Contact in LS-DYNA

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  - One-way contacts
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- Contact thickness
- Contact damping
- Contact friction
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Contact in LS-DYNA (cont'd)

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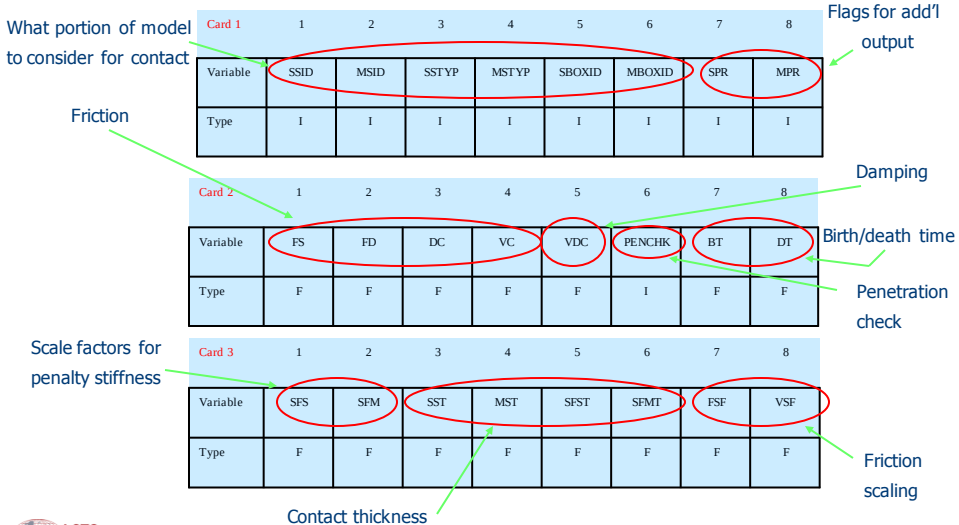
Introduction

- Purpose of contact
  - Allows unmerged Lagrangian elements to interact with each other
    - Parts that impact/push/slide/rub against each other
    - Parts that are 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

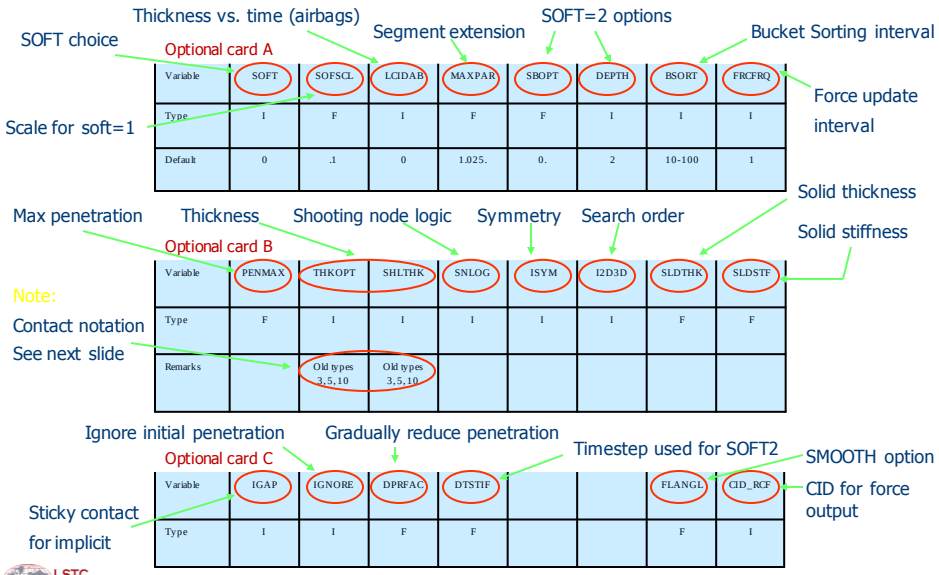
Input Cards for *CONTACT_...

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



Input Cards for *CONTACT_...

- ... Followed by several optional input cards (Cards A,B,C,...)



*CONTROL_CONTACT

- *CONTROL_CONTACT is optional and is usually not needed.
- *CONTROL_CONTACT is used to modify default values for variables governing various aspects of contact behavior.
- Modified default values apply to all contacts *however* variables input in each individual *CONTACT_... command will always take precedence over values set with *CONTROL_CONTACT.

Most Contacts are Penalty-Based

- Penalty-based: A finite contact stiffness is used to resist penetration of nodes or segments into other segments.
- Elastic, compression-only springs resist penetration in the normal direction
  - SOFT on Optional Card A affects method of computing stiffness of contact springs
- Tangential interface springs model contact friction (optional)
  - Coulomb friction coefficient can be a constant or may be defined as a function of relative velocity, interface pressure, direction, etc.
  - Can specify an upper limit for friction stress (function of yield stress)
- Penalty-based contact is stable and tends NOT to excite mesh hourglassing modes (good!)
- Applicable to deformable bodies and to rigid bodies

Penalty Stiffness: SOFT=0

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

$$k = \frac{\alpha K A^2}{V}$$

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:

