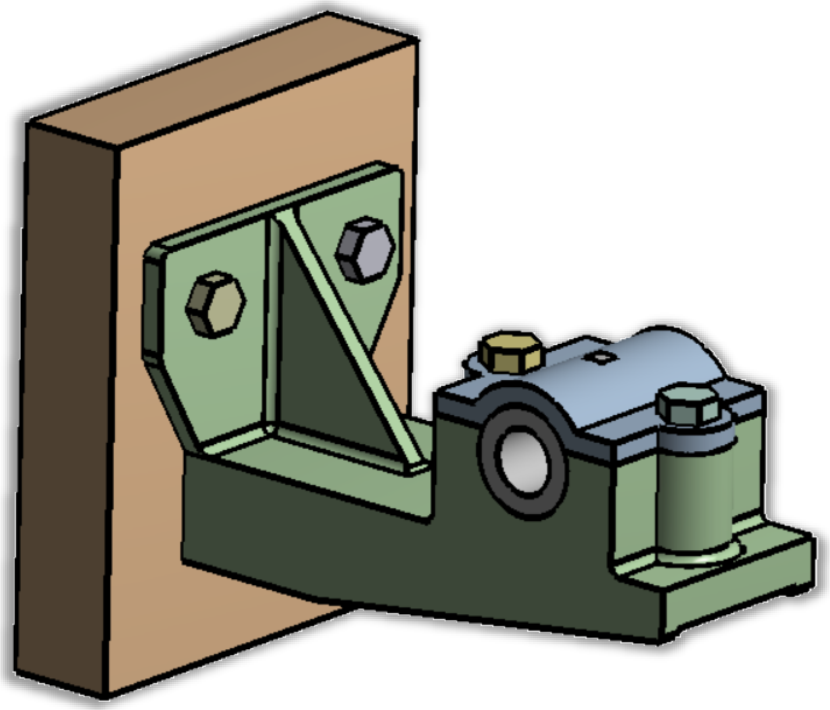
Reviewing Bolt Forces and Result Verification

Best Practices and Results Validation

Verifying Numerical Simulations

- Numerical simulations are extremely useful in engineering design, but they're not always reliable.
- Accurate solvers cannot fix models that are incorrectly defined.
- For instance, if we replace the contact between the wall and the bracket with a bonded contact it takes all the applied force and results in minimal forces being transferred to the bolts. This results in incorrect design assessment.
- Methods for verifying/validating results:
  - Compare against analytical results (if available) – verification
  - Compare against experimental data (if available) – validation
  - Sanity check



Bracket mounted on a wall using bolts

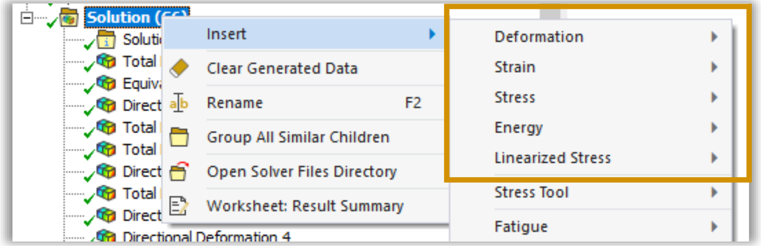
All simulation results MUST be verified!

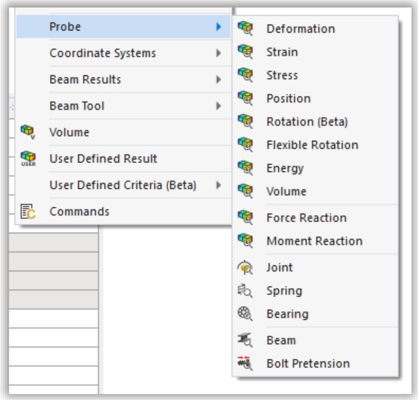
Typical Quantities of Interest

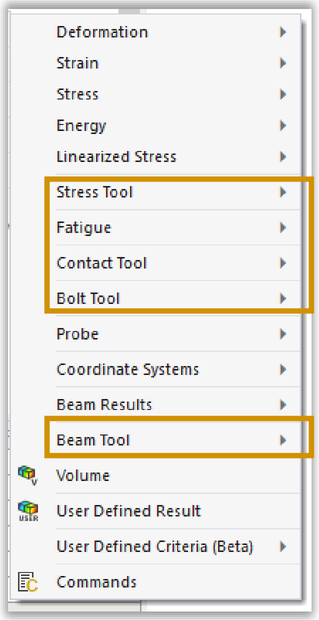
- Quantities of interest vary depending on the objective/application.
- In bolted joints, typical quantities that are of interest are:
  - Preload and adjustment in bolt
  - Reaction forces at contacts and other boundary conditions
  - Stresses and strains (in and around bolts)
  - Deformations
  - Contact pressure
  - Contact penetration, gaps and status

Different Tools in Ansys Mechanical

- Ansys Mechanical provides various techniques to extract results from the solved simulation database.
- These options may be categorized as:
  - Contour Plots – spatial distribution of stresses, strains, deformations, energies, etc.
  - Probes – variables extracted as numerical quantities such as reaction forces, moments, displacements, etc.
  - Tools - Tools that enable post-processing results for multiple items





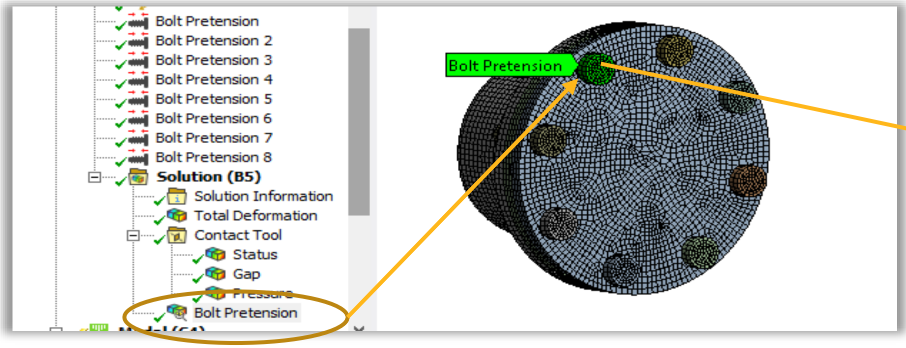


Measuring Bolt Preload

- Preload in the bolt can change due to operational loads.
- Preload results in a change in the grip length (adjustment).
- Measuring these quantities may be of interest in analyzing preloaded bolted joints.
- Methods for measuring preload depends on the way bolt preload is defined.
- One can use different probes to measure both preload and adjustment
  - Pretension probe – if Bolt Pretension Object is used
  - Joint probe – if Translational joint is used

Bolt Pretension Probe

- The Bolt Pretension Probe is useful when examining one bolt load at a time.
- When a Bolt Pretension load is applied, the Ansys Mechanical application reports the following reactions:
  - **Working Load/Preload Reaction** - represents a constrained force reaction from the pretension load. It is the reaction from the applied constraint when a bolt is either specified as Locked, Adjustment, or Increment, and reports a zero value during a step in which you have applied the preload (since there is no reaction at the bolt slice during the preload step). This is essentially the sum of all the forces acting through the pretension cut.



