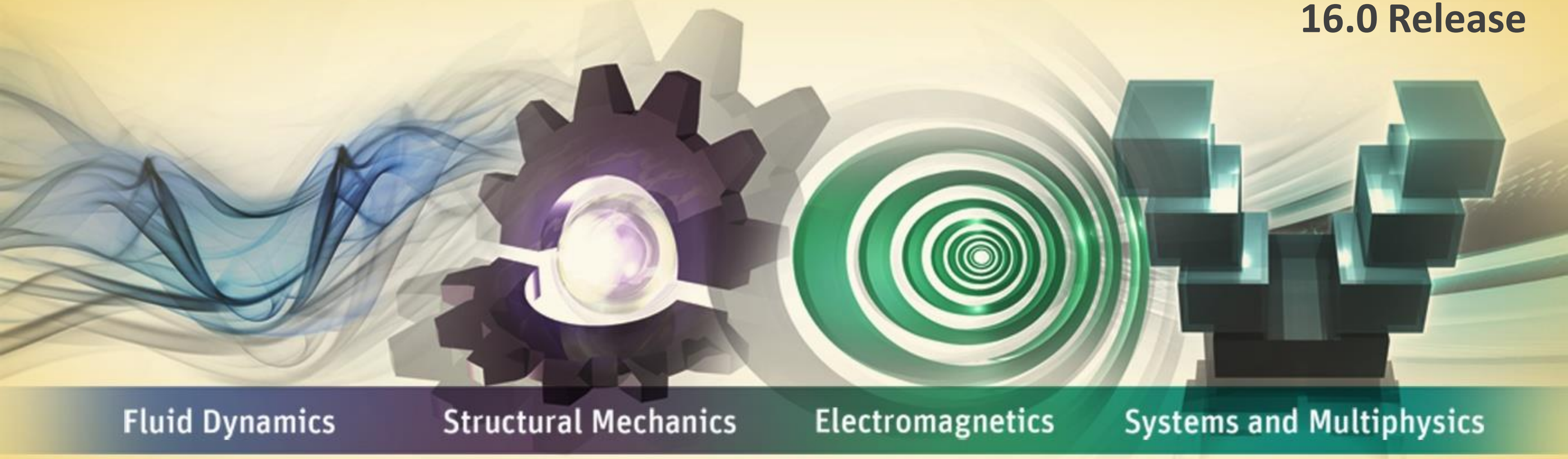
Realize Your Product Promise™

Lecture 3: Introduction to Contact

16.0 Release



ANSYS Mechanical

Introduction to Structural Nonlinearities

Chapter Overview

An introduction to *solid body contact* will be presented in this Lecture:

- **It is assumed that the user has already covered lecture 2 on *General Procedures.***

The Specific topics introduced are:

A. **Basic concept of contact**
B. **Contact Formulations**
C. **Detection Methods**
D. **Trim Contact**
E. **Penetration and Slip Tolerances**
F. **Contact Stiffness**
G. **Workshop 3A**
H. **Pinball Region**
I. **Symmetric vs. Asymmetric**
J. **Body Types in Contact**
K. **Postprocessing Contact Results**
L. **Workshop 3B**

A. Basic Concepts

Contact:

- **When two separate surfaces touch each other such that they become mutually tangent, they are said to be in *contact.***
- **In the common physical sense, surfaces that are in contact have these characteristics:**
- **They do not interpenetrate.**
- **They can transmit compressive normal forces and tangential friction forces.**
- **They often do not transmit tensile normal forces.**
  - **Surfaces are free to separate and move away from each other.**
- **Contact is a *changing-status* nonlinearity. That is, the stiffness of the system depends on the contact status, whether parts are touching or separated.**

... Basic Concepts

Basic Types of contact behaviors available*:

Bonded: No penetration, no separation and no sliding between faces or edges.

No Separation: Similar to bonded, except frictionless sliding can occur along contacting faces.

Frictionless: No penetration allowed, but surfaces are free to slide and separate without resistance.

Rough: Similar to the frictionless setting except no sliding allowed.

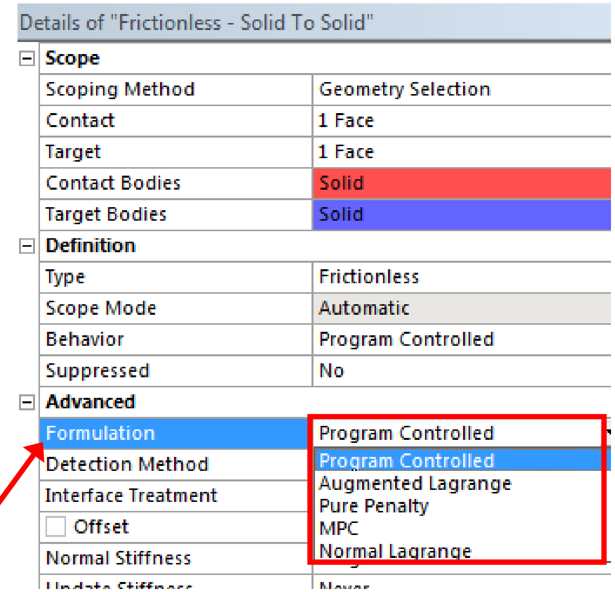
Frictional: Allows sliding with resistance proportional to user defined coefficient of friction, with freedom to separate without resistance.

The implementation of these behaviors will be presented in detail in following slides of this lecture and the next.

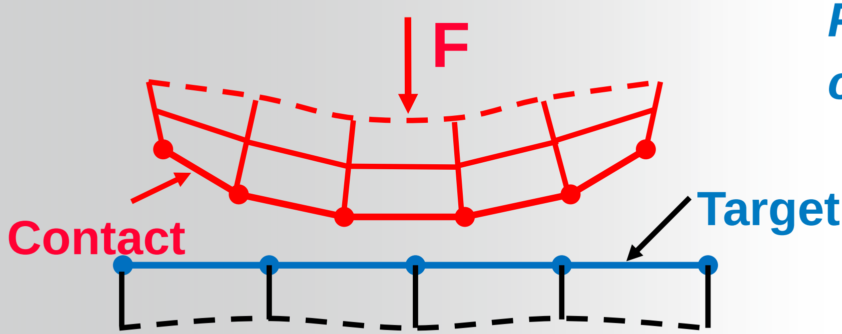
* More advanced behaviors are available thru MAPDL commands. Refer to Chapter 3 of Advanced Connections Course for details.

... Basic Concepts

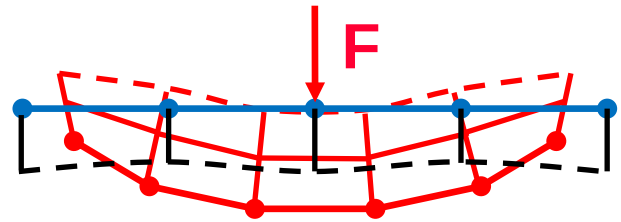
<u>How compatibility is enforced in a contact region:</u>



- **Physical contacting bodies do not interpenetrate. Therefore, the program must establish a relationship between the two surfaces to prevent them from passing through each other in the analysis.**
- **When the program prevents interpenetration, we say that it *enforces contact compatibility.***
- ***Mechanical* offers several different *contact formulations* to enforce compatibility at the contact interface.**



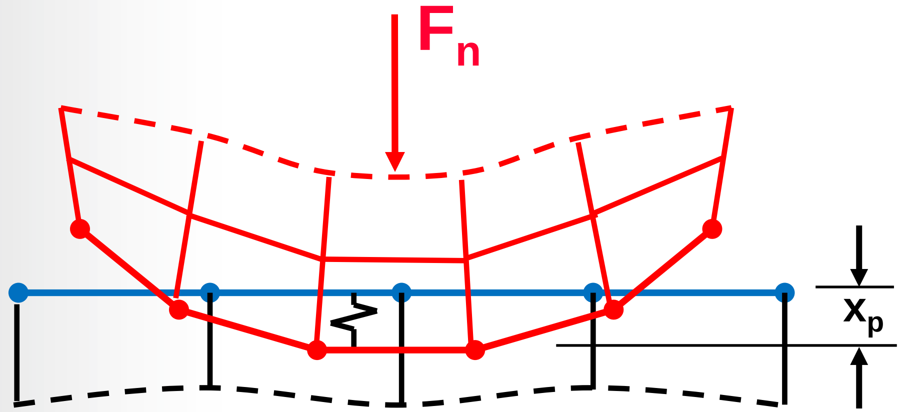
Penetration occurs when contact compatibility is not enforced.



B. Contact Formulations

- ***Pure Penalty:***

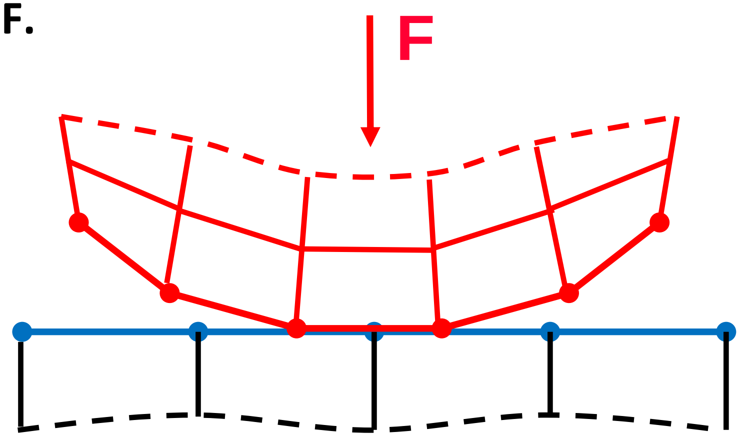
$$F_{normal} = k_{normal} x_{penetration}$$



  - Here, for a finite contact force F_{normal}, there is a concept of contact stiffness k_{normal}. The higher the contact stiffness, the lower the penetration $x_{penetration}$, as shown in the figure.
  - Ideally, for an infinite k_{normal}, one would get zero penetration. This is not numerically possible with penalty-based methods, but as long as $x_{penetration}$ is small or negligible, the solution results will be accurate.

… Contact Formulations

- ***Normal Lagrange:***
  - Adds an extra degree of freedom (contact pressure) to satisfy contact compatibility. Consequently, instead of resolving contact force as contact stiffness and penetration, contact force (contact pressure) is solved for explicitly as an extra DOF.