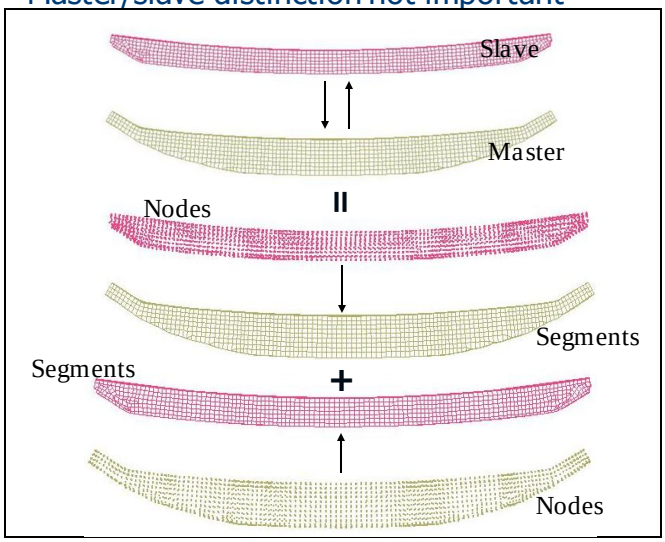
$$k = \frac{\alpha K A}{Max(\,shell\ diagonal\,)}$$

Basic Contact Types

- SURFACE_TO_SURFACE Contacts
- One-way Contacts
- Single Surface Contacts
- Force Transducers

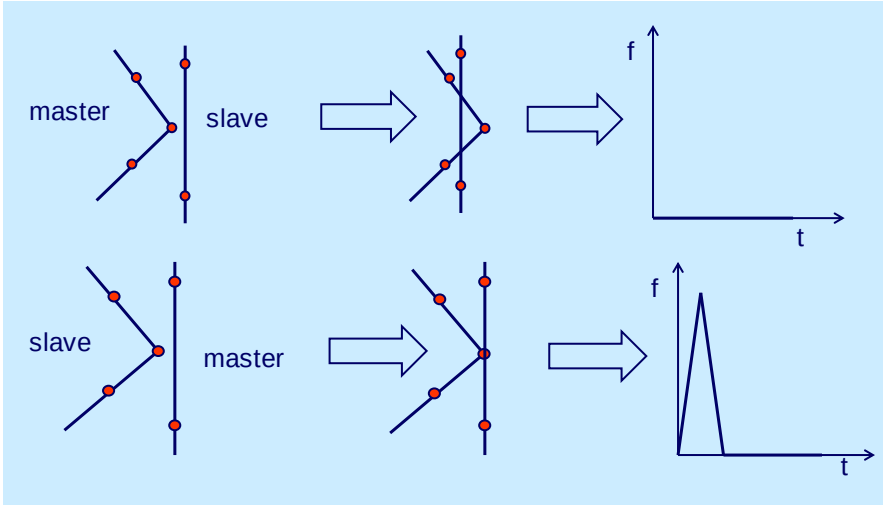
SURFACE_TO_SURFACE Contacts

- Utilize two-way or two-pass algorithm
- Master/slave distinction not important



One-Way Contacts

Only check for slave nodes penetrating master surface



One-way Contacts

- *CONTACT keyword command contains the words NODES_TO_SURFACE or ONE_WAY_SURFACE_TO_SURFACE
- 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)

ONE_WAY_SURFACE_TO_SURFACE

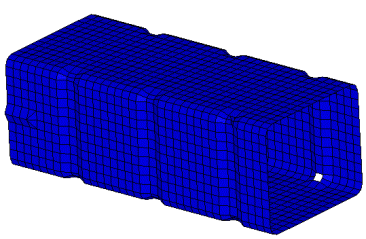
- Just like NODES_TO_SURFACE contact except…
  - Slave side is specified as a set of segments rather than as a set of nodes (part IDs are OK for either type)
  - Provides a way of visualizing pressure distribution on slave surface via "*intfor*" binary database (more on that later)

Single Surface Contacts

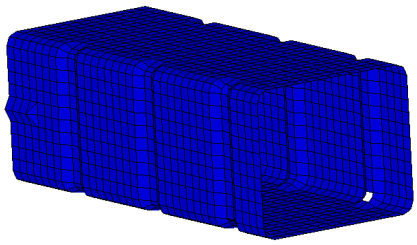
- Treats intra-part contact (self contact) as well as inter-part contact.
- Only the slave side is defined on Card 1; the master side is not specified.
- Often, one *CONTACT_AUTOMATIC_SINGLE_SURFACE is sufficient for treating all contact in a model.
- Other single surface contacts are *CONTACT_AUTOMATIC_GENERAL and *CONTACT_ERODING_SINGLE_SURFACE (more later)

Single Surface Contacts

- Self contact is important when structures buckle.



