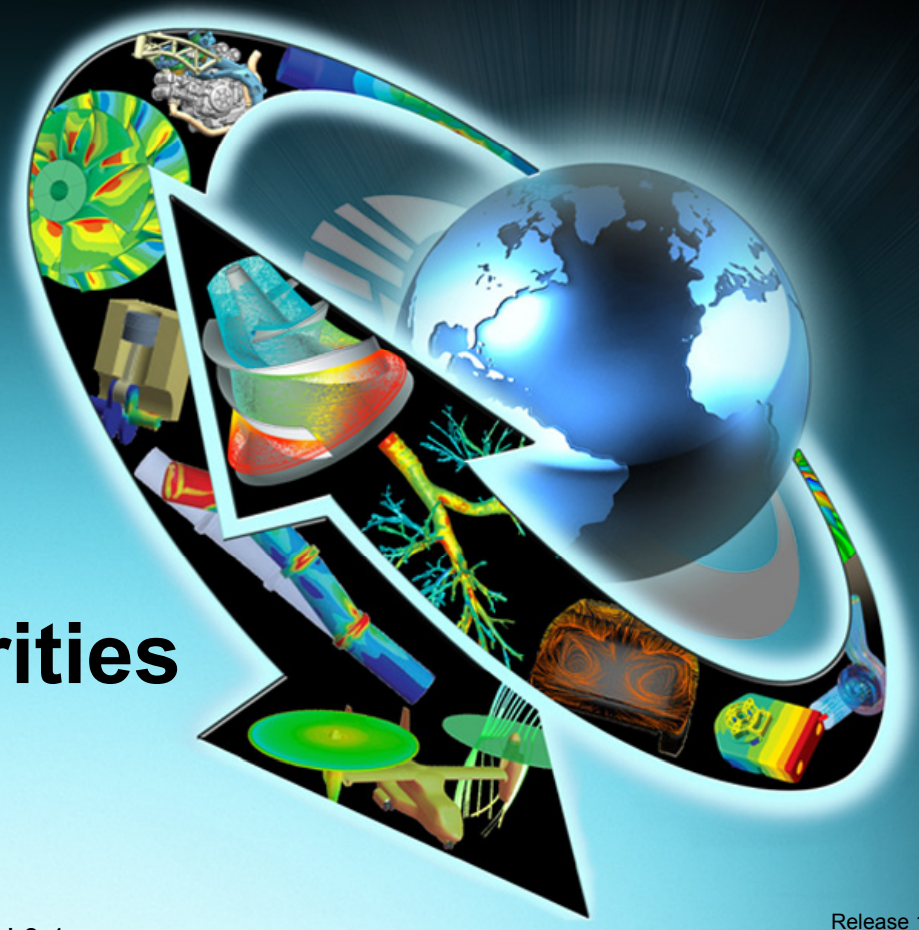
ANSYS®

Customer Training Material

Lecture 3

Introduction to Contact



ANSYS Mechanical Structural Nonlinearities

Chapter Overview

- **An introduction to *solid body contact* will be presented in this chapter:**
  - **It is assumed that the user has already covered Chapter 2 *Nonlinear Structural* prior to this chapter.**
- **The Specific topics introduced are:**

A. Basic concept of contact

B. Contact Formulations

C. Stiffness and Penetration

D. Workshop 3A

E. Pinball Region

F. Symmetric vs. Asymmetric

G. Postprocessing Contact Results

H. Workshop 3B

- **The capabilities described in this Chapter are generally applicable to *ANSYS Structural* licenses and above.**

A. Basic Concepts

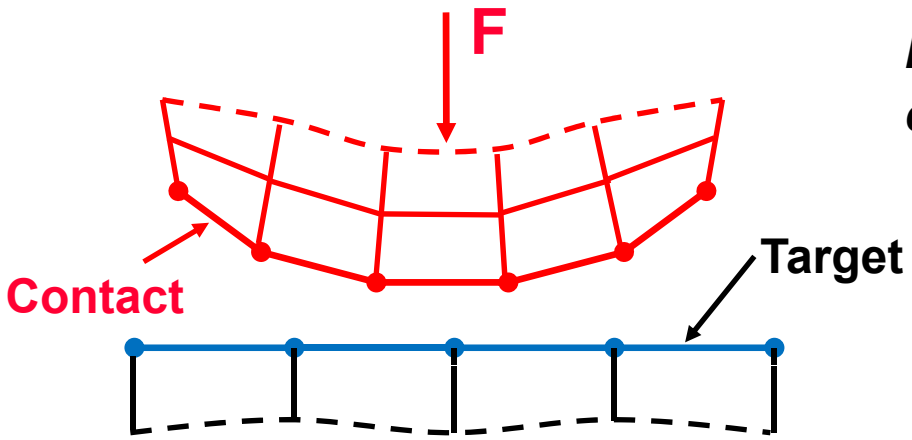
Contact:

- 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.
    - They are therefore 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.

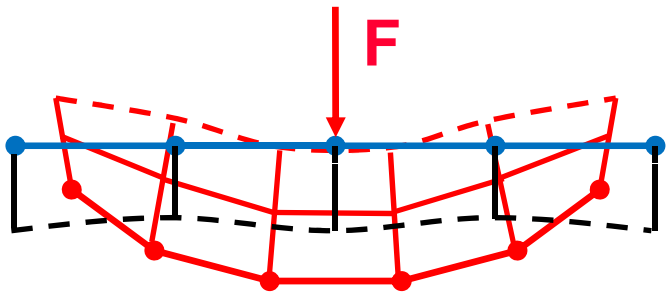
... Basic Concepts

How compatibility is enforced in a contact region:

- **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.***
  - **Workbench Mechanical offers several different *contact formulations* to enforce compatibility at the contact interface.**



Penetration occurs when contact compatibility is not enforced.

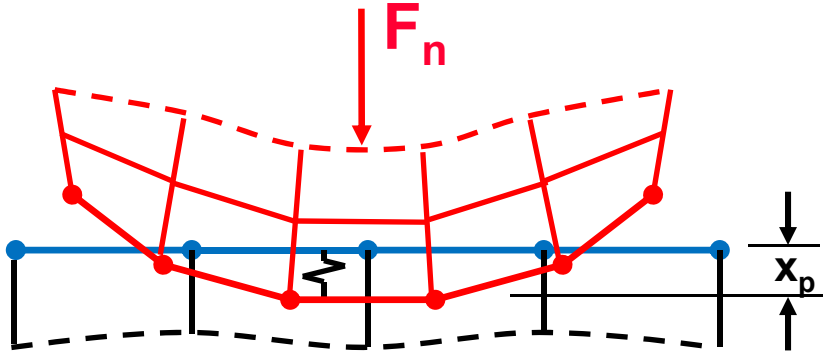


B. Contact Formulations

- **For nonlinear solid body contact of faces, *Pure Penalty* or *Augmented Lagrange* formulations can be used:**
  - **Both of these are penalty-based contact formulations:**

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

  - **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 below**
  - **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

- **The main difference between *Pure Penalty* and *Augmented Lagrange* methods is that the latter augments the contact force (pressure) calculations:**

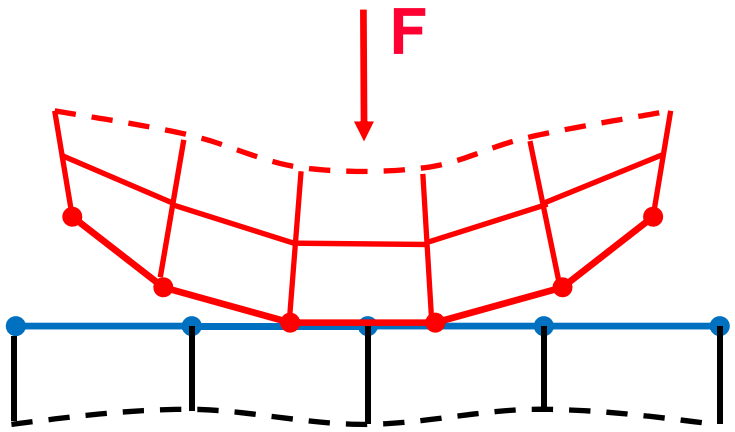
Pure Penalty: $F_{normal} = k_{normal} x_{penetration}$

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}.**

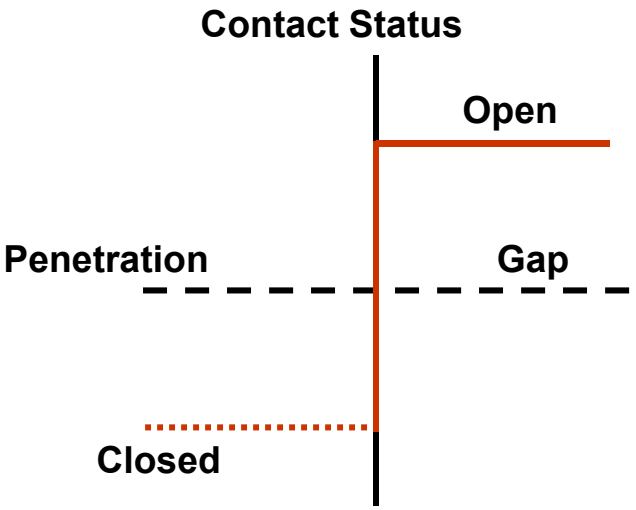
... Contact Formulations

- **Another available option is *Lagrange multiplier* Formulation:**
  - **The Normal Lagrange Formulation 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**

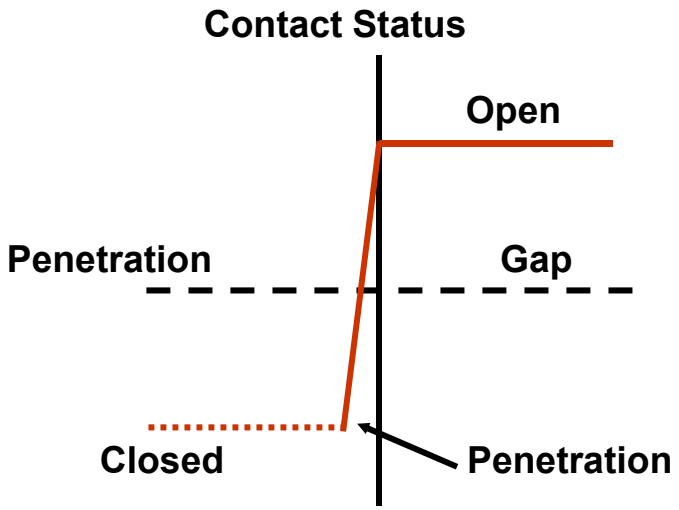


... Contact Formulations

- ***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.**



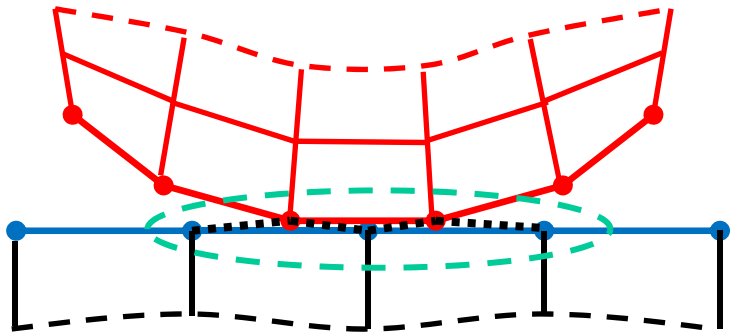
Normal Lagrange Method



Penalty-Based Method

... Contact Formulations

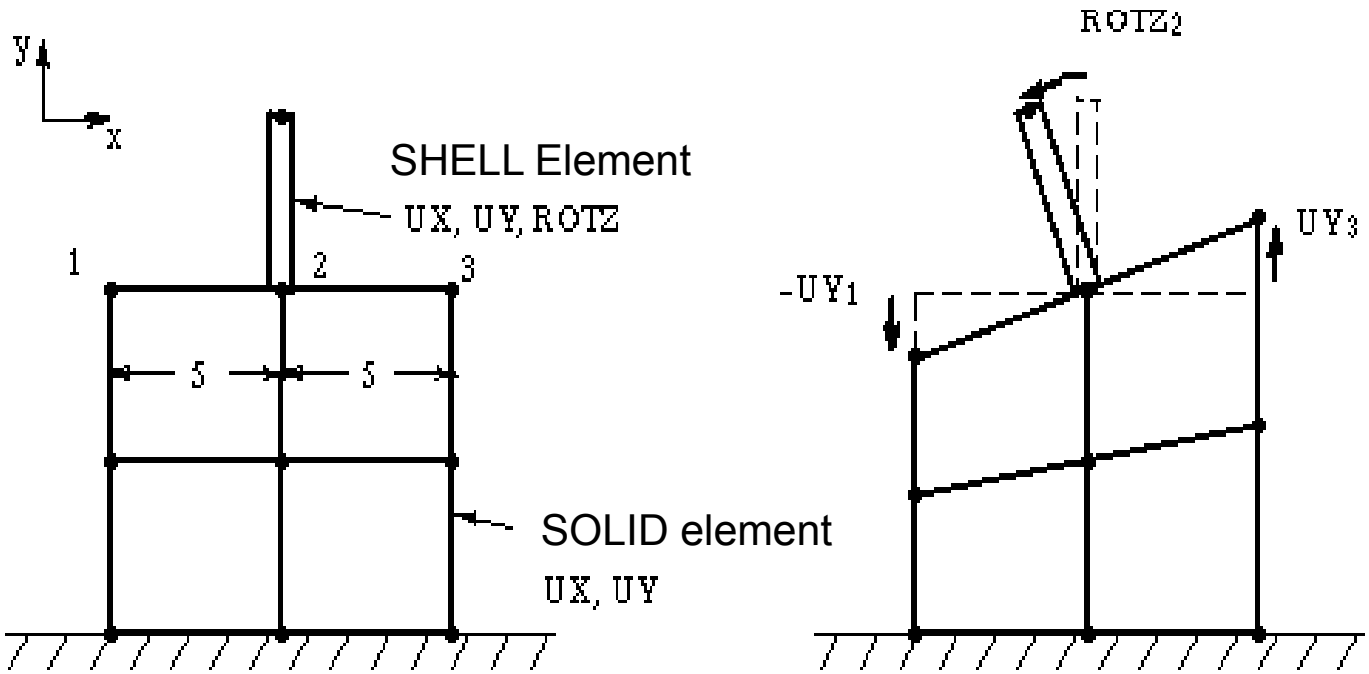
- **For the specific case of "Bonded" and "No Separation" type of contact between two faces, a multi-point constraint (*MPC)* formulation is available.**
  - **MPC internally adds constraint equations to "tie" the displacements between contacting surfaces**
  - **This approach is not penalty-based or 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**



… MPC Formulation

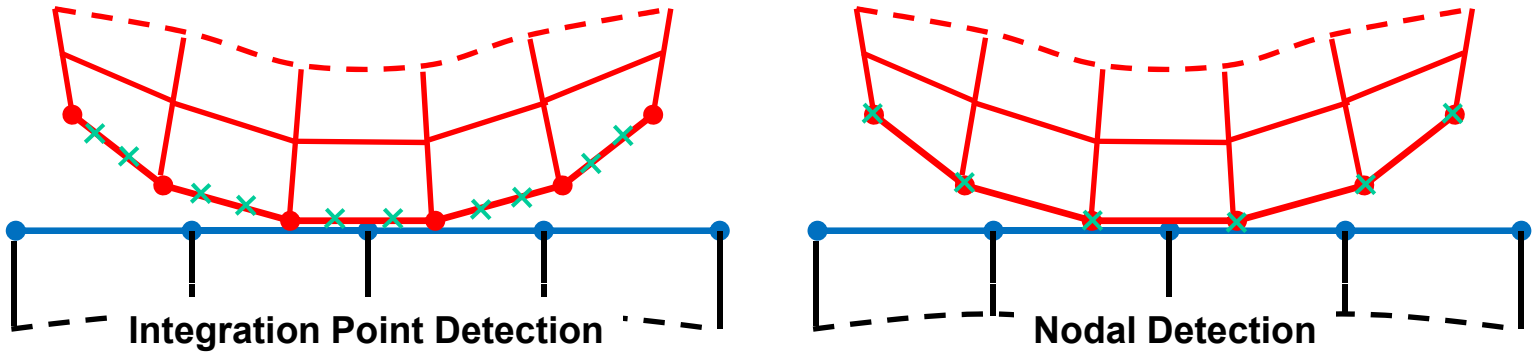
- To illustrate, consider the connection between a shell edge and a solid face. The constraint equation that would transfer action between ROTZ at node 2 and UY at nodes 1 and 3 has this form:

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



... Contact Formulations

- **Contact is detected differently, depending on the formulation used:**
  - **Pure Penalty and Augmented Lagrange Formulations use *integration point detection*. This results in more detection points (10 in this example on left)**
  - **Normal Lagrange and MPC Formulation use *nodal detection* (normal direction from Target). This results in fewer detection points (6 in the example on right)**
  - **Nodal detection may handle contact at edges slightly better, but a localized, finer mesh will alleviate this situation with integration point detection.**