Tabular Data

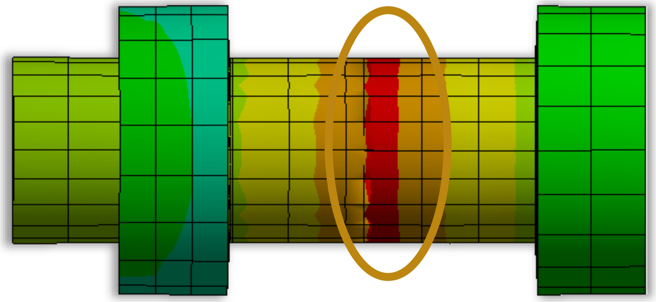
	Time [s]	Bolt Pretension (Adjustment Reaction) [mm]	Bolt Pretension (Working Load) [N]
1	0.1	1.174e-004	0.
2	0.2	2.3482e-004	0.
3	0.3	3.5223e-004	0.
4	0.4	4.6964e-004	0.
5	0.5	5.8704e-004	0.
6	0.6	7.0444e-004	0.
7	0.7	8.2185e-004	0.
8	0.8	9.3925e-004	0.
9	0.9	1.0567e-003	0.
10	1.	1.1741e-003	0.
11	1.1	1.1741e-003	100.09
12	1.2	1.1741e-003	100.19
13	1.3	1.1741e-003	100.28
14	1.4	1.1741e-003	100.38
15	1.5	1.1741e-003	100.48
16	1.6	1.1741e-003	100.57
17	1.7	1.1741e-003	100.67
18	1.8	1.1741e-003	100.77
19	1.9	1.1741e-003	100.87
20	2.	1.1741e-003	100.97

Preload Reaction is the sum of all the forces acting through the pretension cut.

Bolt Adjustment

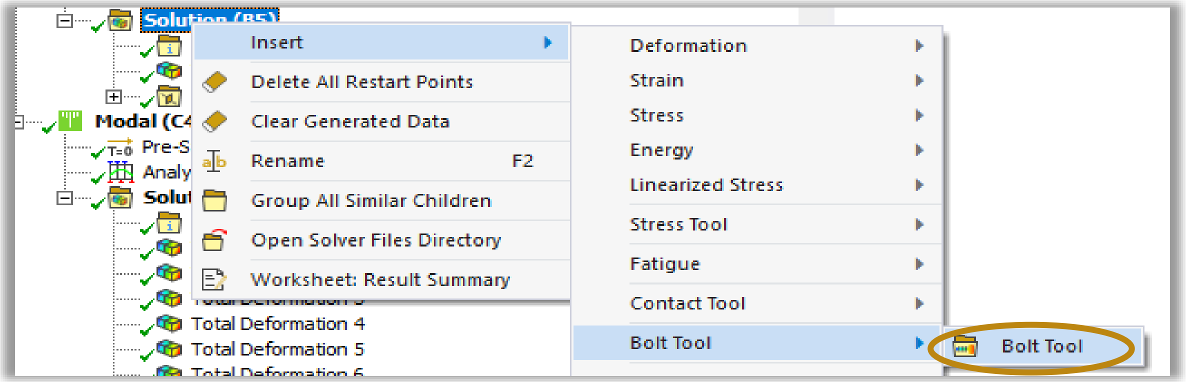
- **Adjustment** – represents the displacement that occurs from the applied pretension measured at the point where the bolt is sliced.
  - Bolt is cut in half with load applied on both ends, thus we see the "overlap" in bolt halves.
  - The overlap is called the "Adjustment" and represents the shortening of the grip length of the bolt, thereby inducing pretension. When the desired pretension is achieved, the new unstretched grip length becomes "locked."

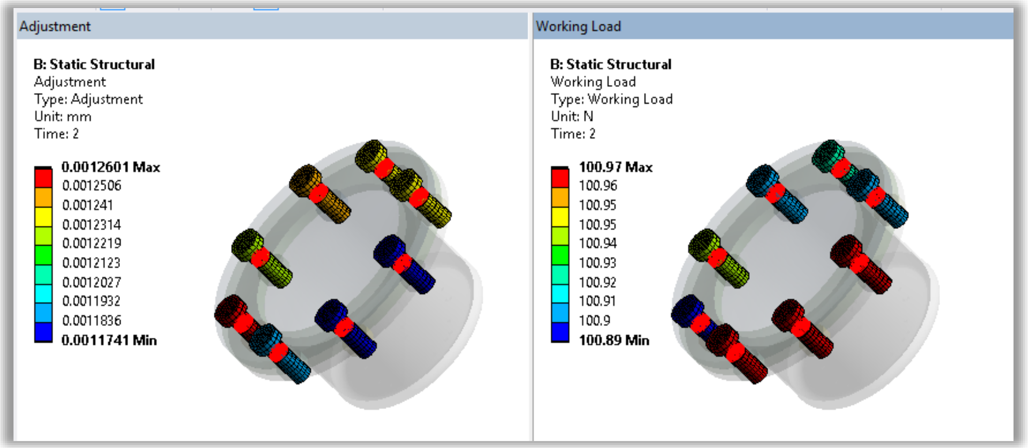
Bolt halves "**overlap**"

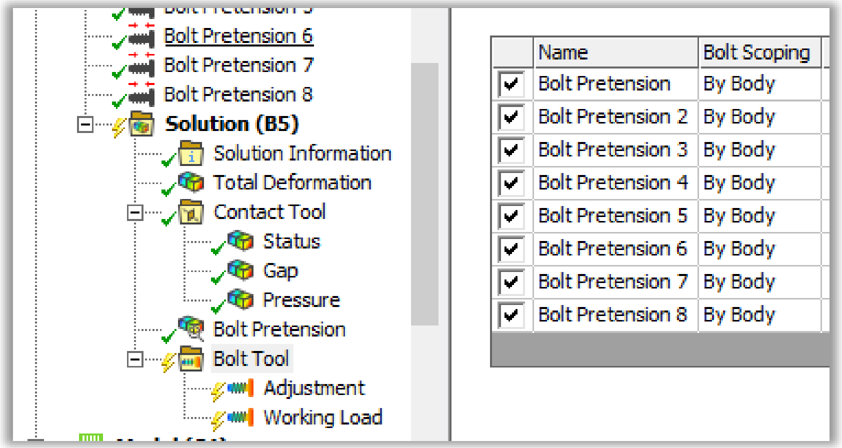


Bolt Tool

- When multiple bolt loads are examined at the same time, the Bolt Tool can be used.
- Available results include:
  - Adjustment
  - Working Load

