_CONTACT.
  - EQ.0: The default is set to 1
  - EQ.1: Minimum of master segment and slave node (default)
  - EQ.2: Use master segment stiffness (old way)
  - EQ.3: Use slave node value
  - EQ.4: Use slave node value, area or mass (type=5) weighted
  - EQ.5: As 4 but inversely proportional to the shell thickness.

PENALTY STIFFNESS VALUE

- Priority for setting SOFT=0 contact stiffness and contact thickness when 4 nodes are shared by multiple elements



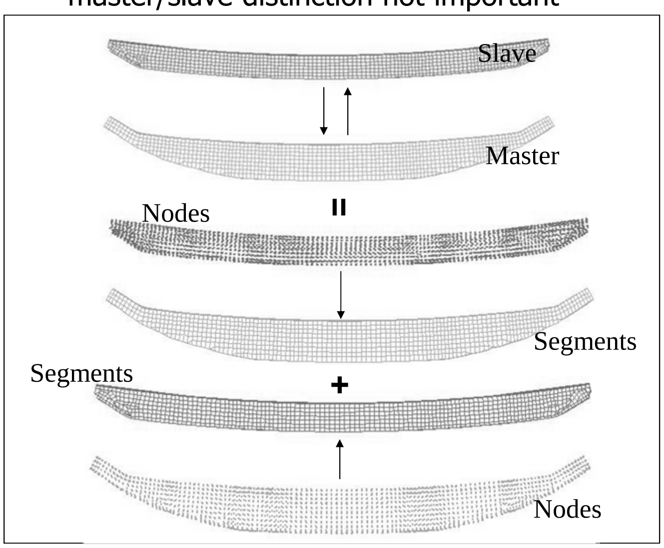
  - First shell encountered
  - If no shell is found, then pick the first brick element.
  - If no shell or brick, pick the first beam element.
  - If null shells are present with brick elements, the stiffness properties always come from null shells rather than the bricks

General Overview of Penalty Contact Types

- SURFACE_TO_SURFACE CONTACTS
- Non AUTOMATIC versus AUTOMATIC CONTACTS
- ONE-WAY CONTACTS
- SINGLE_SURFACE_CONTACTS

Surface_to_Surface Contacts

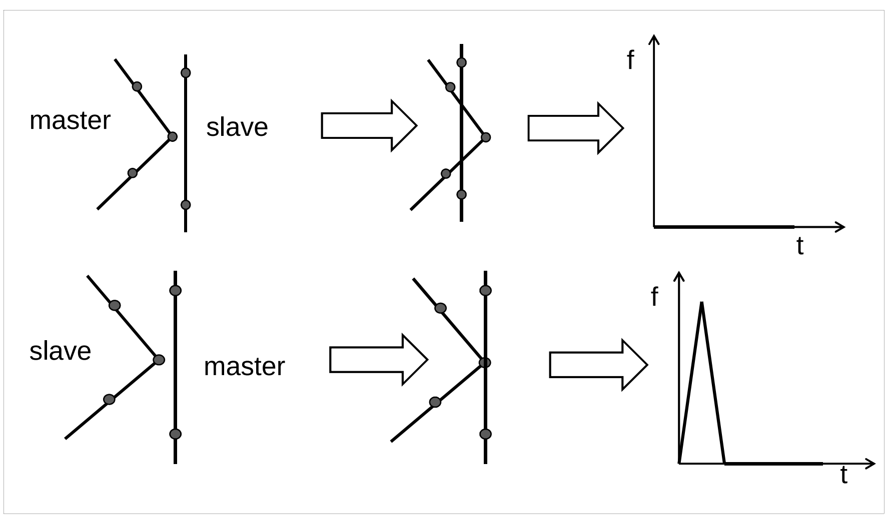
- Utilize two-way (symmetric) treatment
  - master/slave distinction not important



Non-automatic vs. Automatic

- *CONTACT_SURFACE_TO_SURFACE
  - So-called 'non-automatic' contact
  - Shell thickness offsets are optional (SHLTHK at *CONTROL_CONTACT)
  - Segment <u>orientation is important</u>
    - Looks only in one direction
    - Orientation determined by segment (or shell) normals
    - ORIEN in *CONTROL_CONTACT invokes check of orientation during initialization
- *CONTACT<u>_AUTOMATIC_</u>SURFACE_TO_SURFACE
  - Always considers thickness offsets
  - Efficient and robust bucket sorting search method
  - No segment orientation (looks in both directions)

One-Way (Non-symmetric) Contacts



One-way Contacts

- Generally, coarser-meshed side should be master
- Computationally efficient
  - Half the cost of two-way treatment
- Especially well-suited to nodes (slave) impacting rigid bodies (master)
- NON-AUTOMATIC and AUTOMATIC forms available

One-Way Contact Types

- *CONTACT_...
  - NODES_TO_SURFACE
  - ONE_WAY_SURFACE_TO_SURFACE
  - AUTOMATIC_NODES_TO_SURFACE
  - ONE_WAY_AUTOMATIC_SURFACE_TO_SURFACE
  - FORMING_NODES_TO_SURFACE
    - Used frequently for metal forming analyses
  - ERODING_NODES_TO_SURFACE
  - CONSTRAINT_NODES_TO_SURFACE
    - <u>Not</u> a penalty-based contact

One_Way_Surface_to_Surface

- Behaves like NODES_TO_SURFACE contact except…
  - Slave side is specified as a set of segments rather than as a set of nodes (part IDs are OK for either type)
  - Provides a way of visualizing pressure distribution on slave surface via "*intfor*" binary database (more on that later)

Single Surface Contacts

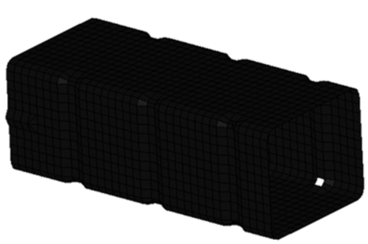
- Treat self-contact (buckling) as well as part-to-part contact
- Only slave side is defined; master side is not specified (master is assumed same as slave)
  - Still utilizes two-way treatment
- Always consider thickness offsets
- No data is written to *rcforc* output file. Must use *CONTACT_FORCE_TRANSDUCER_PENALTY to gather and print contact resultant forces (more on that later).

Single Surface Contacts

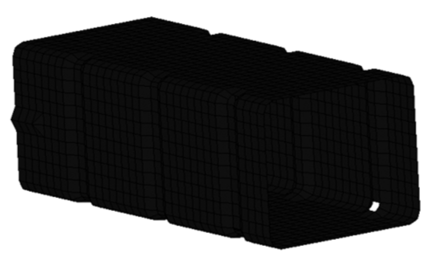
- Types:
  - SINGLE_SURFACE (<u>not</u> recommended; 'old' node-based search)
  - AUTOMATIC_SINGLE_SURFACE (recommended)
  - AIRBAG_SINGLE_SURFACE
  - ERODING_SINGLE_SURFACE
  - AUTOMATIC_GENERAL
  - AUTOMATIC_GENERAL_INTERIOR
- AUTOMATIC_SINGLE_SURFACE is most common contact used in impact simulations
- AUTOMATIC_GENERAL is good for shell edge-to-edge and beam-to-beam contact
  - Not as robust in other applications as AUTOMATIC_SINGLE_SURFACE
  - More costly than AUTOMATIC_SINGLE_SURFACE
- AIRBAG_SINGLE_SURFACE for deploying folded airbags (VERY expensive)

Single Surface Contacts

- Self contact is important for e.g. crushing beams that buckles. The example is a beam crushed by a rigid wall and simulations were done with and without self contact.