… Tangential Behavior

- **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 will be presented with a workshop in next Chapter.**

… Contact Formulation Summary

- **A summary of the contact formulations available in Workbench Mechanical is listed below:**

Formulation	Normal	Tangential	Normal Stiffness	Tangential Stiffness	Type
Augmented Lagrange	Augmented Lagrange	Penalty	Yes	Yes[1]	Any
Pure Penalty	Penalty	Penalty	Yes	Yes[1]	Any
MPC	MPC	MPC	-	-	Bonded,No Separation
Normal Lagrange	Lagrange Multiplier	Penalty	-	Yes[1]	Any

[1] **Tangential stiffness is not directly input by user**

  - **The "Normal Lagrange" method is so named because Lagrange multiplier formulation is used in the *Normal* direction while penalty-based method is used in the tangential direction.**

… Comparison of Formulations

- **The table below summarizes some pros (+) and cons (-) with different contact formulations:**

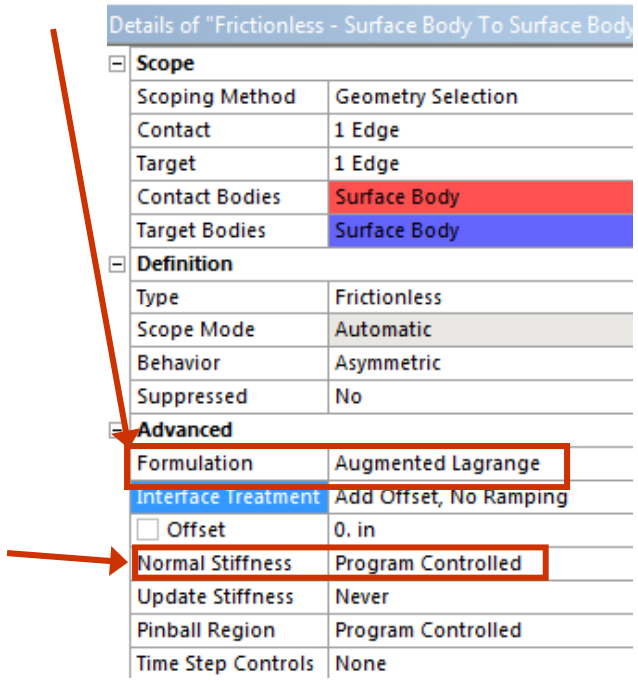
	Pure Penalty		Augmented Lagrange		Normal Lagrange		MPC
+	Good convergence behavior (few equilibrium iterations)	-	May require additional equilibrium iterations if penetration is too large	-	May require additional equilibrium iterations if chattering is present	+	Good convergence behavior (few equilibrium iterations)
-	Sensitive to selection of normal contact stiffness		Less sensitive to selection of normal contact stiffness	+	No normal contact stiffness is required	+	No normal contact stiffness is required
-	Contact penetration is present and uncontrolled		Contact penetration is present but controlled to some degree	+	Usually, penetration is near-zero	+	No penetration
+	Useful for any type of contact behavior	+	Useful for any type of contact behavior	+	Useful for any type of contact behavior	-	Only Bonded & No Separation behaviors
+	Either Iterative or Direct Solvers can be used	+	Either Iterative or Direct Solvers can be used	-	Only Direct Solver can be used	+	Either Iterative or Direct Solvers can be used
+	Symmetric or asymmetric contact available	+	Symmetric or asymmetric contact available		Asymmetric contact only		Asymmetric contact only
+	Contact detection at integration points	+	Contact detection at integration points		Contact detection at nodes		Contact detection at nodes

  - **Note that some topics, such as symmetric contact or contact detection, will be discussed shortly**

C. Contact Stiffness and Penetration

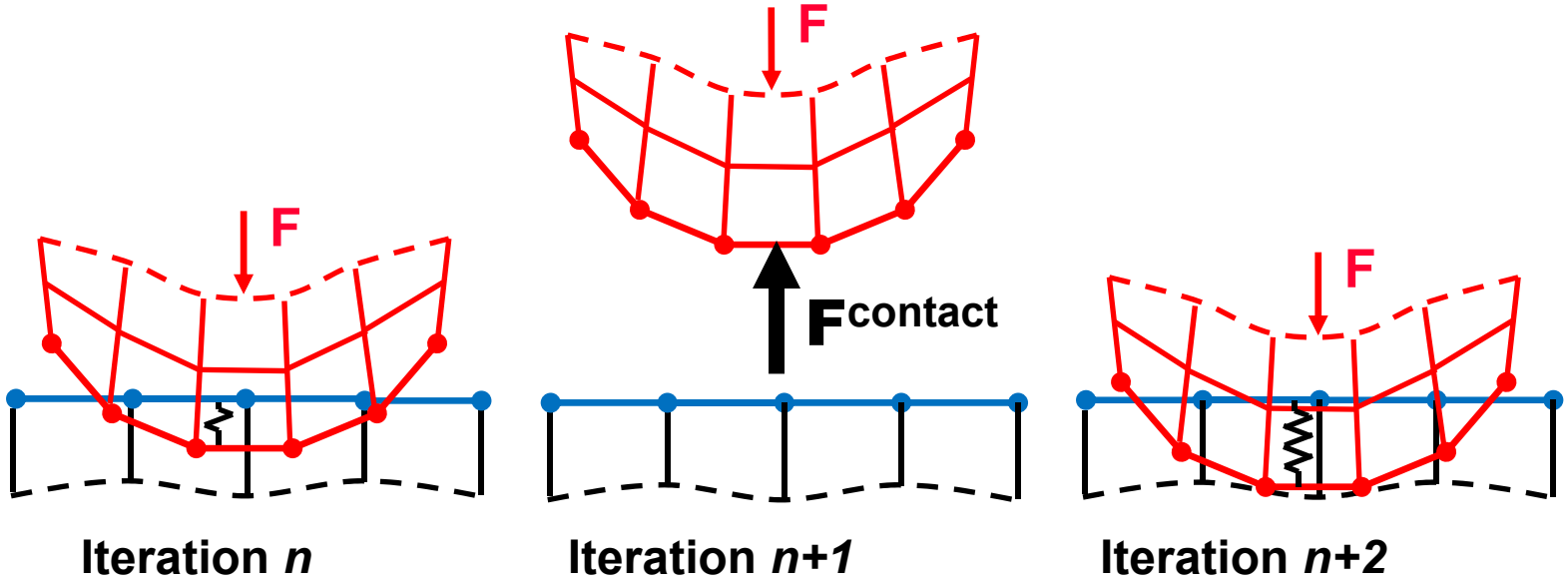
- **Although "Pure Penalty" is the default in Workbench-Mechanical, "Augmented Lagrange" is recommended for general frictionless or frictional contact in large-deformation problems.**
  - **Augmented Lagrange formulation adds additional controls to automatically reduce penetration**

- **The "Normal Stiffness" is the contact stiffness k_{normal} explained earlier, used only for "Pure Penalty" or "Augmented Lagrange"**
  - **This is a relative factor. The use of 1.0 is recommended for general bulk deformation-dominated problems. For bending-dominated situations, a smaller value of 0.1 may be useful if convergence difficulties are encountered.**



... Contact Stiffness and Penetration

- 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



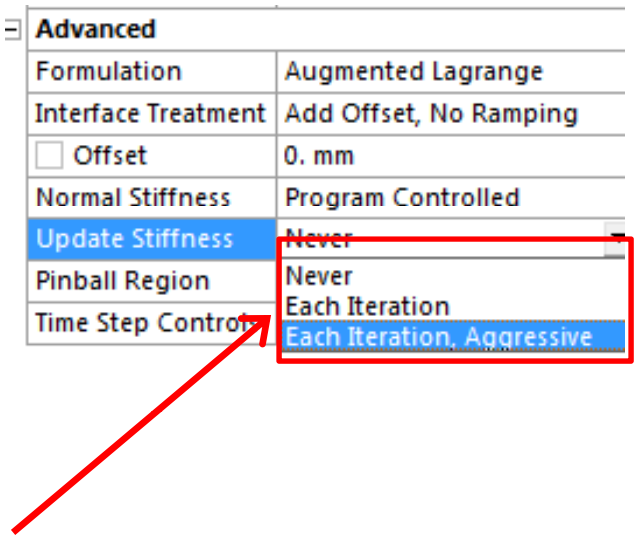
... Contact Stiffness and Penetration

- **The default Normal Stiffness is automatically determined by WB-Mechanical.**
  - **The user may input a "Normal Stiffness Factor" (FKN) which is a multiplier on the code calculated stiffness. The lower the factor, the lower the contact stiffness.**
    - **Default FKN =10 (for Bonded and No Separation behaviors)**
    - **Default FKN=1.0 (for all other behaviors)**

- **Some general guidelines on selection of Normal Stiffness for contact problems:**
  - **For bulk-dominated problems: Use "Program Controlled" or manually enter a "Normal Stiffness Factor" of "1"**
  - **For bending-dominated problems: Manually enter a "Normal Stiffness Factor" of "0.01" to "0.1"**

C. Contact Stiffness and Penetration

- **The normal stiffness can also be automatically adjusted during the solution. If difficulties arise, the stiffness will be reduced automatically.**
  - ***"Each Iteration"*** **sets the program to update stiffness at the end of each equilibrium iteration. This choice is recommended if you are unsure of a Normal Stiffness Factor to use in order to obtain good results.**
  - ***"Each Iteration, Aggressive"*** **also sets the program to update stiffness at the end of each equilibrium iteration, but, this option allows for a broader range in the adjusted value.**

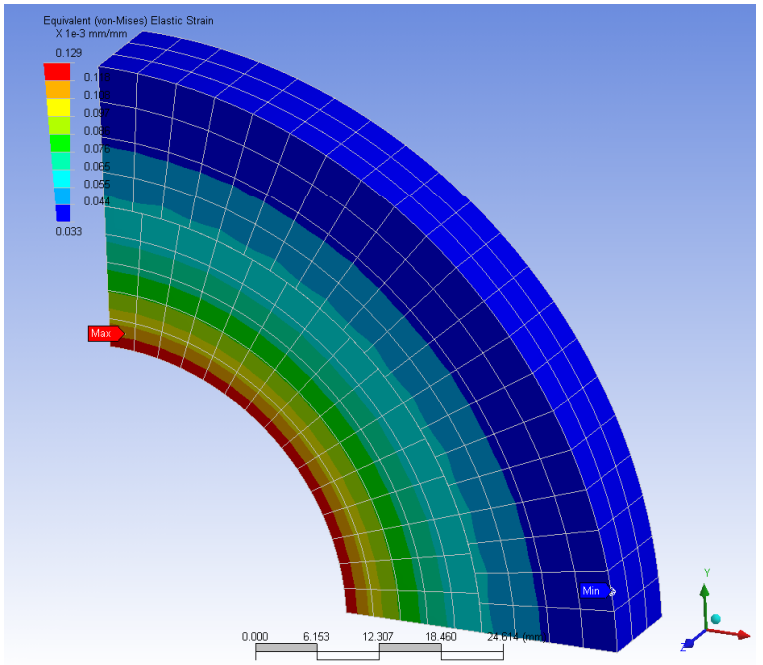


... Contact Stiffness and Penetration

- **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

- **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)**

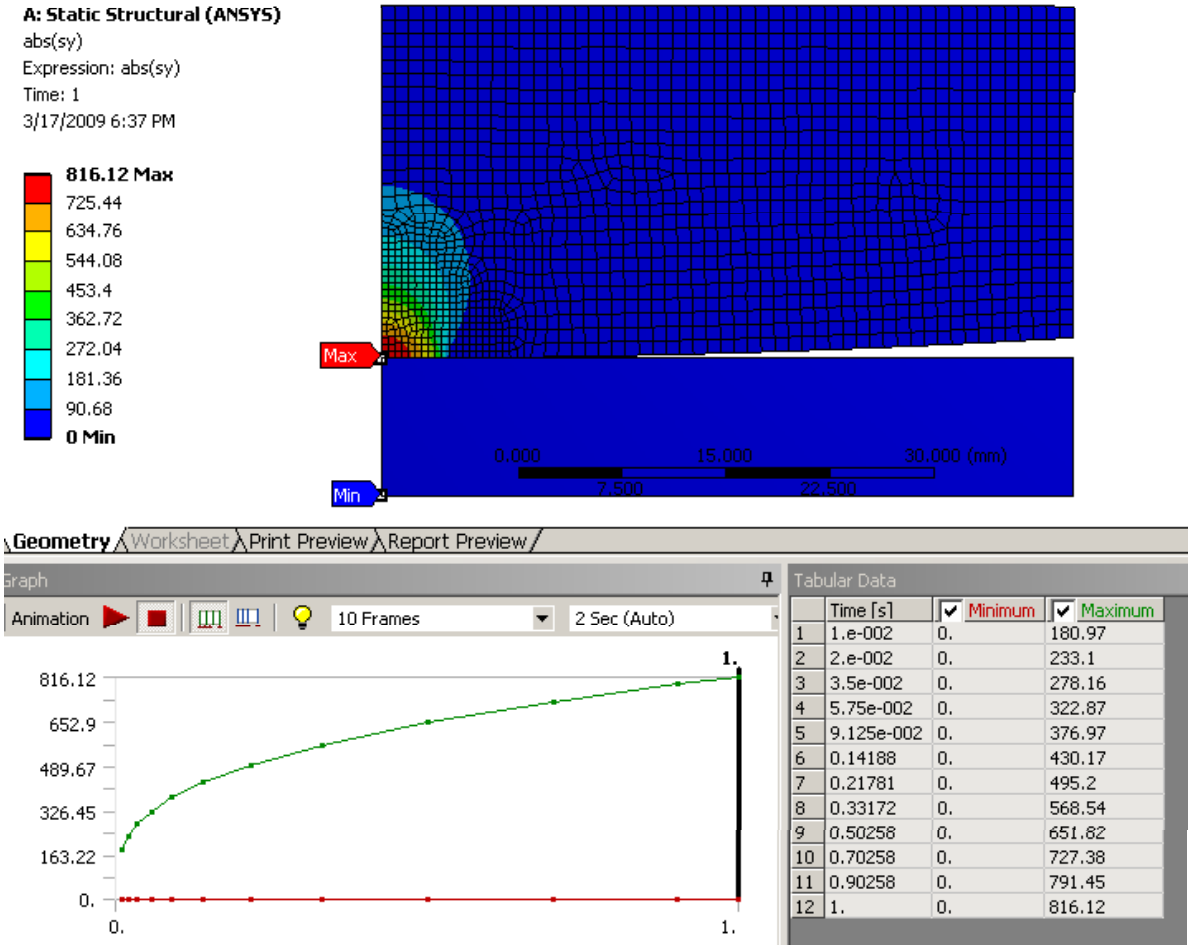


... Contact Stiffness and Penetration

- **For *bonded contact*, Workbench-Mechanical uses Pure Penalty formulation with large Normal Stiffness by default.**
  - **This provides good results since the contact stiffness is high, resulting in small/negligible penetration.**
  - **MPC formulation is a good alternative for bonded contact because of its many nice features.**
- **For *frictionless* or *frictional contact*, consider using either Augmented Lagrange or Normal Lagrange methods.**
  - **The Augmented Lagrange method is recommended, as noted previously, because of its attractive features and flexibility.**
  - **The Normal Lagrange method can be used if the user does not want to bother with Normal Stiffness value and wants zero penetration. However, note that the Direct Solver must be used, which may limit the size of the models solved.**

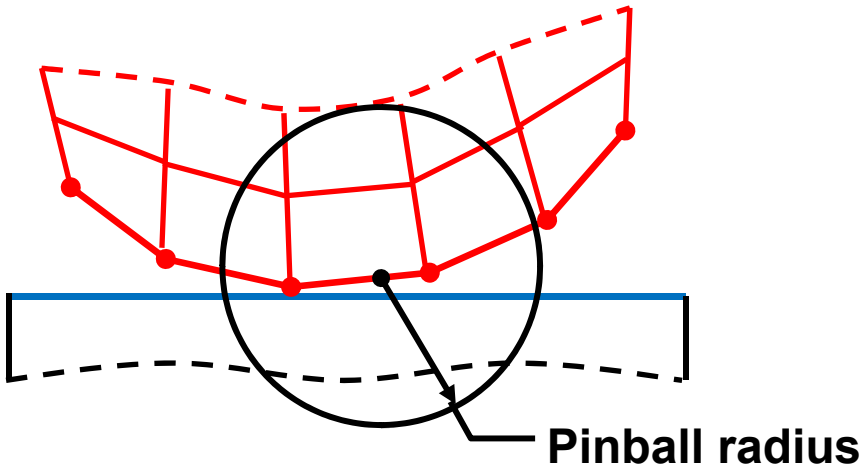
C. Workshop – Contact Stiffness & Penetration

- **Please refer to your *Workshop Supplement* for instructions on*:***
- ***W3A-Contact Stiffness Study***