No contact specified



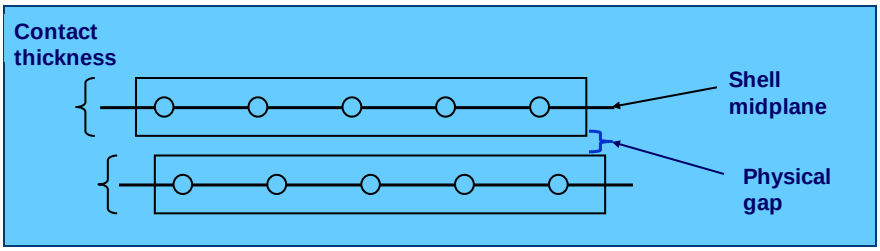
Single surface contact specified

Force Transducers

- Single surface contacts do not output the contact forces produced. In order to plot contact forces, one or more "force transducers" must be defined using *CONTACT_FORCE_TRANSDUCER_PENALTY.
- Force transducers provide a convenient means of contact force retrieval at selected locations, both for single surface contacts and other type contacts as well.
- The slave side on Card 1 tells the force transducer where to gather contact forces for output.
- Cards 2 and 3 are blank.
- It's important to understand that NO contact forces are created by force transducers.
  - Transducers only measure forces from other contact types
  - Measured contact forces are written to rcforc (*DATABASE_RCFORC)

Contact Thickness for Shells

- When we define *CONTACT_AUTOMATIC_... for shell elements, two contact surfaces are established: one below the shell midplane and one above the shell midplane.
- The separation of those two contact surfaces is the "contact thickness".



Two Definitions of Thickness

- **Shell Thickness**
  - Given in *SECTION_SHELL, *ELEMENT_SHELL_THICKNESS, or *PART_COMPOSITE
  - Affects stiffness and mass of the element
  - Can be visualized using LS-PrePost® (Appear > Thick)
- **Contact Thickness**
  - Does NOT affect stiffness or mass of the shell
  - Default contact thickness = shell thickness (exception: see variable SSTHK)
  - Can set or scale default contact thickness directly on Card 3 of *CONTACT or using *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	PENCH K	BT	DT
Type	F	F	F	F	F	I	F	F
Default	0.	0.	0.	0.	0.	0	0.	1.0E20

- Completely optional. Specified by setting VDC to a percentage of critical damping, e.g. 20, 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 internally...
  - k = interface stiffness

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

Contact Friction

Coulomb friction is optional for contact.

Friction is invoked by setting the static friction coefficient FS on Card 2 of *CONTACT.

The friction coefficient can be made a function of relative velocity by also setting the dynamic friction coefficient FD and a decay factor DC, both on Card 2. In this case, an exponential function smoothes the transition from static to dynamic friction. v is the relative velocity between the slave node and the master segment:

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

Contact Friction (continued)

The calculated 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, an option exists to specify a limit on the value of the tangential force:

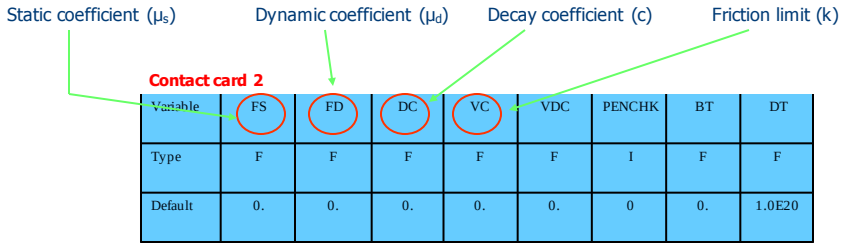
$$f^{n+1} = \min\left(f^{n+1}_{Coulomb}, \kappa A_{master}\right)$$

where A_{master} is the area of the master segment and κ is the coefficient for viscous friction, given as VC on Card 2 of *CONTACT.

A suggested value for κ is to use the yield stress in shear, $\sigma_0/\sqrt{3}$.

Contact Friction (continued)

- Card 2 of *CONTACT



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

- Variables affecting friciton can also be input using *PART_CONTACT, which can be useful when one single surface contact is specifed in a model with many different materials. Here, a set of friction variables is given for each part.

- A more physical way of handling part-to-part friction in one single surface contact is *DEFINE_FRICTION. Here a table of friction variables is given, one set per pair of parts.

ASCII Output Files for Contact

- *DATABASE_*option* where options are:
  - GLSTAT: Global statistics which include contact energy for entire model.
  - RCFORC: Resultant contact forces for each *CONTACT.
  - SLEOUT: Total and frictional contact energy for each *CONTACT.
  - NCFORC: Contact forces at each node (set print flags SPR=1 and/or MPR=1 on Card 1 of *CONTACT)
- The resultant contact forces in the *rcforc* file are in the global coordinate system by default. Optionally, one can 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

Binary Interface Force File for Contact

- 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
  - Further control content with *DATABASE_EXTENT_INTFOR (optional)
- The "interface force file" 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

Contact Energy

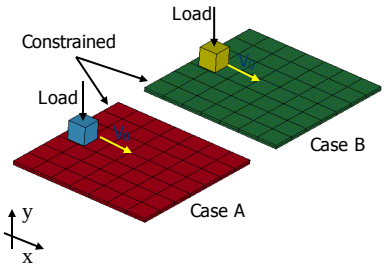
- Contact energy for each *CONTACT is written using *DATABASE_SLEOUT:

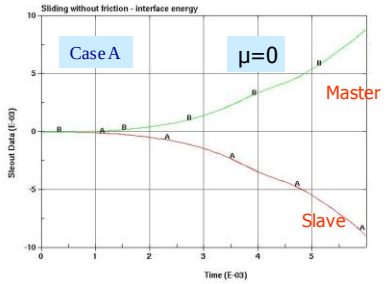
$$E_{contact} = \sum_{i=1}^{slavenodes} \Delta F_i^{slave} \times dist + \sum_{i=1}^{masternodes} \Delta F_i^{master} \times dist$$

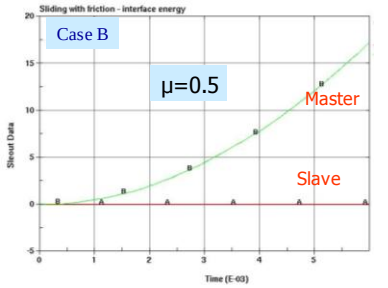
- Both normal-direction contact forces and friction forces contribute to the contact energy.
- In any particular *CONTACT, if the friction coeffs and contact damping are zero, the contact energy is elastic and should return to near zero when parts are out of contact.
- Frictional energy is positive and nonrecoverable, i.e., it's dissipative). Ditto for contact damping energy.
- Large negative contact energy is cause for some concern.

Illustration of Contact Energy

- 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

Regarding Frictional Contact 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 interface force file (*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
  - Set FRCENG=1 in *CONTROL_CONTACT
- Heat transfer across SURFACE_TO_SURFACE contact
  - Add THERMAL option
    - Input conductivity and radiation parameters for contact
    - Hot part can pass heat to cooler part via contact
  - Or 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

"SOFT" on Card A of *CONTACT

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

SOFT on Card A of *CONTACT

- Contact between materials having a wide range of stiffness may require special treatment.
- Similarly, contact involving disparate element sizes may require special treatment.
- Old approach would be:
  - Cover the solid elements with a shell layer that uses *MAT_NULL
  - Increase the penalty stiffness scale factors on Card 3
- Preferred approach is to set SOFT=1 or SOFT=2 on Card A. These options calculate the stiffness based on the nodal masses and the time step.

SOFT=1 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.

SOFT=2 Contact

- SOFT=2 invokes 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 using a unique segment-based approach.
  - SOFT=2 actually opens up a world of powerful contact options, most of which are invoked with SBOPT and DEPTH on Card A.
- SOFT=2 does not work with beams or with NODES_TO_SURFACE type contacts since no segments can be generated from these contacts.

SOFT=2 (continued)

The alternate name for SOFT=2 is **"Segment-Based Contact".**

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

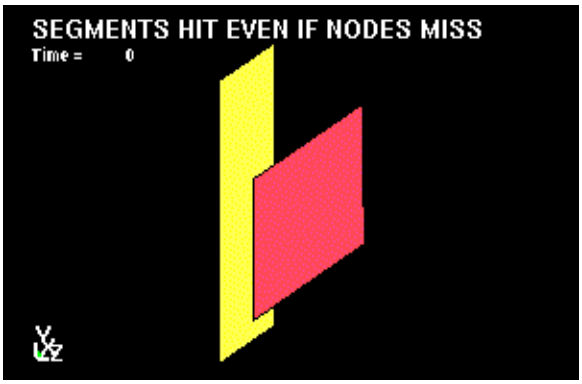
Segment-Based Contact
Detects penetration of one segment into another segment and then applies penalty forces to nodes of both segments.

***Penalty-based contacts with SOFT=0 or SOFT=1.**

SOFT=2 Contact

Segments hit even if nodes miss

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



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

SOFT=2 Contact

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

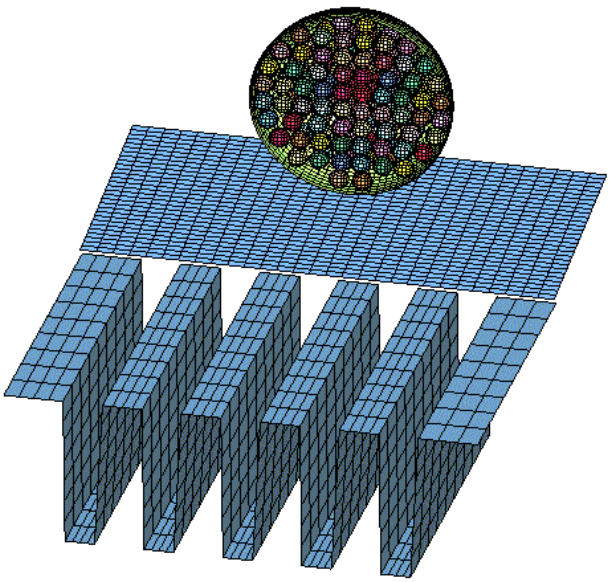
- Initial penetration for each segment pair is stored and subtracted from the current penetration before calculating penalty forces.
- This logic is used continually throughout the simulation so that a segment that penetrates undetected for a brief period will not be shot out by a large contact force when first detected.
- A similar treatment of initial penetrations is achieved for SOFT=0 and SOFT=1 contacts when the variable IGNORE is set to 1 on Card C of *CONTACT.