No contact specified



Self contact specified

Single Surface Contacts

Force Transducers

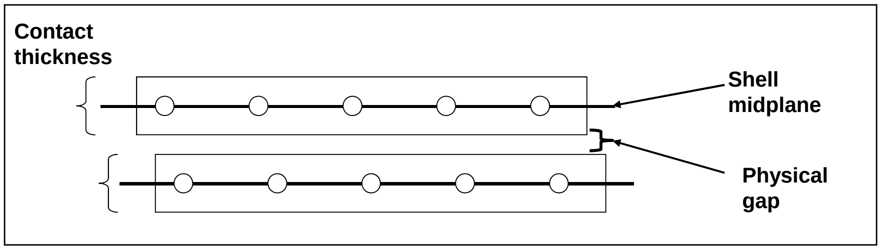
- Single surface contact doesn't write forces to the *rcforc* nor the *ncforc* file. A force transducer has to be specified.
- Transducers provide a convenient means of contact force retrieval at selected locations
- Specify slave side only; or slave and master
- Cards 2 and 3 are blank
- No contact forces are generated by force transducers
  - Transducers only measure forces from non-transducer contact types
  - Measured contact forces retrieved via *DATABASE_RCFORC
- Two options for *CONTACT_FORCE_TRANSDUCER
  - _PENALTY (measures forces from penalty-based contacts)
  - _CONSTRAINT (measures forces from constraint-based contacts)

GENERAL CONTACT OPTIONS

- CONTACT THICKNESS
- CONTACT DAMPING
- CONTACT FRICTION
- CONTACT RELATED OUTPUT FILES
- CONTACT ENERGY

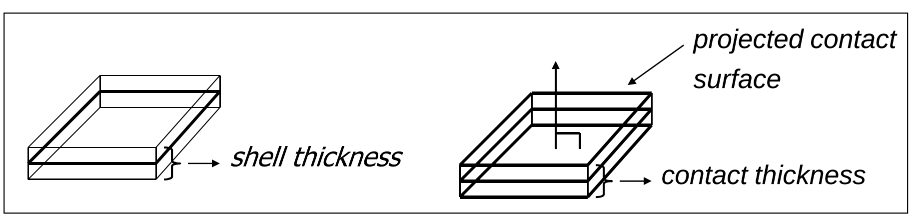
Thickness Offsets

- To include "thickness offsets" means that two contact surfaces, each offset from the shell midplane, are established for a shell element
- All automatic contacts include thickness offsets
- Thickness offsets are optional for non-automatic contacts
  - Controlled by SHLTHK in *CONTROL_CONTACT or in *CONTACT, Optional Card B (SHLTHK)



Two Types of Thickness

- **Shell Thickness**
  - Given in *SECTION_SHELL or *ELEMENT_SHELL_THICKNESS
  - Affects stiffness and mass of the element
  - Can be visualized using LS-PrePost® (Appear > Thick)
- **Contact Thickness**
  - Determines thickness offsets in contact
  - Does NOT affect stiffness or mass of the shell
  - Default contact thickness = shell thickness (exception: see SSTHK)
  - Can set or scale contact thickness directly in *CONTACT or *PART_CONTACT
  - Influences maximum penetration depth allowed before penetrating node is set free (see Table citing "Criterion for node release" in User's Manual)



Viscous Contact Damping

Contact card 2

Variable	FS	FD	DC	VC	VDC	PENCHK	BT	DT
Type	F	F	F	F	F	I	F	F
Default	0.	0.	0.	0.	0.	0	0.	1.0E20

- Specified via VDC on Card 2 of *CONTACT_…
- Damps oscillations normal to the contact surfaces
- Useful for smoothing out noisy contact forces, e.g., as sometimes seen when a part is sandwiched between two other parts

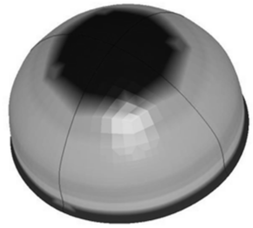
Viscous Contact Damping

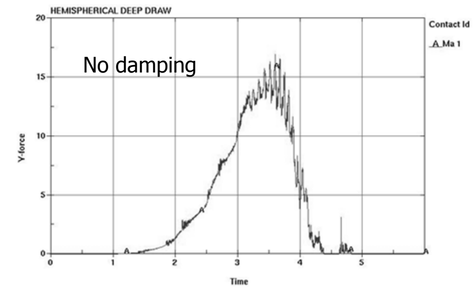
- VDC = percentage of critical damping ($\xi_{cr}=2m\omega$)
  - Twenty percent damping = 20, not 0.20
  - m = min $\{m_{slave}, m_{master}\}$
- Natural frequency of interface, ω, is computed using:
  - k = interface stiffness

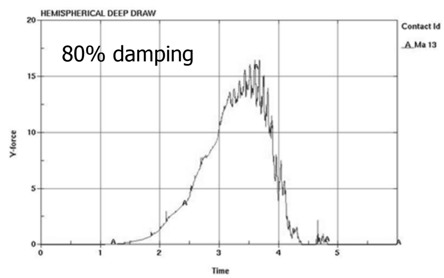
$$\omega = \sqrt{k\,\frac{m_{slave}+m_{master}}{m_{slave}m_{master}}}$$

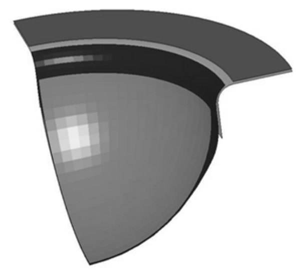
- It is very common to use interface damping in Sheet Metal Forming or any application where contact force time histories appear noisy.

Viscous Contact Damping









FRICTION

- Friction is a important aspect of contact. Generally Coulomb friction is applied. The maximum frictional force is related to the normal force by the Coulomb friction coefficient, μ:

$$F_{MAX} = \mu \left| f_n \right|$$

- From Mech. Eng. Handbook (Marks):

MATERIALS	STATIC	SLIDING
Hard steel on hard steel	0.78 (dry)	.08 (greasy), .42 (dry)
Mild steel on mild steel	0.74 (dry)	.10 (greasy), .57 (dry)
Aluminum on mild steel	0.61 (dry)	.47 (dry)
Aluminum on aluminum	1.05 (dry)	1.4 (dry)
Tires on pavement (40psi)	0.90 (dry)	.69(wet), .85(dry)

FRICTION

There are two coefficient of friction that can be given, a static (FS) and a dynamic one (FD).

An exponential interpolation function smoothes the transition between the static and dynamic coefficients of friction where v is the relative velocity between the slave node and the master segment:

$$\mu = \mu_d + (\mu_s - \mu_d) e^{-c|v|}$$

where

v is velocity and c (input parameter DC) is a decay constant.

If DC=0, the friction coefficient will be equal to FS, regardless of value given FD.

FRICTION

The interface shear stress that develops as a result of Coulomb friction can be very large and in some cases may exceed the ability of the material to carry such a stress. Therefore it is possible to specify a limit on the value of the tangential force:

$$f^{n+1} = \min\left(f^{n+1}_{Coulomb}, \kappa A_{master}\right)$$

where A_{master} is the area of the master segment and κ is the coefficient for viscous friction, given as VC at card 2 of *CONTACT_. Since more than one node may contribute to the shear stress of a segment, it can be that the stress may still in some cases exceed the limit κ. A suggested value for κ is to use the yield stress in shear, $\sigma_0/\sqrt{3}$.

FRICTION

Specifications

- The friction related parameters are given on Card 2 of *CONTACT.

Static coefficient (μ_s) Dynamic coefficient (μ_d) Decay coefficient (c) Friction limit (k)

Contact card 2

Variable	FS	FD	DC	VC	VDC	PENCHK	BT	DT
Type	F	F	F	F	F	I	F	F
Default	0.	0.	0.	0.	0.	0	0.	1.0E20

- Friction can also be given using *PART_CONTACT, which can be useful when a large single surface contact is specified, e.g. in a crash model. Here, a set of friction parameters is given for each part.
- A more physical way of handling part-to-part friction in a large single surface contact is *DEFINE_FRICTION. Here a table of friction parameters is given, one set per pair of parts.

Contact-Related Output Files

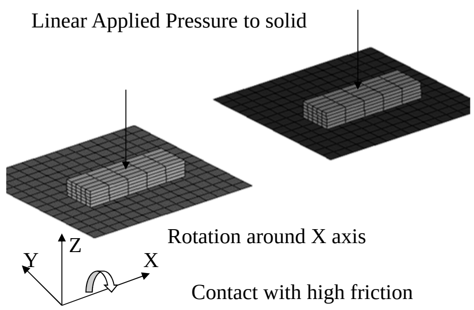
- *DATABASE_*option*
  - ASCII output files
    - GLSTAT: Global statistics
    - RCFORC: Resultant contact forces
    - SLEOUT: Contact energy
    - NCFORC: Contact forces at each node (set *CONTACT print flag SPR=1 and MPR=1)
- The resultant contact forces in the *rcforc* file are in the global coordinate system by default. It is possible to request output in specified local coordinate system using Optional card C.