E. 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 node on a Target surface is within this sphere, WB-Mechanical considers it to be in "near" contact and will monitor its relationship to the contact detection point more closely (i.e., when and whether contact is established). Nodes on target surfaces outside of this sphere will not be monitored as closely for that particular contact detection point.**
  - **If Bonded Behavior is specified within a gap smaller than the Pinball Radius, WB-Mechanical will still treat that region as bonded**



... 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.**

Details of "Frictionless - Solid To Solid"

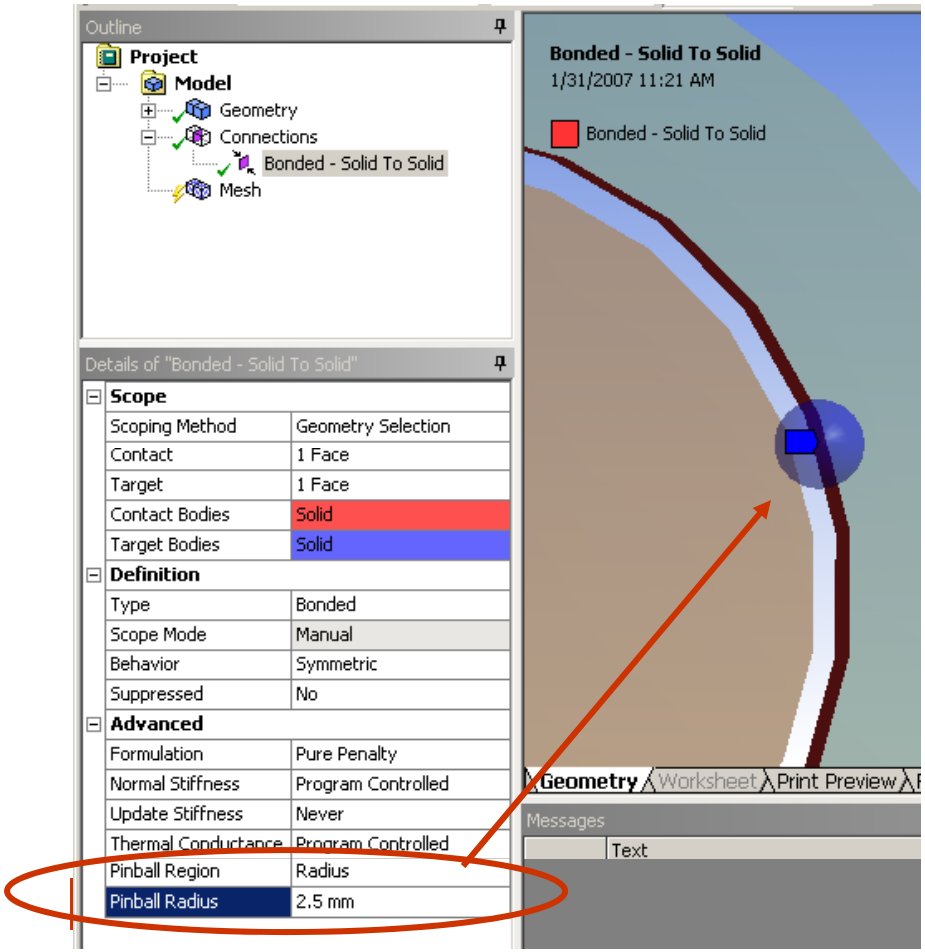
Scope	
Scoping Method	Geometry Selection
Contact	1 Face
Target	1 Face
Contact Bodies	Solid
Target Bodies	Solid
Definition	
Type	Frictionless
Scope Mode	Automatic
Behavior	Symmetric
Suppressed	No
Advanced	
Formulation	Pure Penalty
Interface Treatment	Adjust to Touch
Normal Stiffness	Program Controlled
Update Stiffness	Never
Thermal Conductance	Program Controlled
Pinball Region	Auto Detection Value
Time Step Controls	Program Controlled
	Auto Detection Value
	Radius

- **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

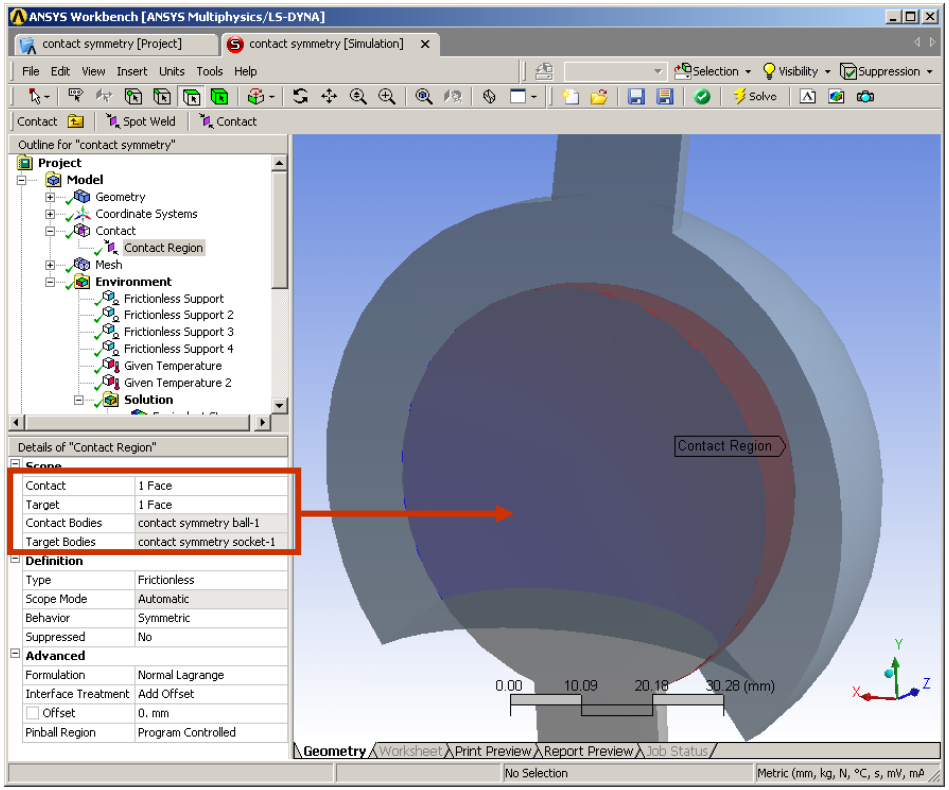
- **"Auto Detection Value" or a user defined Pinball "Radius" will appear as a sphere on the Contact Region for easy verification.**

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.



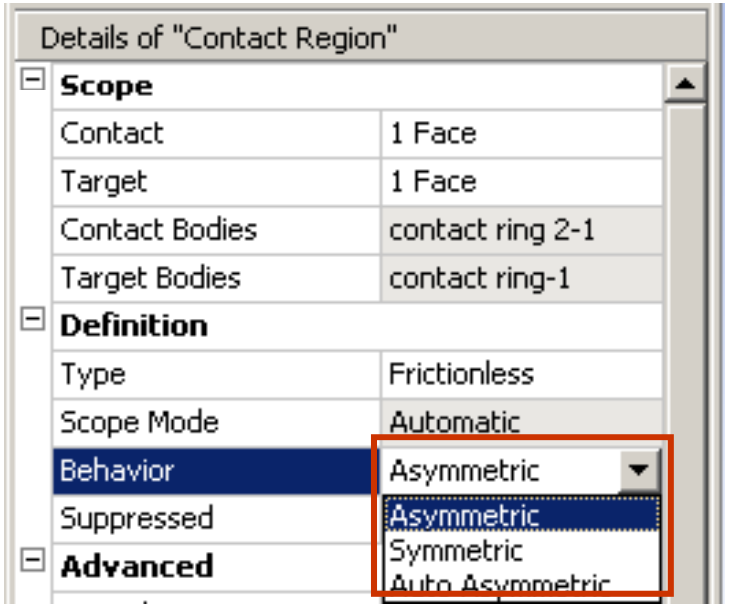
F. Symmetric/Asymmetric Behavior

- **Internally, the designation of *Contact* and *Target* surfaces can be very important**
  - **In WB-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.**



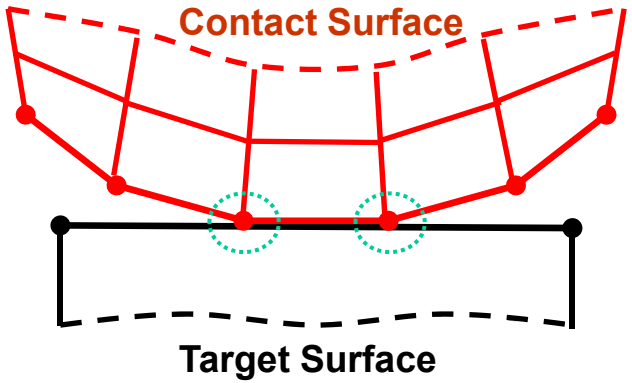
… Symmetric/Asymmetric Behavior

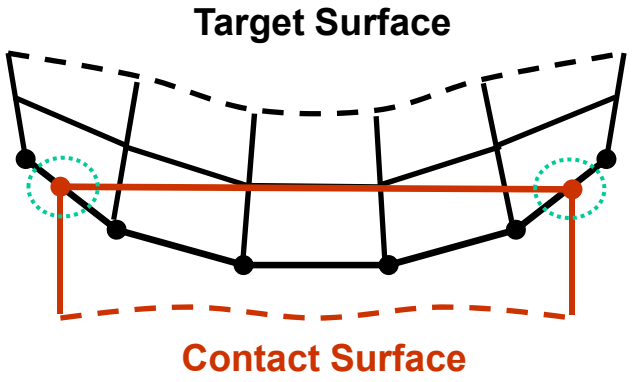
- **By default, WB-Mechanical uses *Symmetric Behavior*.**
  - **This means that the Contact surfaces are constrained from penetrating the Target surfaces *and* the Target surfaces are constrained from penetrating the Contact surfaces.**
- **If the user wishes, *Asymmetric Behavior* can be used:**
  - **For *Asymmetric Behavior*, only the Contact surfaces are constrained from penetrating the Target surfaces.**
  - **In *Auto-Asymmetric Behavior*, the *Contact* and *Target* surface designation may be reversed internally**
    - **Although it is noted that surfaces are constrained from penetrating each other, recall that with Penalty-based methods, some small penetration may occur.**



… Symmetric/Asymmetric Behavior

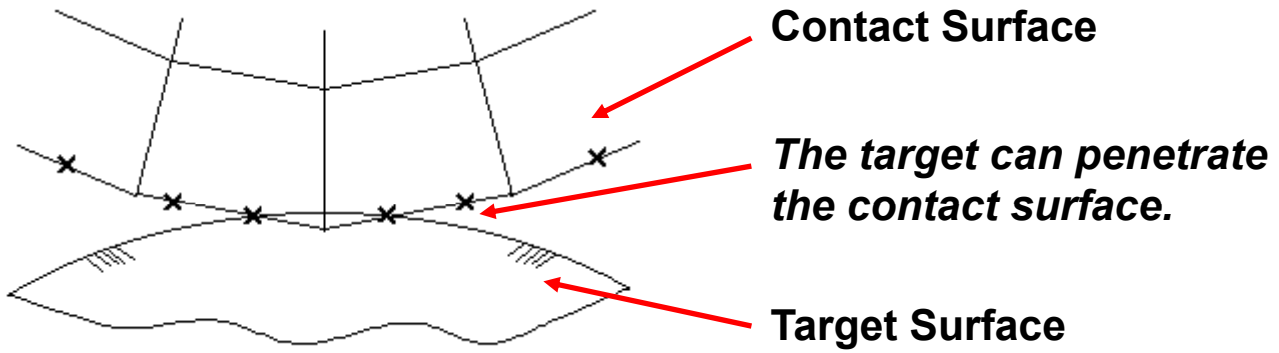
- **For *Asymmetric Behavior*, *the nodes of the Contact surface cannot penetrate the Target surface.* This is a very important rule to remember. Consider the following:**
  - **On the left, the top red mesh is the mesh on the *Contact* side. The nodes cannot penetrate the *Target* surface, so contact 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

- **For Asymmetric Behavior, the integration point detection may allow some penetration at edges because of the location of contact detection points.**
  - **The figure on the bottom illustrates this case:**



- **On the other hand, there are more contact detection points if integration points are used, so each contact detection method has its pros and cons.**

… 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 when Symmetric Behavior 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.**

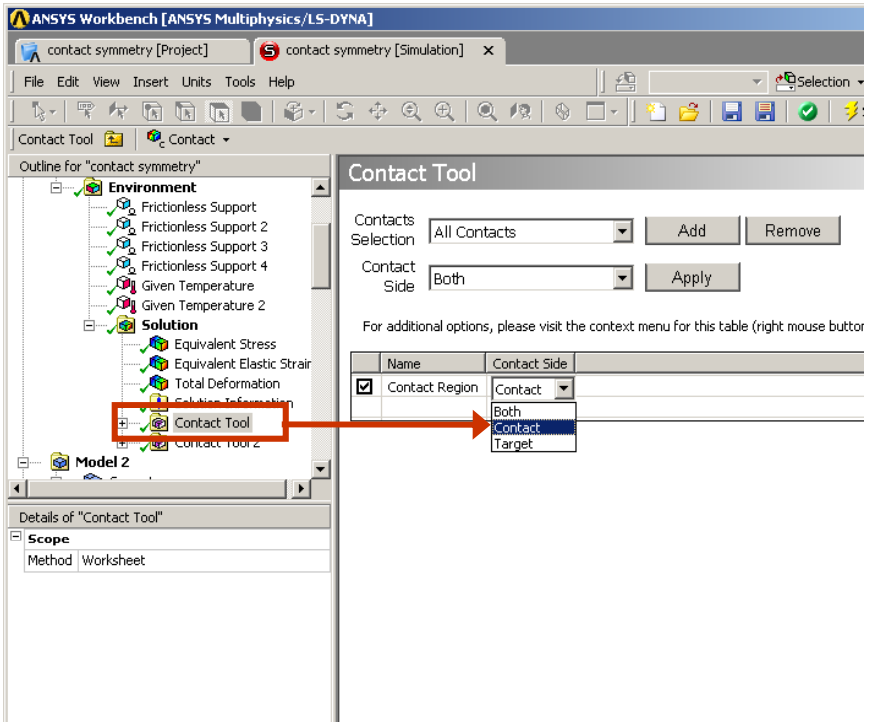
	Specified Option	Pure Penalty	Augmented Lagrange	Normal Lagrange	MPC
Behavior Internally Used	Symmetric Behavior	Symmetric	Symmetric	*Auto-Asymmetric*	*Auto-Asymmetric*
	Asymmetric Behavior	*Asymmetric*	*Asymmetric*	*Asymmetric*	*Asymmetric*
	Auto-Asymmetric Behavior	*Auto-Asymmetric*	*Auto-Asymmetric*	*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 (Default in Workbench-Mechanical)**
  - **More computationally expensive.**
  - **Interpreting data such as actual contact pressure can be more difficult**
    - **Results are reported on both sets of surfaces**
- **Asymmetric Behavior:**
  - **Workbench-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.**