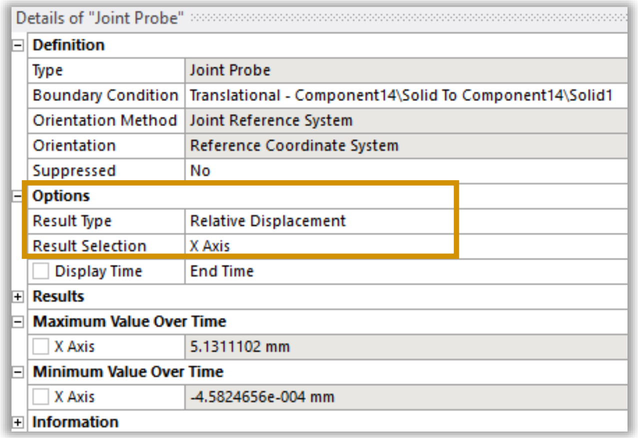






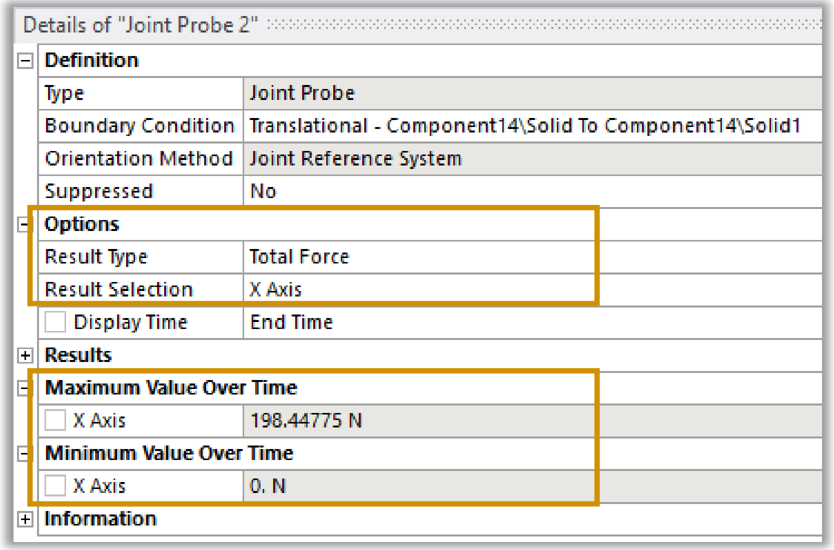
Measuring Bolt Preload Using Joint Probe

- The joint probes enables users to extract reaction forces, moments and relative displacements.
- When a bolt preload is modeled using a translational joint, one can measure the adjustment using Relative Displacement as the result type.
- Preload in the bolt is measured using the result type as “Total Force.” However, note that this value is the change in bolt preload. So total preload is reported as



Details of "Joint Probe"

Definition	
Type	Joint Probe
Boundary Condition	Translational - Component14\Solid To Component14\Solid1
Orientation Method	Joint Reference System
Orientation	Reference Coordinate System
Suppressed	No
Options	
Result Type	Relative Displacement
Result Selection	X Axis
Display Time	End Time
Results	
Maximum Value Over Time	
X Axis	5.1311102 mm
Minimum Value Over Time	
X Axis	-4.5824656e-004 mm
Information	



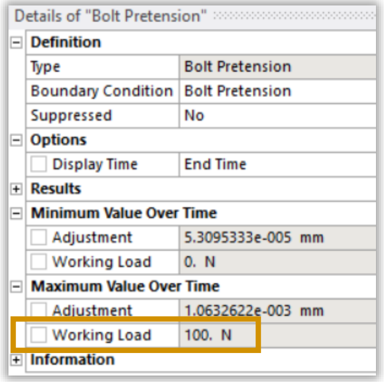
Details of "Joint Probe 2"

Definition	
Type	Joint Probe
Boundary Condition	Translational - Component14\Solid To Component14\Solid1
Orientation Method	Joint Reference System
Suppressed	No
Options	
Result Type	Total Force
Result Selection	X Axis
Display Time	End Time
Results	
Maximum Value Over Time	
X Axis	198.44775 N
Minimum Value Over Time	
X Axis	0. N
Information	

Total Preload = Applied Joint Load + Total Force Joint Probe

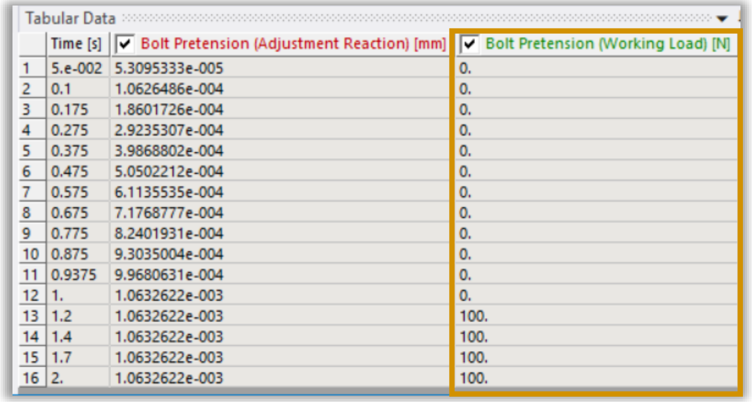
Measuring Adjustment in Bolt Shank

- The change in the grip length due to preload is the adjustment.
- In both the methods for defining bolt preload, the adjustment is reported along with the bolt preload.
- When bolt preload is modeled using a translational joint, one can measure the adjustment using Relative Displacement as the result type.
- Measure of adjustment varies between different methods for the same preload; this is due to difference in the way MPCs are defined in both cases.



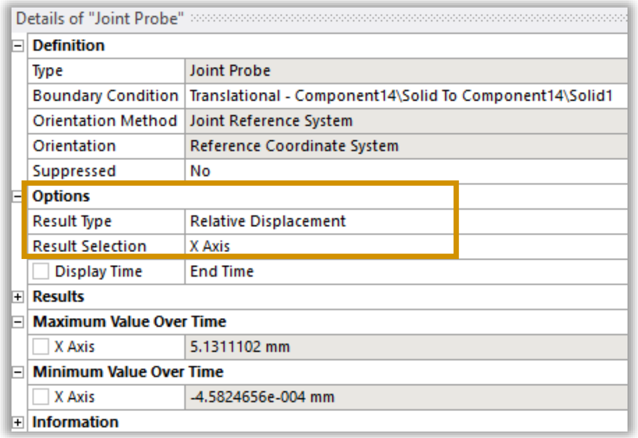
Details of "Bolt Pretension"

Definition	
Type	Bolt Pretension
Boundary Condition	Bolt Pretension
Suppressed	No
Options	
Display Time	End Time
Results	
Minimum Value Over Time	
Adjustment	5.3095333e-005 mm
Working Load	0. N
Maximum Value Over Time	
Adjustment	1.0632622e-003 mm
Working Load	100. N
Information	



Tabular Data

	Time [s]	Bolt Pretension (Adjustment Reaction) [mm]	Bolt Pretension (Working Load) [N]
1	5.e-002	5.3095333e-005	0.
2	0.1	1.0626486e-004	0.
3	0.175	1.8601726e-004	0.
4	0.275	2.9235307e-004	0.
5	0.375	3.9868802e-004	0.
6	0.475	5.0502212e-004	0.
7	0.575	6.1135535e-004	0.
8	0.675	7.1768777e-004	0.
9	0.775	8.2401931e-004	0.
10	0.875	9.3035004e-004	0.
11	0.9375	9.9680631e-004	0.
12	1.	1.0632622e-003	0.
13	1.2	1.0632622e-003	100.
14	1.4	1.0632622e-003	100.
15	1.7	1.0632622e-003	100.
16	2.	1.0632622e-003	100.