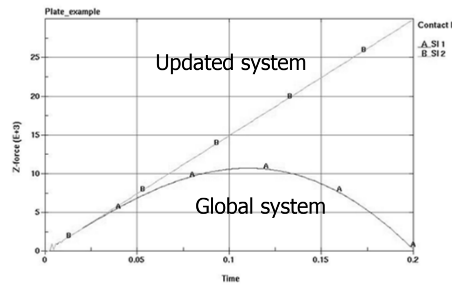
Optional card C

Variable	IGAP	IGNORE	DPRFAC	DTSTIF			FLANGL	CID_RCF
Type	I	I	F	F			F	I

Contact-Related Output

Contact Forces in Local Coordinate System





Contact force (rcforc)
(2 cases)

In this Example:

- The local coordinate system is initially aligned with global.
- Loaded with linearly increasing pressure.
- Local system updated when FLAG=1 at *DEFINE_COORDINATE_NODES.

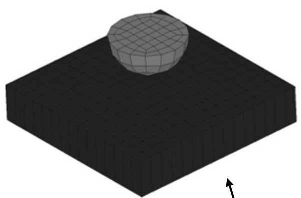
Contact-Related Output Files

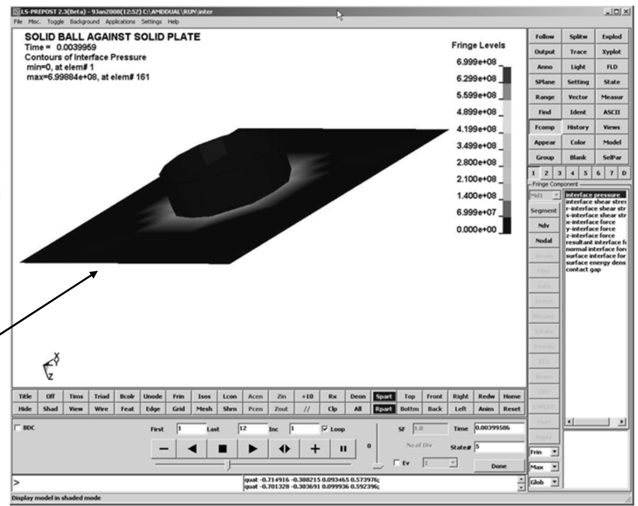
Binary Output (Optional)

- Contact forces and stresses may be written to a binary database (sometimes called the "interface force file")
  - Add *DATABASE_BINARY_INTFOR to specify output interval
  - Set one or both print flags SPR and MPR on card 1 of *CONTACT
  - Include s=*filename* on execution line
  - Control content with *DATABASE_EXTENT_INTFOR (optional)
- The binary database can be read by LS-PrePost
  - Fringe plots of normal and frictional contact stress
  - Time history plots of contact stress on segments, contact force on nodes

*DATABASE_BINARY_INTFOR (cont'd)

- The interface force file shows the contact surfaces that are flagged for output via the print flags on Card 1 of *CONTACT. Select these surfaces in LS-PrePost as you would select a part.





Same Model. Solids shown in d3plot whereas segments shown in interface force file

CONTACT ENERGY

- If unstable or otherwise nonphysical model behavior occurs, trouble with contact is often the root cause. The following ASCII output files can help diagnose problems with contact.
  - *glstat* - overall energy distribution (Global STATistics)
  - *sleout* - contact energy output (SLiding interface Energy)
  - *matsum* - energies by part ID (MATerial SUMmary)

- Unexpectedly large energy values in the *sleout* file and the *matsum* file will help identify the contact(s) and the part(s) that are behaving badly.

SLEOUT FILE

ENERGY CALCULATIONS

- Contact energy is computed for each contact interface as [Theory, 2006]:

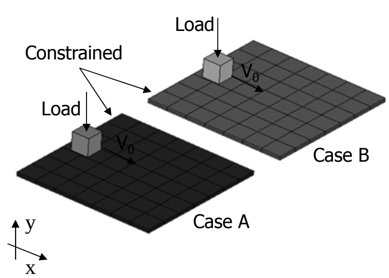
$$E_{contact} = \sum_{i=1}^{slave\ nodes} \Delta F_i^{slave} \times dist + \sum_{i=1}^{master\ nodes} \Delta F_i^{master} \times dist$$

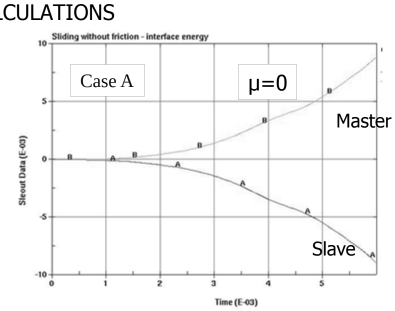
- Both normal and friction/shear forces contribute to the contact energies.
- In any particular contact, if the friction coef. is zero, the slave energy and the master energy will be opposite in sign, will generally mirror each other, and will return to near zero when parts are out of contact. In other words, nonfrictional contact energy is elastic or recoverable.
- Frictional energy is positive and nonrecoverable (it’s dissipative).
- Large negative contact energy is cause for concern.

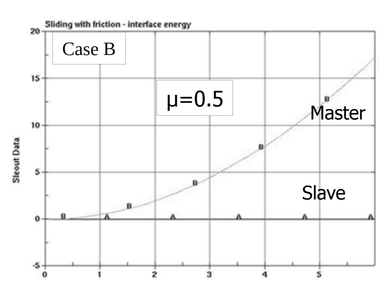
SLEOUT FILE

ENERGY CALCULATIONS

- Case A is without friction
- Case B is with a friction coefficient of 0.5







- Normal (Y) load is ramped linearly
- Small block has initial velocity in X
- Contact energy in A is 100% normal contact energy
- Frictional energy in B >> normal contact energy

CONTACT FRICTIONAL ENERGY

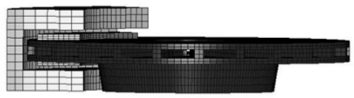
- Frictional energy for each contact is output as a separate line item in sleout for time history plotting
  - *DATABASE_SLEOUT
- Frictional energy is optionally output into the binary contact database (*intfor*)
  - See previous instructions for writing intfor database
  - Set FRCENG=1 in *CONTROL_CONTACT
  - Regions of high friction can then be visually identified with LS-PrePost via fringe plots of "Surface Energy Density"

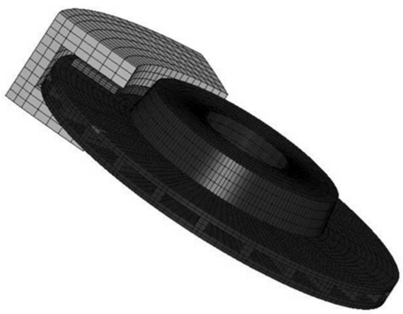
Contact Considerations in Coupled Thermal/Structural Analysis

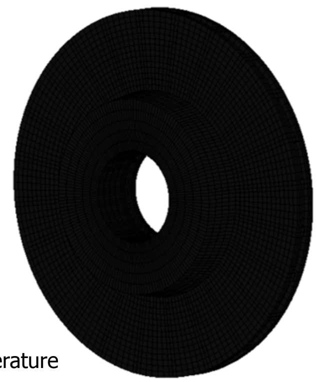
- Contact friction as a heat source
  - Heat generation due to friction may be important for such applications as metal forging, brake design, etc.
  - Contact must be surface_to_surface type; SOFT=0 or 1
  - Set FRCENG=1 in *CONTROL_CONTACT
  - Heat partition between slave and master is 50/50
- Heat transfer across surface_to_surface contact
  - Add THERMAL option (unrelated to friction)
    - Input conductivity and radiation parameters for contact
    - Hot part can pass heat to cooler part via contact
  - Add THERMAL_FRICTION option
    - Able to define friction coefficients as a function of temperature
    - Able to define the thermal contact conductance as a function of temperature and pressure

CONTACT FRICTIONAL ENERGY

- A model of a brake was made to show heat generation due to frictional energy. An initial temperature of 25 was given and an initial velocity is applied. The model is from Dr. A. Shapiro, LSTC [A. Shapiro, 2005a].







Temperature

Contact with Soft Materials

- Soft Constraint Contact (SOFT=1)
- Segment Based Contact (SOFT=2)

Contact with soft materials

- Contact between materials with different material properties can sometimes cause problems.
- The default contact stiffness is often inadequate, e.g., for foam or rubber in contact with metal.
- Old approach would be:
  - Cover the solid elements with a shell layer that uses *MAT_NULL
  - Increase the penalty stiffness scale factors
- Now SOFT=1 or SOFT=2 can be used. These calculate the stiffness based on the nodal masses and the time step.
- SOFT=2 searches for penetration using a very different approach.