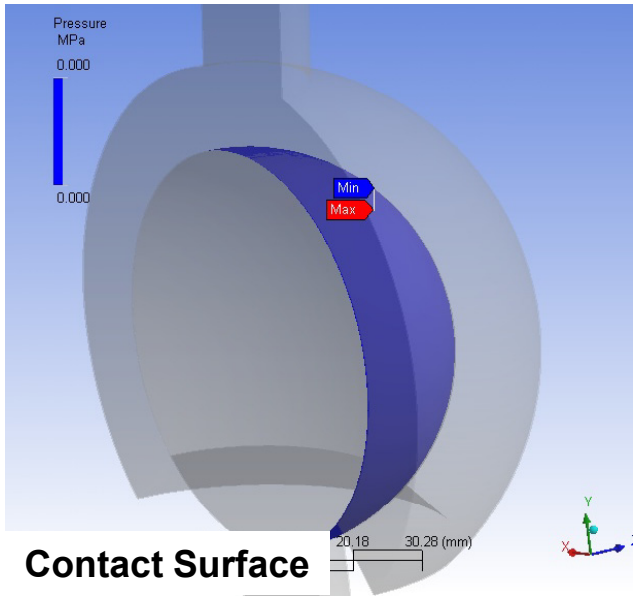
G. Contact results

- 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

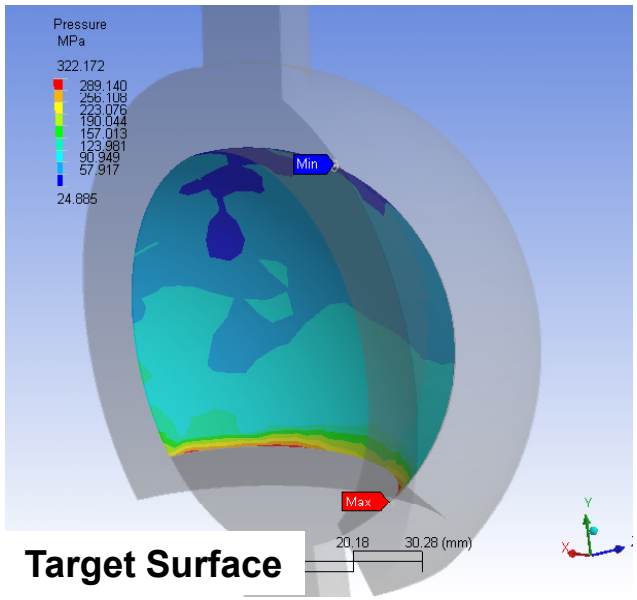


... Contact results

- **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.**



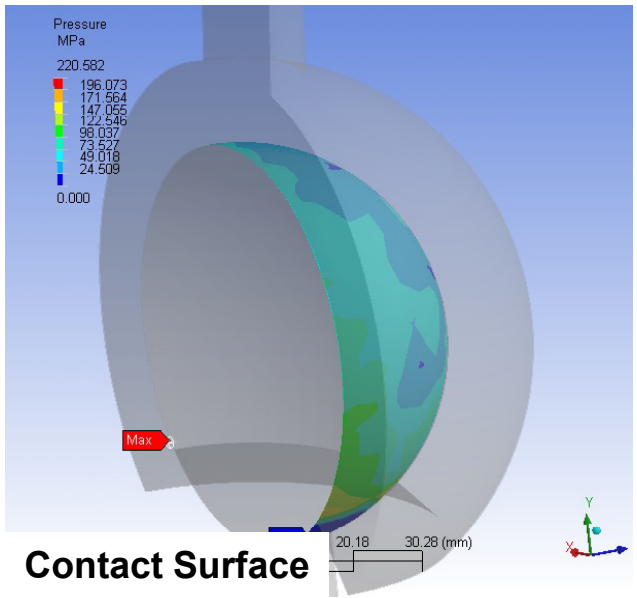
Contact Surface



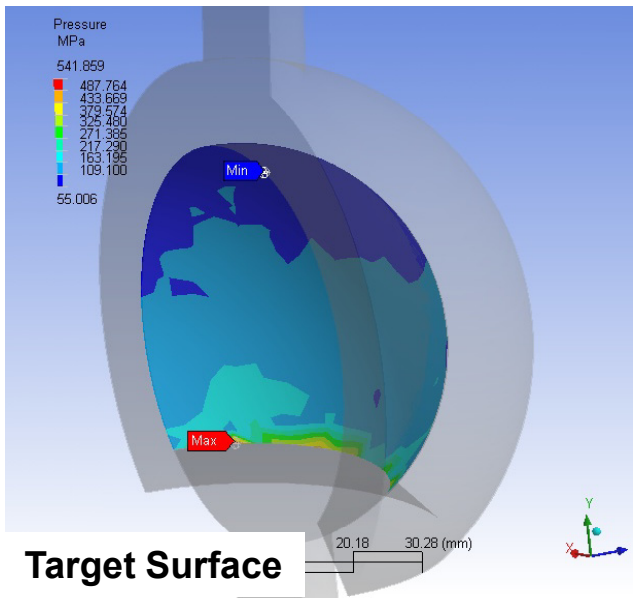
Target Surface

... 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.**



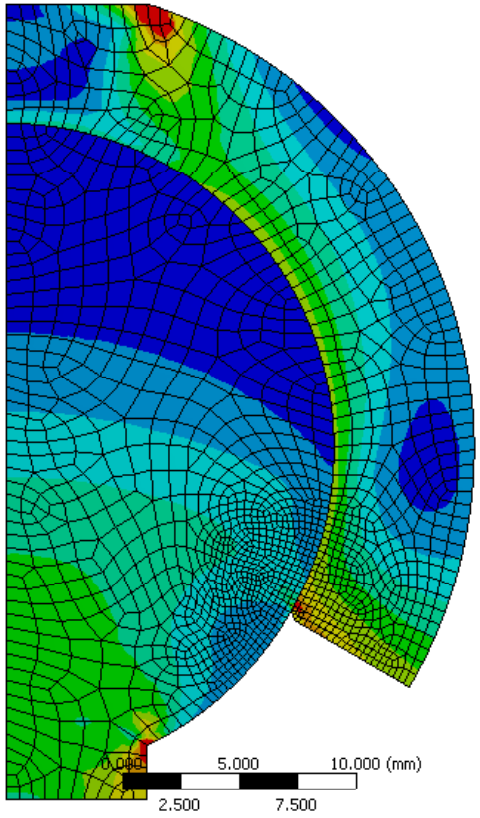
Contact Surface



Target Surface

H. Workshop – Symmetric vs Asymmetric

- **Please refer to your *Workshop Supplement* for instructions on*:***
- ***W3B Symmetric vs Asymmetric***

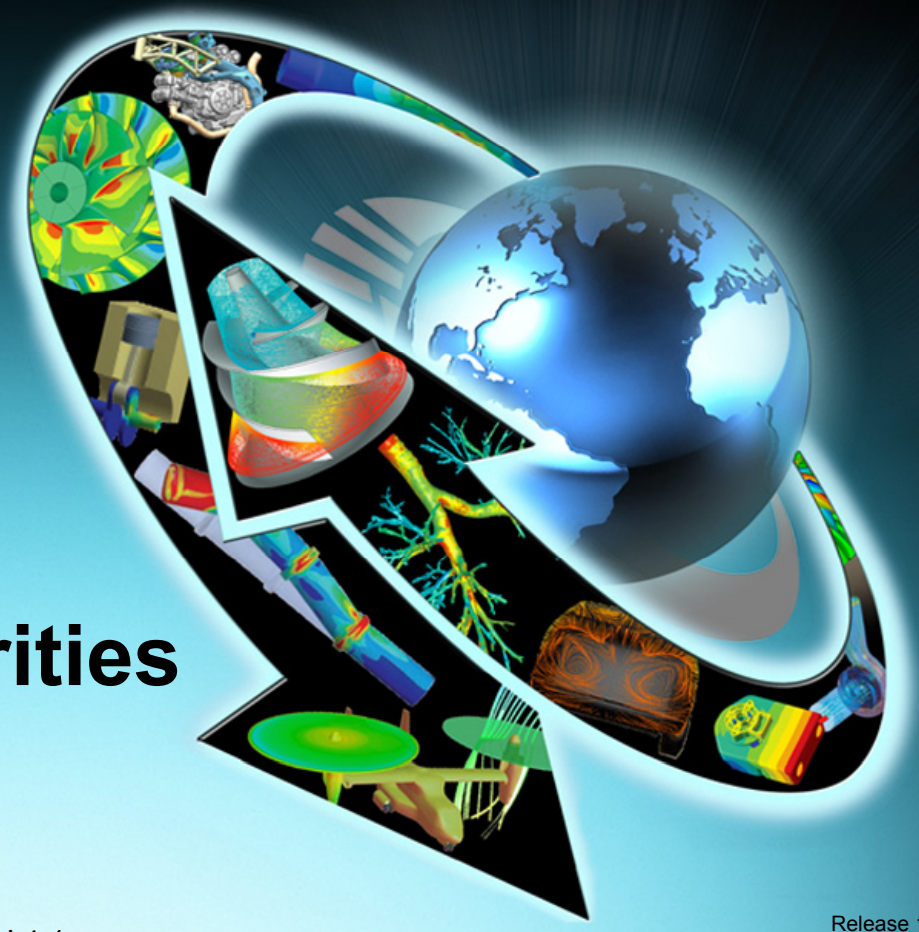


ANSYS®

Customer Training Material

Lecture 4

Advanced Contact



ANSYS Mechanical Structural Nonlinearities

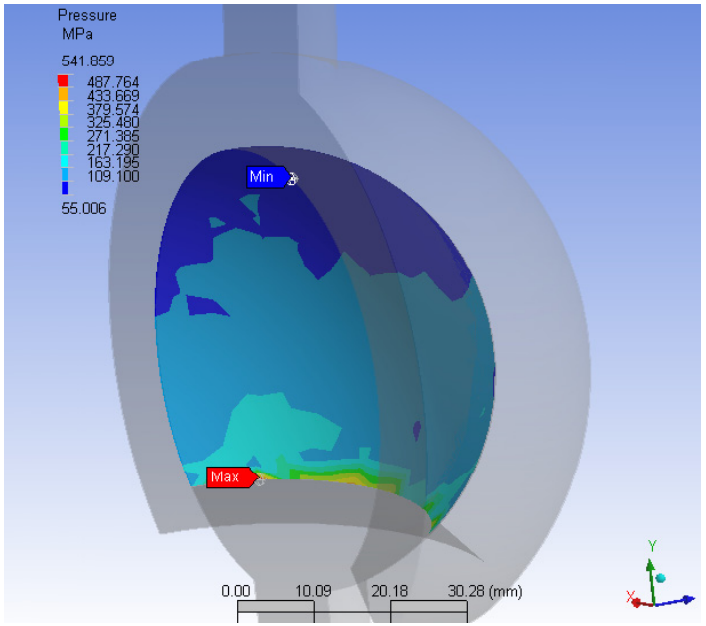
Chapter Overview

- **The various advanced *contact* options will be discussed in detail in this chapter:**
  - **These advanced options are applicable to contact involving both solid and shell body faces and edges.**
  - **It is assumed that the user has already covered Chapters 2 & 3 *Nonlinear Structural* prior to this chapter.**

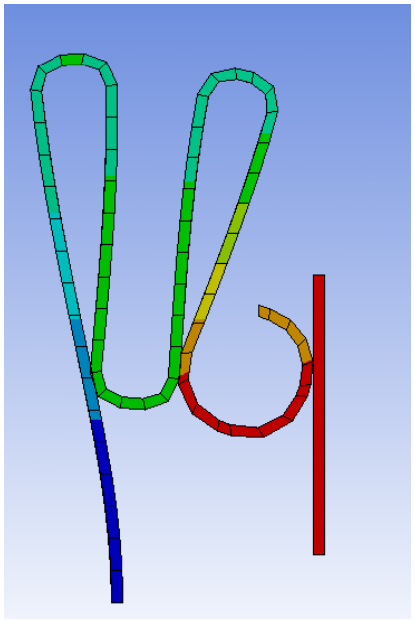
- **The following will be covered in this Chapter:**
  - **A. Body Types in Contact**
  - **B. Auto Contact Detection Options**
  - **C. Interface Treatments**
  - **D. Initial Contact Conditions**
  - **E. Workshop 4A**
  - **F. Time Step Controls**
  - **G. Friction**
  - **H. Workshop 4B**

A. Body Types in Contact

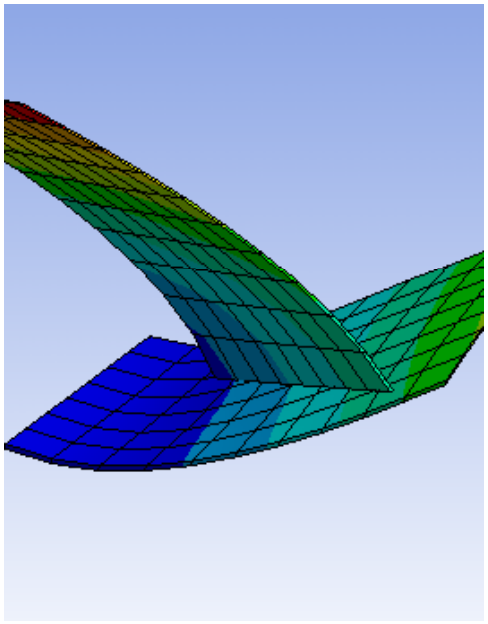
- **WB-Mechanical offers a rich library of Connection Technology Options to simulate many different behaviors between faces and edges of solid and surface bodies (meshed with shell elements).**



Solid Face to Solid Face



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

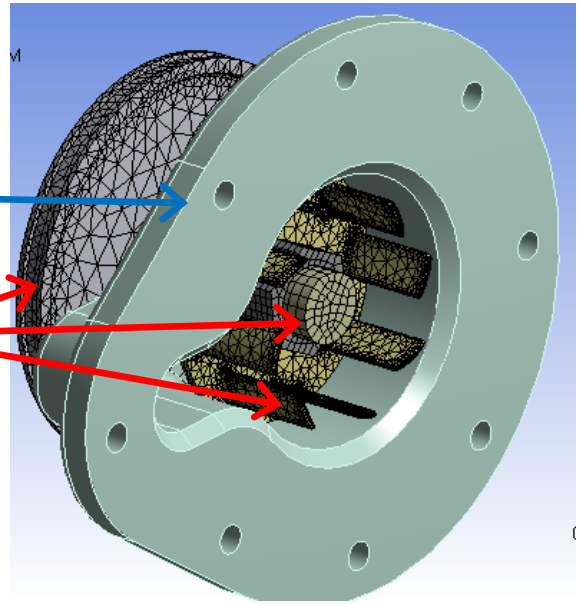


Surface Body Edge to Surface Body (or Solid) Face

... Body Types in Contact

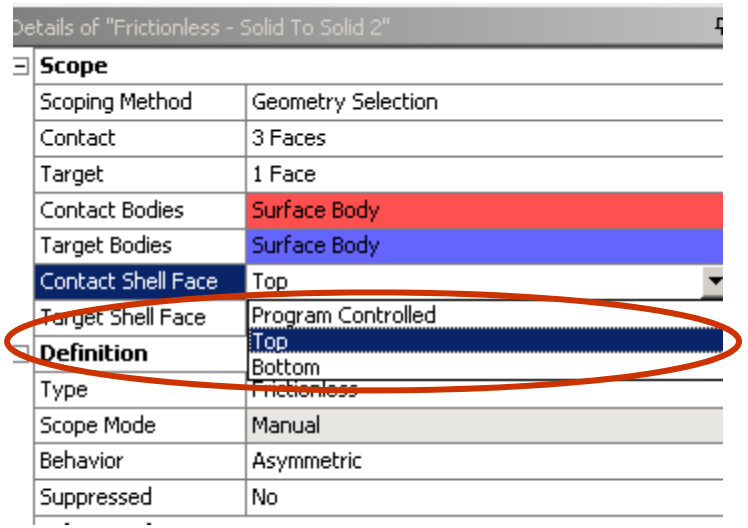
- **WB-Mechanical supports contact relationships between Rigid and Flexible bodies.**
  - **Useful for improved efficiency when one body is considerably stiffer then others**
  - **Only asymmetric behavior is support for rigid-flex contact regions with the Target always on the Rigid side**
  - **There are no contact related results reported on target surfaces associated with *Rigid* 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



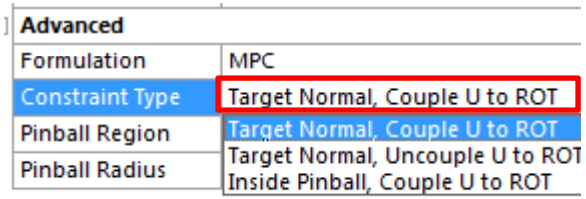
... Body Types in Contact

- 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.