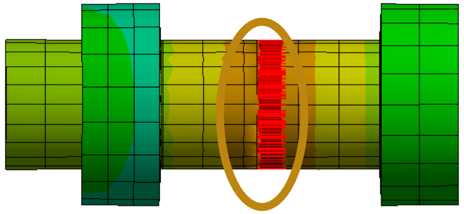
Details of "Joint Probe"

Definition	
Type	Joint Probe
Boundary Condition	Translational - Component14\Solid To Component14\Solid1
Orientation Method	Joint Reference System
Orientation	Reference Coordinate System
Suppressed	No
Options	
Result Type	Relative Displacement
Result Selection	X Axis
Display Time	End Time
Results	
Maximum Value Over Time	
X Axis	5.1311102 mm
Minimum Value Over Time	
X Axis	-4.5824656e-004 mm
Information	

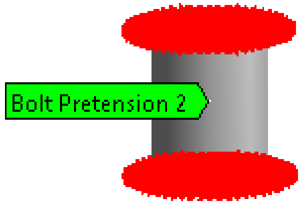
Measuring Adjustment in Bolt Shank (cont.)

- Depending on the method used (solid body bolt or line body bolt), the adjustment may change due to the way MPC equations are written.

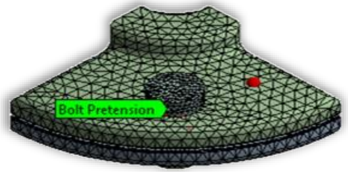
MPC Equations



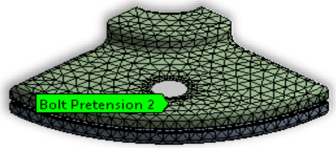
Solid Bolt



Beam Connection



Solid Bolt



Beam Connection

Tabular Data

	Time [s]	Bolt Pretension (Adjustment Reaction) [mm]	Bolt Pretension (Working Load) [N]
1	0.1	1.3738e-002	0.
2	0.2	2.7455e-002	0.
3	0.35	4.8006e-002	0.
4	0.55	7.5379e-002	0.
5	0.75	0.10273	0.
6	0.875	0.11982	0.
7	1.	0.13691	0.
8	1.1	0.13691	5001.3
9	1.2	0.13691	5002.5
10	1.35	0.13691	5004.3
11	1.55	0.13691	5006.7
12	1.75	0.13691	5009.4
13	1.875	0.13691	5011.4
14	2.	0.13691	5013.8

Tabular Data

	Time [s]	Bolt Pretension 2 (Adjustment Reaction) [mm]	Bolt Pretension 2 (Working Load) [N]
1	0.1	1.2007e-002	0.
2	0.2	2.3994e-002	0.
3	0.35	4.195e-002	0.
4	0.55	6.5864e-002	0.
5	0.75	8.9761e-002	0.
6	0.875	0.10469	0.
7	1.	0.11962	0.
8	1.1	0.11962	5001.3
9	1.2	0.11962	5002.5
10	1.35	0.11962	5004.4
11	1.55	0.11962	5007.
12	1.75	0.11962	5009.7
13	1.875	0.11962	5011.9
14	2.	0.11962	5014.3

Tabular Data

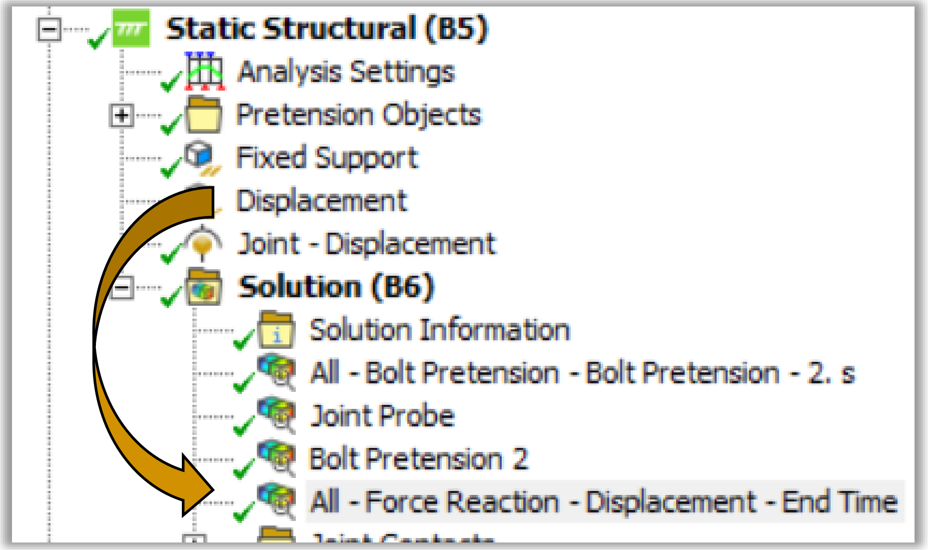
	Steps	Define By	Preload [N]	Preadjustment [mm]	Increment [mm]
1	1.	Load	5000.	N/A	N/A
2	2.	Lock	N/A	N/A	N/A
*					

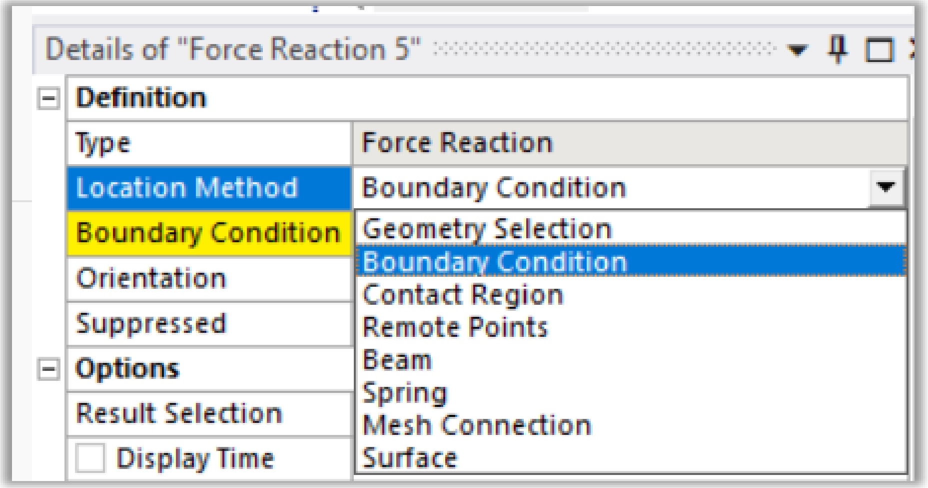
It's recommended to avoid defining preload as adjustment.