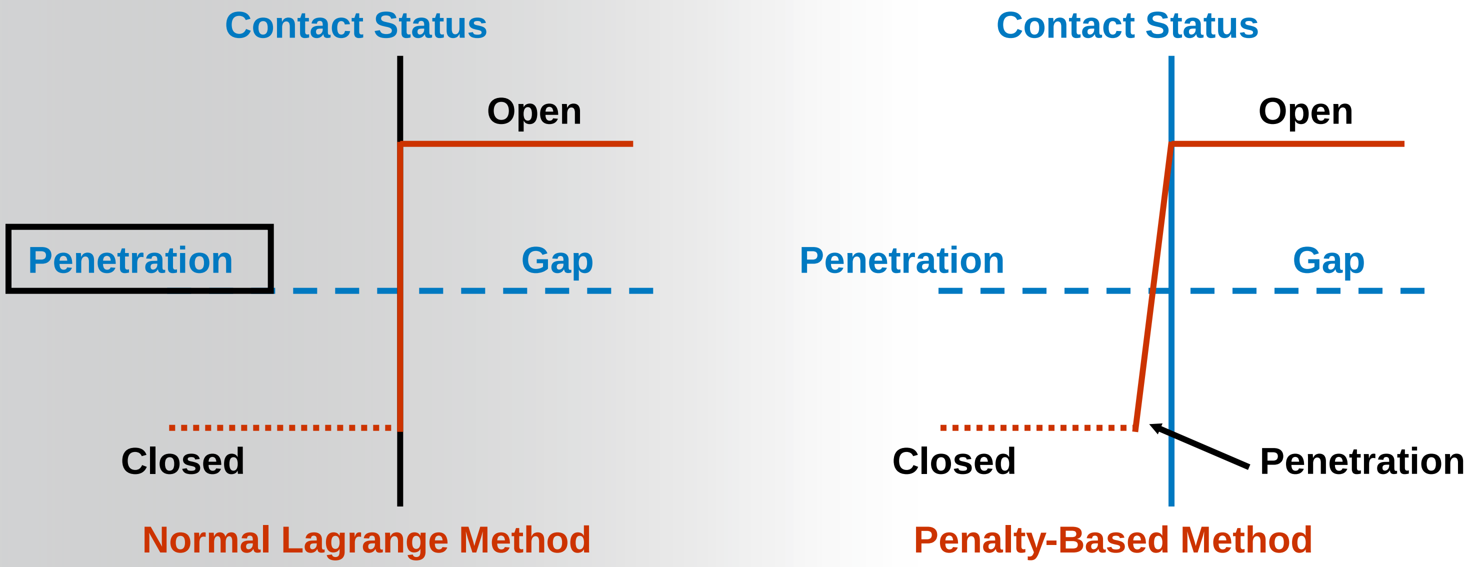
$$F_{normal} = DOF$$

  - Enforces zero/nearly-zero penetration with pressure DOF
  - Does *not* require a normal contact stiffness (zero elastic slip)
  - Requires Direct Solver, which can be more computationally expensive
  - Only applies to forces in directions Normal to contact surface

... Contact Formulations

Chattering is an issue which often occurs with Normal Lagrange method

- If no penetration is allowed (left), then the contact status is either open or closed (a step function). This can sometimes make convergence more difficult because contact points may oscillate between open/closed status. This is called *chattering*
- If some slight penetration is allowed (right), it can make it easier to converge since contact is no longer a step change.



... Contact Formulations

- ***Augmented Lagrange:*** **A penalty based method that "augments" the pure penalty calculation with a extra Lagrangian term:**

Augmented Lagrange:

$$F_{normal} = k_{normal} x_{penetration} + \lambda$$

- **Because of the extra term λ, the augmented Lagrange method is less sensitive to the magnitude of the contact stiffness k_{normal}.**
- **Augmented Lagrange is the default formulation used for *Program Controlled* option**

... Contact Formulations

The aforementioned options relate contact in the *normal* direction. If friction or rough/bonded contact is defined, a similar situation exists in the *tangential* direction.

- **Similar to the *impenetrability condition*, in the tangential direction, the two bodies should not slide relative to each other if they are "sticking"**
- **Pure penalty formulation is always used in the tangential direction**
- **Tangential contact stiffness and sliding distance are the analogous parameters:**

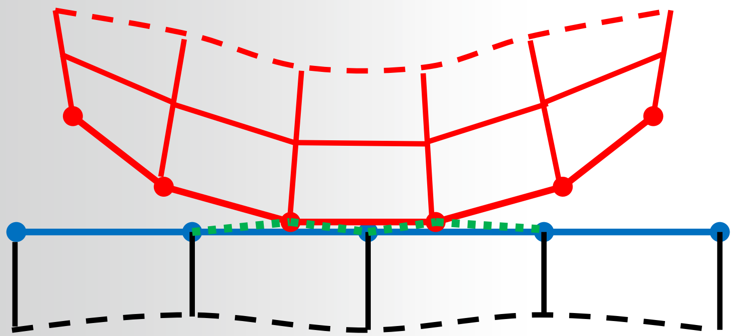
If "sticking": $$F_{tangential} = k_{tangential} x_{sliding}$$

where $x_{sliding}$ ideally is zero for sticking, although some slip is allowed in the penalty-based method.

- **Unlike the Normal Contact Stiffness, the Tangential Contact Stiffness cannot directly be changed by the user.**
- **A more detailed discussion of Frictional contact is presented in the Advanced Contact Course**

... Contact Formulations

- ***Multi-Point Contraint (MPC) Formulation***:
  - Internally adds constraint equations to “tie” the displacements between contacting surfaces

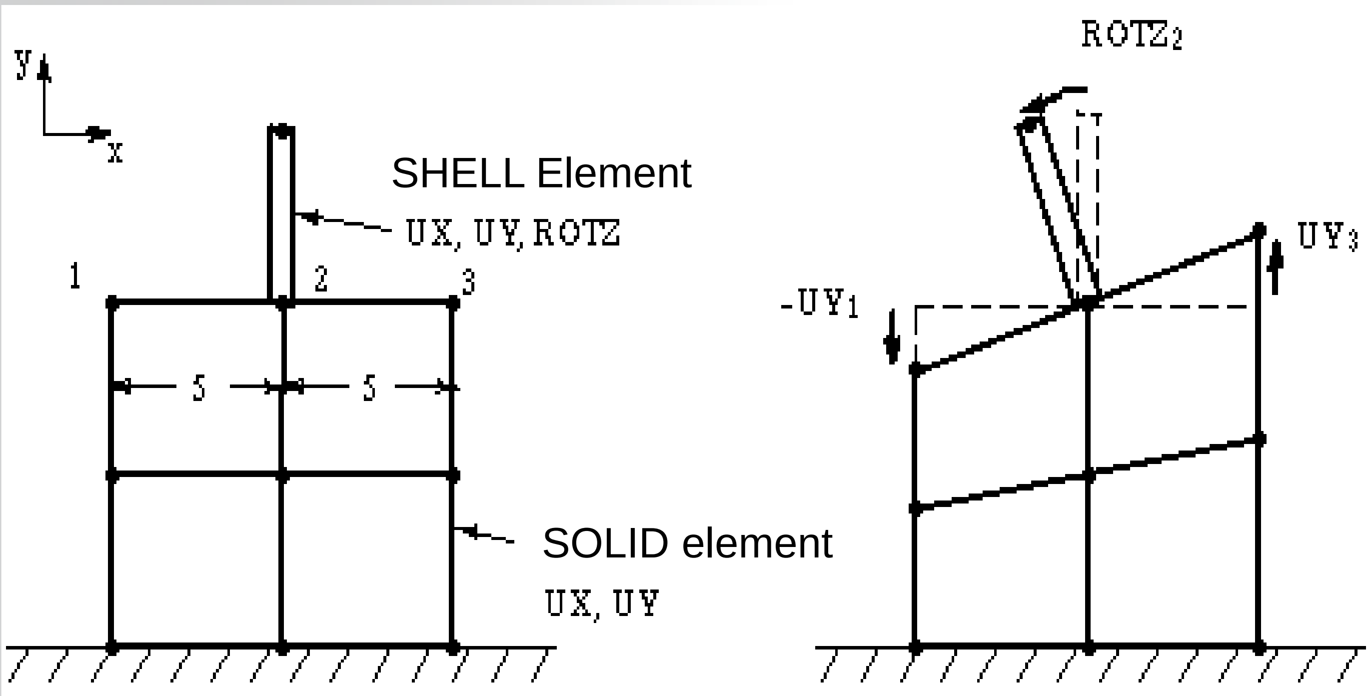


  - This approach is not penalty-based or Lagrange multiplier-based. It is a direct, efficient way of relating surfaces of contact regions which are bonded.
  - Large-deformation effects also are supported with MPC-based bonded contact
  - Applies specifically to “Bonded” and “No Separation” Types of contact

... Contact Formulations

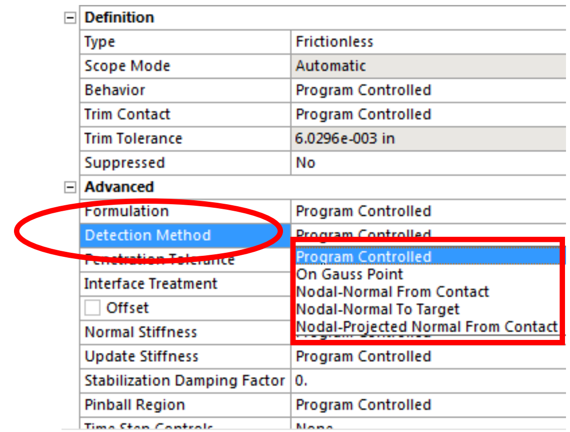
- To illustrate MPC, consider the connection between a shell edge and a solid face. The constraint equation that would transfer action between ROTZ at node 2 and UY at nodes 1 and 3 has this form:

$$0 = UY_3 - UY_1 - 10*ROTZ_2$$

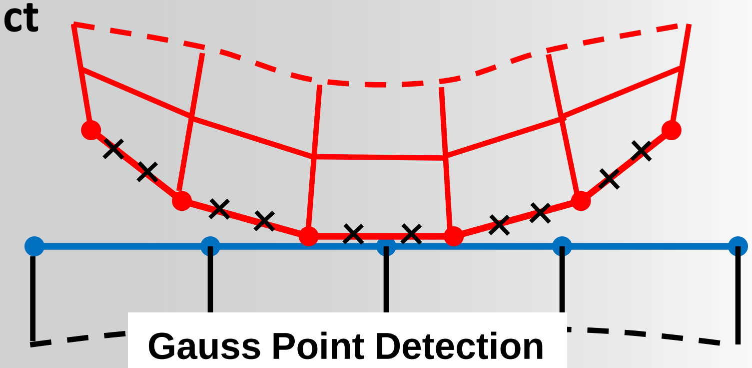


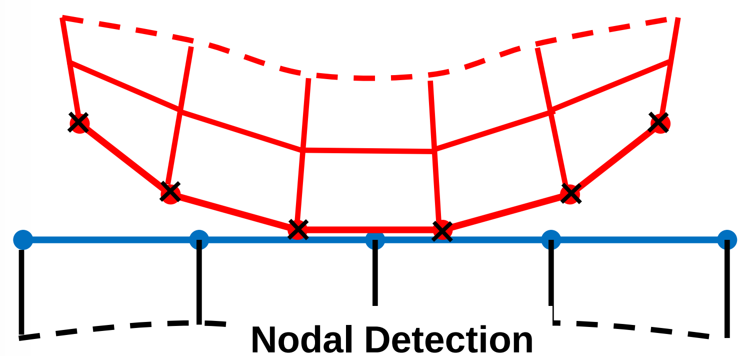
C. Detection Method

Detection Method allows you to choose the location of contact detection used in the analysis in order to obtain a good convergence.