... Body Types in Contact

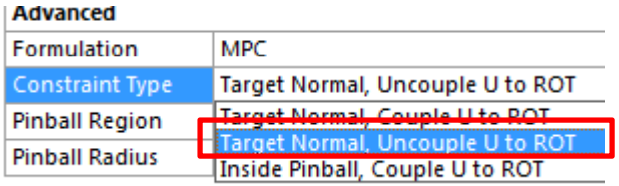
- **With MPC Formulation, there are different Constraint Types available to address unique challenges that can arise when using CEs (constraint equations) to connect entities together.**
  - ***"Target Normal, Couple U to ROT"*** **(default in WB-Mechanical) is sufficient for most applications**
  - **Note, the typical MPC equation listed below establishes a relationship between the rotational DOF of node 6212 on one surface body edge with displacement DOFs on adjacent surface**




```
CONSTRAINT EQUATION NO.  4379 HAS    19 TERMS.  CONSTANT=  0.000000
NODE=    6212  DIR= ROTY  COEFFICIENT=  1.000000
NODE=    5504  DIR= UX    COEFFICIENT= 0.1637390
NODE=    5504  DIR= UY    COEFFICIENT= 0.3567330E-01
NODE=    5504  DIR= UZ    COEFFICIENT=-0.3658861E-01
NODE=    5505  DIR= UX    COEFFICIENT= 0.1637390
NODE=    5505  DIR= UY    COEFFICIENT= 0.3567330E-01
NODE=    5505  DIR= UZ    COEFFICIENT= 0.1663785E-01
NODE=    5546  DIR= UX    COEFFICIENT=-0.1637390
NODE=    5546  DIR= UY    COEFFICIENT=-0.3567330E-01
NODE=    5546  DIR= UZ    COEFFICIENT= 0.1663785E-01
NODE=    5545  DIR= UX    COEFFICIENT=-0.1637390
NODE=    5545  DIR= UY    COEFFICIENT=-0.3567330E-01
NODE=    5545  DIR= UZ    COEFFICIENT=-0.3658861E-01
```

... Body Types in Contact

- ***"Target Normal, Uncouple U to ROT"*** **creates CEs that separate the rotational and displacement DOFs into separate equations to improve results for special applications to remove artificial stiffness at the connection.**



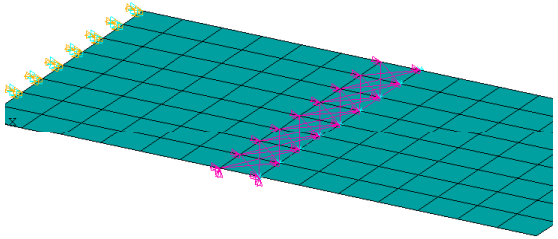

```
CONSTRAINT EQUATION NO.  4327 HAS     5 TERMS.  CONSTANT=  0.000000
NODE=     5916  DIR= UX    COEFFICIENT=  1.000000
NODE=     5176  DIR= UX    COEFFICIENT=-0.8160472E-01
NODE=     5177  DIR= UX    COEFFICIENT=-0.3053572
NODE=     5218  DIR= UX    COEFFICIENT=-0.4837571
NODE=     5217  DIR= UX    COEFFICIENT=-0.1292809

CONSTRAINT EQUATION NO.  4328 HAS     5 TERMS.  CONSTANT=  0.000000
NODE=     5916  DIR= UY    COEFFICIENT=  1.000000
NODE=     5176  DIR= UY    COEFFICIENT=-0.8160472E-01
NODE=     5177  DIR= UY    COEFFICIENT=-0.3053572
NODE=     5218  DIR= UY    COEFFICIENT=-0.4837571
NODE=     5217  DIR= UY    COEFFICIENT=-0.1292809

CONSTRAINT EQUATION NO.  4329 HAS     5 TERMS.  CONSTANT=  0.000000
NODE=     5916  DIR= UZ    COEFFICIENT=  1.000000
NODE=     5176  DIR= UZ    COEFFICIENT=-0.8160472E-01
NODE=     5177  DIR= UZ    COEFFICIENT=-0.3053572
NODE=     5218  DIR= UZ    COEFFICIENT=-0.4837571
NODE=     5217  DIR= UZ    COEFFICIENT=-0.1292809
```

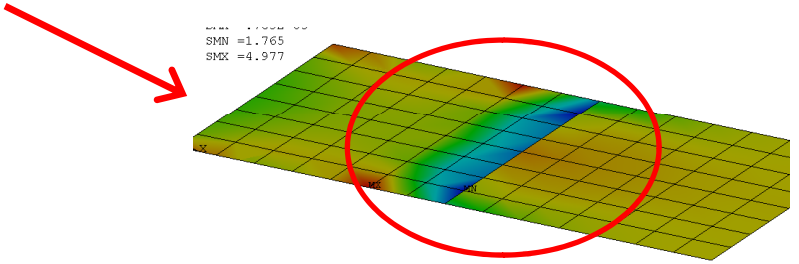
... Body Types in Contact

- **For example, consider the case of two surface body edges connected together with MPCs**

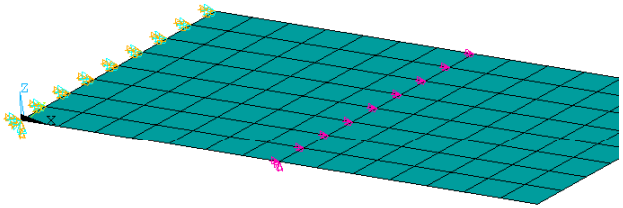
Advanced	
Formulation	MPC
Constraint Type	Inside Pinball, Couple U to ROT
Pinball Region	Target Normal, Couple U to ROT
Pinball Radius	Target Normal, Uncouple U to ROT
	Inside Pinball, Couple U to ROT

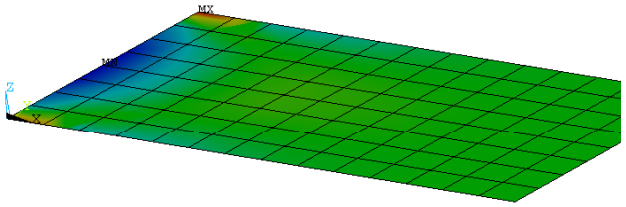
  - **The default, *"Target Normal, Couple U to ROT"*, creates too many constraints, causing an artificial stiffness at the connection and resulting in a discontinuity of stress and strain distribution that should not be there**





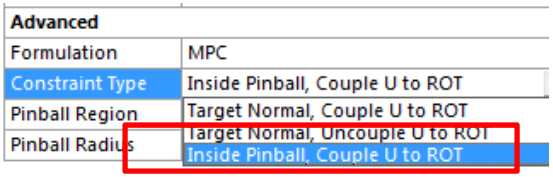
  - ***"Target Normal, Uncouple U to ROT"* produces expected results**



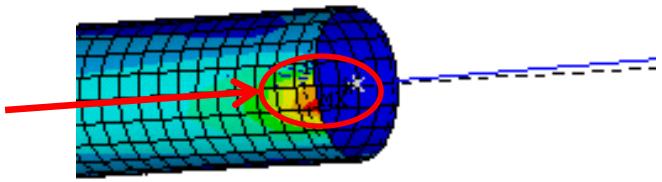


... Body Types in Contact

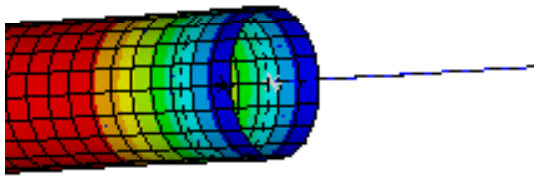
- ***"Inside Pinball, Couple U to ROT"*** **is similar to default, but allows contact detection around entire target master node, regardless of element normal direction**
  - **This option is especially helpful for unique applications of connecting a line body edge (vertex) with a shell or solid face or edge***



Only localized MPCs created with Default based on beam element normal direction



"Inside Pinball, Couple U to ROT" **option properly creates CEs using nodes around entire perimeter of shell edge, regardless of beam element normal direction**



*** Line body edge to Shell Edge contact is Beta in WB-Mechanical at Release 13**

... Body Types in Contact

The Following Table identifies supported contact types, formulations and whether symmetry is respected for various contact geometries

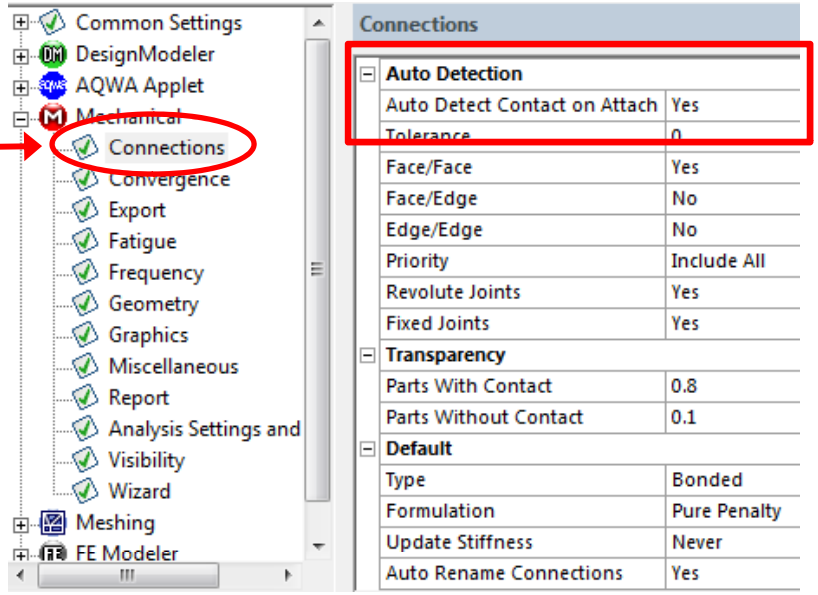
Contact Geometry	Solid Body Face (Scope = Contact)	Solid Body Edge (Scope = Contact)	Surface Body Face (Scope = Contact)	Surface Body Edge (Scope = Contact)
Solid Body Face (Scope = Target)	• **Types:** All • **Formulations:** All • **Symmetry Respected:** Yes	• **Types:** ○ Bonded ○ No Separation • **Formulations:** All • **Symmetry Respected:** No	• **Types:** All • **Formulations:** All • **Symmetry Respected:** Yes	• **Types:** All • **Formulations:** ○ Augmented Lagrange ○ Pure Penalty ○ MPC • **Symmetry Respected:** No
Solid Body Edge (Scope = Target)	Not supported for solving[1]	• **Types:** All • **Formulations:** All • **Symmetry Respected:** No	Not supported for solving[1]	• **Types:** All • **Formulations:** All • **Symmetry Respected:** No
Surface Body Face (Scope = Target)	• **Types:** All • **Formulations:** All • **Symmetry Respected:** Yes	• **Types:** All • **Formulations:** All • **Symmetry Respected:** No	• **Types:** All • **Formulations:** All • **Symmetry Respected:** Yes	• **Types:** All • **Formulations:** ○ Augmented Lagrange ○ Pure Penalty ○ MPC • **Symmetry Respected:** No
Surface Body Edge (Scope = Target)	Not supported for solving[1]	• **Types:** All • **Formulations:** ○ Augmented Lagrange ○ Pure Penalty ○ MPC • **Symmetry Respected:** No	Not supported for solving[1]	• **Types:** All • **Formulations:** ○ Augmented Lagrange ○ Pure Penalty ○ MPC • **Symmetry Respected:** No

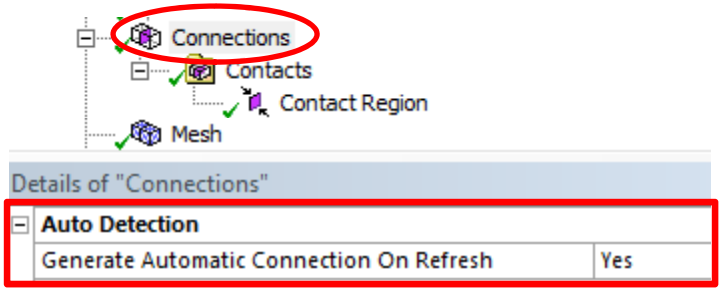
1 - For Face/Edge contact, faces must always be designated as targets and edges must always be designated as contacts.

B. Auto Contact Detection Options

- By default, when an assembly is imported or updated from a CAD system, contact is automatically detected and contact regions are assigned for face/face conditions.
- The switch to activate auto detection can be controlled in two ways:

From Utility Menu=>Tool =>Options Dialogue Box under the Mechanical Connections Settings for auto detection upon attaching geometry



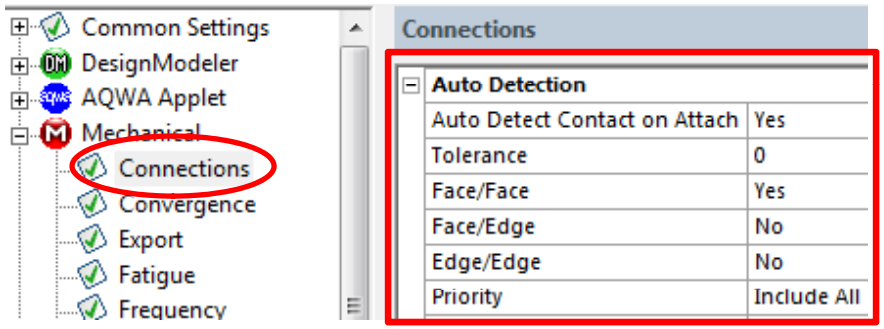


By highlighting “Connections” branch in the Project tree for auto detection upon model refreshing.

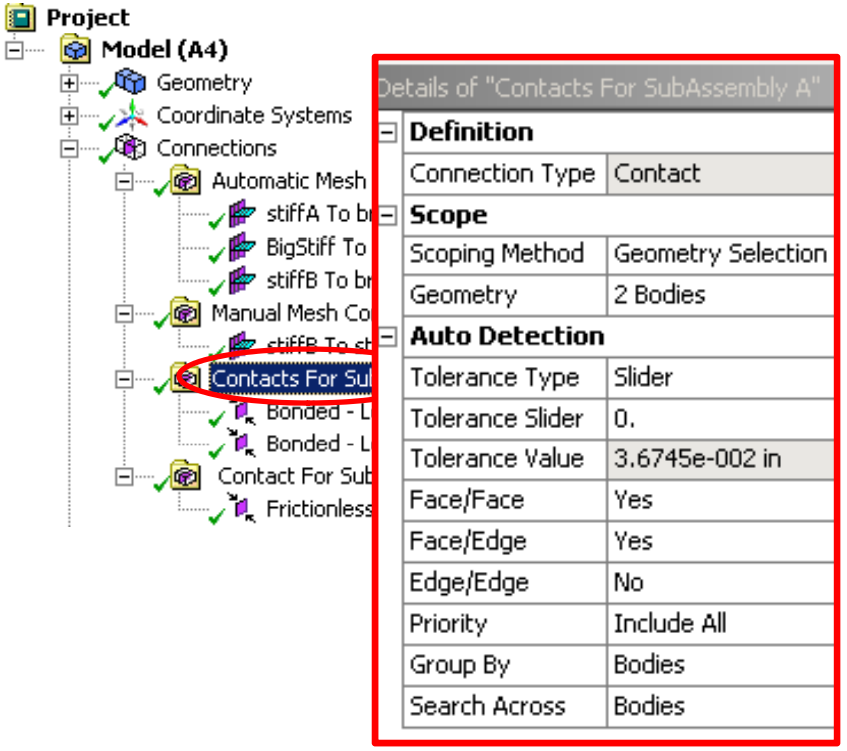
... Auto Contact Detection Options

- **The auto detection parameters can be controlled globally (from Tools Options Dialogue Box) or locally (from the details windows associated with individual contact folders)**

Global control of all connections

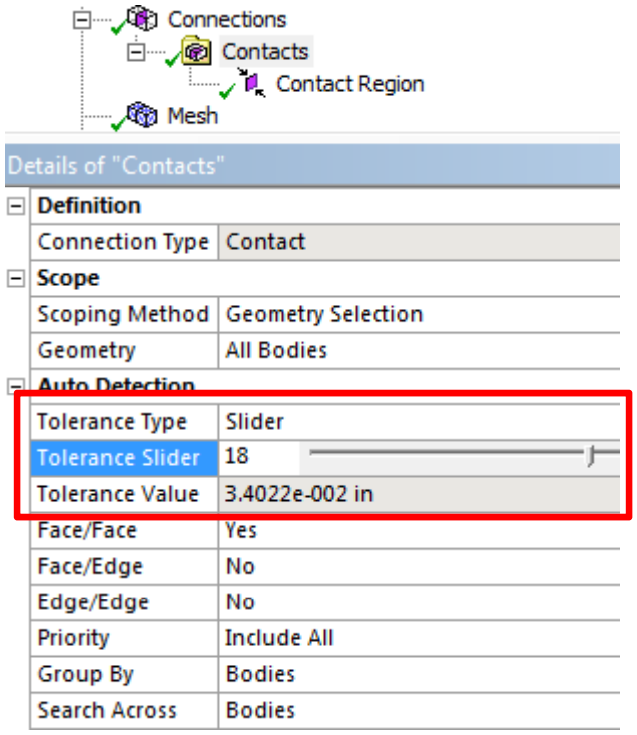


Local control of grouped connections

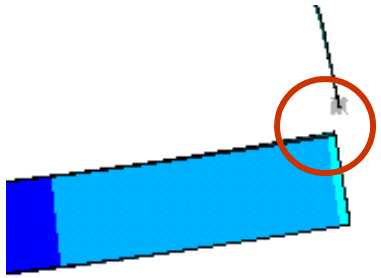


... Auto Contact Detection Options

- **Although the default settings are sufficient for most contact problems, these additional controls broaden the range of capabilities**



Tolerance Type, Tolerance Value, and Tolerance Slider: Bodies in an assembly that were created in a CAD system may not have been placed precisely, resulting in small overlaps or gaps along the contact regions between bodies. You can account for any imprecision by specifying contact detection tolerance (applicable to automatic contact detection only).



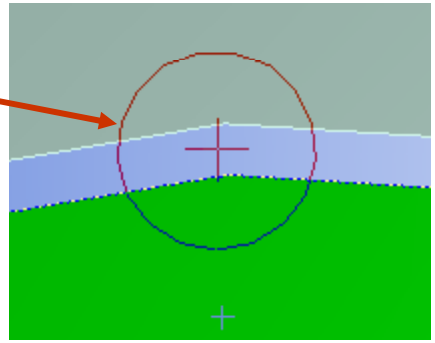
... Auto Contact Detection Options

- To tighten the contact detection between bodies, move the Tolerance Slider bar closer to +100. To loosen the contact detection, move the Tolerance Slider bar closer to -100.
  - A tighter tolerance means that the bodies have to be within a smaller region (of either gap or overlap) to be considered in contact; a loose tolerance will have the opposite effect.

- Contact detection tolerance can also be adjusted using an exact distance by changing the Tolerance Type to Value and entering a specific distance in the Tolerance Value field.
  - A circle appears around the current cursor location as shown here.

