Contact in LS-DYNA

A good overview of contact is presented in a four part series in archived FEA Information newsletters available at …

www.Feapublications.com

The series is contained in the August, September, October, and December 2001 newsletters.

Helpful info on contact and other LS-DYNA topics is available on-line at …

www.lstc.com/help

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 identified a variety of ways on Card 1 of *CONTACT**
  - By part ID(s) (include or exclude)
  - By node sets or segment sets
  - By boxes (include or exclude)

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

Search Methods

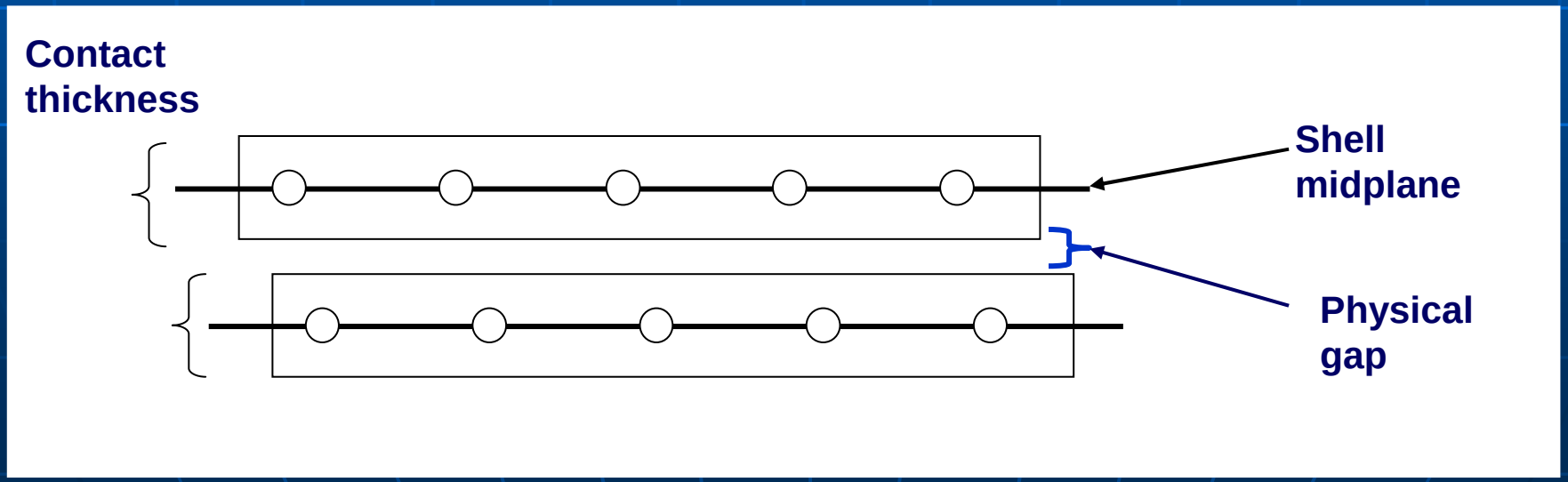
- 'Old' Node-based search (Sect. 23.6 in Theory Manual)
  - Used by non-automatic contacts
  - Not good for disjoint or irregular meshes
  - Requires correct orientation of segments
- Bucket Sort Approach (Sects. 23.8.1 and 23.11)
  - Used by automatic contacts with SOFT=0 or 1
  - Bucket sorting approach works for non-continuous surfaces
  - Orientation of segments doesn't matter (searches for contact from either side of a shell)
- SOFT=2 Segment-based contact
  - Searches for segments penetrating segments

Methods of Calculating Contact Forces

- Penalty-based
  - By far, most common approach
  - Uses a finite contact stiffness
- Tied
  - Usually constraint-based
  - Sometimes penalty-based
- Others
  - Constraint by forces (contact_constraint)
  - Constraint by displacement (contact_sliding_only)
    - Suited for high explosive gas-to-structure interaction

Shell 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



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
  - 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 6.1 in User's Manual)

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. 23.3 and 23.7 in Theory Manual