- **Pure Penalty and Augmented Lagrange Formulations use *Gauss point detection* by default. This results in more detection points (10 in this example on left) and is generally considered more accurate than nodal detection.**
- **Normal Lagrange and MPC Formulation use *Nodal- Normal to Target* by default. This results in fewer detection points (6 in the example on right)**
- **Options are applicable to 3D face-face and 2D edge-edge contact**

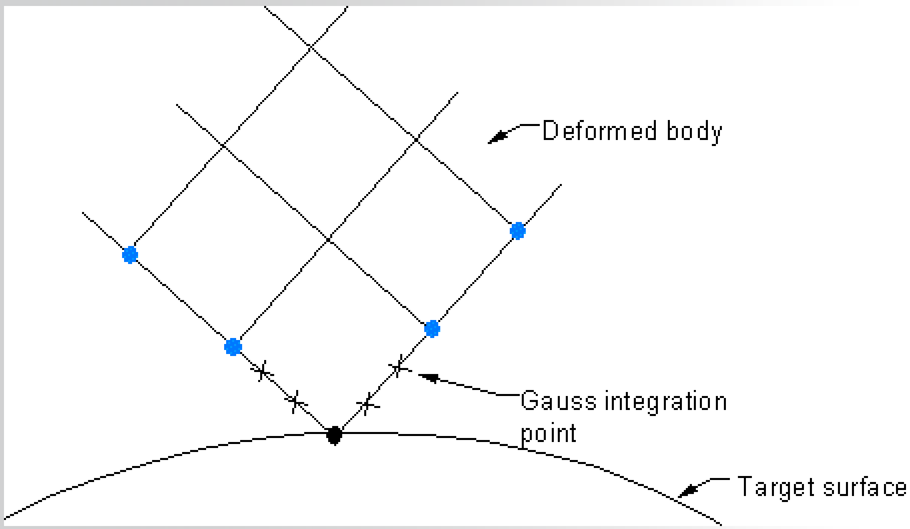


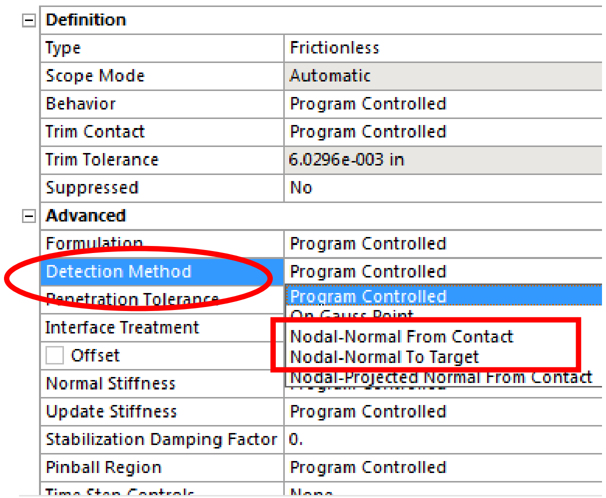


... Detection Method

It is sometimes necessary to force a *Nodal* detection method:

- **Should only be used for corner or edge contact**



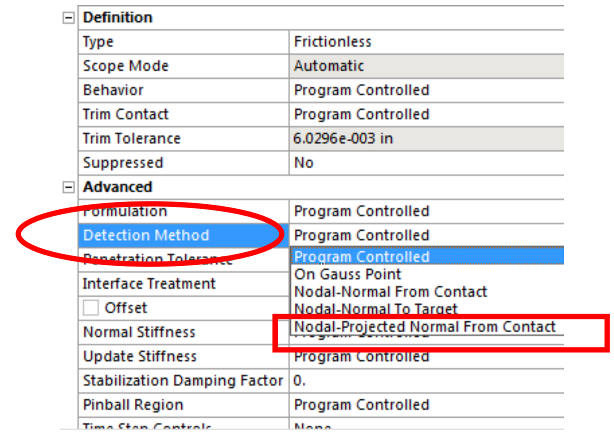


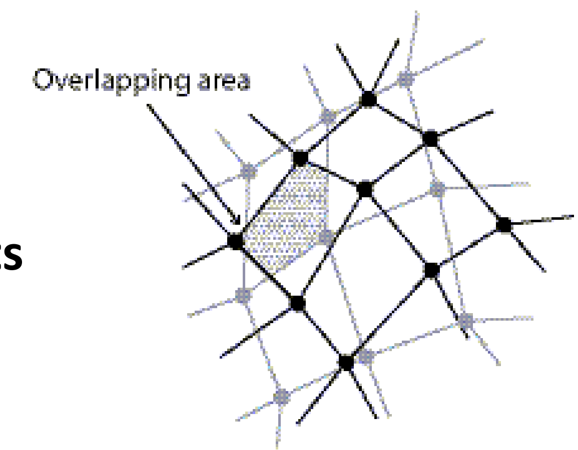
- ***Normal from Contact* or *Normal to Target* dictates the direction of forces to be applied at the interface. This usually requires extra calculations to determine correct "Normal" direction. Hence, gauss detection is preferred whenever possible.**

... Detection Method

Nodal-Projection Normal from Contact:

- **Enforces a contact constraint on an overlapping region of the contact and target surfaces. The contact penetration/gap is computed over the overlapping region in an average sense.**
- **It provides more accurate contact tractions and stresses of underlying elements compared with other settings.**
- **Results are less sensitive to the designation of the contact and target surface.**
- **It satisfies moment equilibrium when an offset exists between contact and target surfaces with friction.**
- **Calculated Contact force distribution has smoother variation across multiple target elements.**

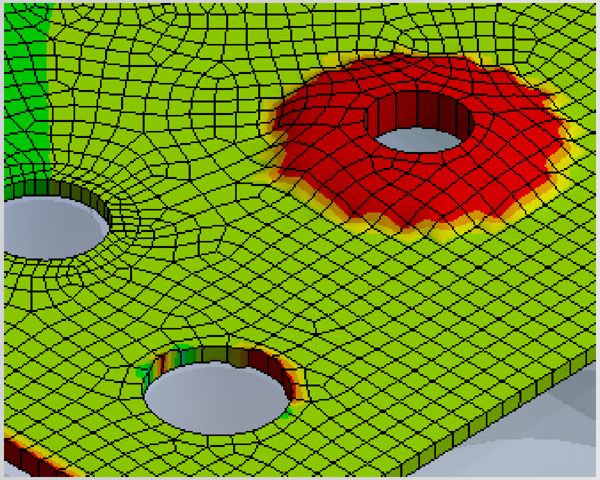




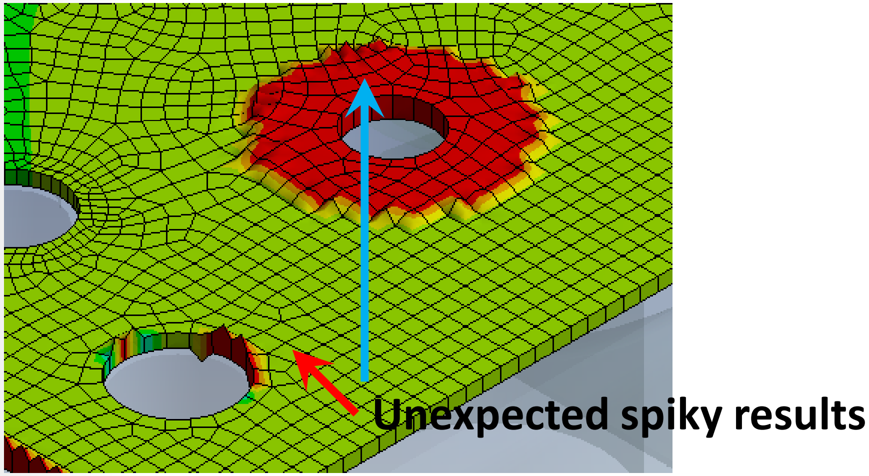
Contact Detection Methods: Notes

Nodal – Projected Normal From Contact

- Always use Projection method for contact involving gasket layers so that stress and strain distribution near contacting edges is more smooth
- Avoid use the projected contact in conjunction with MPC bonded contact. It causes increased bandwidth for the global equation set and leads to poor performance.
- For 3D higher order elements, use Normal Lagrange in conjunction with projection based option for the best accuracy.



Using Projected contact



Using Gauss detection

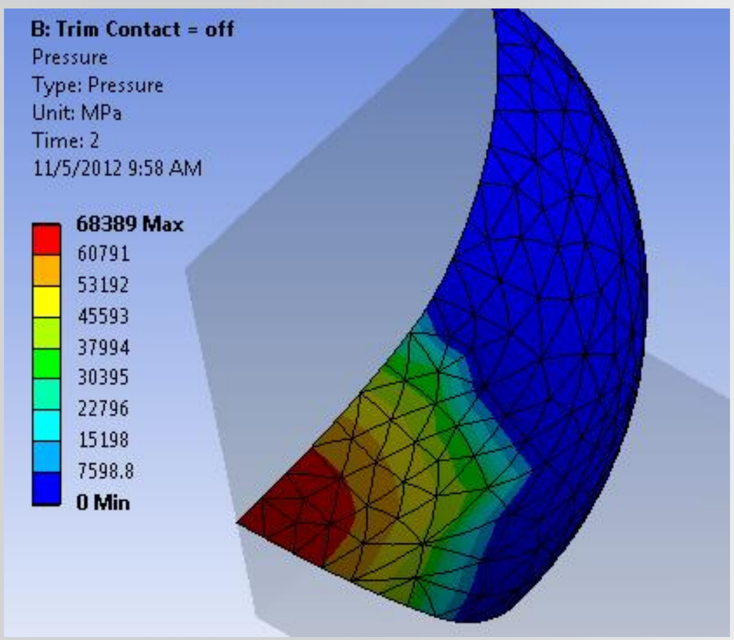
D. Trim Contact

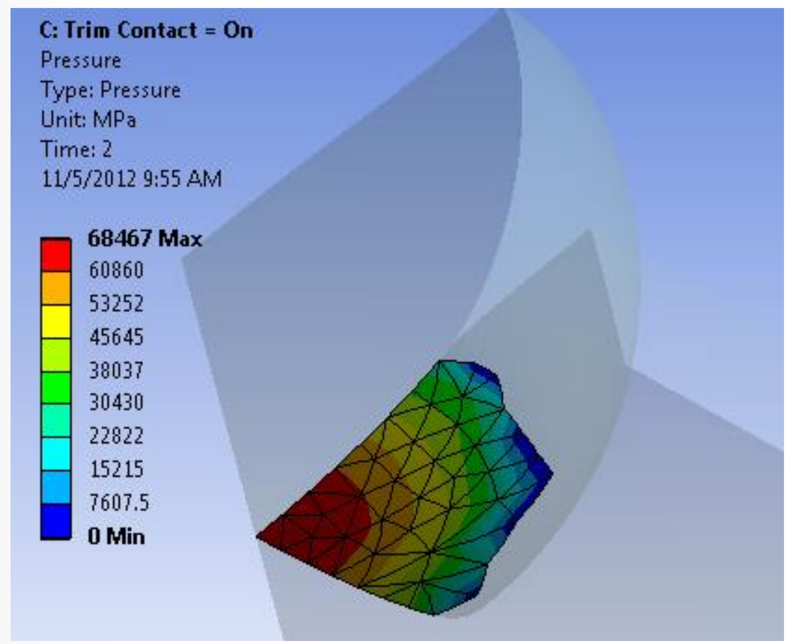
“Trim Contact” automatically reduces the number of contact elements generated within each pair, thereby speeding up processer time.