Some 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: depth of surface penetration is also checked at segment edges
  - 13,23,33: tweaks to 3 for better energy conservation (13) and improved robustness (23,33)
  - 5, 25, 35: adds check for edge-to-edge penetration

Contact Example

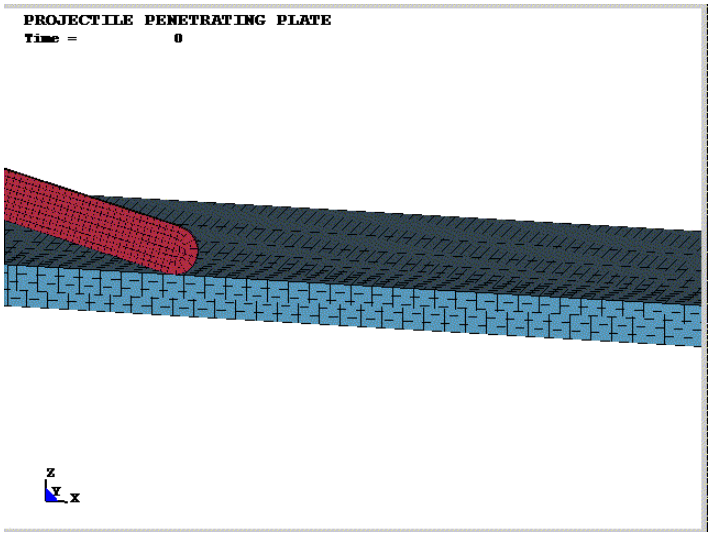
***CONTACT_AUTOMATIC_SINGLE_SURFACE, SOFT=2**



Eroding Contact

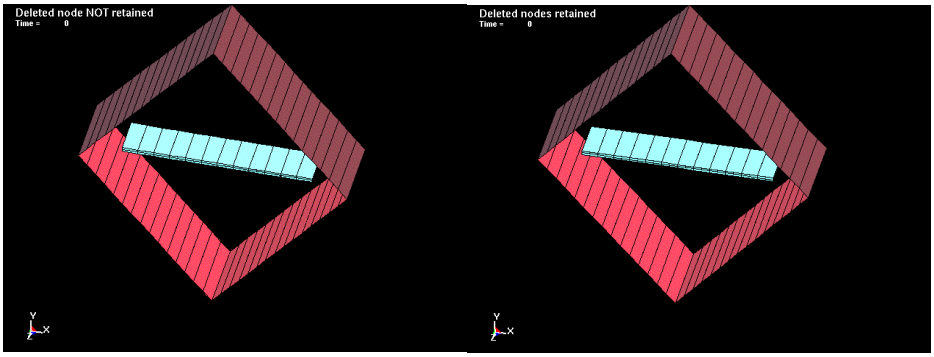
- Contact surface is updated as elements on free surface are deleted.
- Elements are deleted according to material failure criteria, not directly due to eroding contact.
- Time step may be affected but can bypass this effect on time step by setting ECDT=1 in *CONTROL_CONTACT.
- As slave nodes become 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".
- *CONTACT_ERODING_SINGLE_SURFACE is single surface version of eroding contact (recommended) and includes SOFT=1 and SOFT=2 options.