Details of "Contacts"	
Definition	
Connection Type	Contact
Scope	
Scoping Method	Geometry Selection
Geometry	All Bodies
Auto Detection	
Tolerance Type	Value
Tolerance Value	3.4022e-002 in
Face/Face	Yes
Face/Edge	No
Edge/Edge	No

Graphical Illustration of user defined tolerance value for contact detection



Existing gap between CAD parts

... Auto Contact Detection Options

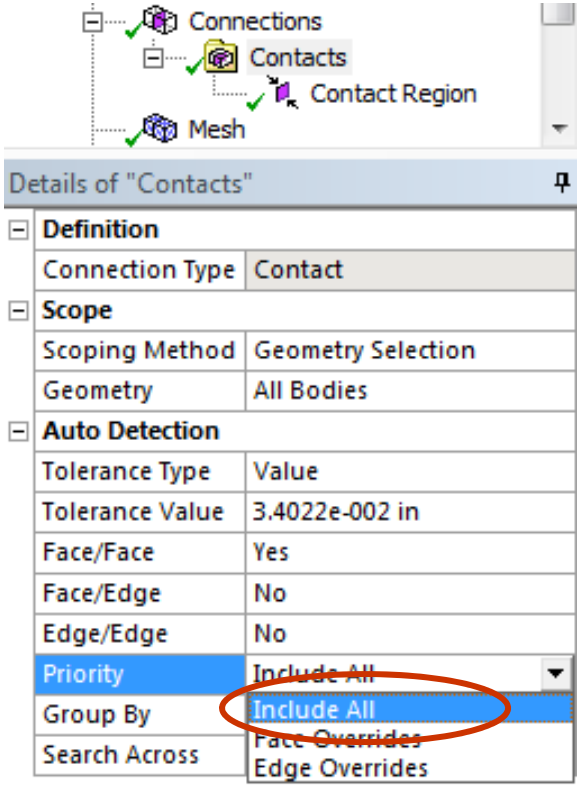
- **Types of Contact Detection available between solid and surface bodies:**
  - **Face/Face: contact between faces of different bodies**
  - **Face/Edge: contact between faces and edges of different bodies**
  - **Edge/Edge: contact between edges of different bodies**

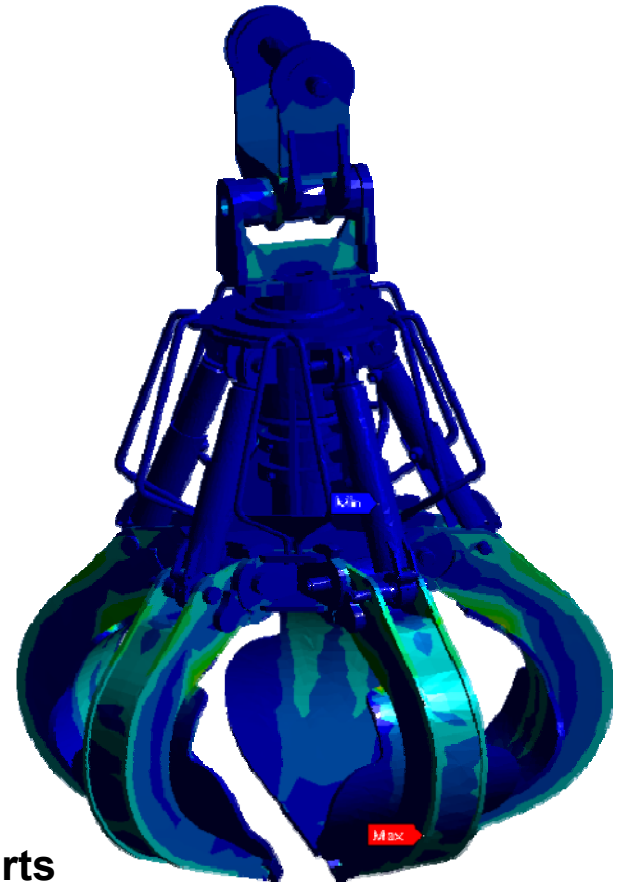
- **Face/Edge and Edge/Edge contact only applies to solid and surface bodies.**
  - **Contact relationships involving line bodies are not supported.**

- **For Face/Edge detection, faces are always designated as targets and edges are always designated as contacts.**
  - **You can select any combination of contacts to be detected during "Create Automatic Connections". You can also set default preferences for these contact filter options.**

... Auto Contact Detection Options

- **Priority: For very large models the number of contact regions can sometimes become overwhelming and redundant, especially when multiple types of contact are allowed.**





- **209 parts**
- **450 symmetric contact pairs**
- **1.15million DOFs**

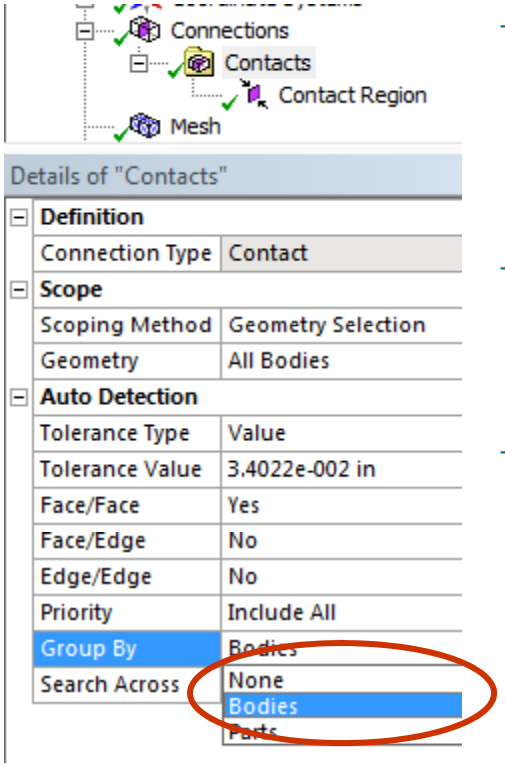
... Auto Contact Detection Options

- **Priority (cont'd)**
  - ***"Face Overrides"*** **gives Face/Face contact precedence over both Face/Edge and Edge/Edge contact. Face Overrides also gives Face/Edge contact precedence over Edge/Edge contact.**
    - **In general, when Face Overrides priority is set with Face/Edge and Edge/Edge contact, no Edge/Edge contact pairs will be detected.**
  - ***"Edge Overrides"*** **gives Edge/Edge contact precedence over both Face/Edge and Face/Face contact. Edge Overrides also gives Face/Edge contact precedence over Face/Face contact.**
    - **In general, when Edge Overrides priority is set with Face/Edge and Face/Face contact, no Face/Face contact pairs will be detected.**

... Auto Contact Detection Options

- **Group By:**

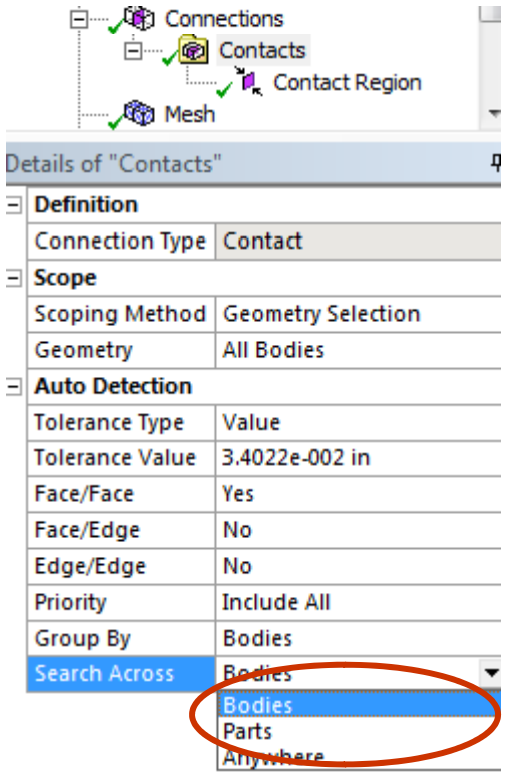
Setting "Group By" equal to "Bodies" (default) or to Parts means that contact faces and edges that lie on the same bodies or same parts will be "grouped into a single region.



- **Automatically generated pairs may have multiple selections on the source side, or on the target side, or on both sides. Using one of these options can minimize the number of contact regions created.**
- **Any regions generated will have only one entity scoped to its source and target (that is, one face or one edge).**
- **Choosing None avoids excessive contact search times in the ANSYS solver if there are a large number of source/target faces in a single region.**

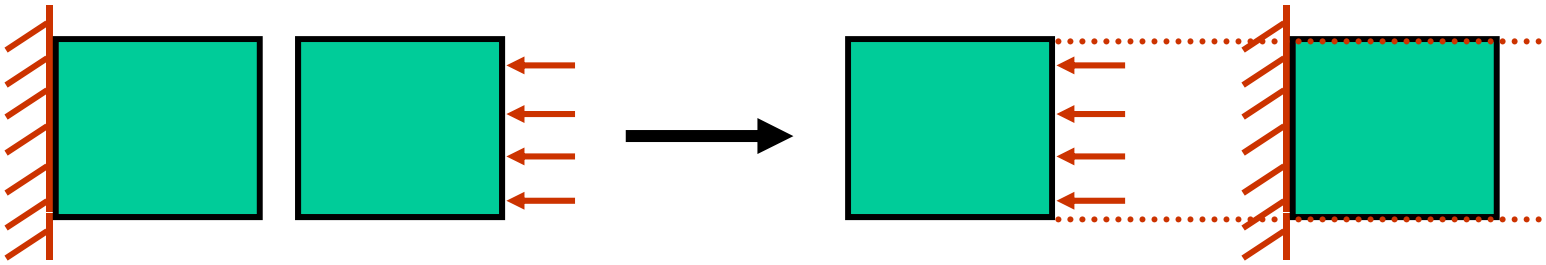
... Auto Contact Detection Options

- **Search Across:** **Enables automatic contact detection through the following options:**
  - **Bodies (default): Between bodies.**
  - **Parts: Between only bodies of different parts, that is, not between bodies within the same multibody part.**
    - **For a body within a multibody part that does not touch another body, you must manually insert a Connections object to connect the bodies.**
  - **Anywhere: Detects any self-contact.**



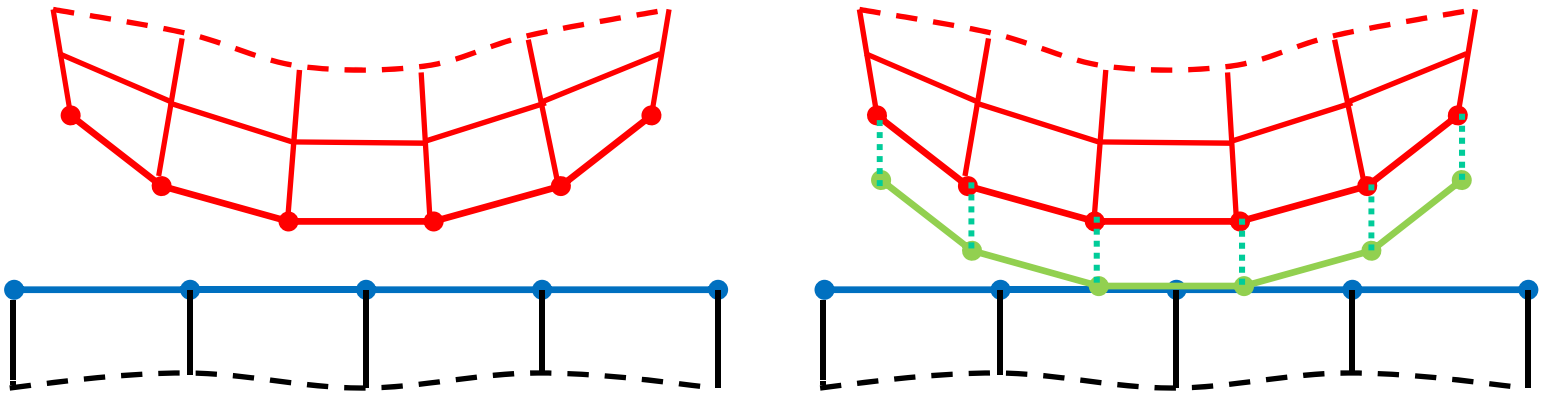
C. Interface Treatment

- In the previous Chapter, it was noted that for Bonded Behavior, a large enough Pinball Radius may allow any gap between Contact and Target surfaces to be ignored
- For Frictional or Frictionless Behavior, bodies can come in and out of contact with one another. Consequently, an initial gap is not automatically ignored since that may represent the geometry.
- However, the finite element method does not allow for rigid-body motion in a static structural analysis. If an initial gap is present and a force loading is applied, initial contact may *not* be established, and one part may "fly away" relative to another part.



… Interface Treatment

- **To alleviate situations where a clearance or gap is modeled but needs to be ignored to establish initial contact for Frictional or Frictionless Behavior, the Interface Treatment can internally *offset* the Contact surfaces by a specified amount.**
  - **On the left is the original model (mesh). The top red mesh is the body associated with the Contact surfaces**
  - **The Contact surface can be offset by a certain amount, as shown on the right in light green. This will allow for initial contact to be established.**

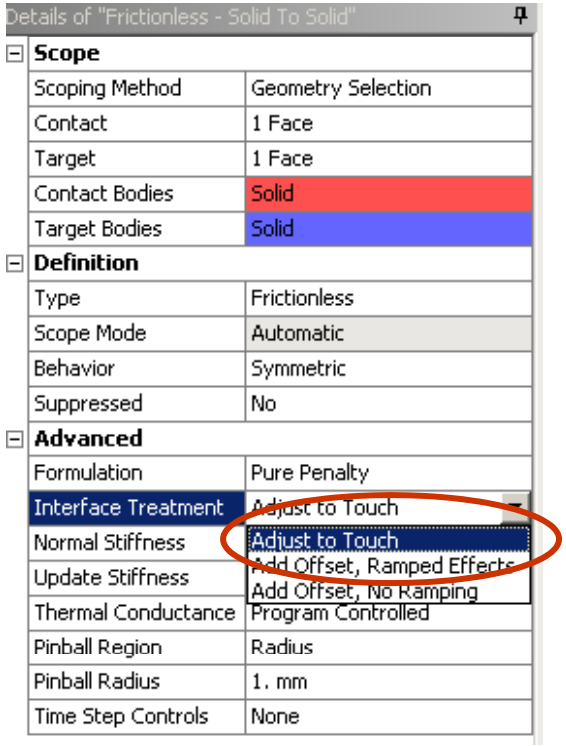


… Interface Treatment

- **Important notes of Contact Offset Feature:**
  - **It will have the effect of a change in geometry at the contact interface since a “rigid” region will exist between the actual mesh and the offset Contact surface.**
  - **It is intended for applications where this adjustment is small enough to have a negligible effect on overall results.**
  - **It has proven to be a useful tool to establish initial contact in static analyses without having to modify the CAD geometry.**

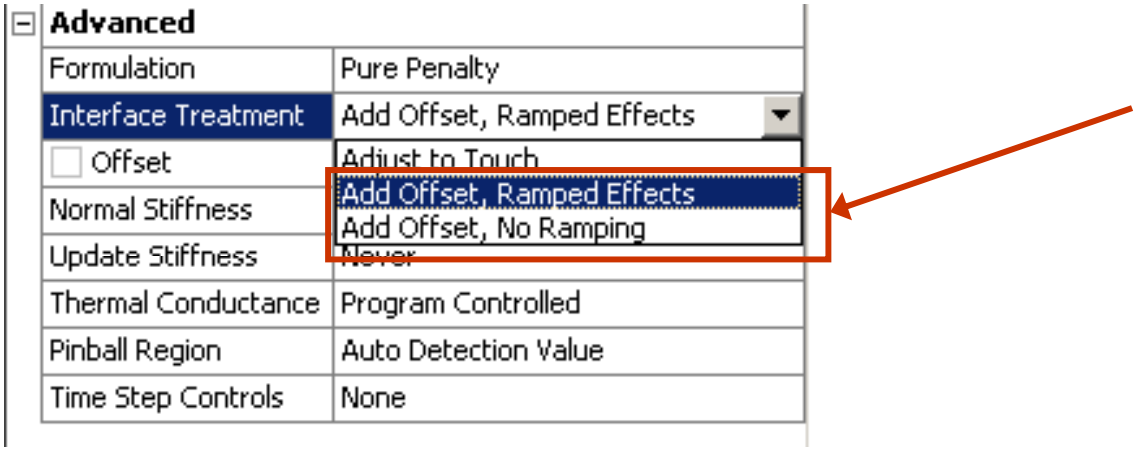
… Interface Treatment

- **In the Details view, the user can select "Adjusted to Touch" or "Add Offset"**
  - **"Adjusted to Touch" will let WB-Mechanical determine what contact offset amount is needed to close the gap and establish initial contact. Note that the size of the Pinball Region will affect this automatic method, so ensure that the Pinball Radius is greater than the smallest gap distance.**
  - **"Add Offset" allows the user to specify a positive *or* negative distance to offset the contact surface. A positive value will tend to close a gap while a negative value will tend to open a gap.**
    - **This can be used to model initial interference fits without modifying the geometry. Model the geometry in just-touching position and change the positive distance value to the interference value.**