Definition	
Type	Frictionless
Scope Mode	Automatic
Behavior	Program Controlled
Trim Contact	Program Controlled
Trim Tolerance	6.0296e-003 in
Suppressed	No

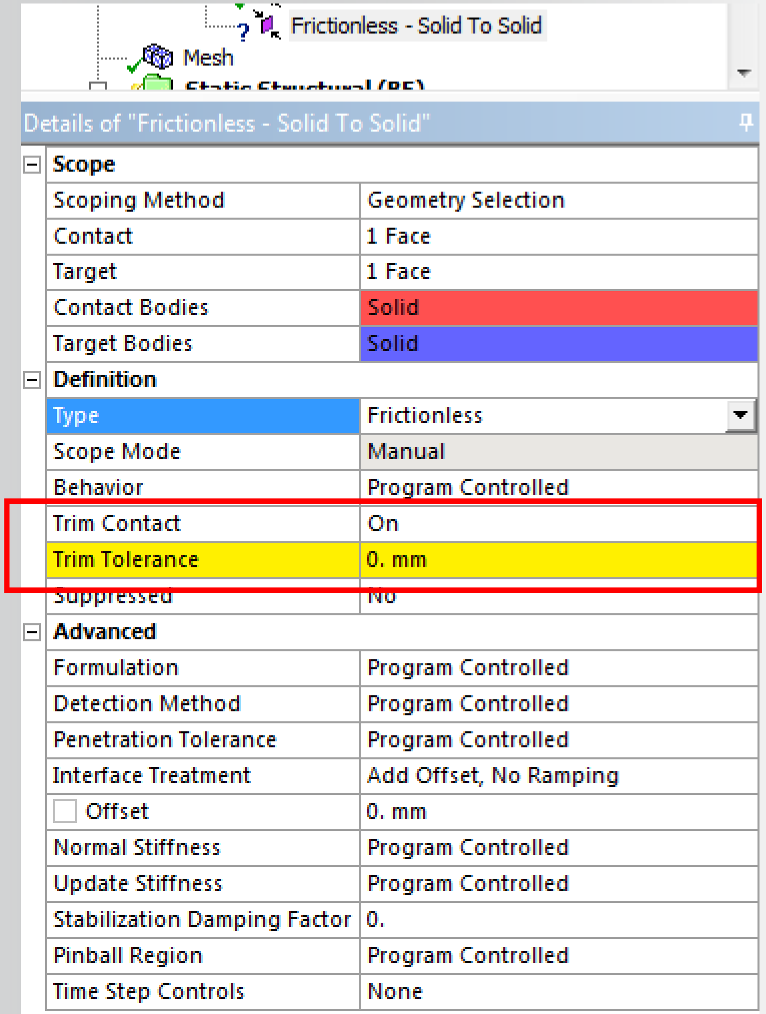
“Program Controlled” will typically turn Trim Contact ON. However, no trimming is done for manually created pairs.

Consider turning Trim Contact off for large deflection sliding





... Trim Contact



Frictionless - Solid To Solid

Mesh

Details of "Frictionless - Solid To Solid"

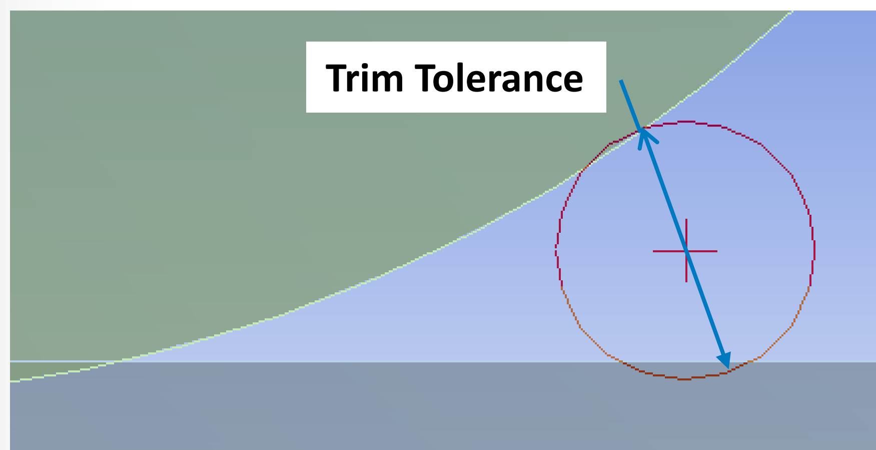
Scope	
Scoping Method	Geometry Selection
Contact	1 Face
Target	1 Face
Contact Bodies	Solid
Target Bodies	Solid
Definition	
Type	Frictionless
Scope Mode	Manual
Behavior	Program Controlled
Trim Contact	On
Trim Tolerance	0. mm
Suppressed	No
Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Penetration Tolerance	Program Controlled
Interface Treatment	Add Offset, No Ramping
Offset	0. mm
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Stabilization Damping Factor	0.
Pinball Region	Program Controlled
Time Step Controls	None

Trim Tolerance:

Defines the upper bounding box dimension used for the trimming operation.

For automatic contacts, this property displays the value that was used for contact detection and it is a read-only field.

For manual contacts, user can enter any value greater than zero.



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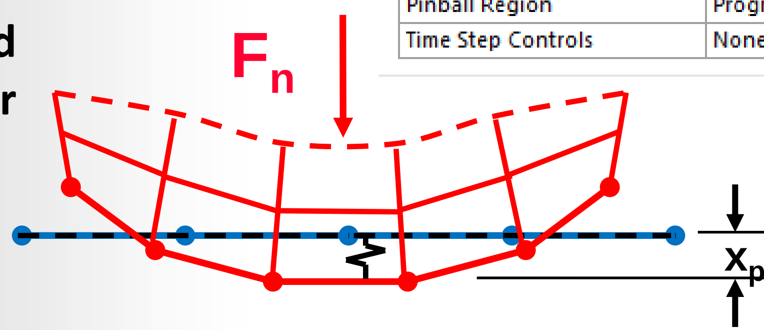
E. Penetration and Slip Tolerances

Penetration Tolerance:

- **Contact compatibility is satisfied in normal direction if normal penetration (Xp) is within allowable tolerance (TOLN)**
  - **Can be defined as a *Factor* (of underlying element depth) or as a *Value.***
  - **Default =0.1*element depth (surf-surf)**
  - **Only applies to Penalty based formulations (Pure Penalty or Augmented Lagrange)**

Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Penetration Tolerance	Program Controlled
Elastic Slip Tolerance	Program Controlled
Interface Treatment	Add Offset, No Ramping
Offset	0. mm
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Stabilization Damping Factor	0.
Pinball Region	Program Controlled
Time Step Controls	None



Pure Penalty: $F_{normal} = k_{normal} x_{penetration}$

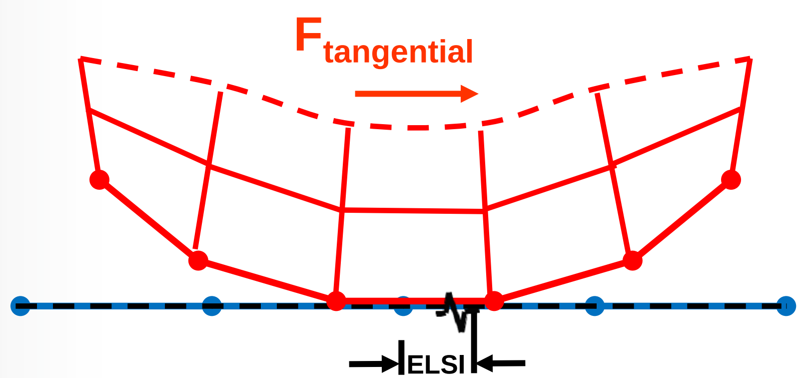
Augmented Lagrange: $F_{normal} = k_{normal} x_{penetration} + \lambda$

... Penetration and Slip Tolerances

Elastic Slip Tolerance:

- **Contact compatibility is satisfied in tangential direction if Elastic Slip (ELSI) is within allowable tolerance (SLTO).**
  - **Defined as a Factor of average underlying element length or as a value**
  - **Applies to bonded, rough and frictional contact behaviors to enforce compatibility in tangential direction.**
  - **Only exposed when applicable.**
  - **Default SLTO=1% of average element length**

Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Penetration Tolerance	Program Controlled
Elastic Slip Tolerance	Program Controlled
Interface Treatment	Add Offset, No Ramping
Offset	0. mm
Normal Stiffness	Program Controlled
Update Stiffness	Program Controlled
Stabilization Damping Factor	0.
Pinball Region	Program Controlled
Time Step Controls	None



$$F_{tangential} = k_{tangential} ELSI$$

F. Contact Stiffness

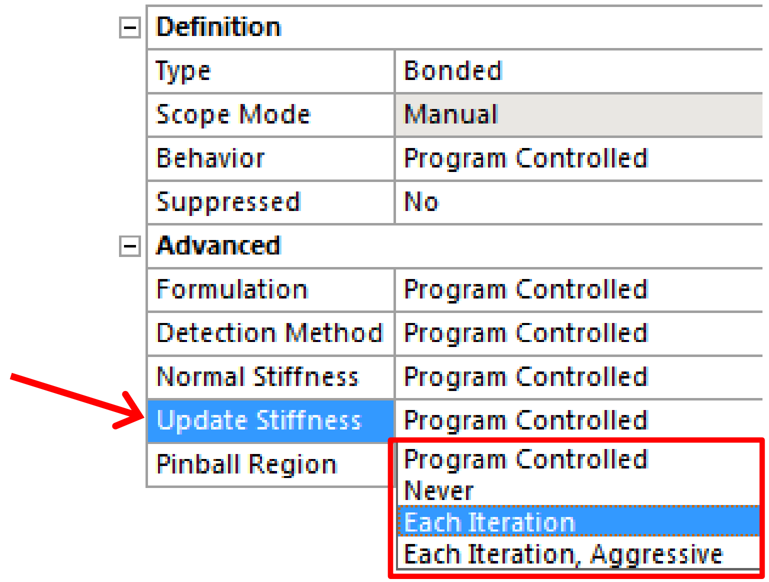
- *Normal Stiffness* is actually a multiplier or factor (FKN) on the code calculated stiffness explained earlier.
  - FKN=10 by default for bonded and no-separation behaviors
  - FKN=1.0 by default for all other behaviors
  - For bending-dominated situations, if convergence difficulties are encountered, a smaller value (FKN =0.01 - 0.1) may be helpful.
  - Only applies to Penalty based formulations (Pure Penalty or Augmented Lagrange)

Advanced	
Formulation	Program Controlled
Detection Method	Program Controlled
Penetration Tolerance	Program Controlled
Interface Treatment	Add Offset, No Ramping
Offset	0. in
Normal Stiffness	Manual
Normal Stiffness Factor	1.
Update Stiffness	Program Controlled
Stabilization Damping Factor	0.
Pinball Region	Program Controlled
Time Step Controls	None