Ansys

Force Reaction Probe

- A force reaction probe is used to extract reaction forces.
- It can be used to extract forces from
  - Contact connections
  - Boundary conditions
  - Remote points, etc.
- Force reactions can be used to balance the forces in static analysis to verify the proper transfer of forces.
- Drag-and-drop the contact or boundary condition to Solution to insert the force reaction probe.

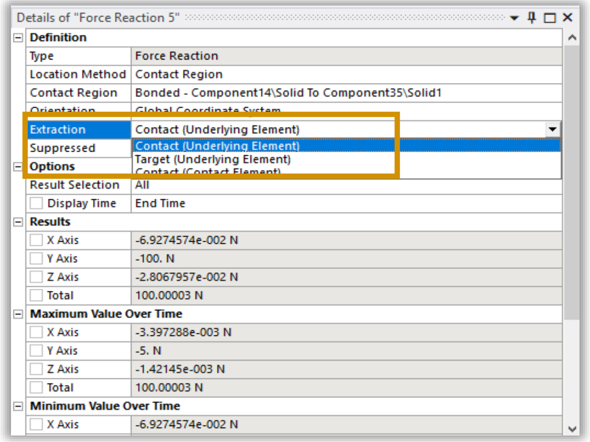


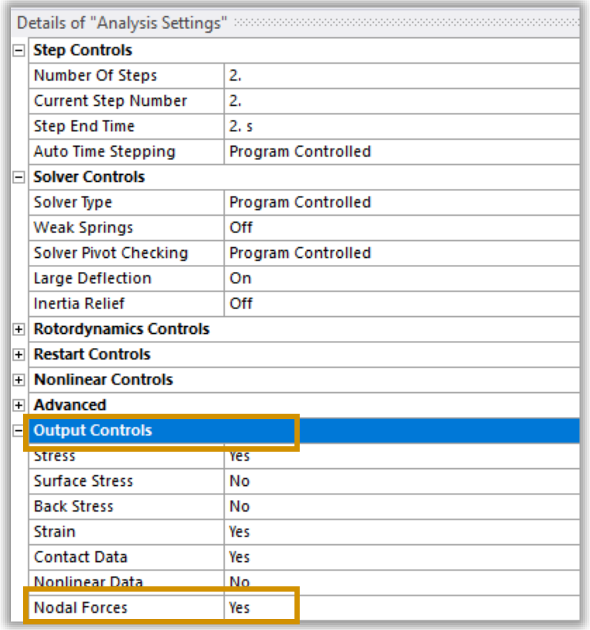


Be careful if the object scoped to geometry is shared between multiple similar objects.

Force Reaction Probe (cont.)

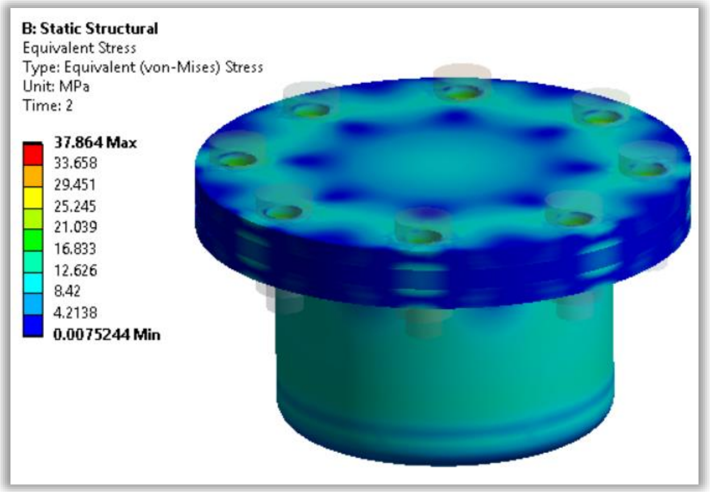
- The force reaction probe can be used for extracting contact forces using the same procedure.
- This method reports the summation of forces from the nodes from underlying solid elements.
- To extract these results one must turn ON writing nodal forces to the results file prior to running.
- This can be done from Analysis Settings > Output Controls.

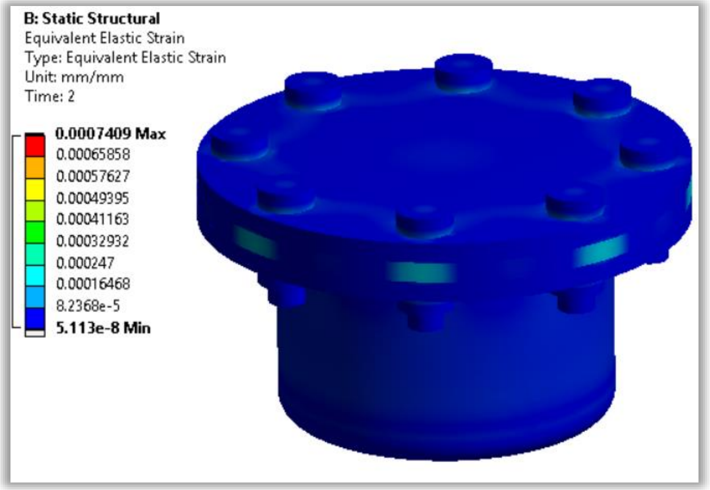




Stresses, Strains around Bolts

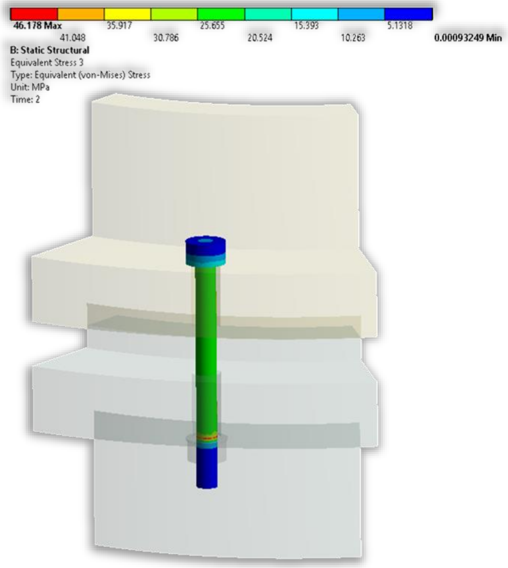
- Contour plots are commonly used in structural analysis.
- Stresses and strains help identify portions of the model that are prone to failure.
- Stresses can help identify if the bolts can yield under operational load.
- One can extract the normal and shear components or equivalent value using these result objects.
- Each object can also export the data to text files.