Contact with soft materials

Soft Constraint Formulation (SOFT=1)

- SOFT parameter is prescribed on Optional Card A of *CONTACT_...
- The calculated contact stiffness for SOFT=1 is based on stability of a spring-mass system considering nodal mass m and the global initial time step Δt_0:

$$k = 0.5 \cdot SOFSCL \frac{m}{\Delta t_0^2}$$

- SOFSCL is an optional stiffness scale factor that can be specified at Optional Contact Card A and it is only valid for SOFT=1.

Contact with soft materials

Soft Constraint Formulation (SOFT=1)

- If the current time step increases, then the increase time step is used in calculating the SOFt=1 contact stiffness
- The actual stiffness used when SOFT=1 is the maximum of the SOFT=0 stiffness and SOFT=1 stiffness:

$$k_{used} = Max\left\{k_{soft=0}, k_{soft=1}\right\}$$

- As mentioned SOFT=1 is usually recommended for contact involving soft materials, e.g., foams, but also for contact between parts of dissimilar mesh densities

Contact with soft materials

Segment-Based Contact (SOFT=2)

- SOFT=2 is an alternative, penalty-based contact algorithm for shells, solids, and thick shells.
- Computes stiffness in a manner similar to SOFT=1 (stability criterion based on mass and time step).
- Searches for penetration in a unique way (more later).
- Does <u>not</u> work with beams or with NODES_TO_SURFACE type contacts since no segments can be generated from these contacts.

Contact with soft materials

Segment-Based Contact (SOFT=2)

- The contact is invoked by setting SOFT=2 on optional card A.
- The stiffness is calculated in similar fashion as SOFT=1:

$$k = 0.5 \cdot SLSFAC \begin{Bmatrix} SFS \\ or \\ SFM \end{Bmatrix} \left(\frac{m_1 m_2}{m_1 + m_2} \right) \left(\frac{1}{\Delta t_0} \right)^2$$

Contact with soft materials

Segment-Based Contact (SOFT=2)

The name, "Segment-Based Contact"
is motivated by the most fundamental difference between segment-based contact and the standard LS-DYNA® penalty contact:

Standard* Contact
Detects penetration of nodes into segments and applies penalty forces to the penetrating node and the segment nodes.

Segment-Based Contact
Detects penetration of one segment into another segment and then applies penalty forces to nodes of both segments.

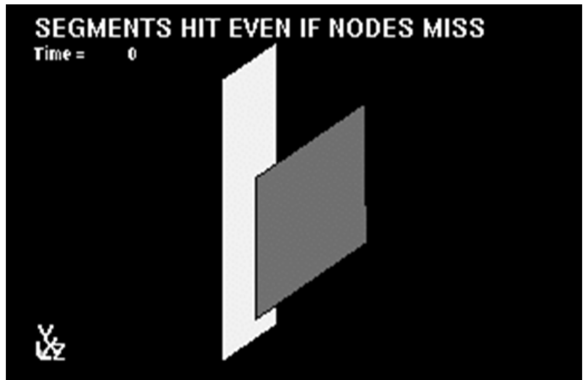
***Standard contact refers to penalty-based contacts with SOFT=0 or SOFT=1.**

Contact with soft materials

Segment-Based Contact (SOFT=2)

Segments hit even if nodes miss

Because penetration of segments through segments is checked rather than penetration of nodes through segments.



Segment-based contact is a good option if contact surface is not smooth, perhaps having sharp corners or edges.

Contact with soft materials

Segment-Based Contact (SOFT=2)

- Segment-Based Contact is implemented for these contact types:
  - SURFACE_TO_SURFACE (3)
  - AUTOMATIC_SURFACE_TO_SURFACE (a3)
  - SINGLE_SURFACE (4)
  - ONE_WAY_SURFACE_TO_SURFACE (10)
  - AUTOMATIC_ONE_WAY_SURFACE_TO_SURFACE (a10)
  - AUTOMATIC_SINGLE_SURFACE (13)
  - AIRBAG_SINGLE_SURFACE (a13)
  - ERODING_SURFACE_TO_SURFACE (14)
  - ERODING_SINGLE_SURFACE (15)

Contact with soft materials

Segment-Based Contact (SOFT=2)

Initial penetrations are ignored , that is, there is no perturbation of the geometry to alleviate initial penetations.

- Initial penetration for each segment pair is stored and subtracted from the current penetration before calculating penalty forces.
- This logic is used continually throughout the simulation so that a segment that penetrates undetected for a brief period will not be shot out by a large contact force when first detected.
- Similar treatment of initial penetrations to SOFT=0 or 1 with parameter IGNORE set to 1 at Optional contact card C or *CONTROL_CONTACT.

Contact with soft materials

Segment-Based Contact (SOFT=2)

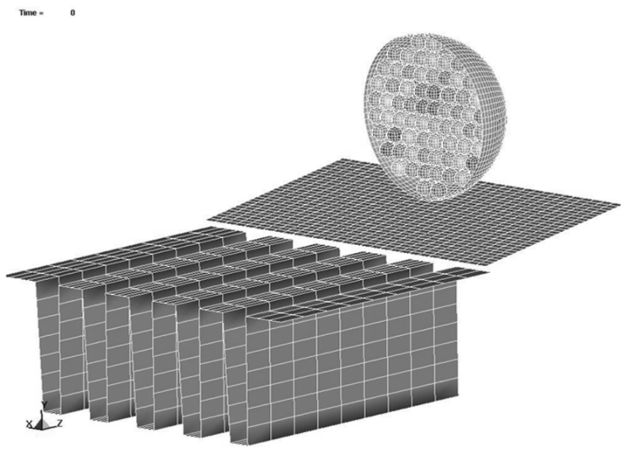
Additional Options for SOFT=2 Contact

- SBOPT on Opt. Card A
  - 2 (default): assumes planar segments
  - 3: (recommended) takes into consideration segment warpage
  - 4: additional logic for sliding between parts
  - 5: use options 3 and 4
- DEPTH on Opt. Card A
  - 2 default measurement of surface penetration depth
  - 3: (recommended) depth of surface penetration is also checked at segment edges
  - 5: same as 2 but adds check for edge-to-edge penetration
  - 13,23: tweaks to 3 for better energy conservation (13) and improved robustness (23)

Contact with soft materials

Segment-Based Contact (SOFT=2)

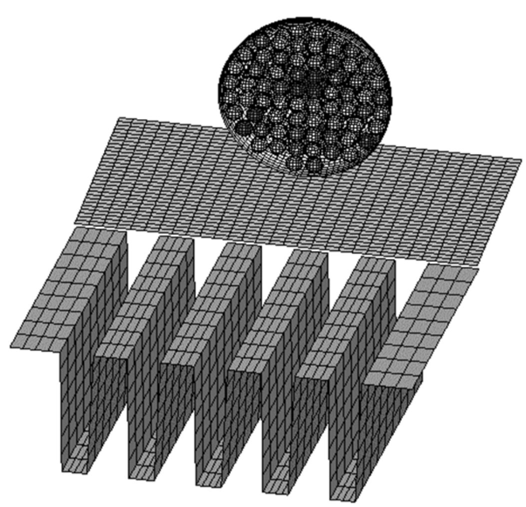
Falling Balls using *contact_automatic_single_surface, SOFT=2



Contact with soft materials

Segment-Based Contact (SOFT=2)

Falling Balls using *contact_automatic_single_surface, SOFT=2

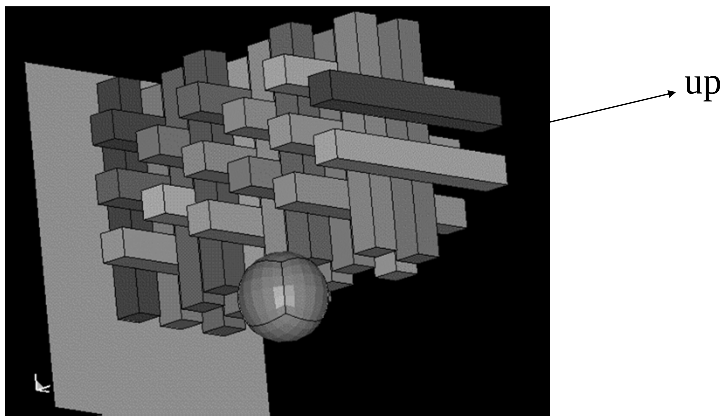


Contact with soft materials

Segment-Based Contact (SOFT=2)

Falling Blocks using Segment-Based Contact

One brick element defines each block. Nodes do not make contact with contact segments.