... Contact Stiffness

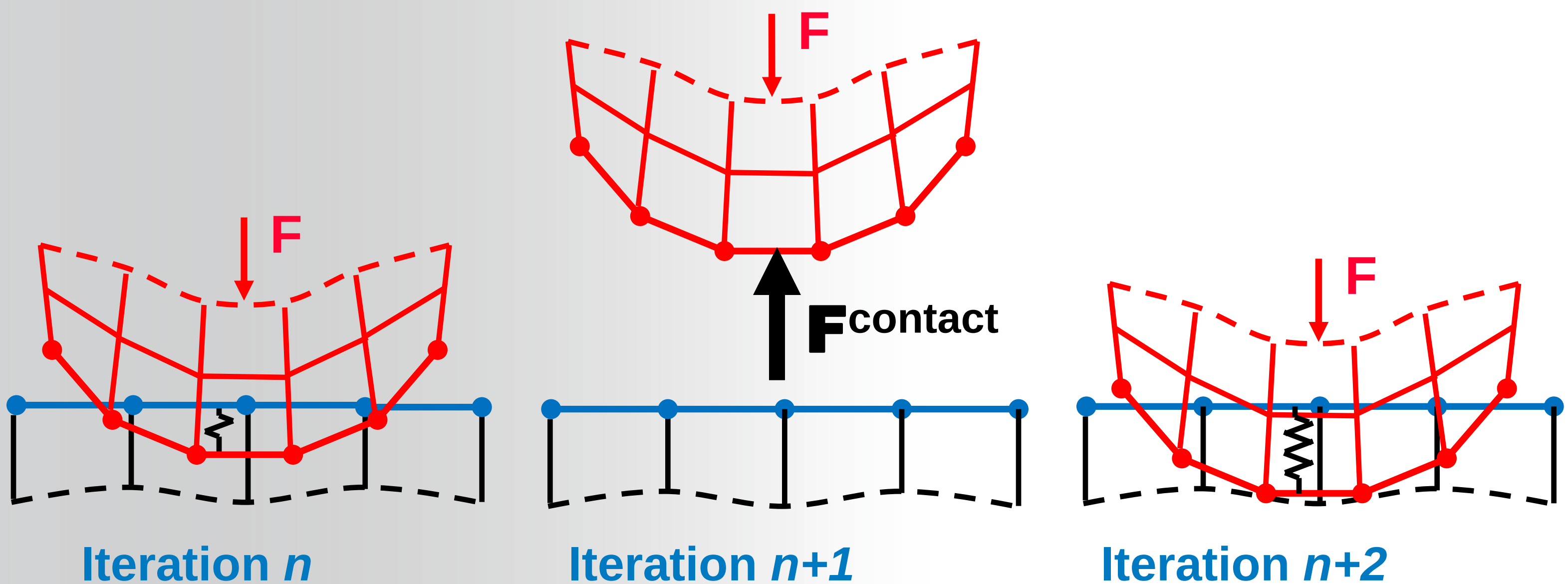
The normal stiffness can also be automatically adjusted during the solution to enhance convergence. If difficulties arise, the stiffness will be reduced automatically.

- **By default, *Update Stiffness* will occur at the end of each equilibrium iteration.**
- **The *"Each Iteration, Aggressive"* option allows for a broader range of adjustment.**



… Contact Stiffness

- The *Normal Contact Stiffness* k_{normal} is the most important parameter affecting both accuracy and convergence behavior.
  – A large value of stiffness gives better accuracy, but the problem may become more difficult to convergence.
  – If the contact stiffness is too large, the model may oscillate, with contacting surfaces bouncing off of each other



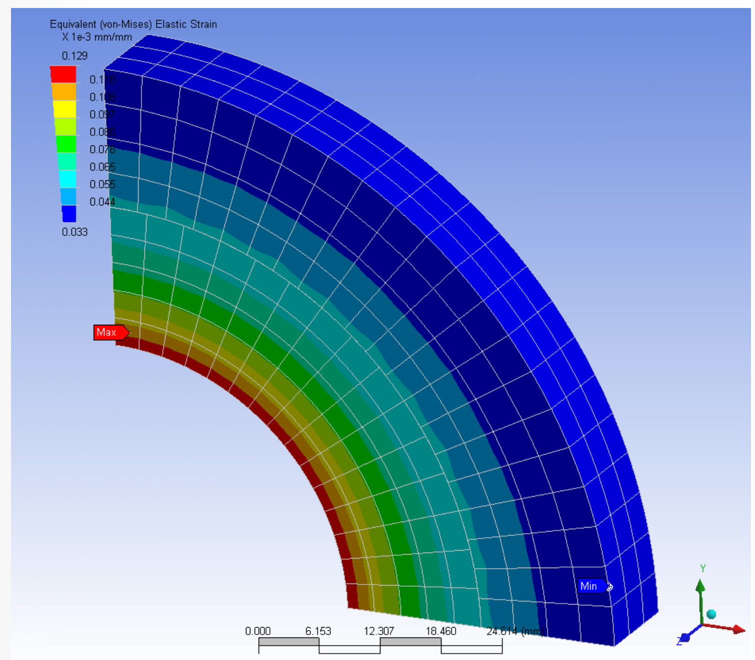
... Contact Stiffness

Example showing effect of contact stiffness:

Formulation	Normal Stiffness	*Max Deform		*Max Eqv Stress		*Max Contact Pressure		Max Penetration	Iterations
Augmented Lagrage	0.01	2.84E-03	1%	26.102	1%	0.979	36%	2.70E-04	2
Augmented Lagrage	0.1	2.80E-03	0%	25.802	0%	1.228	20%	3.38E-05	2
Augmented Lagrage	1	2.80E-03	0%	25.679	0%	1.568	2%	4.32E-06	3
Augmented Lagrage	10	2.80E-03	0%	25.765	0%	1.599	4%	4.41E-07	4
Normal Lagrange	-	2.80E-03	0%	25.768	0%	1.535	0%	3.17E-10	2

*Tabulated % differences are with respect to the Normal Lagrange result

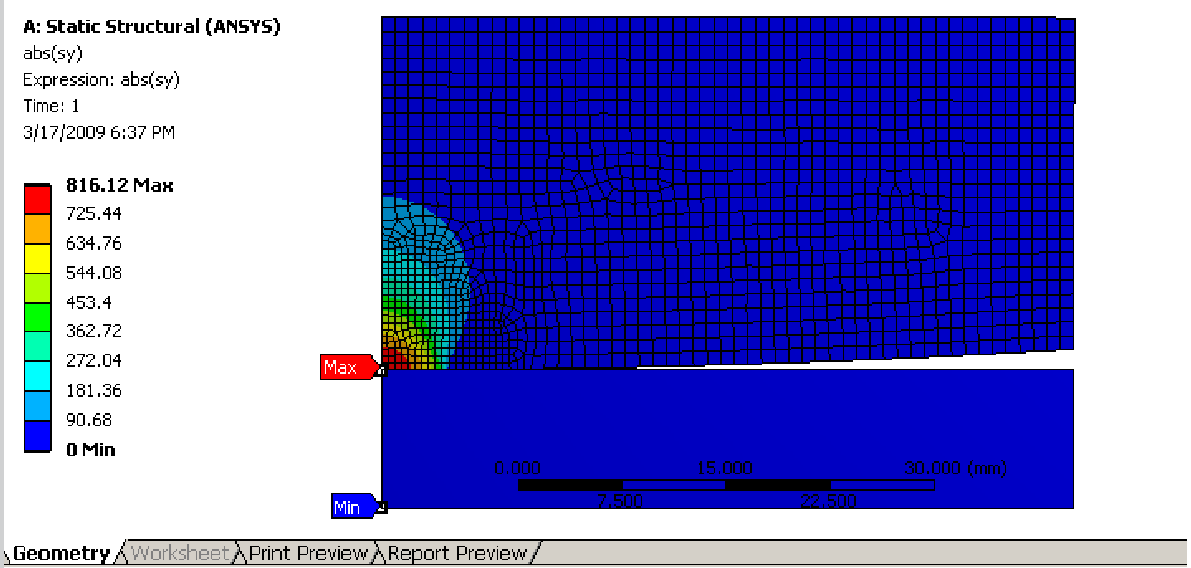
As is apparent from the above table, the lower the contact stiffness factor, the higher the penetration. However, it also often makes the solution faster/easier to converge (fewer iterations)

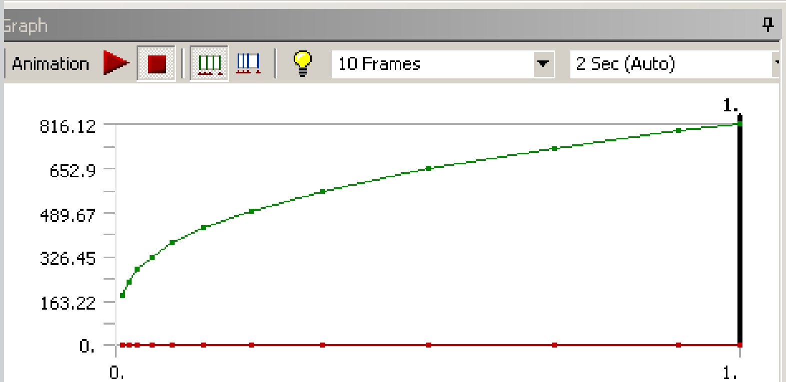


G. Workshop – Contact Stiffness & Penetration

Please refer to your *Workshop Supplement* for instructions on:

Workshop 3A-Contact Stiffness Study



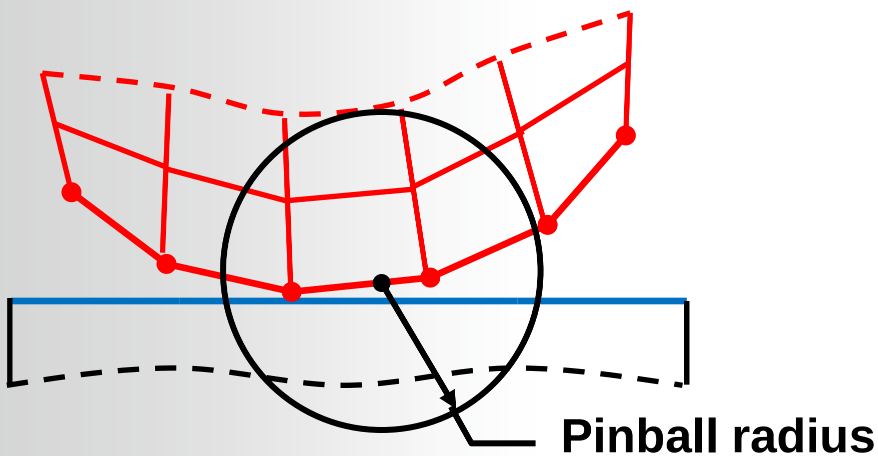


Tabular Data

	Time [s]	Minimum	Maximum
1	1.e-002	0.	180.97
2	2.e-002	0.	233.1
3	3.5e-002	0.	278.16
4	5.75e-002	0.	322.87
5	9.125e-002	0.	376.97
6	0.14188	0.	430.17
7	0.21781	0.	495.2
8	0.33172	0.	568.54
9	0.50258	0.	651.82
10	0.70258	0.	727.38
11	0.90258	0.	791.45
12	1.	0.	816.12

H. Pinball Region

- **The Pinball Region is a contact element parameter that differentiates between far field open and near field open status. It can be thought of as a spherical boundary surrounding each *contact detection point***
  - **If a detection point is close to the target surface within this sphere, *Mechanical* considers it to be in a"near" open condition and will record and track the gap more closely (i.e., when and whether contact is established). Gaps for detection point away from the target a distance larger than this sphere outside of this sphere will not be recorded or monitored.**
  - **If Bonded Behavior is specified within a gap smaller than the Pinball Radius, *Mechanical* will still treat that region as bonded, but ignore the gap.**