Contact 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:**

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

Contact Stiffness: SOFT=1

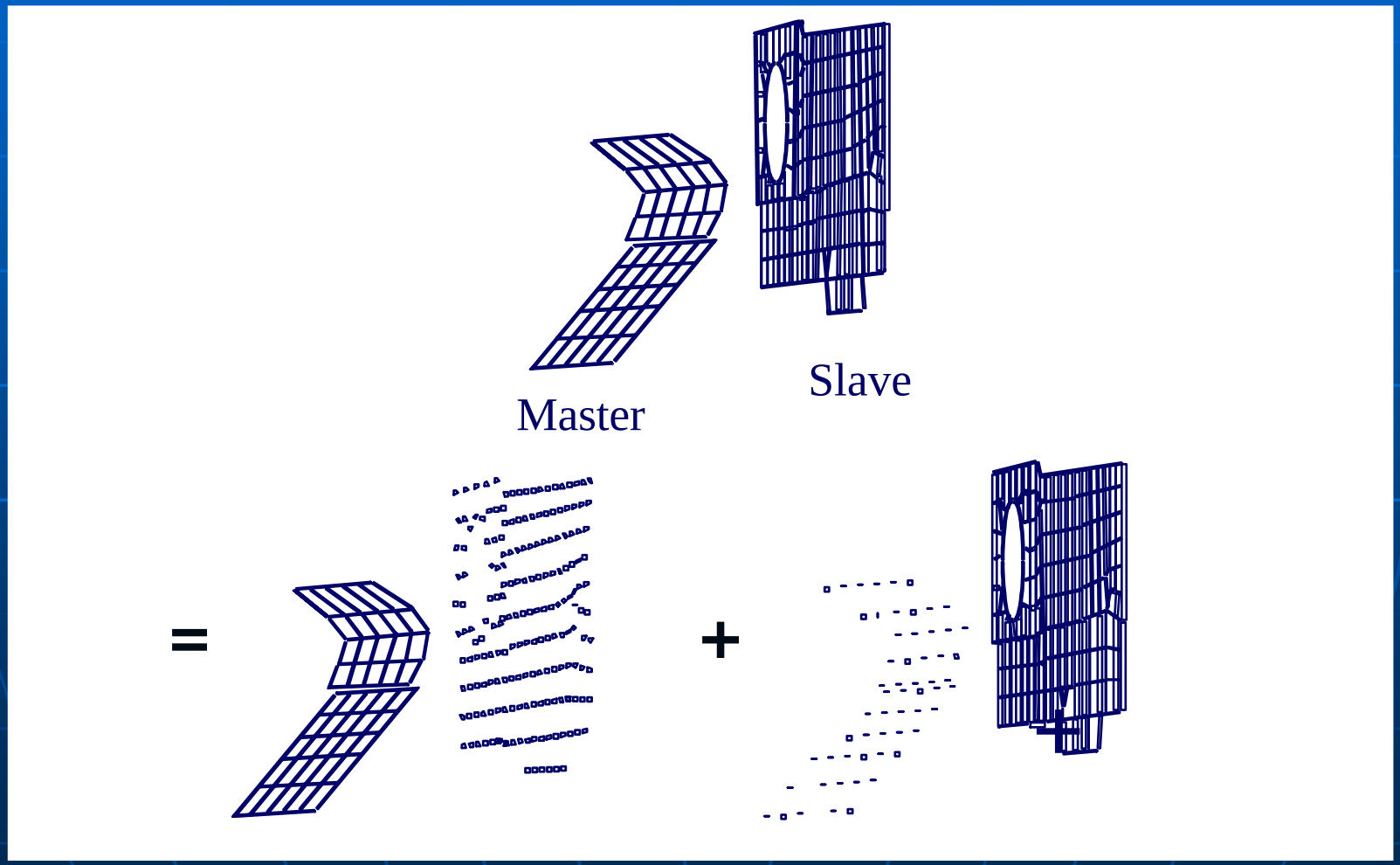
- **SOFT parameter is prescribed on Opt. Card A of *CONTACT**
- **SOFT=1 contact stiffness is maximum of …**
  - The SOFT=0 stiffness (see previous page), and
  - A stiffness calculated based on stability of a spring-mass system considering…
    - Nodal masses
    - Global timestep, Δt

$$k = SOFSCL \frac{m}{\Delta t^2}$$

- **SOFT=1 is usually recommended for contact involving soft materials, e.g., foams, or for contact between parts of dissimilar mesh densities**

