Connecting Bolts Represented as Beam Elements

Connecting Bolts with the Rest of an Assembly

Modeling Bolts

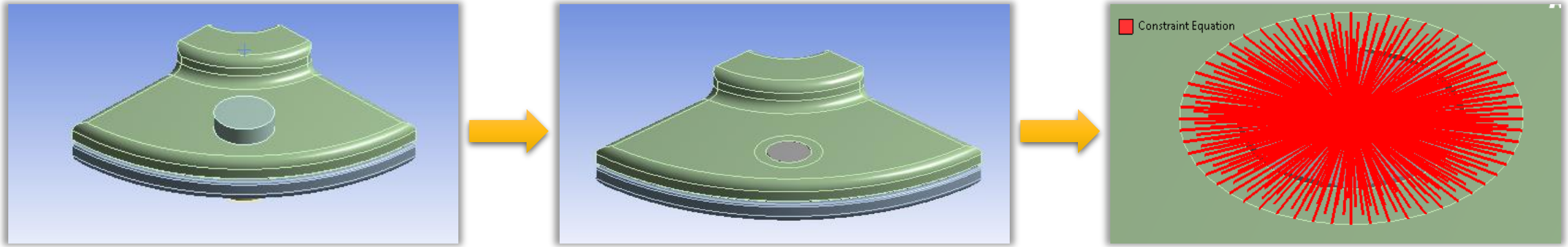
- In an assembled structure, modeling bolts as solid bodies usually results in computationally large models that can take a long time to solve.
- It can be very efficient to model the bolts as line bodies rather than solid bodies, especially if tens or hundreds of bolts are present.

Modeling Bolts as Beam Connections

- No need for the bolt geometry
- Mesh with beam elements, which may reduce the model size significantly for assemblies with many bolts
- Suitable when modeling the effect of the preload
- Used for a large assembly with a large number of bolts when the performance of the entire assembly is important
- Details of the stress of the bolt joint would not be available