Eroding Contact Example



Eroding Contact

Example: Effect of Deleted Nodes on Contact



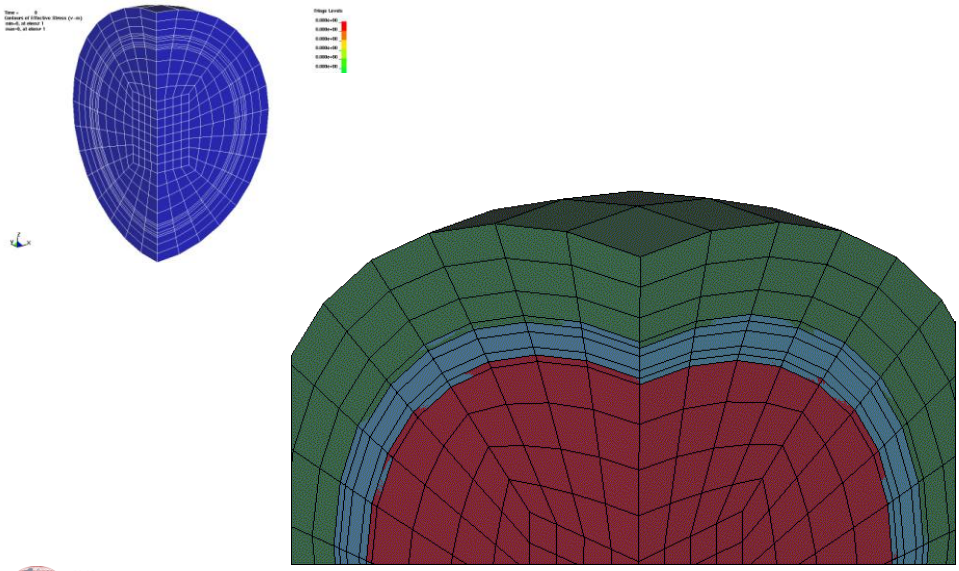
ENMASS=0 ENMASS=1

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

Interference Contact

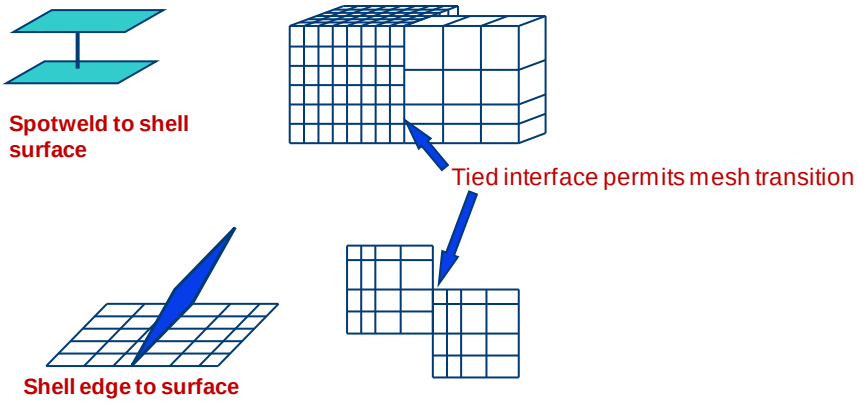
Example: Multi-layer sphere with compressed core



Tied Contacts

- Good for tying parts with disparate meshes.
- Tied contact requires that:
  - 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 tolerance based on element dimensions.
    - Tolerance can usually be overridden, e.g., by specifying a negative contact thickness.
  - If the two 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.

Tied Contact Applications



Tied Contact Guidelines

- BE SELECTIVE. 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 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
  - Brittle failure based on tensile and shear forces
  - After failure, reverts to non-automatic NODES_TO_SURFACE contact
- TIEBREAK_SURFACE_TO_SURFACE
  - Failure based on tensile and shear stresses
  - 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 (OPTION=1), or tying in normal direction while allowing to slide with friction (OPTION=4)

  - OPTIONs for modeling composite delamination
    - Fringing of delamination via the *intfor* database
    - 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

Alternatives to Tied Contact

- *CONSTRAINED_*option* sometimes offers alternatives to tied contacts for tying nodes to other nodes or to surfaces. *Option*s include:
  - SPOTWELD (inserts a massless, rigid beam between 2 nodes; includes failure criterion)
  - GENERALIZED_WELD_(SPOT,BUTT,FILLET) (includes failure criterion)
  - 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 of constraint)
  - TIED_NODES_FAILURE (ties coincident nodes until strain-based failure criterion is reached allowing solids to break apart)

MPP Contact

- **SMP** and **MPP** refer to the 2 distinct methods of parallelization available in LS-DYNA
  - **MPP** = Massively Parallel Processing (or Distributed Memory Parallel)
  - **SMP** = Shared Memory Parallel
  - Hybrid shares characteristics of SMP and MPP
- 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 executables, results may not be identical.
- Change in MPP's decomposition of model can affect contact forces
  - *CONTROL_MPP_DECOMPOSITION_CONTACT_ISOLATE will prevent this by processing a particular contact with a single processor/core but at the cost of increased run time.

MPP Contact

- There are certain variables in *CONTACT that are not used or are set elsewhere when running MPP LS-DYNA.

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 MPP Cards for Contact

- MPP option added to the *CONTACT_... command, e.g., *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE_MPP causes 1 or 2 additional line(s) of input to be read *before* the mandatory contact cards. These cards apply only when running MPP LS-DYNA.
  - 1st MPP card

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 2nd MPP card is read if "&" is placed in column 1 of the first field.

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

Some Variables set with _MPP Contact Option

- IGNORE: 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.
- BCKT: Bucket sort frequency. This field is the only way to specify the bucket sort frequency for the MPP code. The BSORT option on optional card A is ignored. Default BUCKET is 200 cycles in MPP, which is larger than the default bucket sort interval in SMP.
- PARMAX: The spatial extension factor for contact segments. This supercedes the MAXPAR parameter on optional card A. The default for PARMAX is 1.0005 (MPP) while the default for MAXPAR (SMP) is 1.025.
- CPARM8: Special controls for beam-to-beam and shell edge-to-edge contact behavior of *CONTACT_AUTOMATIC_GENERAL.
- GRPABLE: Invokes "groupable" contact to improve computational efficiency when there are many contacts in the model. See also *CONTROL_MPP_CONTACT_GROUPABLE.

2D Contact

- For models that use 2D element formulations (plane stress, plane strain, or axisymmetric), the contact algorithms discussed previously are not valid. It is necessary to use *CONTACT_2D_*option*.
- 2D Element formulations include:
  - Shell formulations 12-15 (analogous to solids in 3D)
  - Beam formulations 7,8 (analogous to shells in 3D)
- CONTACT_2D_AUTOMATIC_... is recommended
  - Includes SURFACE_TO_SURFACE, SINGLE_SURFACE, and TIED options
- The 2D contacts automatically handle erosion