Surface_to_Surface Contacts

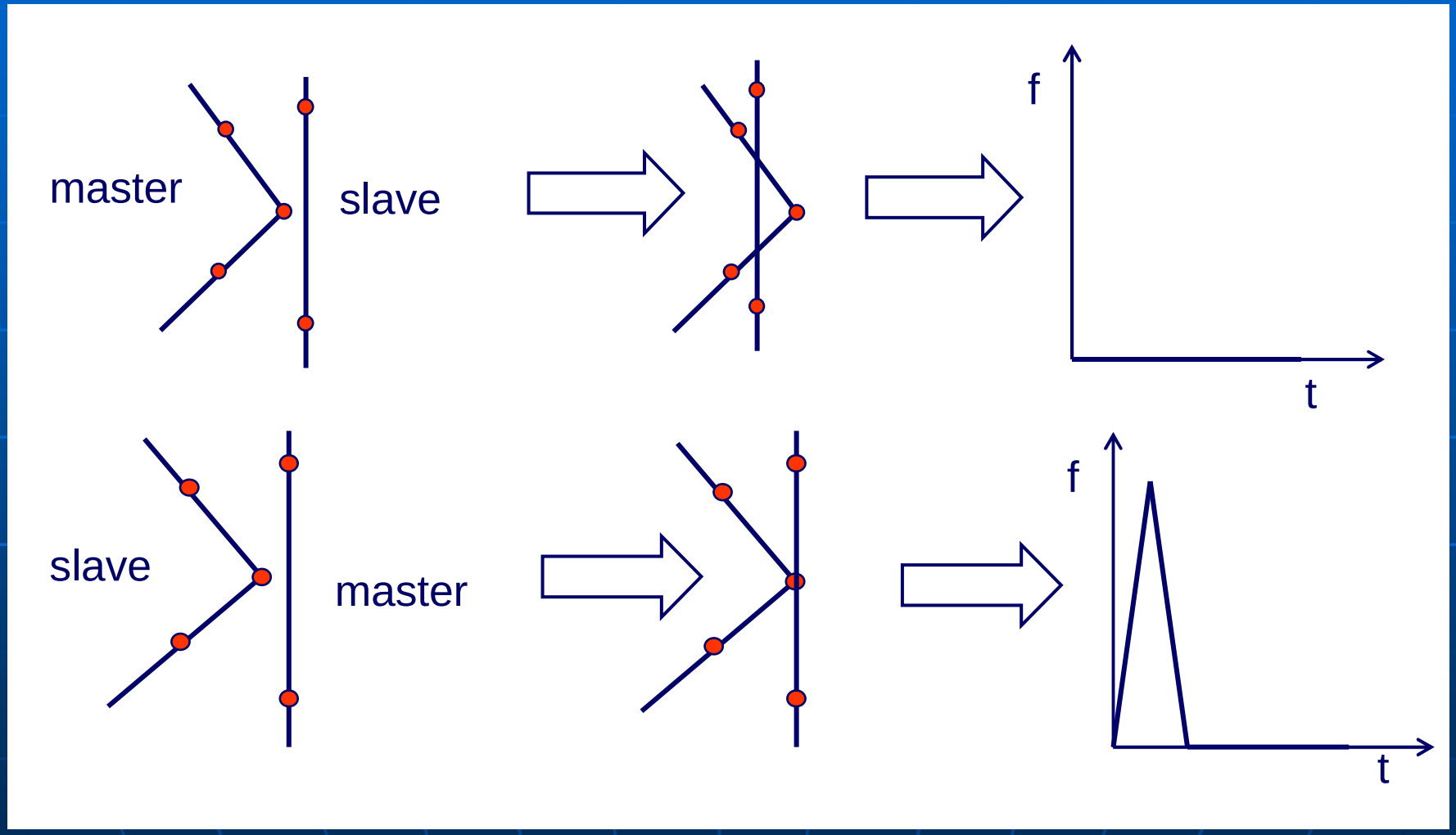
- **Utilize two-way (symmetric) treatment**
  - master/slave distinction not important



Non-automatic vs. Automatic

- ***CONTACT_SURFACE_TO_SURFACE**
  - So-called 'non-automatic' contact
  - Shell thickness offsets are optional (SHLTHK)
  - Segment orientation is important
    - Orientation determined by segment (or shell) normals
    - ORIEN in *control_contact invokes check of orientation during initialization
- ***CONTACT_AUTOMATIC_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 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
    - Not 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
  - Provides a way of visualizing pressure distribution on slave surface via "INTFOR" binary database (more on that later)

Single Surface Contacts

- Treats 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 shell thickness offsets
- No data is written to RCFORC output file. Must use *contact_force_transducer_penalty to gather and print contact resultant forces

Single Surface Contacts

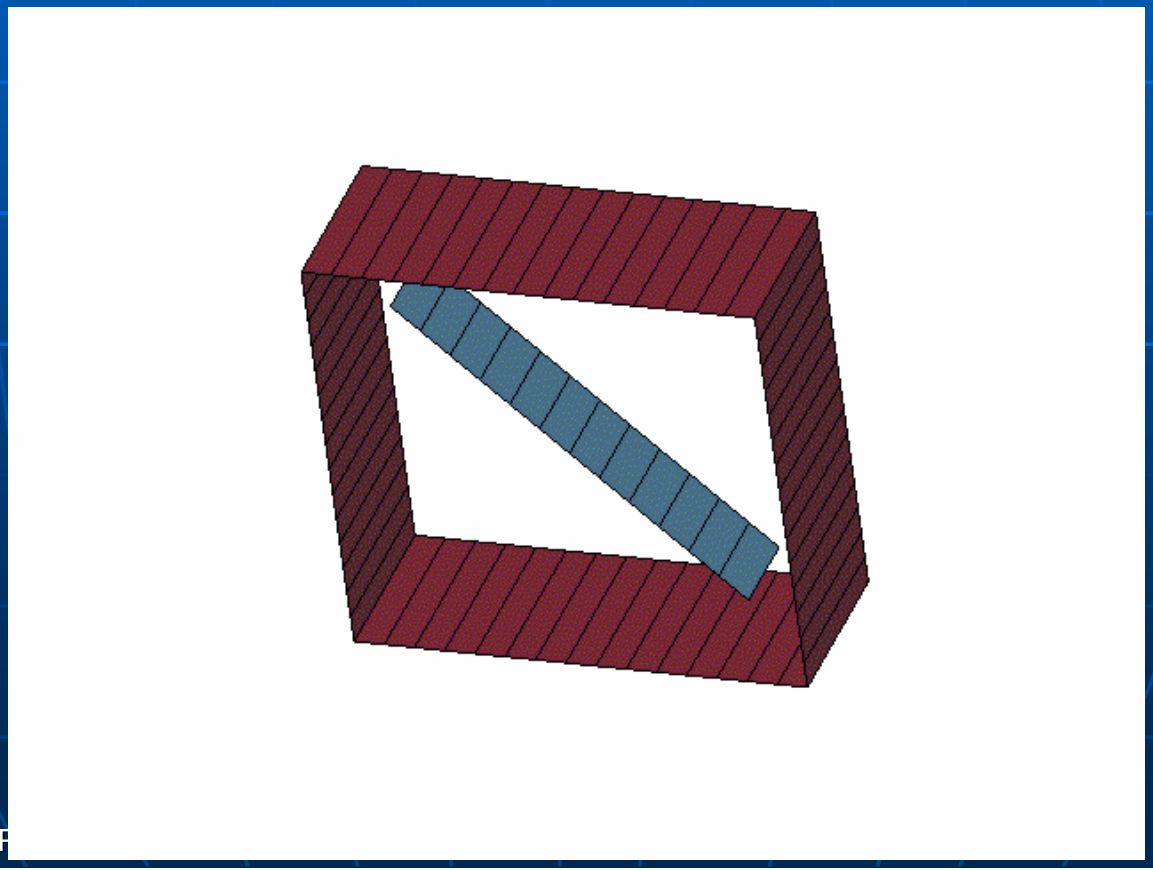
- Types:
  - SINGLE_SURFACE (not recomended; 'old' node-based search)
  - AUTOMATIC_SINGLE_SURFACE (recommended)
  - AIRBAG_SINGLE_SURFACE
  - ERODING_SINGLE_SURFACE
  - AUTOMATIC_GENERAL
  - AUTOMATIC_GENERAL_INTERIOR
- AUTOMATIC_SINGLE_SURFACE is most common contact used in impact simulations
- AUTOMATIC_GENERAL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