Special Feature Contacts

- Eroding Contact
- Contact in Sheet Metal Forming
- Airbag Contact
- Interior Contact
- Inteference Contact

Eroding Contact

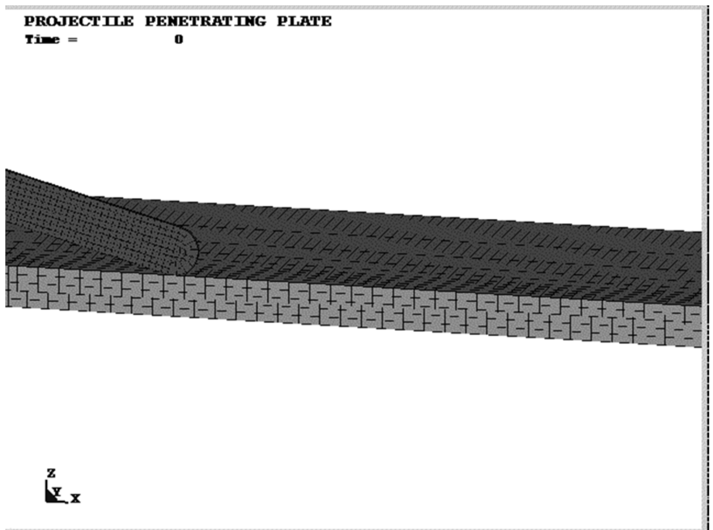
- Contact surface is updated as elements on free surface are deleted
  - Elements are deleted according to material failure criteria, not directly due to eroding contact.
- Time step is automatically adjusted, if needed, to satisfy eroding contact time step
  - Recognizes that eroding contact is generally used in high velocity simulations?
  - Can bypass effect of eroding contact on time step by setting ECDT=1 in *CONTROL_CONTACT
- As slave nodes become unattached/free due to element deletion, those nodes may optionally continue to be considered in the contact
  - ENMASS in *CONTROL_CONTACT controls this feature
  - Free nodes are seen in LS-PrePost® by toggling “Deleted Nodes on”

Eroding Contact

- *CONTACT_ERODING_SINGLE_SURFACE (recommended)
  - Based on CONTACT_AUTOMATIC_SINGLE_SURFACE
  - Segment orientation not important
  - Slave side only; by part or part set
- *CONTACT_ERODING_NODES_TO_SURFACE
  - Slave side should be all-inclusive node set
  - Bucket sort after each time step in which an element is deleted
  - Recommended for bird-to-blade contact in bird strike simulations
- *CONTACT_ERODING_SURFACE_TO_SURFACE
  - Slave and master side by part or part set

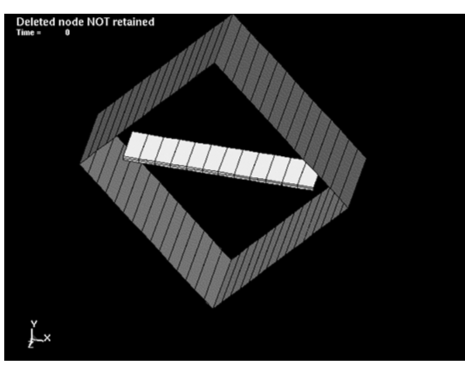
Eroding Contact

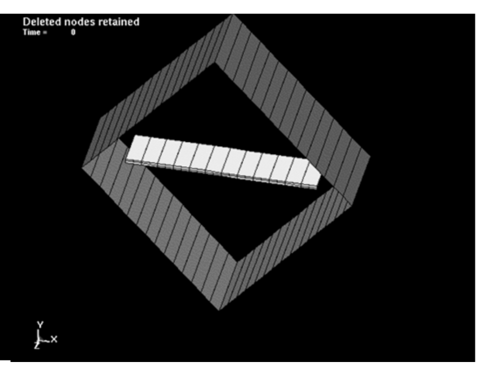
Example: Projectile Penetrating Plate



Eroding Contact

Example: Effect of Deleted Nodes on Contact





ENMASS=0

ENMASS=1

Contact in Sheet Metal Forming

- *CONTACT_DRAWBEAD
  - Approximates complex behavior of a drawbead
- *CONTACT_FORMING_...
  - NODES_TO_SURFACE, SURFACE_TO_SURFACE, ONE-WAY_SURFACE_TO_SURFACE options
  - Master (tool) side may be comprised of disjoint and irregularly-shaped segments (as in IGES surfaces)
  - Permits use of negative shell thickness offsets (tool and workpiece midplanes are coincident)
  - Must be used when 'look ahead' h-adaptivity is invoked for workpiece (adaptivity discussed in later section))

Airbag Contact

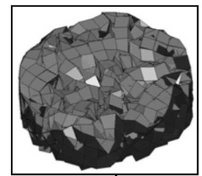
Airbag Deployment

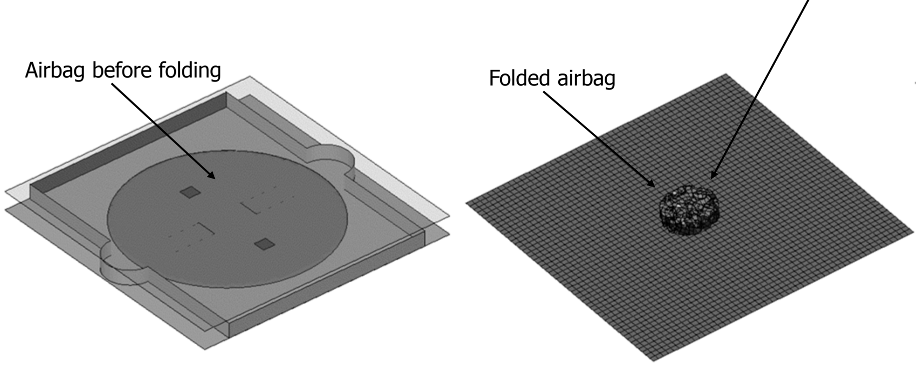
- Fabric-to-fabric contact as a folded airbag deploys is a uniquely difficult problem. As such, LS-DYNA has special airbag contact options.
  - During deployment the fabric elements change directions rapidly and are initially very close due to folding
  - The material is often very soft and the thickness of the bag is rather thin. This can also give problems when the bag is in contact with e.g. dummies.

Airbag Contact

Airbag folding simulation followed by airbag deployment

- A folding process is first simulated and the folded geometry is then used in a simulation where the airbag is deployed. The example shows that even with a very difficult geometry, the airbag deployment can be carried out with very good contact behaviour. The model is created by Dr. A. Haufe at DYNAmore GmbH.





Airbag – Contact Recommendation

- For fabric self contact, use *CONTACT_AIRBAG_SINGLE_SURFACE with…
  - SOFT=2 (optional card A)
  - SBOPT=3 (optional card A)
  - DEPTH=3 (optional card A)

- The default penalty stiffness factors are recommended

- For SOFT=1 and SOFT=2 contacts, DTSTIF on Opt. Card C of *CONTACT can be use to specify the time step used for the penalty stiffness calculation. This is useful when a validated airbag with time step "A" is inserted into a full vehicle model with time step "B".
  - The step size from the airbag validation simulation is then specified as DTSTIF (positive value)
  - Negative DTSTIF invokes curve that specifies (time step for contact stiffness calculation) vs. time

Airbag – Contact Recommendation

- For airbag-to-structure contact, (structure could be seatbelt shells, occupant, instrument panel, etc.),
  - Use *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE with …
    - SOFT=2 (optional card A)
    - SBOPT=3 (optional card A)
    - DEPTH=3 or 5 (optional card A)
  - The default penalty stiffness factors are recommended
  - Increase contact thickness of fabric to 2 - 4 mm.

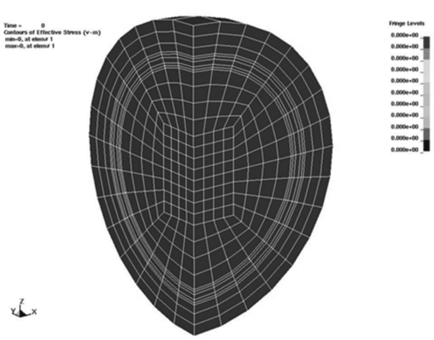
CONTACT_INTERIOR

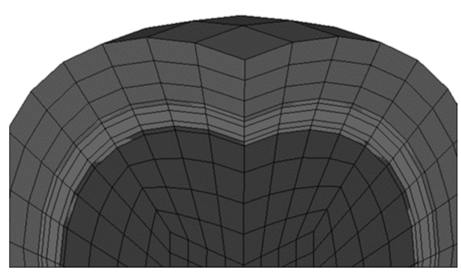
- Sometimes used to help prevent negative volumes in solid foam elements that undergo severe deformations.
- Input includes …
  - Part set ID
  - Penalty scale factor
  - Crush activation factor (fraction of initial thickness)
- There is now an option for improved treatment of large shearing deformations (TYPE=2).