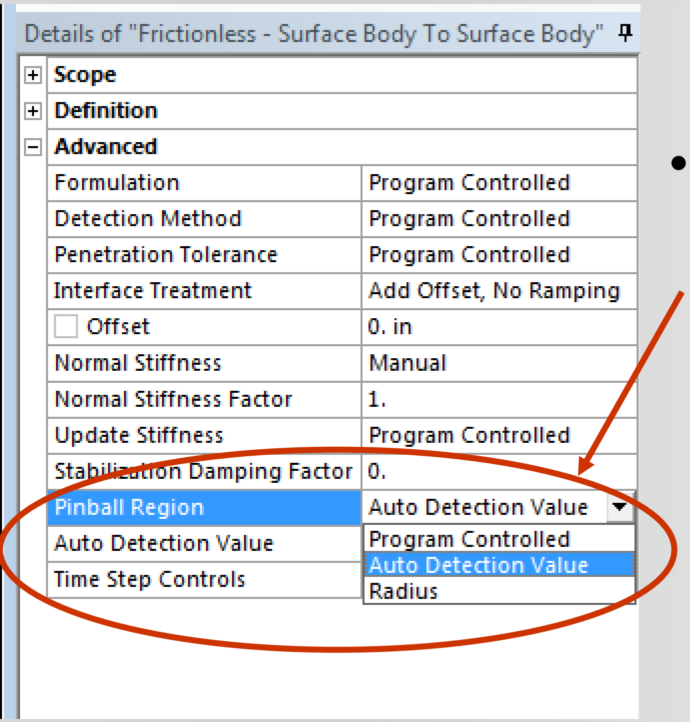
… Pinball Region

There are several uses for the Pinball Region:

- Provides computational efficiency in contact calculations, by differentiating "near" and "far" open contact when searching for which possible elements can contact each other in a given Contact Region.
- Determines the amount of allowable gap for bonded contact. If MPC Formulation is active, it also affects how many nodes will be included in the MPC equations.
- Determines the depth at which initial penetration will be resolved if present

… Pinball Region

There are three options for controlling the size of the Pinball Region for each contact detection point.

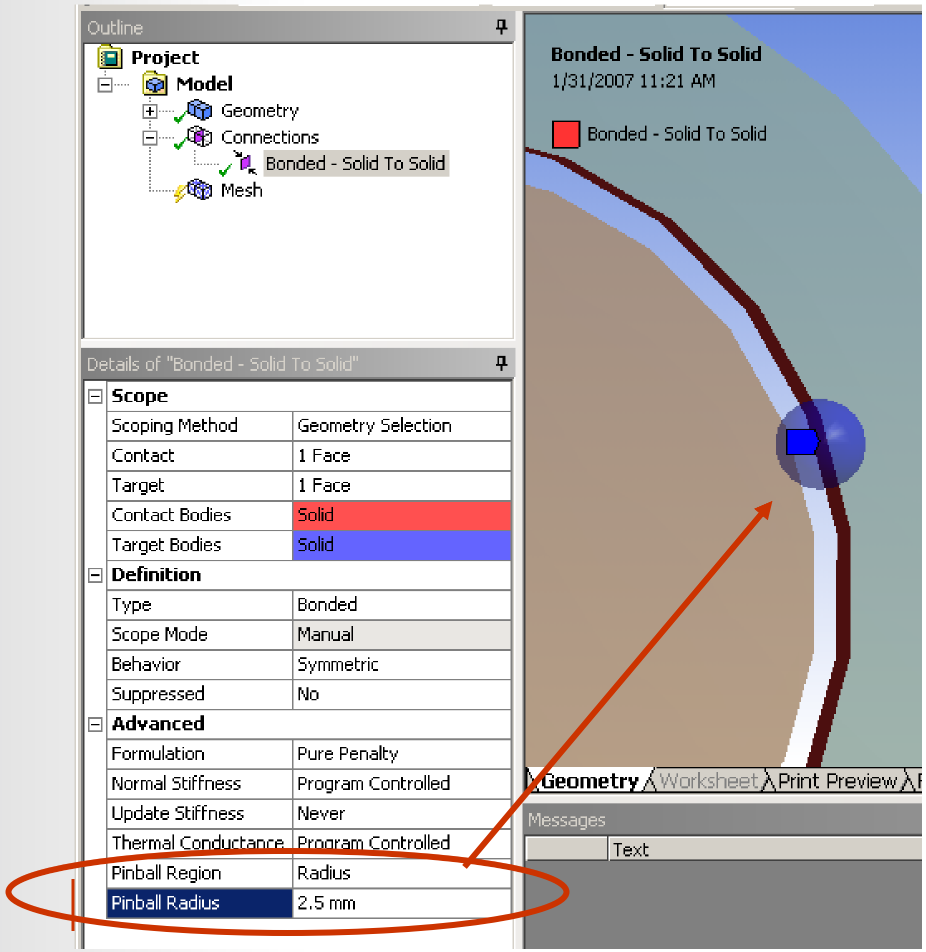


- Program Controlled - (default) The pinball region will be calculated by the program based on underlying element type and size.
- Auto Detection Value - The pinball region will be equal to the Tolerance Value as set on the Global Contact Settings.
  - Ensures that contact pairs created through the automatic contact detection have a Pinball Radius that envelops gap between target and contact.
  - Recommended option for cases where the automatic contact detection region is larger than the program controlled pinball value. In such cases, some contact pairs that were detected automatically may not be initially closed at start of solution.
- Radius - User manually specifies a value for the pinball region.

… Pinball Region

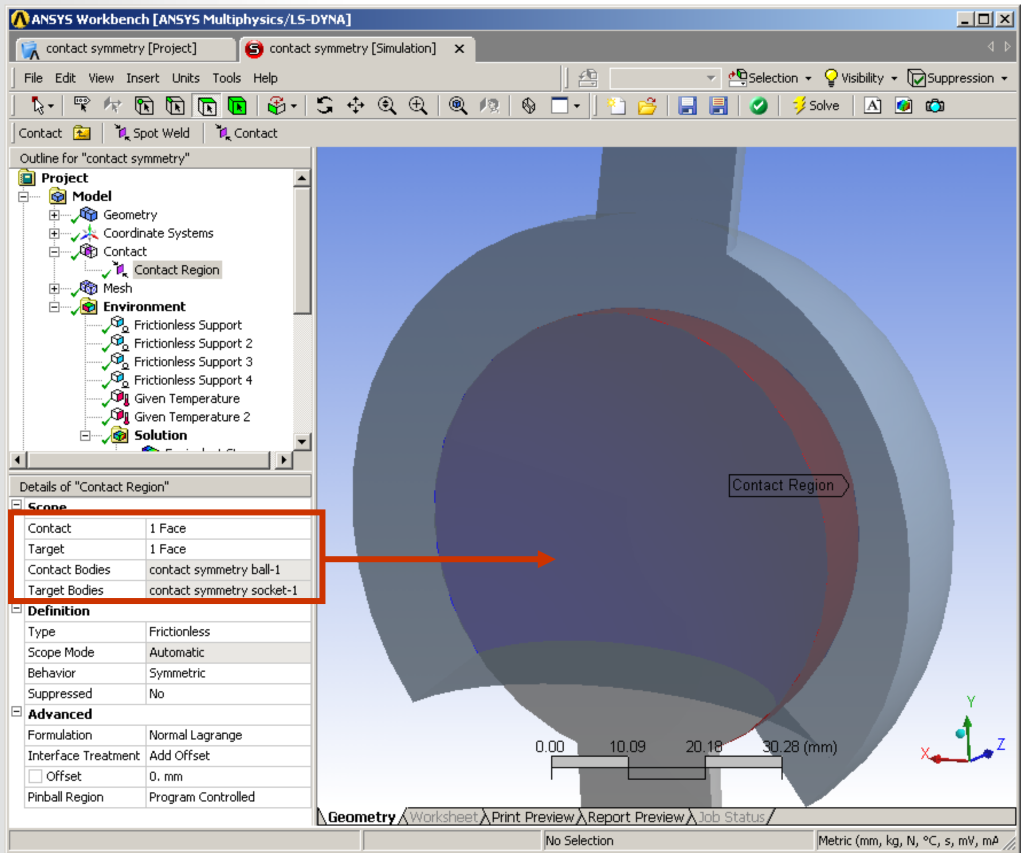
“Auto Detection Value” or a user defined Pinball “Radius” will appear as a sphere on the Contact Region for easy verification.

By specifying a Pinball Radius, one can visually confirm whether or not a gap will be ignored in Bonded Behavior.
The Pinball Region can also be important in initial interference problems or large-deformation problems.

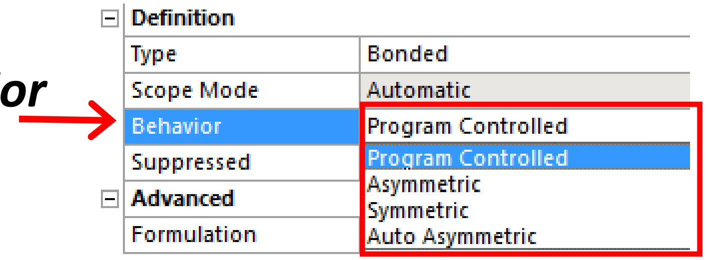


I. Symmetric/Asymmetric Behavior

- **Internally, the designation of *Contact* and *Target* surfaces can be very important**
  - **In *Mechanical,* under each "Contact Region," the *Contact* and *Target* surfaces are shown. The normals of the *Contact* surfaces are displayed in red while those of the *Target* surfaces are shown in blue.**
  - **The *Contact* and *Target* surfaces designate which two pairs of surfaces can come into contact with one another.**



… Symmetric/Asymmetric Behavior

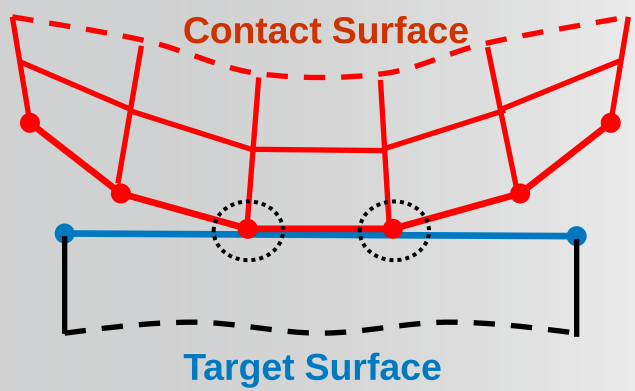


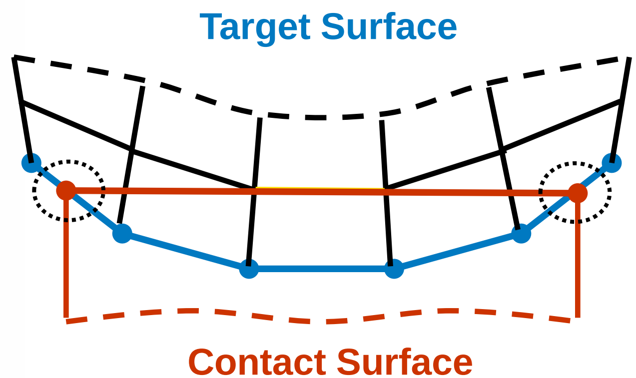
The concept of Symmetric vs Asymmetric *Behavior* only applies to penalty based methods

- *Asymmetric Behavior*
  - Only the contact surfaces are constrained from penetrating the target surfaces.
  - Internally, contact elements are meshed onto the red surface and corresponding target elements are meshed onto the blue surface, constituting one contact “pair”.
- *Symmetric Behavior*.
  - The contact surfaces are constrained from penetrating the target surfaces *and* the target surfaces are constrained from penetrating the contact surfaces.
  - Internally, the program uses two contact pairs with contact and target elements residing on both red and blue surfaces.
- *Auto-Asymmetric* (Default behavior with Program controlled option)
  - The program evaluates the contact region and chooses which surface should be meshed with contact elements and which should be meshed with target elements.
  - Internally, this may or may not result in one contact pair, but the contact elements may end up on the blue surface and target elements on the red surface.