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.
- Timestep is automatically adjusted to satisfy contact timestep
  - Recognizes that eroding contact is generally used in high velocity simulations
  - Can bypass effect of eroding contact on timestep via ECDT parameter (*CONTROL_CONTACT)
- As slave nodes become unattached/free due to element deletion, those nodes may continue to be considered in the contact (mass conserved)
  - 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)**
  - similar to AUTOMATIC_SINGLE_SURFACE)
- ***CONTACT_ERODING_NODES_TO_SURFACE**
  - Slave side should be all-inclusive set of nodes
- ***CONTACT_ERODING_SURFACE_TO_SURFACE**



Segment-Based Contact (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).
- Searches for penetration in a unique way (next slide).
- Does not work with beams or with nodes_to_surface type contacts.
- Invoked by:
  - Creating a contact definition in the usual way, and then
  - Setting soft=2 on optional card A
- Not included in MPP prior to version 970

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.

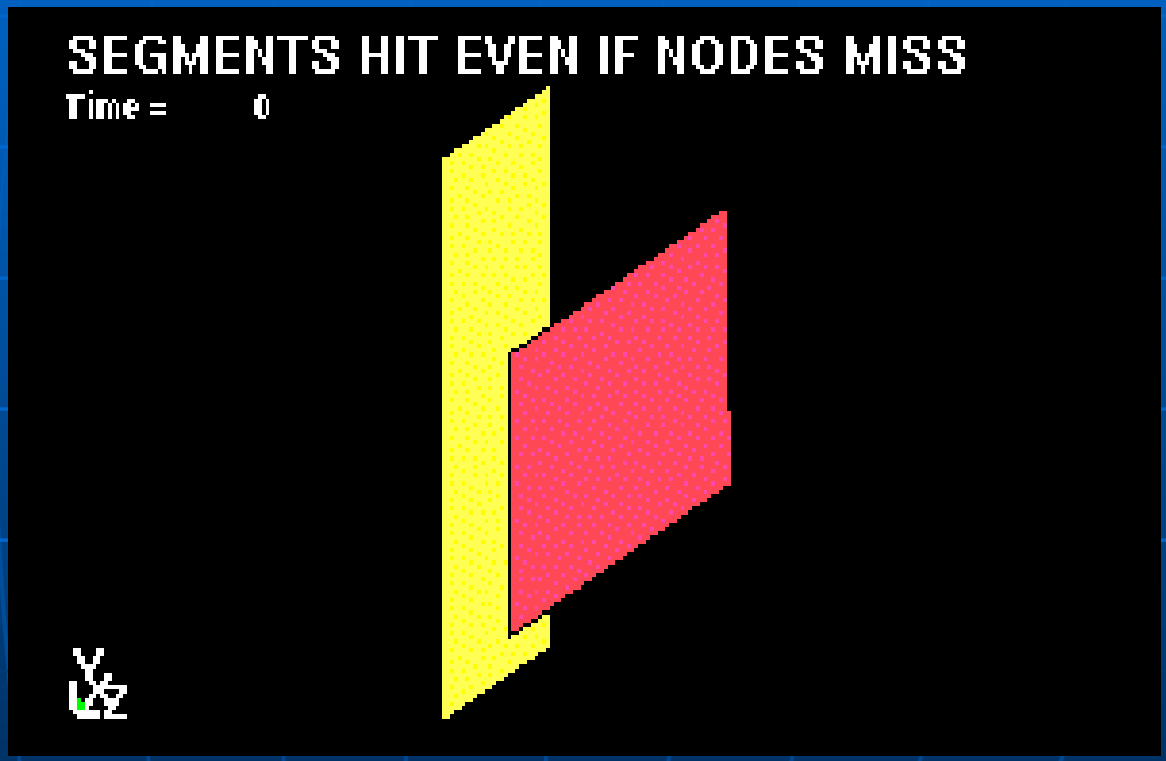
Segment-Based Contact
detects penetration of one segment into another segment and then applies penalty forces to the segment nodes.