Rigid Walls

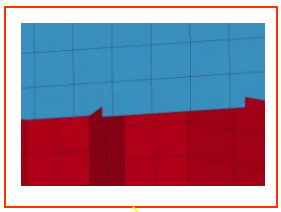
- *RIGIDWALL_*option* is often used as an alternative to *CONTACT for defining unmeshed, rigid contact surfaces having simple shapes such as…
  - Planar (_PLANAR or _GEOMETRIC_FLAT)
  - Rectangular prism (_GEOMETRIC_PRISM)
  - Cylindrical prism (_GEOMETRIC_CYLINDER)
  - Spherical (_GEOMETRIC_SPHERE)
- Contact can include friction or can include a "stick" condition.
- Contact using *RIGIDWALL_*option* dissipates energy, i.e., impact is plastic.
  - Dissipated energy is reported in glstat as "stonewall energy".
  - 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

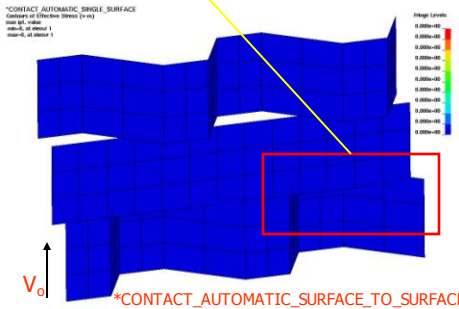
- Rigid walls may be stationary or moving
- Spatial extent of rigidwall can be finite or infinite
- Slave nodes can be from rigid parts only if RWPNAL.GT.0 in *CONTROL_CONTACT (invokes a penalty-based formulation)
- The rigidwall forces are written to *rwforc* according to *DATABASE_RWFORC

Special
Contact Situations

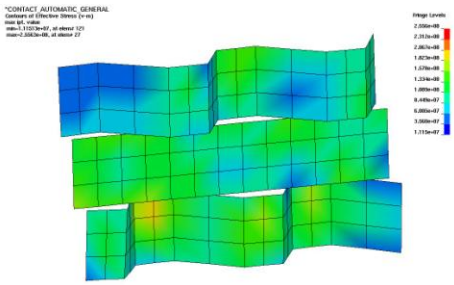
Exterior Shell Edge-to-Edge Contact



Recommend
*CONTACT_AUTOMATIC_GENERAL or
*CONTACT_AUTOMATIC_SINGLE_SURFACE
with SOFT=2 and DEPTH=5.



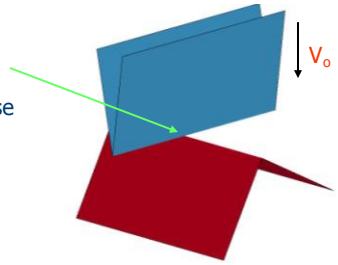
*CONTACT_AUTOMATIC_SURFACE_TO_SURFACE



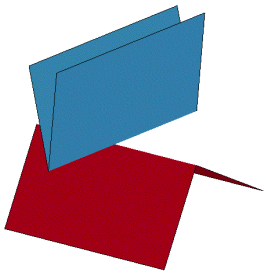
*CONTACT_AUTOMATIC_GENERAL

Interior Shell Edge-to-Edge Contact

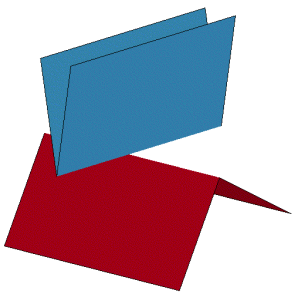
Regular *CONTACT_AUTOMATIC_GENERAL can't handle shell edge contact if the edges are **internal shell edges**. Interior edges needs to have null beams superimposed or, an easier approach is to use *CONTACT_AUTOMATIC_GENERAL_INTERIOR.



*CONTACT_AUTOMATIC_GENERAL

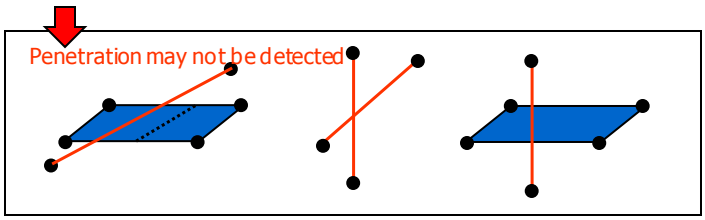


*CONTACT_AUTOMATIC_GENERAL_INTERIOR



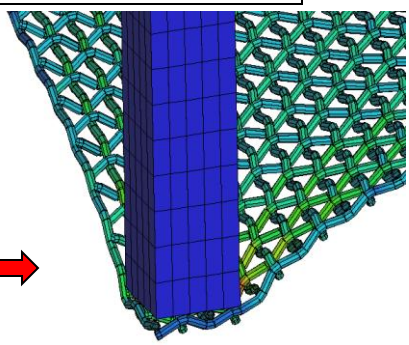
Beam Contact

Most contact types only check for penetration of beam nodes through segments. Envision the beam contact surface as a sphere around each beam node.