… Symmetric/Asymmetric Behavior

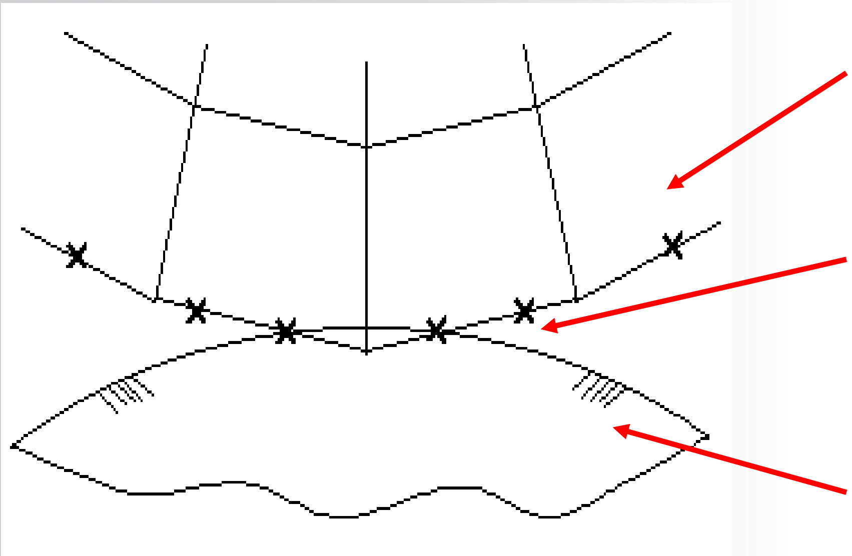
- For *Asymmetric Behavior, the nodes of the Contact surface cannot penetrate the Target surface.* This is a very important rule to remember. Consider the following:
  - On the left, the top red mesh is the mesh on the *Contact* side. The nodes cannot penetrate the *Target* surface, so contact is established correctly
  - On the right, the bottom red mesh is the *Contact* surface whereas the top is the *Target*. Because the nodes of the *Contact* cannot penetrate the *Target*, too much actual penetration occurs.





… Symmetric/Asymmetric Behavior

- Asymmetric Behavior (integration points only residing on one side), may allow some penetration at edges because of the location of contact detection points.
- The figure on the bottom illustrates this case:



Contact Surface

The target can penetrate the contact surface.

Target Surface

… Symmetric/Asymmetric Behavior

The following guidelines can be beneficial for proper selection of contact surfaces for *Asymmetric* behavior:

- **If a convex surface comes into contact with a flat or concave surface, the flat or concave surface should be the *Target* surface.**
- **If one surface has a coarse mesh and the other a fine mesh, the surface with the coarse mesh should be the *Target* surface.**
- **If one surface is stiffer than the other, the stiffer surface should be the *Target* surface.**
- **If one surface is higher order and the other is lower order, the lower order surface should be the *Target* surface.**
- **If one surface is larger than the other, the larger surface should be the *Target* surface.**

… Symmetric/Asymmetric

- **Only *Pure Penalty* and *Augmented Lagrange* formulations actually support Symmetric Behavior.**
- ***Normal Lagrange* and *MPC* require Asymmetric Behavior.**
  - **Because of the nature of the equations, Symmetric Behavior would be overconstraining the model mathematically, so Auto-Asymmetric Behavior is used even when Symmetric Behavior is selected.**
- **It is always good for the user to follow the general rules of thumb in selecting Contact and Target surfaces noted on the previous slide for any situation below where Asymmetric Behavior is used.**

	Specified Option	Pure Penalty	Augmented Lagrange	Normal Lagrange	MPC
Behavior Internally Used	Symmetric Behavior	Symmetric	Symmetric	*Auto-Asymmetric*	*Auto-Asymmetric*
	Asymmetric Behavior	*Asymmetric*	*Asymmetric*	*Asymmetric*	*Asymmetric*
	Auto-Asymmetric Behavior	*Auto-Asymmetric*	*Auto-Asymmetric*	*Auto-Asymmetric*	*Auto-Asymmetric*
Reviewing Results	Symmetric Behavior	*Results on Both*	*Results on Both*	*Results on Either*	*Results on Either*
	Asymmetric Behavior	Results on Contact	Results on Contact	Results on Contact	Results on Contact
	Auto-Asymmetric Behavior	*Results on Either*	*Results on Either*	*Results on Either*	*Results on Either*
Notes	Symmetric Behavior	Easier to set up	Easier to set up	Let program designate	Let program designate
	Asymmetric Behavior	Efficiency and control	Efficiency and control	User has control	User has control
	Auto-Asymmetric Behavior	Let program designate	Let program designate	Let program designate	Let program designate

… Symmetric/Asymmetric

Symmetric Behavior:

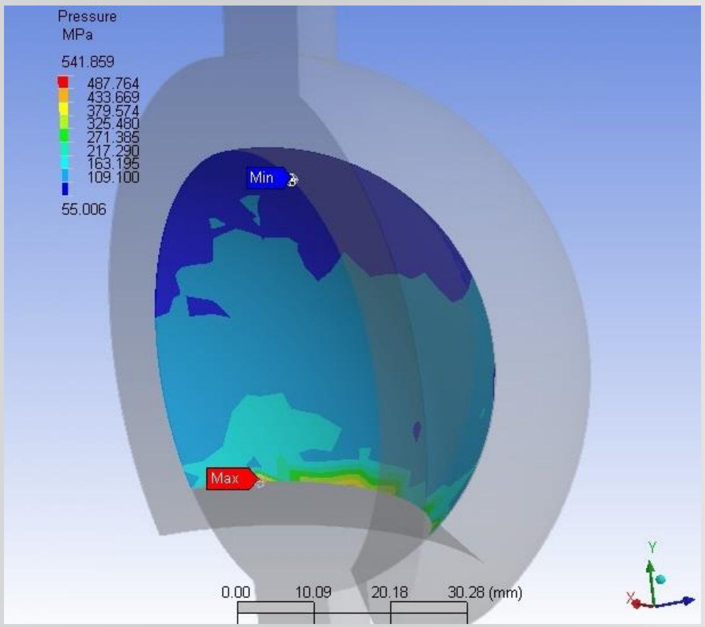
- Easier to set up
- More computationally expensive.
- Interpreting data such as actual contact pressure can be more difficult
  - Results are reported on both sets of surfaces

Asymmetric Behavior:

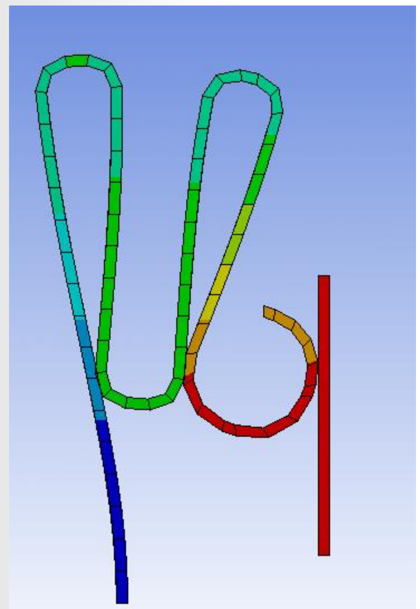
- Mechanical can automatically perform this designation (Auto-Asymmetric) or…
- User can designate the appropriate surface(s) for contact and target manually .
  - Selection of inappropriate Contact vs.Target may affect results.
- Reviewing results is easy and straightforward. All data is on the contact side.

J. Body Types in Contact

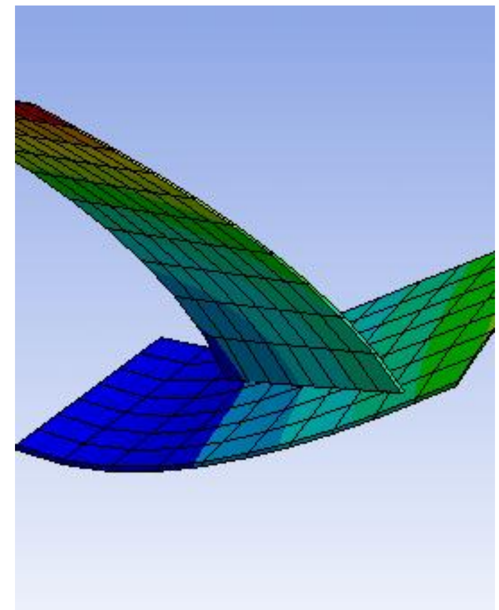
Mechanical **offers a rich library of Connection Technology Options to simulate many different behaviors between faces and edges of solid and surface bodies (meshed with shell elements).**



Solid Face to Solid Face



Surface Body Face to Surface body (or Solid body) Face

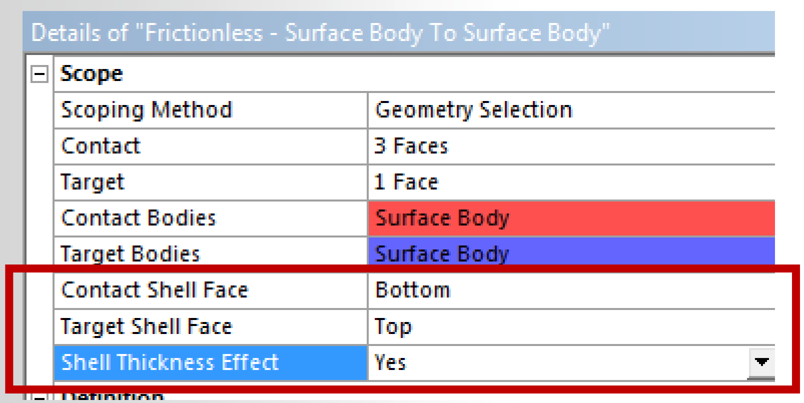


Surface Body Edge to Surface Body (or Solid) Face

... Body Types in Contact

When modeling contact between surface body faces, it is important to recognize that a surface body has a surface area, but no volume.