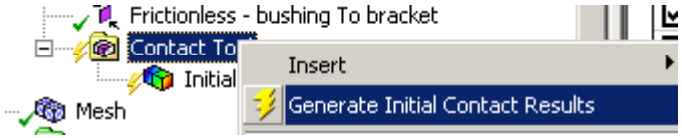
… Interface Treatment

- **"Add Offset, Ramped Effects" - Applies the interference gradually over several substeps within a load step.**
  - **This option is useful to enhance convergence for challenging interference problems.**
- **"Add Offset, No Ramping" - Applies the interference all at once in first substep.**

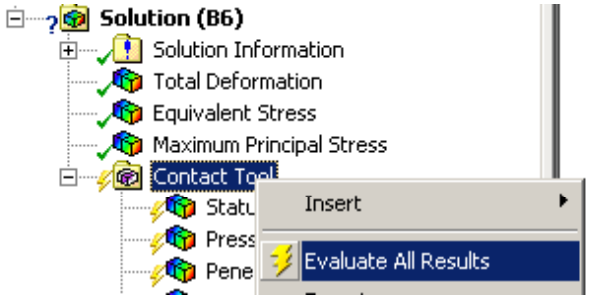


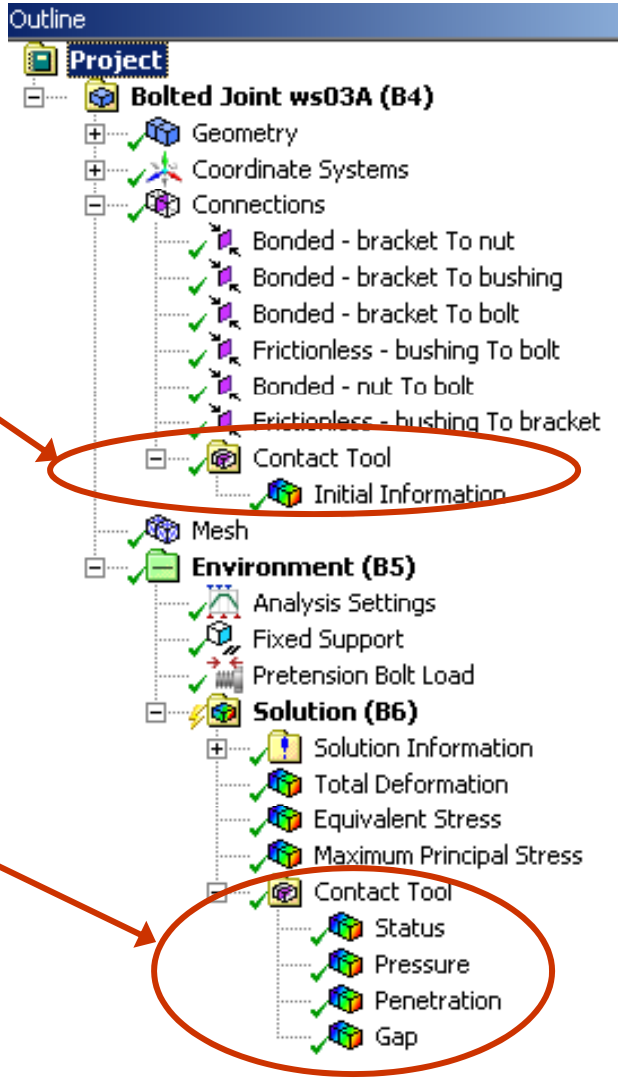
D. Contact Tool

- **The Contact Tool is an object that allows you to examine assembly contact:**
  - **Before loading to verify initial Information (Status, gap, penetration, pinball,..etc)**
    - **Insert under a Connections branch**



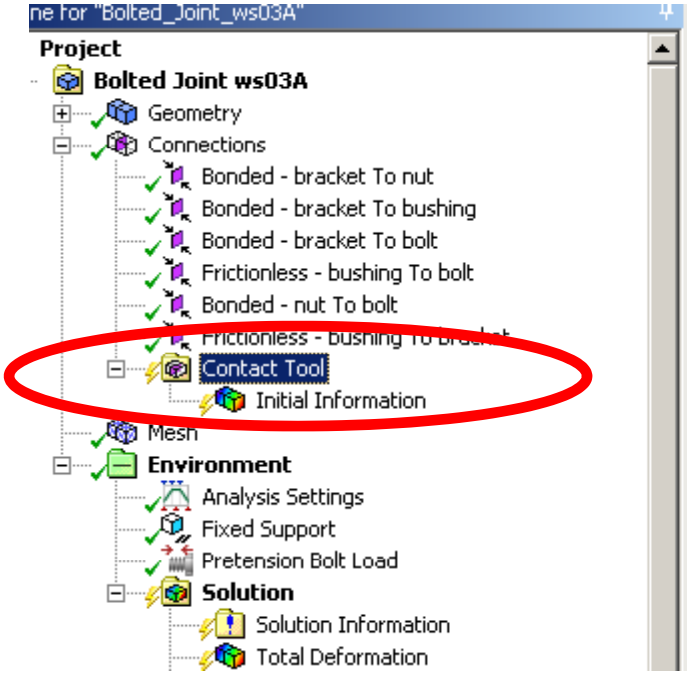
  - **As part of the final solution to verify final information and the transfer of loads (forces and moments) across the various contact regions.**
    - **Insert under a Solution branch object**

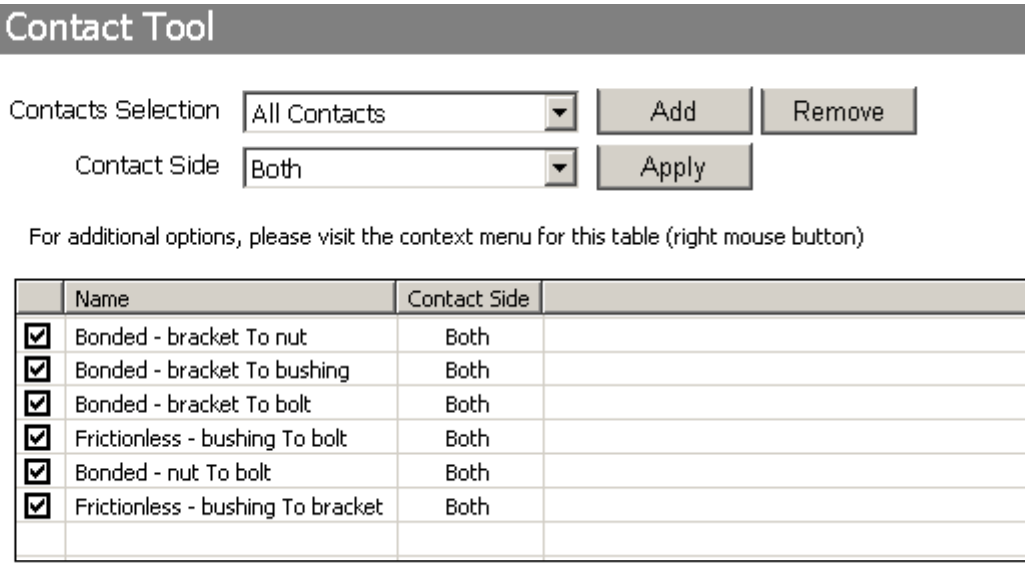




... Contact Tool – Initial Information

- **Initial contact information can be scoped to evaluate all regions or specific regions of interest on both contact and/or target sides.**





... Contact Tool – Initial Information

- **Information such as status, number of elements contacting, penetration, pinball, etc… for each region can be very useful for verification and troubleshooting**

Name	Contact Side	Type	Status	Number Contacting	Penetration (mm)	Gap (mm)	Geometric Penetration (mm)	Geometric Gap (mm)	Resulting Pinball (mm)	Real Constant
Bonded - bracket To nut	Contact	Bonded	Closed	16.	0.	0.	1.3643e-012	0.75631	0.9839	5.
Bonded - bracket To nut	Target	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	0.
Bonded - bracket To bushing	Contact	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	7.
Bonded - bracket To bushing	Target	Bonded	Closed	25.	0.	0.	1.5916e-012	1.819e-012	1.0833	8.
Bonded - bracket To bolt	Contact	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	9.
Bonded - bracket To bolt	Target	Bonded	Closed	268.	0.	0.	0.31281	0.30317	0.3291	10.
Frictionless - bushing To bolt	Contact	Frictionless	Near Open	0.	0.	0.13058	0.	N/A	8.582	11.
Frictionless - bushing To bolt	Target	Frictionless	Near Open	0.	0.	0.13006	0.	N/A	3.0728	12.
Bonded - nut To bolt	Contact	Bonded	Closed	49.	0.	0.	0.5	0.	0.7012	13.
Bonded - nut To bolt	Target	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	14.
Frictionless - bushing To bracket	Contact	Frictionless	Near Open	0.	0.	1.5	0.	N/A	8.663	15.
Frictionless - bushing To bracket	Target	Frictionless	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	0.

Color Legend

Red	The contact status is open but the type of contact is meant to be closed. This applies to bonded and no separation contact types.
Yellow	The contact status is open. This may be acceptable.
Orange	The contact status is closed but has a large amount of gap or penetration. Check penetration and gap compared to pinball and depth.
Gray	Contact is inactive. This can occur for MPC and Normal Lagrange formulations. It can also occur for auto asymmetric behavior.

... Contact Tool – Initial Information

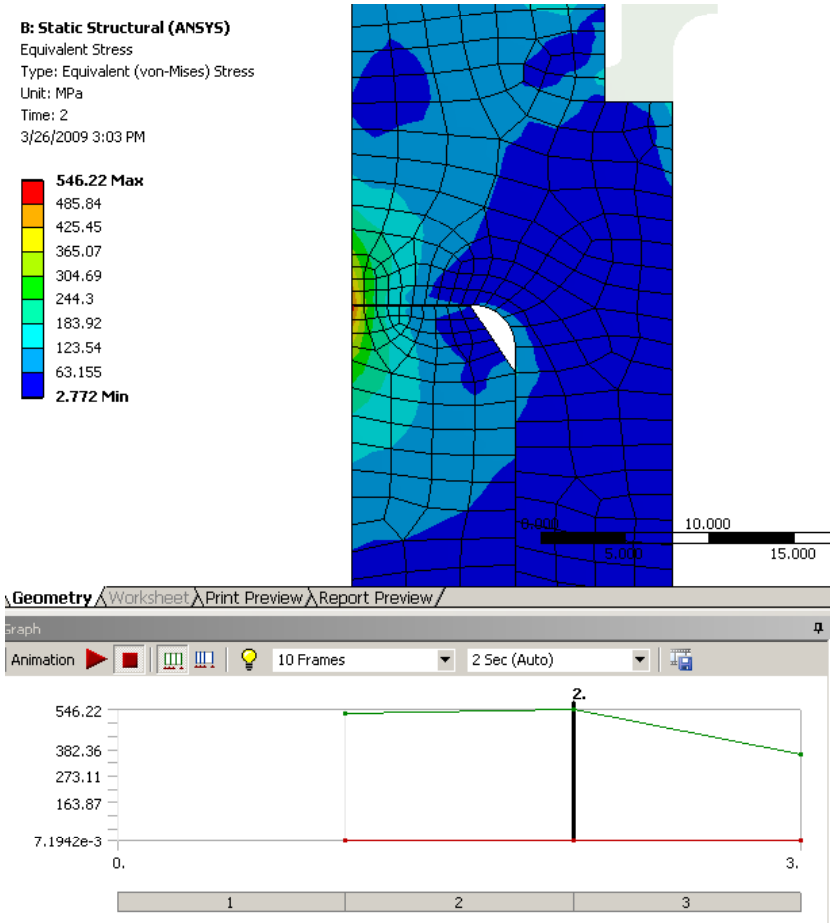
- "Geometric Gap" and "Geometric Penetration" are the physical gap and penetration that exists at a contact region between solid bodies
- "Gap" and "Penetration" are derived values resulting from Add Offset adjustments or between surface bodies

Name	Contact Side	Type	Status	Number Contacting	Penetration (mm)	Gap (mm)	Geometric Penetration (mm)	Geometric Gap (mm)	Resulting Pinball (mm)	Real Constant
Bonded - bracket To nut	Contact	Bonded	Closed	16.	0.	0.	1.3643e-012	0.75631	0.9839	5.
Bonded - bracket To nut	Target	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	0.
Bonded - bracket To bushing	Contact	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	7.
Bonded - bracket To bushing	Target	Bonded	Closed	25.	0.	0.	1.5916e-012	1.819e-012	1.0833	8.
Bonded - bracket To bolt	Contact	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	9.
Bonded - bracket To bolt	Target	Bonded	Closed	268.	0.	0.	0.31281	0.30317	0.3291	10.
Frictionless - bushing To bolt	Contact	Frictionless	Near Open	0.	0.	0.13058	0.	N/A	8.582	11.
Frictionless - bushing To bolt	Target	Frictionless	Near Open	0.	0.	0.13006	0.	N/A	3.0728	12.
Bonded - nut To bolt	Contact	Bonded	Closed	49.	0.	0.	0.5	0.	0.7012	13.
Bonded - nut To bolt	Target	Bonded	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	14.
Frictionless - bushing To bracket	Contact	Frictionless	Near Open	0.	0.	1.5	0.	N/A	8.663	15.
Frictionless - bushing To bracket	Target	Frictionless	Inactive	N/A	N/A	N/A	N/A	N/A	N/A	0.

- The "N/A" designation appears in the following locations and situations:
  - All result columns when the contact pair is inactive (row is gray, or Inactive appears under the Status column).
  - The Geometric Gap column for Frictionless, Rough, or Frictional contact Types and an Interface Treatment set to Add Offset.

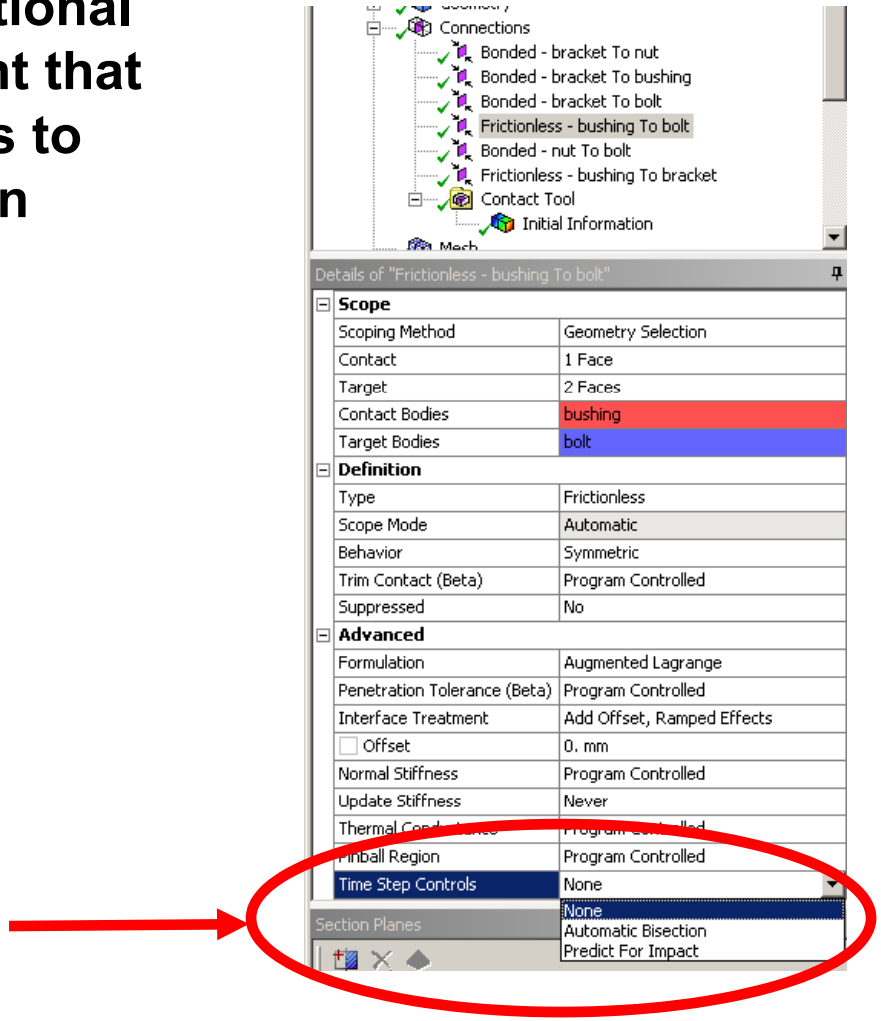
E. Workshop – Contact Surface Offset

- **Please refer to your *Workshop Supplement* for instructions on:**
- ***W4A- Contact Surface Offset***