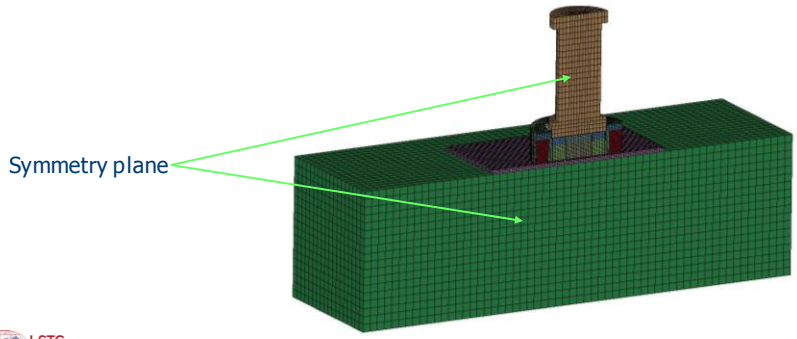
To detect contact along the *entire length* of each beam element, use *CONTACT_AUTOMATIC_GENERAL (for beam to beam) or *CONTACT_AUTOMATIC_BEAMS_TO_SURFACE (for beams to surface). For these, envision the beam contact surface as a cylinder along the beam's longitudinal axis.

Example: Woven fabric modeled with beam elements.



Models with Symmetry Planes

- Models with symmetry planes have exterior segments on the symmetry planes. So that these segments are not considered in the contact treatment, be sure to …
  - 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_...



Initial Penetrations

- Care should be taken to adequately account for shell thickness and beam diameter when constructing the mesh. Failure to do so will result in initial contact 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 negative contact energy and improper contact behavior.
- **Recommended:** By using SOFT=2 or by setting IGNORE=1 or 2 (via *CONTROL_CONTACT or *CONTACT), 'initial' penetrations are NOT removed. Rather, the contact thickness is initially reduced according to the penetration and is adjusted upwards as the penetration decreases.
  - This is effective only for small initial penetrations less than ½ the shell thickness or ½ the beam diameter.

Checking for Initial Penetrations

- Look for "Warning" in messag (or mes**** in MPP)
  - Initial penetrations are reported when IGNORE=0 or 2.
- Use LS-PrePost to check for initial penetrations.
  - Application>Model Checking>General Checking>Contact Check>Check produces a fringe plot of penetrations.
- To some extent, LS-PrePost can adjust the mesh to remove initial penetrations, but it's generally better to construct the mesh properly in the first place to avoid initial penetrations.

Contact Summary (Recommendations)

- *CONTACT_AUTOMATIC_SINGLE_SURFACE with SOFT=1 and IGNORE=2 is effective for most explicit impact simulations.
  - Combines robustness and efficiency.
  - One all-encompassing contact is not significantly more expensive than several smaller ones.
  - Use *CONTACT_FORCE_TRANSDUCER to output contact forces
- Switch to SOFT=2 to invoke "segment-based" contact if SOFT=1 is observed to be unsatisfactory.
  - Somewhat more expensive than SOFT=1 but may be more effective, especially for non-smooth contact surfaces.
  - SOFT=2 is applicable to *CONTACT_AUTOMATIC_SURFACE_TO_SURFACE and *CONTACT_AUTOMATIC_SINGLE_SURFACE.
  - Also set SBOPT and DEPTH when using SOFT=2 (see Manual)
    - Start with SBOPT=3 and DEPTH=13
- Use *CONTACT_AUTOMATIC_GENERAL for shell edge-to-edge contact and beam-to-beam contact
  - If there are interior shell edges that are seen to penetrate, try *CONTACT_AUTOMATIC_GENERAL_INTERIOR (expensive!)

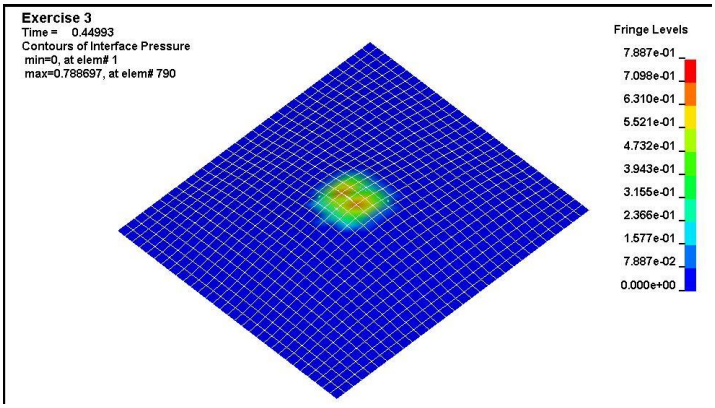
Contact Summary (Recommendations)

- 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 on Opt. Card B.
  - Offsets contact surface from element surface.
- A one-way contact is effective if one side is rigid
  - *CONTACT_AUTOMATIC_NODES_TO_SURFACE or *CONTACTT_AUTOMATIC_ONE_WAY_SURFACE_TO_SURFACE
  - Make the rigid part the master side.
- Rigid parts should have reasonable mesh refinement to adequately distribute contact forces

Contact Summary (Recommendations)

- Contact behavior in high velocity impacts may benefit from …
  - Reduction in time step scale factor TSSFAC in *CONTROL_TIMESTEP
  - Reduction in bucket sorting interval
    - BSORT for SMP
    - BCKT for MPP
- Use ERODING type contact if element deletion is invoked
  - Updates the contact surface as elements erode
- Avoid redundant contact specification, that is, do not specify more than one *CONTACT_... for any particular interaction.

Exercise 3



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