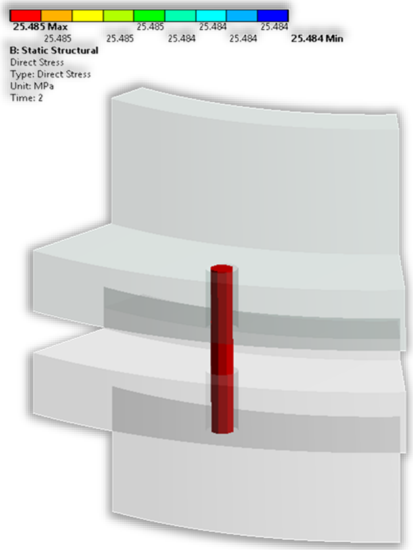




Stresses in Bolt

- Stresses in bolts may also be used to check if the bolt is close to its proof load.
- Such results can also be used in subsequent analyses to study fatigue in bolts.
- Extracting stresses in bolts depends on how the bolt is modeled.
- For solid elements, the procedure is the same as extracting stresses around the bolt.
- For beam elements modeled using Beam Connections, one can use user-defined results to extract this data.
- For beam elements modeled using line bodies, one can use Beam Tool to extract this data.



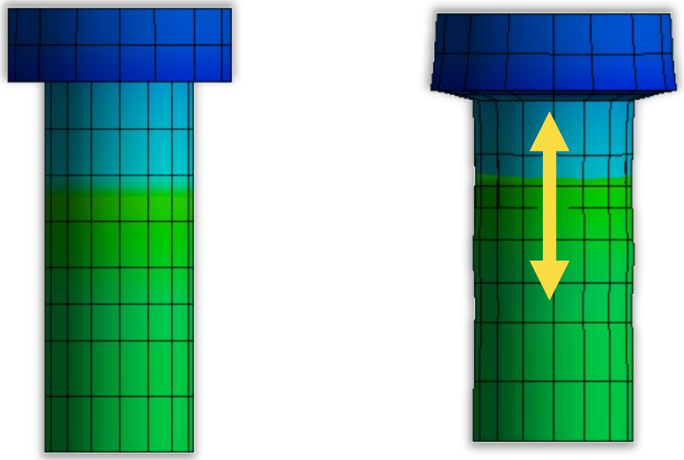


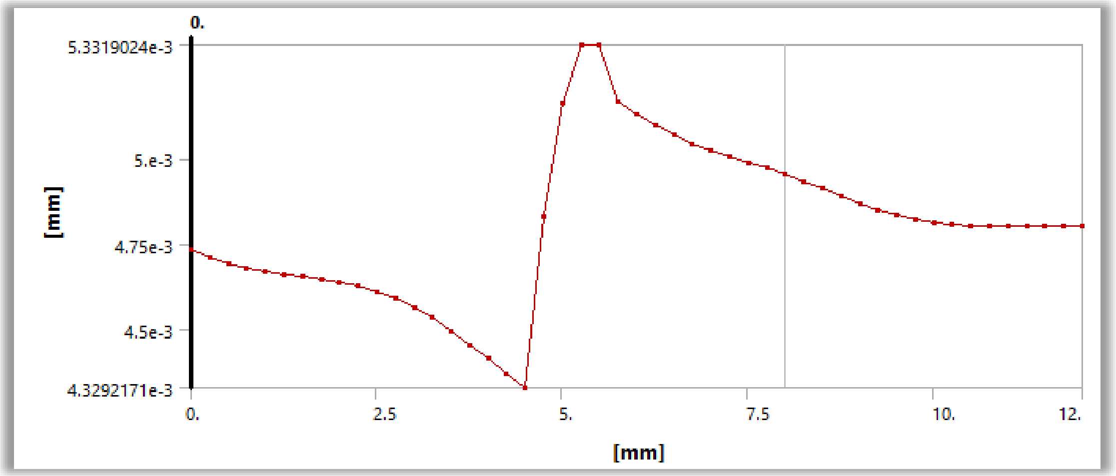
Details of "User Defined Result"

Scope	
Scoping Method	Result File Item
Item Type	Element Name IDs
Solver Component IDs	188
Definition	
Type	User Defined Result
Expression	= beamdirect
Input Unit System	Metric (mm, kg, N, s, mV, mA)
Output Unit	
By	Time

Deformations In and Around Bolts

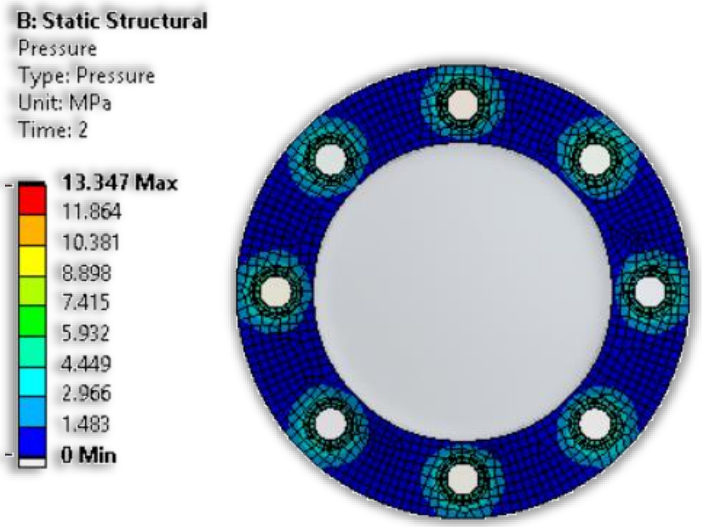
- Total and directional deformations are nodal displacements that can extracted using result objects.
- Notice that when we plot deformation on the bolt, it reports displacements that it collapses into itself while applying pretension.
- This overlap is nothing but adjustment.