***standard contact refers collectively to these 9 contact types: 3, a3, 10, a10, 4, 13, a13, 14, and 15 with soft=0 or soft=1.**

Segment-Based Contact (SOFT=2)

Segments hit even if nodes miss

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



Segment-based contact is a good option if geometry is angular, that is, has sharp corners or edges.

Segment-Based Contact (SOFT=2)

- **Segment-Based Contact is implemented for:**
  - Surface_to_surface (3)
  - Automatic_surface_to_surface (a3)
  - Single_surface (4)
  - One_way_surface_to_surface (10)
  - Automatic_one_way_to_surface (a10)
  - Automatic_single_surface (13)
  - Airbag_single_surface (a13)
  - Eroding_surface_to_surface (14)
  - Eroding_single_surface (15)

Segment-Based Contact (SOFT=2)

Initial penetrations are ignored

- Initially penetrated nodes are not moved at the start of the analysis.
- 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 node that penetrates undetected will not be shot out by a large penalty force when first detected.
  - So-call "shooting node logic" parameter SNLOG as no effect
- Similar treatment of initial penetrations to SOFT=0 or 1 with parameter IGNORE set to 1.

Segment-Based Contact (SOFT=2)

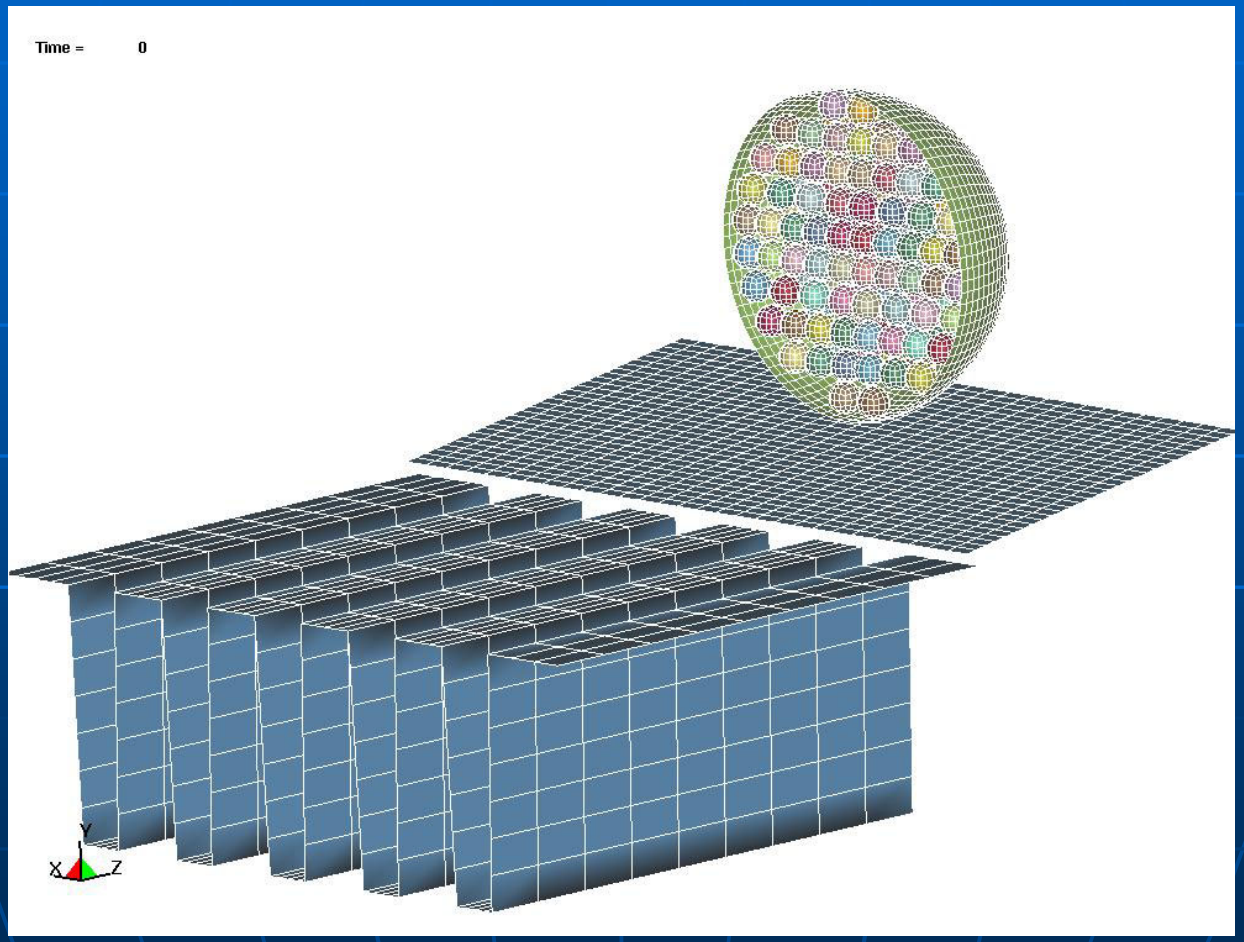
Additional Options for SOFT=2 Contact

- **SBOPT** on Opt. Card A
  - 2 (default): assumes planar segments
  - 3: takes into consideration segment warpage
  - 4: sliding option
  - 5: use options 3 and 4

- **DEPTH** on Opt. Card A
  - 2 (default): checks for surface penetrations
  - 3: same as 2 but depth of penetration is also checked at segment edges
  - 5: same as 2 but adds check for edge-to-edge penetration

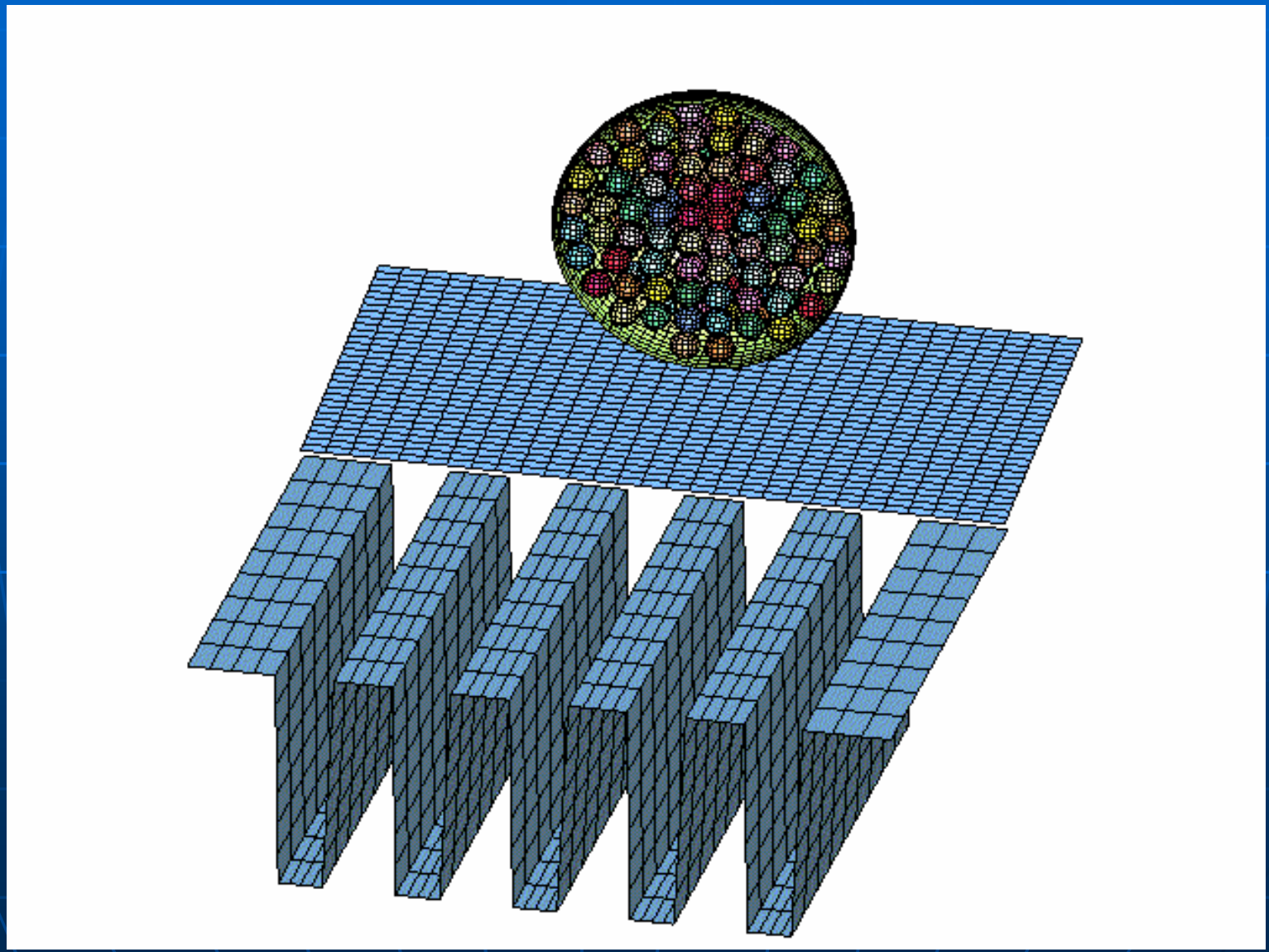
Segment-Based Contact (SOFT=2)