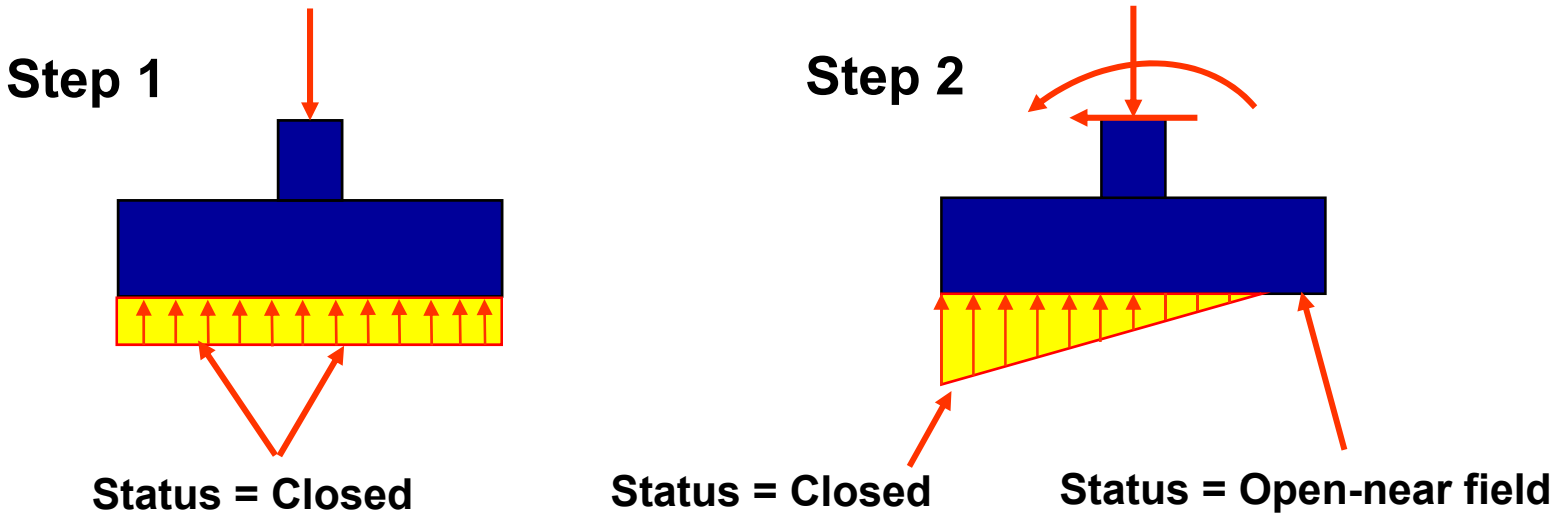
F. Time Step Controls

- **Time Step Controls offers an additional layer of convergence enhancement that allows bisections and adjustments to time step size based on changes in contact behavior.**
- **This choice is displayed only for nonlinear contact:**
  - **Frictionless**
  - **Rough**
  - **Frictional**



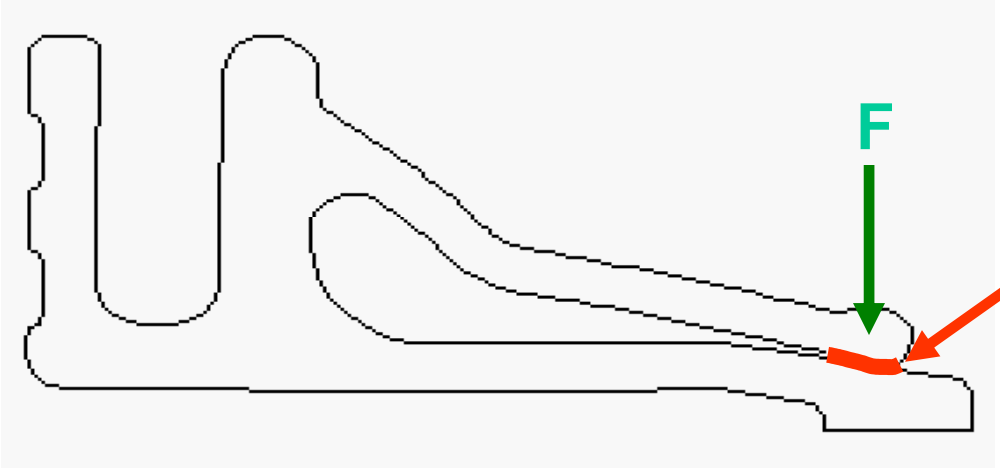
… Time Step Controls

- By default, changes in contact behavior do not influence automatic time stepping. This is appropriate for most analyses when bisections triggered by contact status change might be a detriment to overall run time efficiency.
- In the example below, there is no benefit to reducing the time step because of the contact status change (from closed to open). Yet, auto time stepping for other criteria often still is desirable.



… Time Step Controls

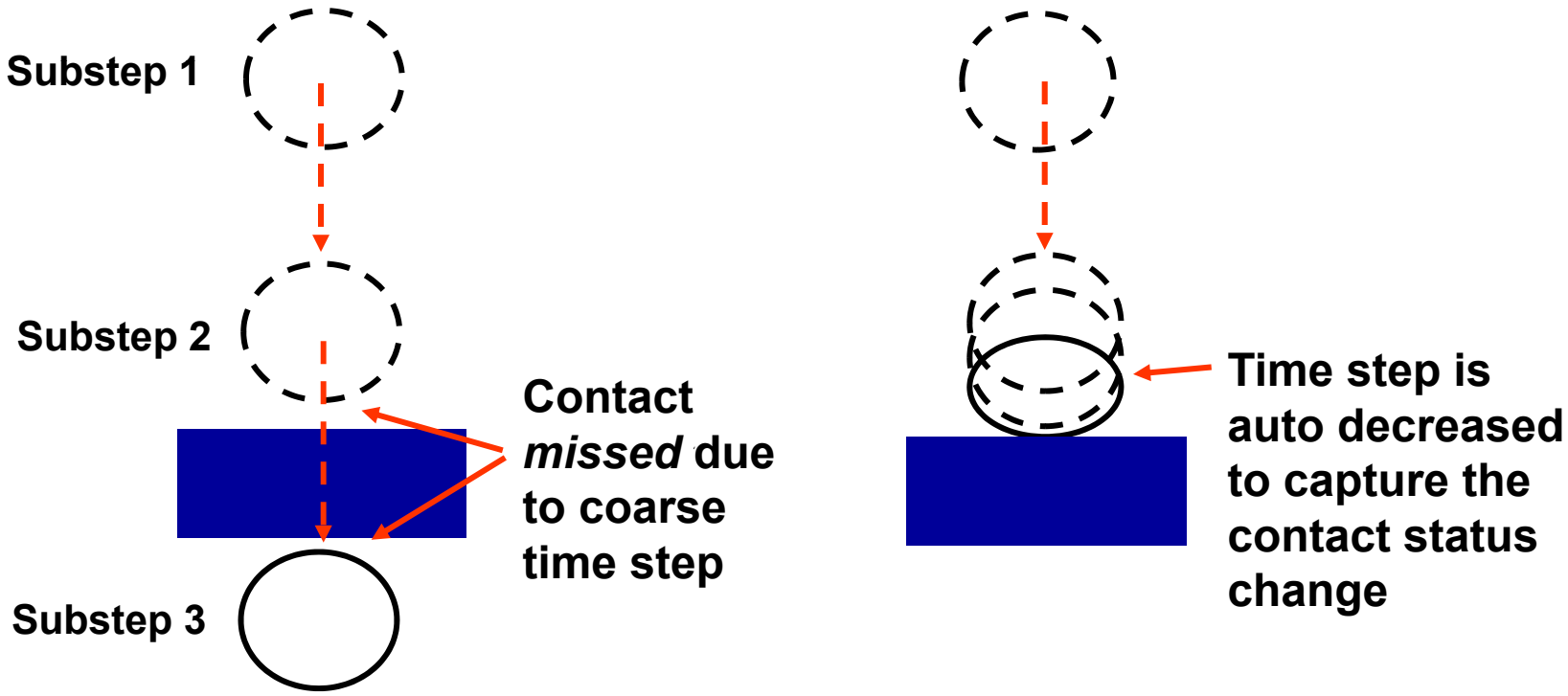
- Automatic Bisection - Contact behavior is reviewed at the end of each substep to determine whether excessive penetration or drastic changes in contact status have occurred. If so, the current substep is re-evaluated using a "bisected" time increment (reduced by half).
- In the example below, automatic bisection might enhance convergence when a localized contact status change results in a dramatic change in the stiffness response of the overall structure.



Use auto time step for contact status change in this region only.

… Time Step Controls

- **Predict for Impact - Same as the Automatic Bisection option except that this option also predicts the minimal time increment needed to detect future changes in contact status.**
  - **Recommended if impact is anticipated.**



G. Frictional Contact Options

- In addition to the above, *frictional contact* is available with *ANSYS Structural* licenses and above.
- In general, the tangential or sliding behavior of two contacting bodies may be frictionless or involve friction.
  - Frictionless behavior allows the bodies to slide relative to one another without any resistance.
  - When friction is included, shear forces can develop between the two bodies.
- Frictional contact may be used with small-deflection or large-deflection analyses

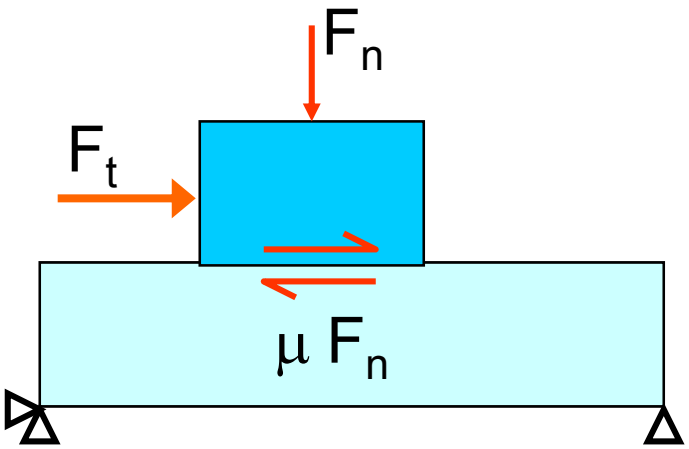
… Frictional Contact Options

- **Friction is accounted for with Coulomb's Law:**

$$F_{tangential} \leq \mu \cdot F_{normal}$$

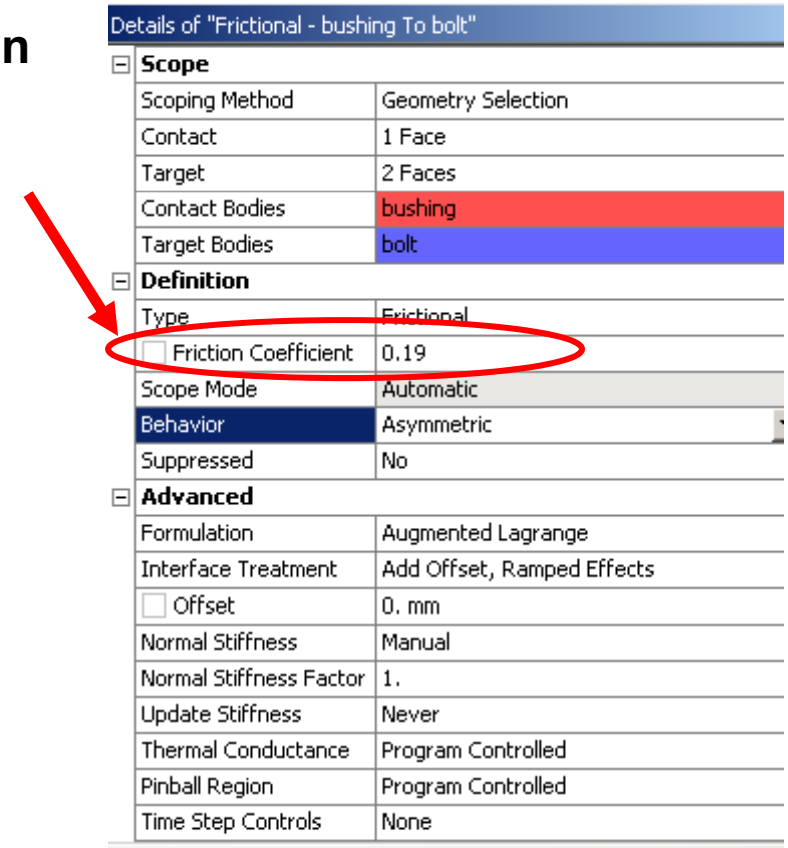
where μ is the coefficient of static friction

- **Once the tangential force $F_{tangential}$ exceeds the above value, sliding will occur**



… Frictional Contact Options

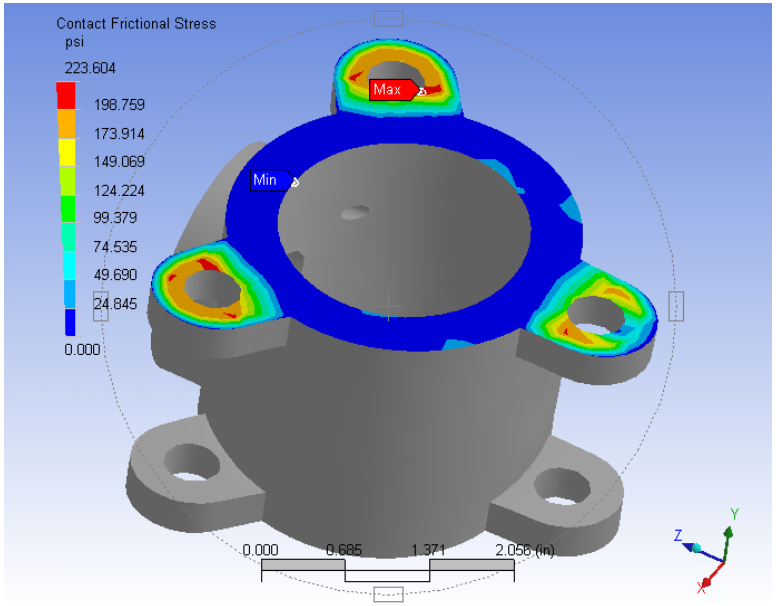
- **In addition to the above, *frictional contact* is available with *ANSYS Structural* licenses and above.**
- **For frictional contact, a "friction coefficient" must be input**
  - **A Friction Coefficient μ of 0.0 results in the same behavior as "frictionless" contact**
  - **The contact formulation, as noted earlier, is recommended to be set to "Augmented Lagrange"**

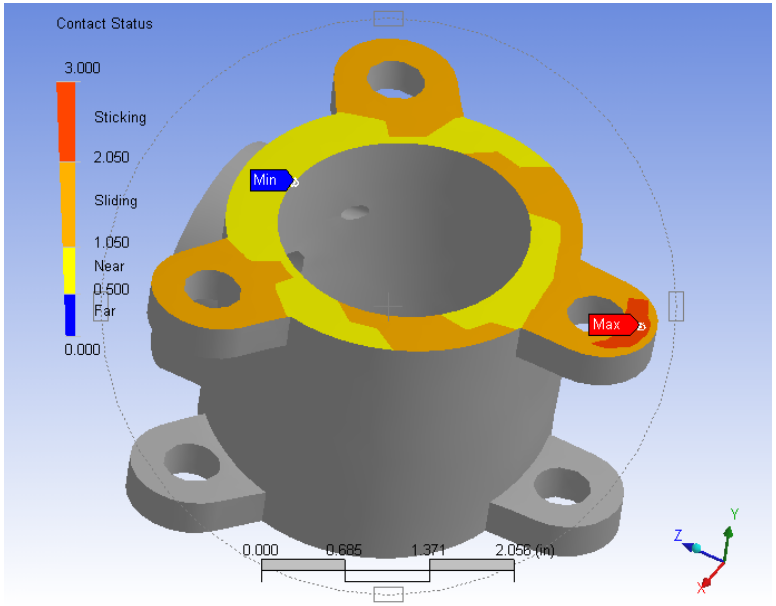


Details of "Frictional - bushing To bolt"	
Scope	
Scoping Method	Geometry Selection
Contact	1 Face
Target	2 Faces
Contact Bodies	bushing
Target Bodies	bolt
Definition	
Type	Frictional
Friction Coefficient	0.19
Scope Mode	Automatic
Behavior	Asymmetric
Suppressed	No
Advanced	
Formulation	Augmented Lagrange
Interface Treatment	Add Offset, Ramped Effects
Offset	0. mm
Normal Stiffness	Manual
Normal Stiffness Factor	1.
Update Stiffness	Never
Thermal Conductance	Program Controlled
Pinball Region	Program Controlled
Time Step Controls	None

… Reviewing Friction Related Results

- If frictional contact is present, additional contact output is available
  - Contact Frictional Stress and Contact Sliding Distance can be reviewed to get a better understanding of frictional effects
  - For Contact Status, “Sticking” vs. “Sliding” results differentiate which contacting areas are moving





H. Workshop – Contact with Friction

- **Please refer to your *Workshop Supplement* for instructions on:**
- ***W4B-Contact with Friction***