- **The thickness of a surface body is assigned by the user as a property in the Details window associated with the surface body**
- **When generating general frictionless or frictional contact involving surface bodies,**
  - **It is necessary to identify which side (top or bottom) of the surface body is involved in the contact relationship. Failure to do this might result in contact not being recognized.**
  - **It is also necessary to recognize that contact occurs at the midplane of the surface body, by default. Shell thickness effect can be switched if necessary.**



… Body Types in Contact

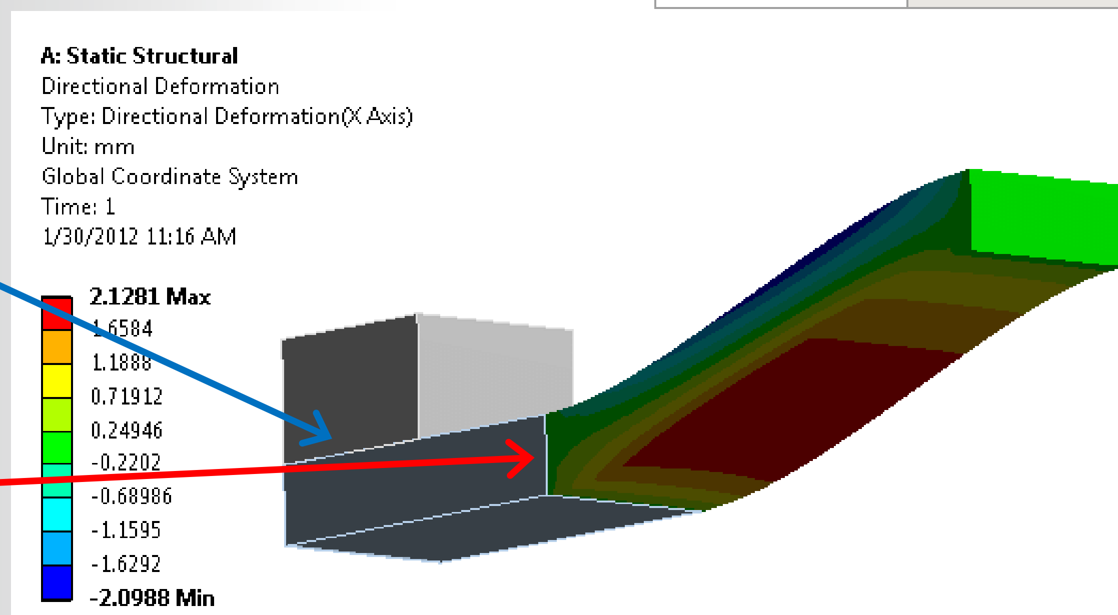
- *Mechanical* supports contact relationships with rigid bodies.
  - Rigid to Rigid
  - Rigid to Flexible
  - Useful for improved efficiency when certain ‘rigid’ bodies in the model are considerably stiffer then other ‘flexible’ bodies

Details of "Part 1"

Graphics Properties	
Definition	
Suppressed	No
Stiffness Behavior	Rigid
Reference Temperature	By Environment
Material	
Assignment	Structural Steel
Bounding Box	
Properties	
Statistics	
CAD Attributes	
PartTolerance	0.000001

Contact between two rigid bodies

Contact between one rigid and one flex body



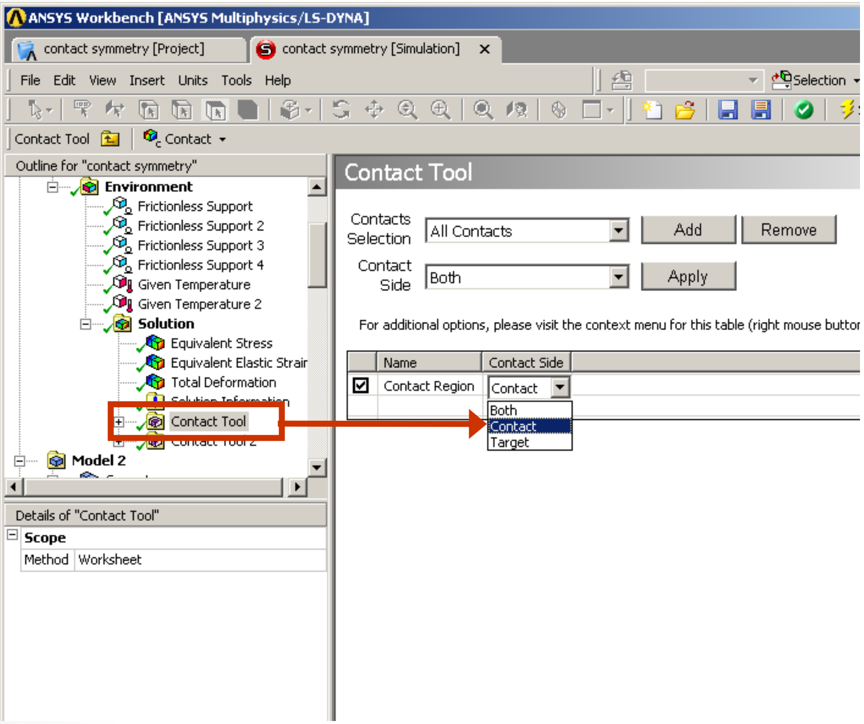
... Body Types in Contact

- **Rigid-to-Rigid contact features**
  - Program Controlled setting for *Formulation* is Penalty Method
  - Program Controlled setting *Behavior* is under-defined
    - User must always set this to asymmetric manually
  - Contact related results are only available on the side defined as "Contact"

- **Rigid-to-Flexible contact features**
  - Program Controlled setting for *Formulation* is Augmented Lagrange
  - Program Controlled setting for *Behavior* is asymmetric
  - User must always define contact surface on flexible body and target surface on rigid body.
  - Contact related results are only available on the side defined as "Contact"

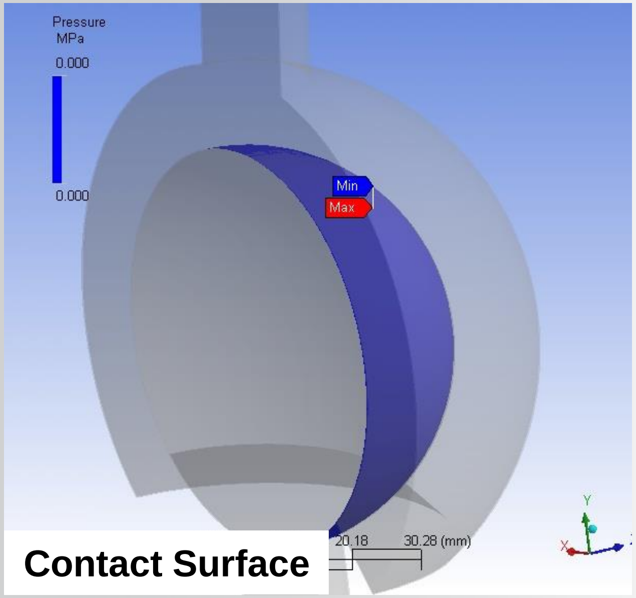
K. Contact results

- **For Symmetric Behavior, results are reported for both Contact and Target surfaces.**
- **For any resulting Asymmetric Behavior, results are only available on Contact surfaces.**
- **When viewing the Contact Tool worksheet, the user may select Contact or Target surfaces to review results.**
- **For Auto-Asymmetric Behavior, the results may be reported on *either* the Contact or Target**
- **For Asymmetric Behavior, zero results are reported for Target**

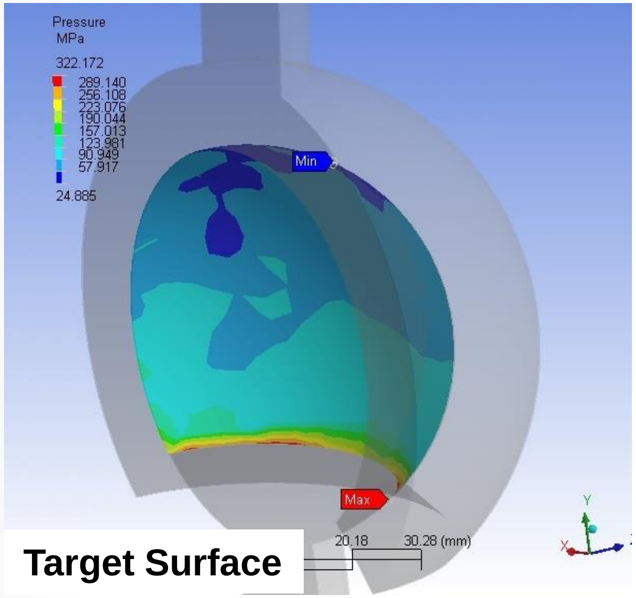


... Contact results

- **For example, consider the case below of Normal Lagrange Formulation with Symmetric Behavior specified.**
  - **This results in auto-asymmetric behavior. Since it is automatic, WB-Mechanical may reverse the Contact and Target specification.**
- **When reviewing Contact Tool results, one can see that the Contact side reports no (zero) results while the Target side reports true Contact Pressure.**



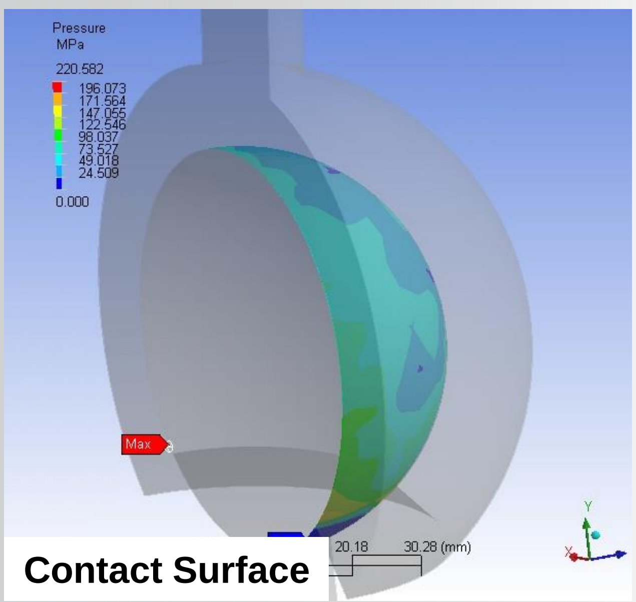
Contact Surface



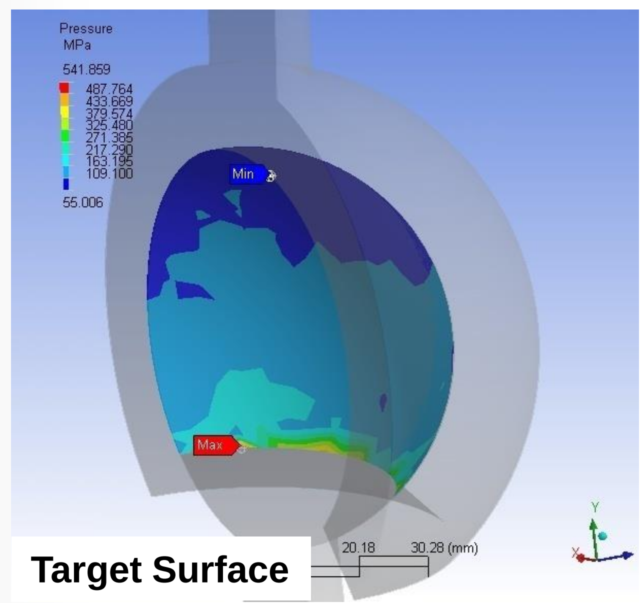
Target Surface

... Contact results

- **In another situation, Augmented Lagrange Formulation with Symmetric Behavior is used**
  - **This results in true symmetric behavior, so both set of surfaces are constrained from penetrating each other**
- **However, results are reported on *both* Contact and Target surfaces. This means that the "true" contact pressure is an average of both results.**



Contact Surface



Target Surface

L. Workshop – Symmetric vs Asymmetric

Please refer to your *Workshop Supplement* for instructions on:

W3B Symmetric vs Asymmetric