Falling Balls using Segment-Based Contact



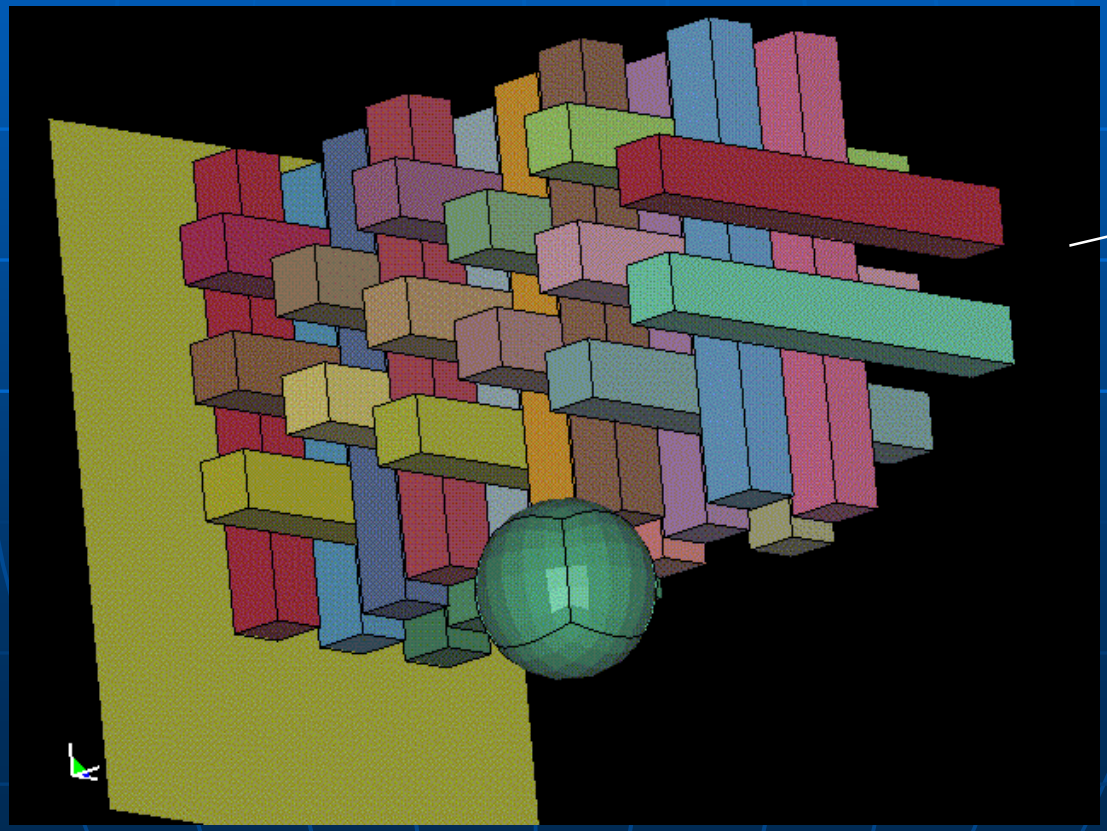
Segment-Based Contact (SOFT=2)

Falling Balls using Segment-Based Contact



Falling Blocks using Segment-Based Contact

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



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)
- Version 970 includes option for improved treatment for large shearing deformations (TYPE=2).

2D Contact

- ***CONTACT_2D_<option>**
  - Must be used to treat contact among axisymmetric and plane strain elements
    - Shell formulations 12-15
    - Beam formulations 7,8
  - CONTACT_2D_**AUTOMATIC**_... is generally preferred for explicit simulations
  - Non-automatic CONTACT_2D... is generally preferred for implicit simulations

Force Transducers

***CONTACT_FORCE_TRANSDUCER_option**

- Provides a convenient means of contact force retrieval at select locations
- Specify slave side only
- 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)

Viscous Contact Damping

- **Specified via VDC on Card 2 of *contact…**
- **Damps oscillations normal to the contact surfaces**
- **VDC = percentage of critical damping ($2m\omega$)**
  - Twenty percent damping = 20, not 0.20
  - $m = \min \{m_{slave}, m_{master}\}$
- **Natural frequency of interface is computed using:**
  - k = interface stiffness
- **Useful for smoothing out noisy contact forces, e.g., as sometimes seen when a part is sandwiched between two other parts**

Relevant Keyword Cards
Contact-Related Output

- ***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)
  - Binary output file
    - *DATABASE_BINARY_INTFOR - contact forces and stresses (can be used for fringe plotting)
      - set print flag(s) on card 1 of *contact_ SPR=1 and MPR=1
      - include s=filename on execution line
    - The binary file can be read by LS-PREPOST