Interference Contact

- This contact is for modeling parts that are intended to have an interference fit.
- The initial penetration check is not done for this contact.
- The input mesh is for the unstressed parts which will show the parts overlapping slightly. The penetration due to this overlap is removed by the contact forces thus inducing stress and deformation into the parts.
- The contact stiffness scale factor is ramped from 0 to 1.0 over a finite time to avoid a sudden, large application of contact force.
- Shell thickness is considered.
- Specify the contact using segment sets having correct orientation.
- Types:
  - *CONTACT_NODES_TO_SURFACE_INTERFERENCE
  - *CONTACT_ONE_WAY_SURFACE_TO_SURFACE_INTERFERENCE
  - *CONTACT_SURFACE_TO_SURFACE_INTERFERENCE

Contact Interference





2D Contact

2D Contact

- For models that use 2D element formulations (plane stress, plane strain, or axi-symmetric), the contact algorithms discussed previously are not valid. It is necessary to use *CONTACT_2D_*option*, developed specific for 2D.

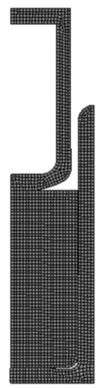
- 2D Element formulations are:
  - Shell formulations 12-15
  - Beam formulations 7,8

- The 2D contacts automatically handle erosion

- Single surface contact behavior is obtained by setting the master side to zero

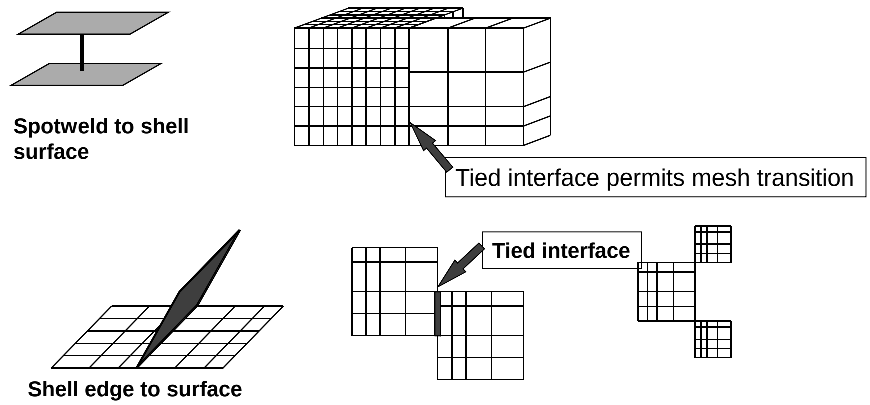
2D Contact

- CONTACT_2D_AUTOMATIC_... is generally preferred for explicit simulations.
- Non-automatic CONTACT_2D… is generally preferred for implicit simulations.



Tied Contact

Tied Contact Applications



Tied Contacts

- Good for tying parts with disparate meshes
- Criteria for tying a slave node
  - The slave node lies within the orthogonal projection of a master segment, and…
  - The gap between the slave node and its master segment is less than a specific value based on element dimensions
    - Tolerance can usually be overridden, e.g., by specifiying a negative contact thickness
  - If criteria are not met, node is not tied and a warning is issued
- Most tied contacts are constraint-based and are therefore not for rigid bodies
- OFFSET or TIEBREAK options invoke penalty-based treatment

Practical Guidelines

Tied Contact

- Specify only the nodes or segments you want to be considered for tying (node sets or segment sets rather than parts or part sets)
- Side with finer mesh should be slave side
- Use *CONTACT_TIED_SHELL_EDGE_TO_SURFACE… types when tying shells-to-shells; *CONTACT_SPOTWELD for spotweld beams to shells
  - These tie translational and *rotational* DOF
- If a physical offset between tied surfaces is desired, …_CONSTRAINED_OFFSET or …_BEAM_OFFSET are preferred as these will transfer moments in a beam-like manner
  - …CONSTRAINED_OFFSET is constraint-based and thus cannot be used with rigid bodies
  - …BEAM_OFFSET is an option only with TIED_SHELL_EDGE_TO_SURFACE

Tied Contacts with *Failure*

- Segment orientation is important to distinguish tension from compression
- TIEBREAK_NODES_TO_SURFACE
  - Failure based on tensile and shear <u>forces</u>
  - After failure, reverts to non-automatic NODES_TO_SURFACE contact
- TIEBREAK_SURFACE_TO_SURFACE
  - Failure based on tensile and shear <u>stresses</u>
  - After failure, reverts to non-automatic SURFACE_TO_SURFACE contact
  - Option for post-failure stress-vs-gap curve
- TIED_SURFACE_TO_SURFACE_FAILURE
  - Constraint-based tied contact with failure stresses

Tied Contacts with *Failure* (cont'd)

- **AUTOMATIC_SURFACE_TO_SURFACE_TIEBREAK**
- **AUTOMATIC_ONE_WAY_SURFACE_TO_SURFACE_TIEBREAK**

  - Many OPTIONs, e.g., tying parts *after* they come into contact (1), or tying in normal direction while allowing to slide with friction (4)

  - Options for modeling composite delamination
    - Fringing of delamination via the *intfor* database (ONE_WAY only)
    - OPTIONs 8,10,11 for shells-to-shells
    - OPTIONs 6,7,9 for solids-to-solids, tshells-to-tshells
    - OPTIONs 9, 11 similar to *MAT_138 (COHESIVE_MIXED_MODE) with cohesive elements
      - Features bilinear traction-separation law, mixed mode delamination, and peak tractions as function of element size

  - After failure, reverts to automatic contact

Tied Contacts with Failure

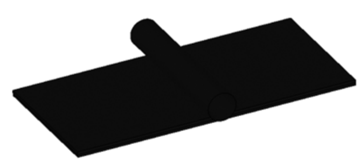
- Test of different fracture modes with DYCOSS Discrete Crack model (Type 9 is used on *CONTACT_AUTOMATIC_ONE_WAY_ SURFACE_TO_SURFACE_TIEBREAK).

Mode I Fracture

Mode II Fracture

Mode III Fracture

Mixed Mode Fracture



Final Word on Tying

- *CONSTRAINED_*option* sometimes offers alternatives to tied contacts for tying nodes to other nodes or to surfaces
  - SPOTWELD (inserts a massless, rigid beam between 2 nodes; includes failure criterion)
  - GENERALIZED_WELD…
  - NODAL_RIGID_BODY (set of nodes becomes a rigid body)
  - EXTRA_NODES (adds nodes to an existing rigid body)
  - TIE-BREAK (for edge-to-edge tying of shells with strain-based failure)
  - TIED_NODES_FAILURE (ties coincident nodes until strain-based failure criterion is reached)

MPP Contact

- MPP = Massively Parallel Processing (or Distributed Memory Parallel)
- SMP = Shared Memory Parallel

- One of the main differences between MPP LS-DYNA and SMP LS-DYNA is the implementation of the contact algorithms.
- When the same input deck is run with SMP and MPP, results may not be identical. This is largely due to differences in the contact.

MPP Contact

- There are certain flags that can only be set for the MPP contact – the regular flags under *CONTACT (below) are not all valid or have different implementations.

Card 1

Variable	SSID	MSID	SSTYP	MSTYP	SBOXID	MBOXID	SPR	MPR

Card 2

Variable	FS	FD	DC	VC	VDC	PENCHK	BT	DT
						X		

Card 3

Variable	SFS	SFM	SST	MST	SFST	SFMT	FSF	VSF
							X	X

Optional Card A

Variable	SOFT	SOFSCL	LCIDAB	MAXPAR	SBOPT	DEPTH	BSORT	FRCFRQ
				X		X	X	

Optional Card B

Variable	PENMAX	THKOPT	SHLTHK	SNLOG	ISYM	I2D3D	SLDTHK	SLDSTF

Optional Card C

Variable	IGAP	IGNORE	DPRFAC	DTSTIF				
			X	X				

Optional Contact Input for MPP

- MPP option added to *CONTACT_... command, e.g., *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_**MPP** causes additional line(s) of input to be read before the mandatory contact cards, Cards 1-3.

Variable	IGNORE	BUCKET	LCBUCKET	NS2TRACK	INITITER	PARMAX		CPARM8
Type	I	I	I	I	I	F		I
Default	0	200	none	3	2	1.0005		0

- The following card is only read if “&” is placed in column 1 of the first field.