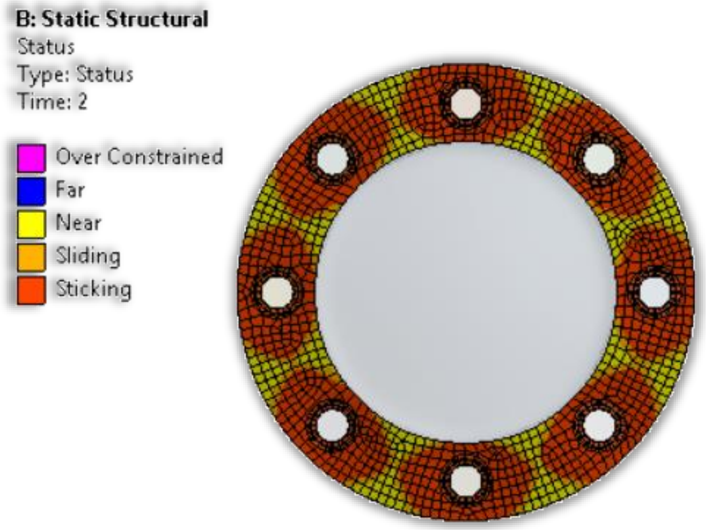




Contact Pressure and Status

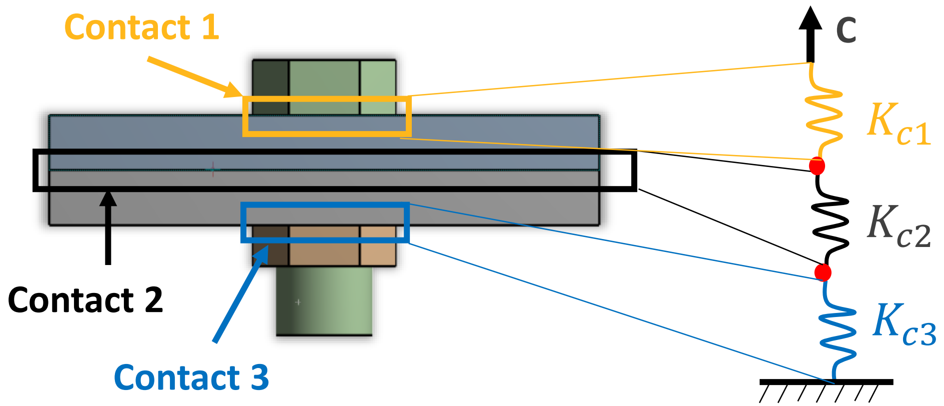
- Contact pressure is another common quantity of interest in analyzing bolted structures such as gaskets and seals.
- Contact pressure generated due to bolt preload is often used to assess the performance of a seal.
- In Ansys Mechanical, it’s available under Contact Tool.
- Another quantity that may be useful is Contact Status, which is also available under Contact Tool.
- Contact status helps us identify the regions of contact that are closed, open or sliding due to loads.





Verifying Contact in Bolted Joints

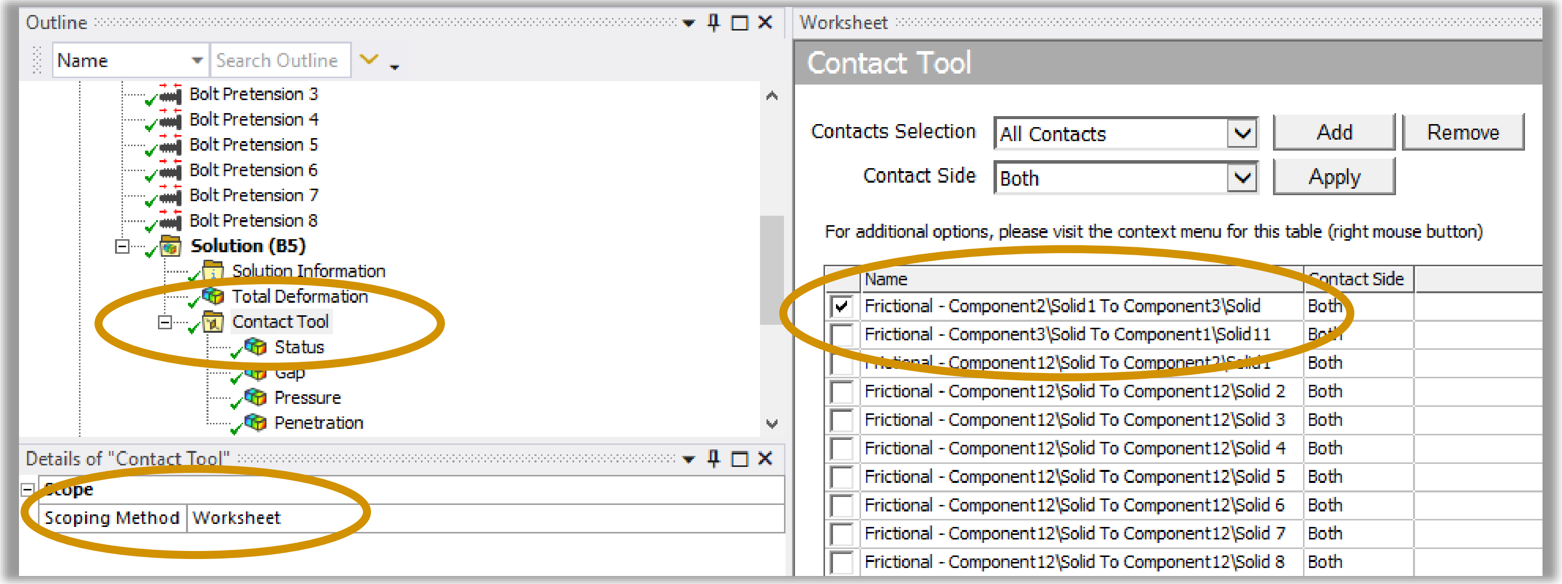
- Contact between two surfaces can be represented by a spring whose stiffness is equal to the contact stiffness.
- Contacts in a bolted joint can be represented as three springs in series and contact penetration is deformation of spring.
- As contact stiffness increases, penetration decreases.
- If the contact penetration is zero, then the calculated adjustment is due to deformation of the mating parts. This is the ideal case.
- But if the contact penetration is very large, the calculated bolt adjustment is not very accurate, which in turn results in inaccurate contact forces



Contact results must be verified!