Relevant Keyword Cards
*CONTROL_CONTACT

- Sets up default controls for all contacts
- Global contact penalty scale factor (Default=0.10) [SLSFAC]
  - Effect is cummulative with penalty scale factor specified on card 3 of *contact
- Scale factor for rigid-body-to-fixed-rigidwall interaction [RWPNAL]
- Consider shell thickness for non-automatic contacts [SHLTHK]
- Consider shell thickness changes for single surface [THKCHG]
  - Must also set flag in *control_shell so that membrane straining produces change in shell thickness
- Penalty stiffness calculation method when SOFT=0 [PENOPT]
- Automatically check/reorient contact segment normals [ORIEN]

Relevant Keyword Cards
*CONTROL_CONTACT

- Contact treatment of nodes freed due to element deletion [ENMASS]
- Bucket sorting frequency in no. of timesteps [NSBCS]
- Disable consideration of shell edge length for contact thickness [SSTHK]
- Disable control of timestep by eroding contact [ECDT]
- IGNORE parameter for treatment of 'initial' penetrations [IGNORE]

Practical 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
    - Perturbs geometry. May initiate buckling.
    - No guarantee that all initial penetrations will be removed using this approach
  - By setting IGNORE=1 (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.

Practical 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 (v. 970)
- **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.

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 (exclude beams)
  - 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 generally reliable for simple geometries where contact orientation can be established reliably from the outset
  - Shell thickness consideration is not mandatory
  - Correct contact orientation is critical (check)
  - Preferred for implicit simulations

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 disparate meshes or materials
  - Modify penalty scale factor on Card 3 of *contact
  - Set SOFT=1 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)

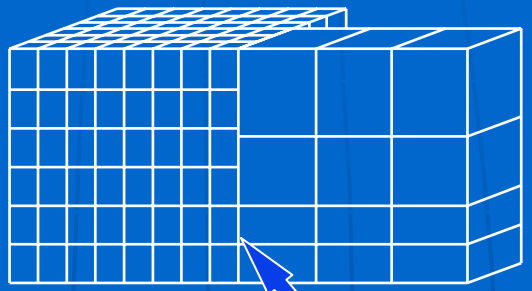
Practical Guidelines

General Tips

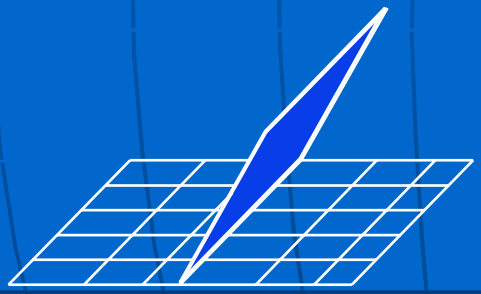
- Set IGNORE=1 if d3hsp reports lots of small initial penetrations
  - Crossed shell midplanes never OK
- Default bucket sorting interval is generally OK. For the most contacts the sort is performed every 100 cycles. This can be changed using *contact or *control_contact. High velocity impacts may see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

Tied Contact Applications

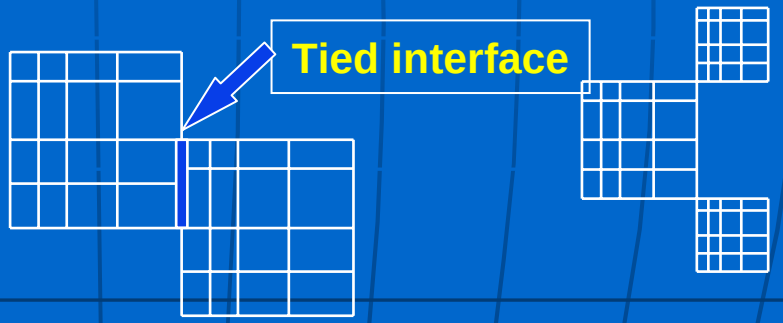
Spotweld to shell surface



Tied interface permits mesh transition



Shell edge to surface



Tied Contacts

- **Good for tying parts with disparate meshes**
- **Criteria for tying**
  - The slave node lies within the orthogonal projection of a master segment, and…
  - the projected distance is within a tolerance
    - Tolerance can be set with negative value of contact thickness
- **Most tied contacts impose kinematic constraints**
  - Constraint-based tied contacts are not for rigid bodies
- **OFFSET or TIEBREAK options invoke penalty-based treatment**
  - OK for rigid bodies

Tied Contacts with Failure

- Orientation is important to distinguish tension from compression
- TIEBREAK_NODES_TO_SURFACE
  - 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
- AUTOMATIC_…_TIEBREAK
  - Special options, e.g., tying parts AFTER they come into contact
  - After failure, reverts to automatic contact

Practical Guidelines
Tied Contact

- Specify the contact using segment sets
- Side with finer mesh should be slave side
- Use tied_shell_edge_to_surface… types when tying shells or spotweld beams
  - Includes tying of 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, **not** tied_nodes_to_surface or tied_surface_to_surface

Tying Parts

- ***CONSTRAINED_<option> offers alternative to tied contacts in tying nodes to other nodes or surfaces**
  - spotweld
  - generalized_weld…
  - nodal_rigid_body
  - extra_nodes
  - tie-break (for edge-to-edge tying of shells with failure)
  - tied_nodes_failure