Variable		CHKSEGS	PENSF	GRPABLE				
Type		I	F	I				
Default		0	1.0	0				

MPP CONTACT SPECIFICATION

- IGNORE (IPTRACK): Is the same as the "ignore initial penetrations" option on the *CONTROL_CONTACT card and also can be specified in the normal contact control cards. It predates both of those, and isn't really needed anymore since both of those now ARE honored by the MPP code.
- BUCKET (BSORTFQ): Bucketsort frequency. This field is the only way to specify the bucketsort frequency for the MPP code. The BSORT option on optional card A is ignored. Default BUCKET is 200 cycles (MPP), which is larger than default BSORT (SMP).
- LCBUCKET (BSORTLC): Loadcurve for bucketsort frequency. Again, the normal input for this is ignored by MPP.
- NS2TRACK (#TRACK): Numbers of potential contact segments to track for each slave node. The normal input for this (DEPTH on optional card A) is ignored. Default is 3.
- INITITER: Numbers of iterations to perform when trying to eliminate initial penetrations.

MPP CONTACT SPECIFICATION

- PARMAX: The parametric extension distance for contact segments. The MAXPAR parameter on optional card A is not used. The default for PARMAX is 1.0005 (MPP) while the default for MAXPAR (SMP) is 1.025.
- CPARM8: Exclude beam to beam contact from the same part ID. This is only for *CONTACT_AUTOMATIC_GENERAL.
- CHKSEGS: Special element check is done and elements are removed from the contact, if the elements are badly shaped. Only valid for SURFACE_TO_SURFACE and NODE_TO_SURFACE contacts.
- PENSF: This is used with the ignore option. It multiplies the penetration distance and will then push the penetrating node out against the surface. Values recommended is between 0.98 and 0.99 but should be less than 1.
- GRPABLE: This is still under development. It activates a new set of contacts that are faster and scales better that the regular contacts. Some contacts uses this option already when running MPP.

MPP CONTACT SPECIFICATION

- In the earlier versions of MPP-DYNA, the special contact flags were given in the *p-file*.

ID is 333

Ignore initial penetrations

100 cycles between bucket sorting

Activate MPP card 2

```
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_ID_MPP
333
1,100
&
 , , ,1
1,2,3,3
0.1,
1.,1.
```

Using new experimental contact

Regular contact definition

MPP CONTACT GUIDELINES

- To isolate any given contact to a single processor, use *CONTROL_MPP_DECOMPOSITION_CONTACT_ISOLATE
- Forming contact in MPP is not meant to be used with solid elements (slave side). SMP may behave okay in such a case.
- BUCKET can be decreased to e.g. 100 if contact is not reacting to penetration.
- *The ONE_WAY_SURFACE in MPP is similar to the SURFACE_TO_SURFACE contact in SMP.
- *For _TIED contact the setting of SST and MST (Card 3 - *CONTACT) to a negative number in order to specify the tying distance does not work in MPP.
- The use of *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE with SOFT=2 will be the contact that will give most similar results between MPP-DYNA and SMP.

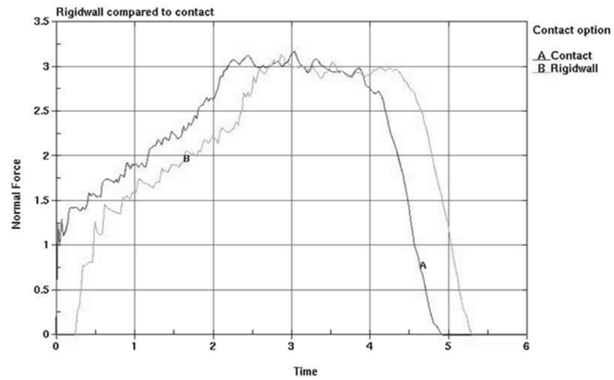
Rigid Walls

Rigid Walls

- *RIGIDWALL_*option* is often used as an alternative to *CONTACT for defining <u>un</u>meshed, rigid contact surfaces of various shapes…
  - Planar (_PLANAR or _GEOMETRIC_FLAT)
  - Rectangular prism (_GEOMETRIC_PRISM)
  - Cylindrical prism (_GEOMETRIC_CYLINDER)
  - Spherical (_GEOMETRIC_SPHERE)
- Nodes that are slave to the rigidwall have their velocity in the direction normal to the rigidwall set to zero upon contact. The slave nodes can still move tangential to the rigidwall surface, with or without friction.
- Contact using *RIGIDWALL_*option* dissipates energy, i.e., impact is plastic. Dissipated energy is reported in glstat as "stonewall" energy and is the difference in the kinetic energy for the slave nodes before and after impact.
- In contrast, contact with a meshed rigid surface using *CONTACT_*option* conserves energy, i.e., impact is elastic (except for dissipation due to contact friction).

Rigid Walls

- Rigidwalls may be stationary or moving
- Spatial extent of rigidwall can be finite or infinite
- Slave nodes can be from rigid parts only if RWPNAL.GT.0 in *CONTROL_CONTACT
- The rigidwall forces are written to *rwforc* according to *DATABASE_RWFORC

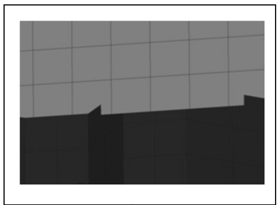


Contact: 444 Sec
Rigidwall: 344 Sec

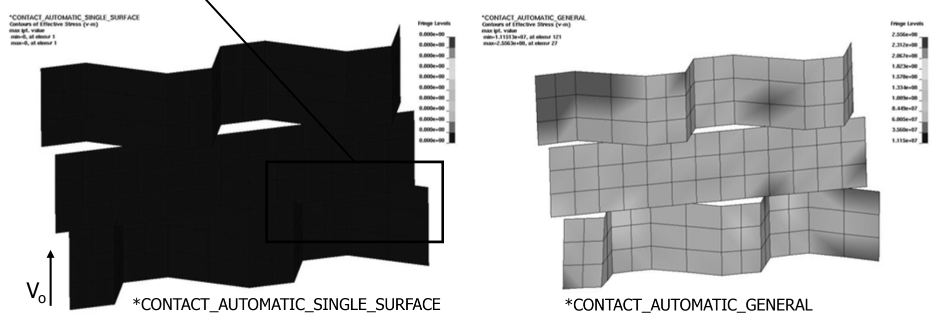
Difficult or Unsual Contact Situations

Unusual Contact Situations

Shell Edge to Shell Edge Contact



Not all contacts can handle the difficult shell edge to shell edge contact. This is not handled e.g. by ordinary *CONTROL_AUTOMATIC_SINGLE_SURFACE nor by *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE, but it is solved with *CONTACT_AUTOMATIC_GENERAL, *CONTACT_SINGLE_EDGE, and *CONTACT_AUTOMATIC_SINGLE_SURFACE with SOFT=2 and DEPTH=5.



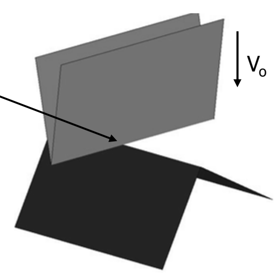
*CONTACT_AUTOMATIC_SINGLE_SURFACE

*CONTACT_AUTOMATIC_GENERAL

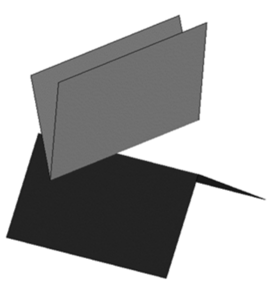
Unusual Contact Situations

Shell Edge to Shell Edge Contact

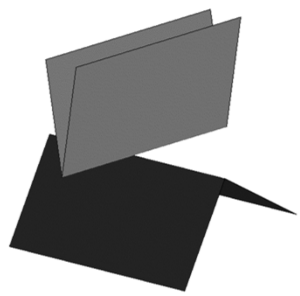
The *CONTACT_AUTOMATIC_GENERAL can't handle shell edge contact if the edges are so-called internal shell edges. Interior edges needs to have null beams superimposed or, an easier approach is simply to use *CONTACT_AUTOMATIC_GENERAL_INTERIOR.