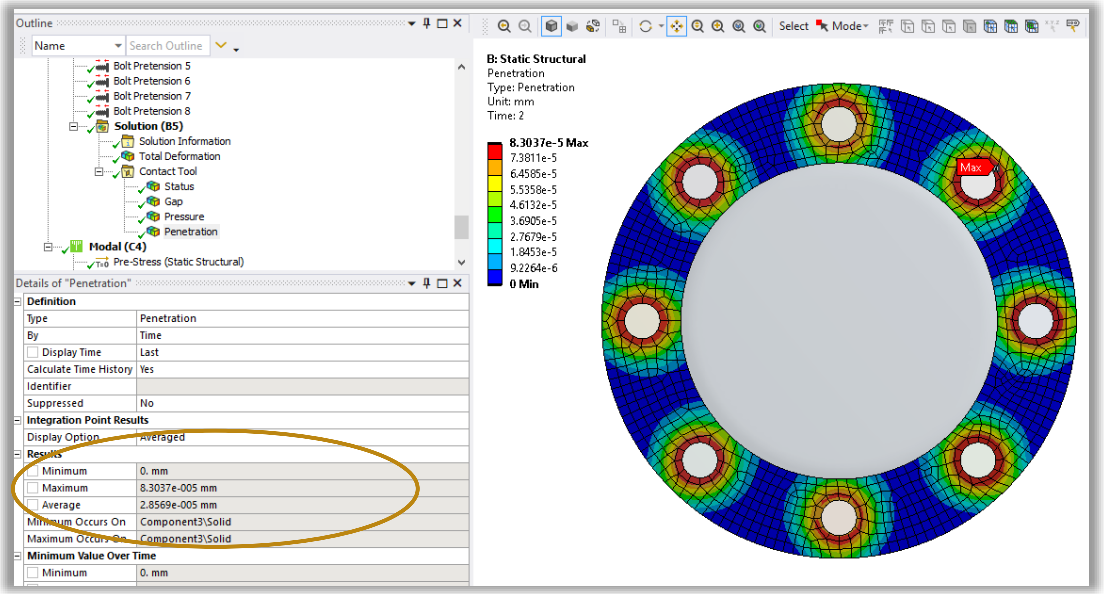
Contact Tool

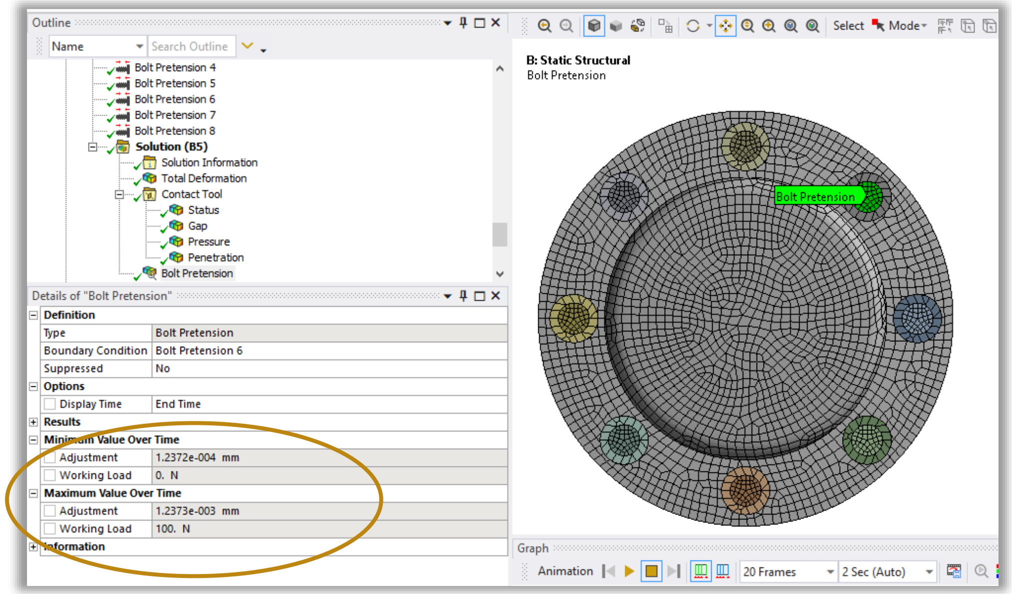
- Contact Penetration and other contact results can also be post-processed using Contact Tool.
- Using the Worksheet scoping we can specify contacts of interest for post-processing.



Contact Tool (cont.)

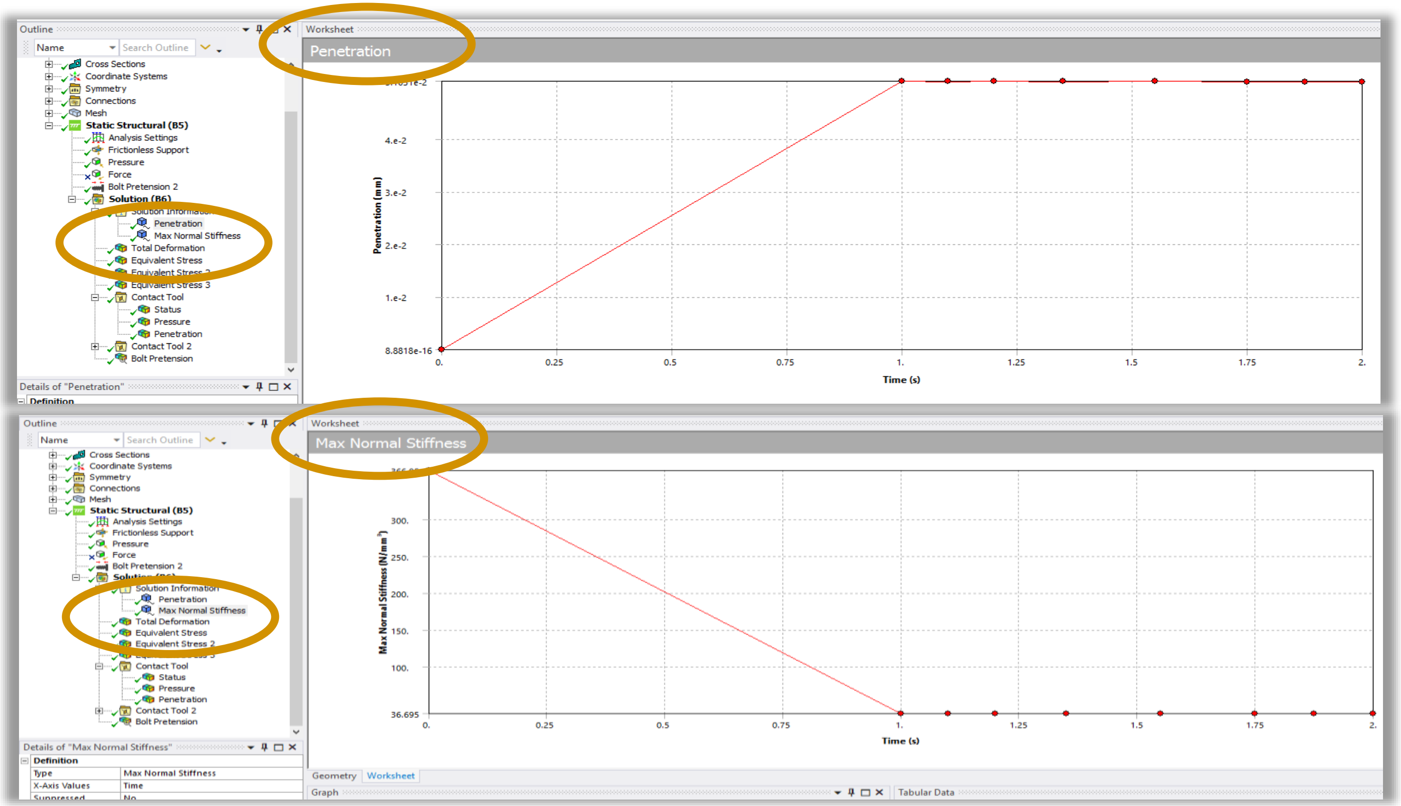
- Contact penetration between mating surfaces should be smaller than the bolt adjustment in order to get accurate results.





Contact Results Tracker

- Using Result Tracker for Contact Penetration and Normal Stiffness we can monitor their behavior during the solution.



Ansys