*CONTACT_AUTOMATIC_GENERAL



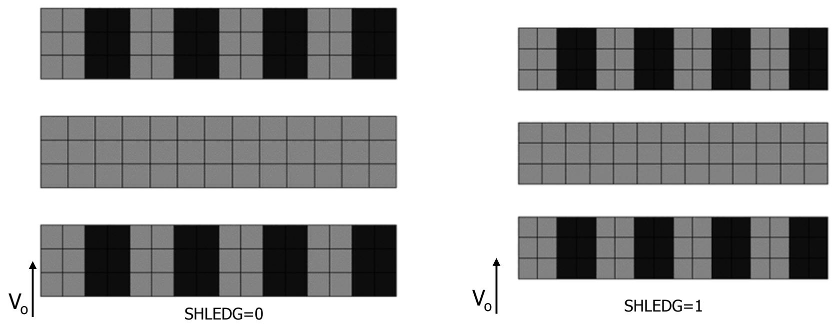
*CONTACT_AUTOMATIC_GENERAL_INTERIOR



Unusual Contact Situations

Shell Edge Contact

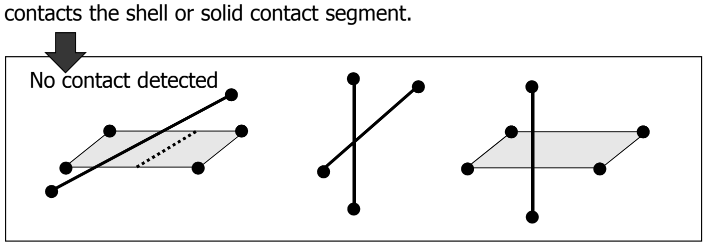
In automatic contacts, the contact surface wraps around the exterior shell edges. In some cases it may be preferred not to have this extension of contact beyond the shell edge. For SOFT=2 thickness on the shell edge can be avoided by setting SHLEDG=1 in *CONTROL_CONTACT (card 6).



Unusual Contact Situations

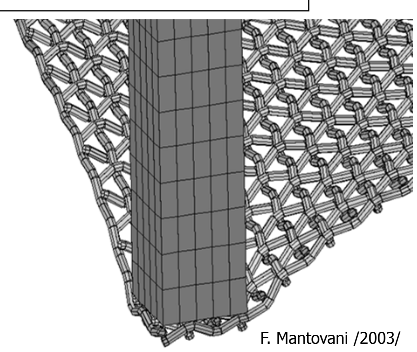
Beam Contact

When a beam contacts a shell or solid, contact will usually only be detected if a beam node contacts the shell or solid contact segment.



The only contacts that **can** detect contact along the entire beam length are *CONTACT_AUTOMATIC_GENERAL (for beam to beam) and *CONTACT_AUTOMATIC_BEAMS_TO_SURFACE (for beams to surface).

An example of where beam to beam contact is important is in the highly detailed modeling of woven fabric.

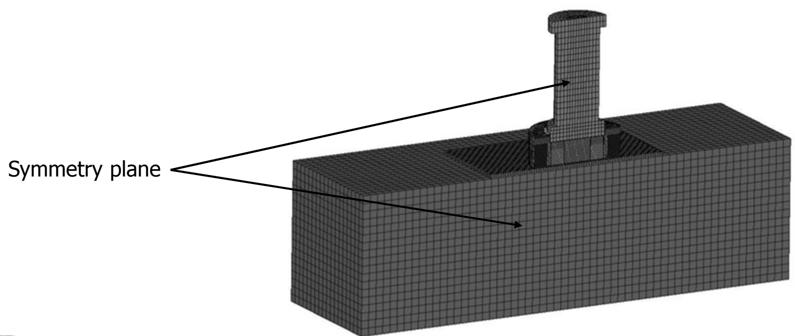


F. Mantovani /2003/

Unusual Contact Situations

Contact on a Symmetry Plane

- Models with symmetry planes can have contact problems on or near the symmetry plane. This happens because segments on the symmetry plane are wrongly seen as exterior segments. To avoid this problem:
  - Set ISYM=1 in card 5 of *CONTROL_CONTACT (affects all contacts), or
  - Set ISYM=1 in Optional card B of *CONTACT_..., or
  - For eroding contact, set ISYM=1 on card 4 of *CONTACT_ERODING_...



Practical Contact Guidelines

Practical Contact Guidelines
Initial Penetrations

- When automatic contacts are used, care should be taken to adequately offset shell midplanes when constructing the mesh. Failure to do so will produce initial penetrations.
  - Default treatment is to project each initially penetrating slave node back to the master surface
    - This perturbs the geometry nonphysically and may affect the solution.
    - No guarantee that all initial penetrations will be detected and removed which may lead to other problems down the road.
  - By setting IGNORE=1 or 2 (via *CONTROL_CONTACT or *CONTACT), 'initial' penetrations are NOT removed. Rather, the contact thickness is reduced according to the penetration. The contact thickness will increase (up to a maximum of the full contact thickness) as the penetration decreases.
  - SOFT=2 contact always ignores initial penetrations, handling them in a manner similar to setting IGNORE=1

Practical Contact Guidelines
Identifying Initial Penetrations

- Look for "Warning" in d3hsp file
  - Initial penetrations are reported when IGNORE=0
  - IGNORE=2 same as IGNORE=1 but with warning messages printed.
- The following will work when IGNORE=0
  - Toggle between State 0 and State 1 using State button in LS-PrePost. State 0 is geometry before initialization; State 1 is geometry after initialization
  - Fringe resultant displacement at State 1. Nonzero displacement at state 1 indicates moved nodes due to initial penetration.
- Use LS-PrePost® to identify and fix penetrating nodes. This is done at Page 5 – Conchk. A description of the feature can be found in [Feainformation, January, 2006].

Practical Guidelines

General Tips

- *CONTACT_AUTOMATIC_SINGLE_SURFACE with SOFT=1 is recommended for most explicit impact simulations
  - Perhaps the most efficient and reliable contact
  - One 'global' contact is not significantly more expensive than several small ones
  - Use *CONTACT_FORCE_TRANSDUCER to monitor forces
- Use *CONTACT_AUTOMATIC_GENERAL sparingly where needed
  - More expensive but good for shell edge-to-edge contact and beam-to-beam contact
  - If there are interior shell edges in contact, try *CONTACT_AUTOMATIC_GENERAL_INTERIOR as alternative to adding null beams to shell edges
- Non-automatic contacts are not recommended for explicit simulations but may be OK for simple geometries where contact orientation can be established reliably from the outset
  - Shell thickness consideration is <u>not</u> mandatory
  - Correct contact orientation is critical (check)

Practical Guidelines

General Tips

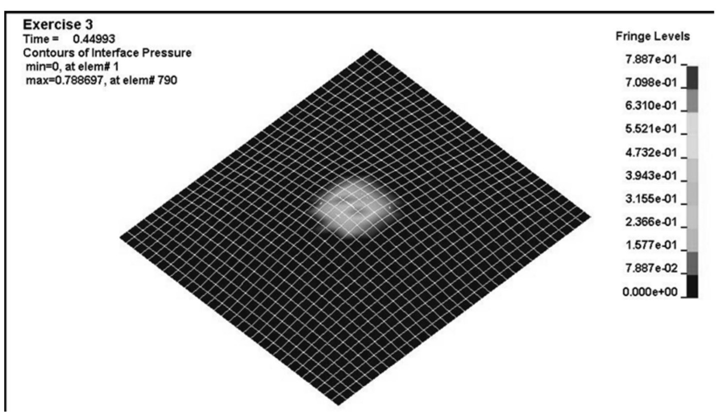
- If contact breaks down for very thin shells, increase the contact thickness (to no less than 1 or 2 mm)
- Contact involving solid elements may benefit from using SLDTHK and SLDSTF on Opt. Card B (easy alternative to coating solid faces with *MAT_NULL shells)
- Make coarser mesh the master side if a one-way contact is used
- Avoid redundant contact specification
- Default contact stiffness may have to be changed for contact between different meshes or materials
  - Modify penalty scale factor on Card 3 of *contact, or preferably…
  - Set SOFT=1 or 2 on optional card A in *CONTACT
- Avoid sharp corners in geometry if possible.
  - Round-off corners using finer mesh
  - Alternately, use segment-based contact (SOFT=2)

Practical Guidelines

General Tips

- Set IGNORE=1 if d3hsp reports lots of small initial penetrations, or set SOFT=2
  - Crossed shell midplanes never OK
- Default bucket sorting interval is generally OK. For the most contacts the sort is performed every 100 cycles. This can be changed using *CONTACT or *CONTROL_CONTACT. High velocity impacts may see improved contact behavior with a more frequent bucket sort or a reduced time step
- Rigid parts should have reasonable mesh refinement to adequately distribute contact forces (and to give accurate mass properties)

Exercise 3



- Specifying contact in LS-DYNA®.
- Using the interface force file.