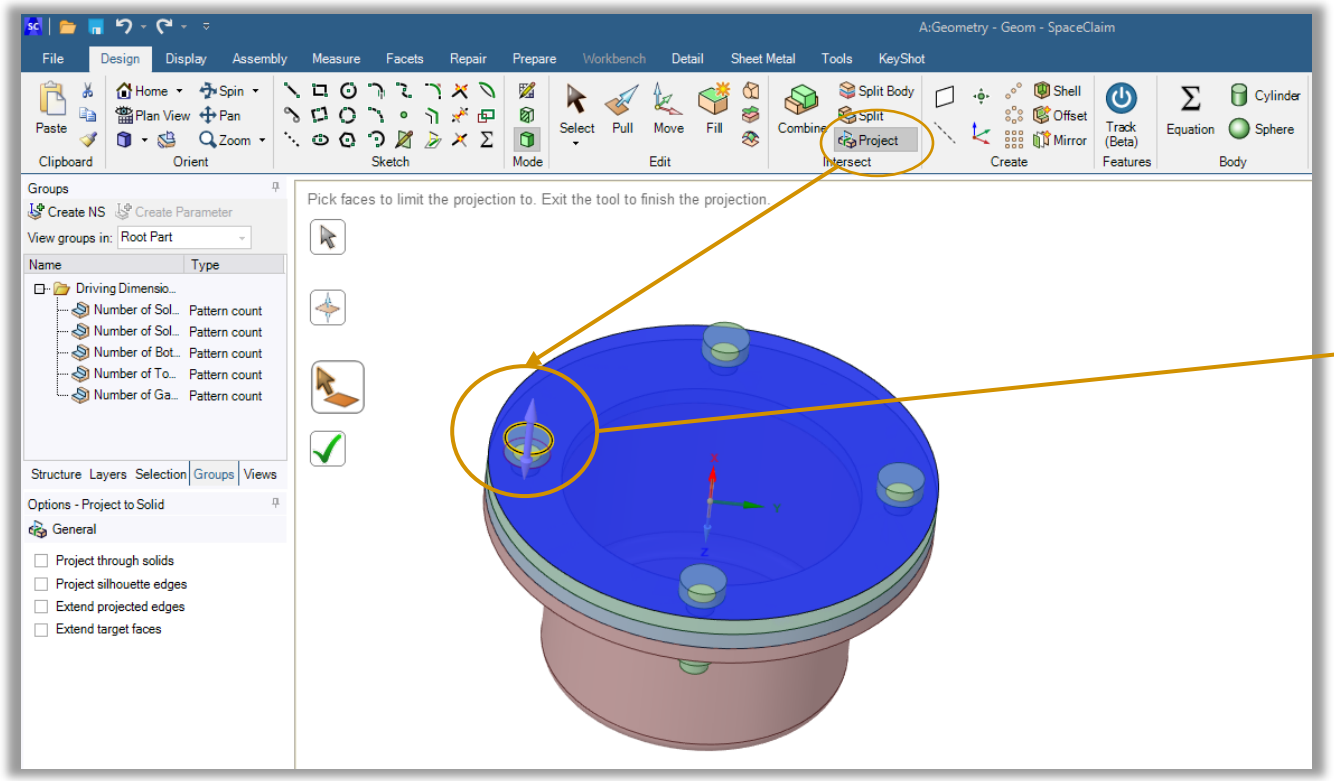
Preparing Geometry – Beam Connection

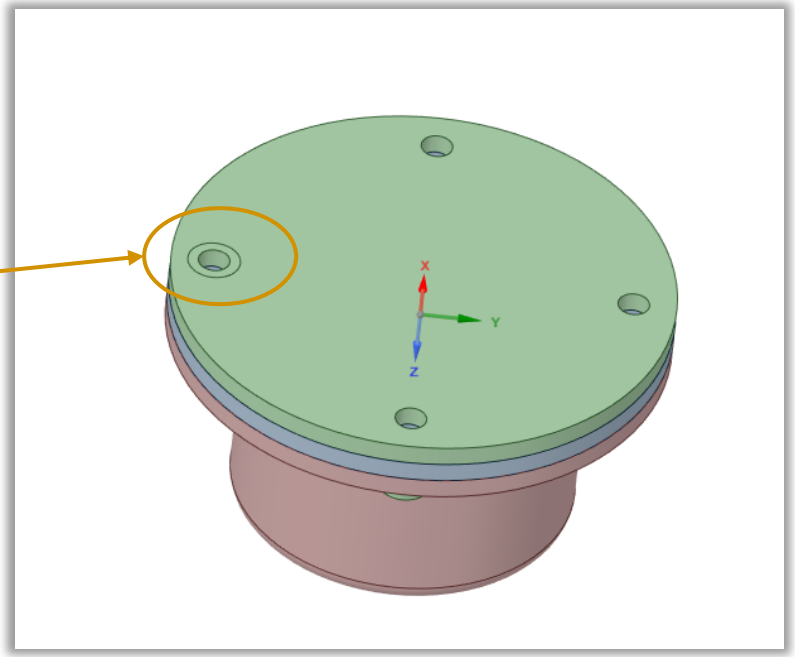
- When using Beam Connections, we don't need the geometries for bolts, washers or nuts. However, before deleting/suppressing these bodies, we should prepare geometry for analysis.
- Geometry preparation includes:
  - Imprint the face of the washer/bolt head/nut on the geometry. Although you could tie the vertex of the beam connection to the edge, it is more accurate to tie it to the area representing the region contacting the bolt head/washer/nut. The preload will be distributed on the finite area, which is more accurate.



Preparing Geometry – Beam Connection (cont.)

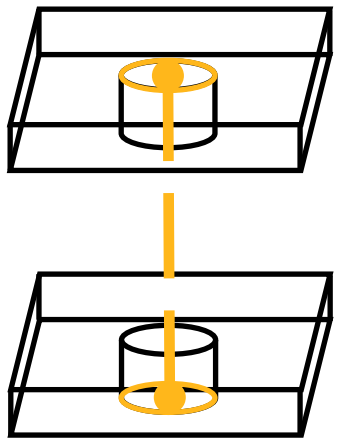
- In Ansys SpaceClaim, the imprint can be created by using the "Project" feature.





Beam Connections for Bolts

- A popular way of representing a bolt is by using beam connections.
- This method does not require a solid bolt geometry or a line body for the bolts.
- Beam elements are created by Ansys Mechanical when a beam connection is scoped to two holes.
- This is also a vertex-edge/face connection.



Details of "Circular - SYS\Solid211 To SYS\Solid21"

Graphics Properties	
Definition	
Material	Structural Steel
Cross Section	Circular
Radius	2. mm
Suppressed	No
Beam Length	4.9999999 mm
Element APDL Name	
Scope	
Scope	Body-Body
Reference	
Scoping Method	Geometry Selection
Applied By	Remote Attachment
Scope	1 Face
Body	SYS\Solid211
Coordinate System	Global Coordinate System
Reference X Coordinate	17.320508 mm
Reference Y Coordinate	4.9999999 mm
Reference Z Coordinate	10. mm
Reference Location	Click to Change
Behavior	Rigid
Pinball Region	All
Mobile	
Scoping Method	Geometry Selection
Applied By	Remote Attachment
Scope	1 Face
Body	SYS\Solid21
Coordinate System	Global Coordinate System
Mobile X Coordinate	17.320508 mm
Mobile Y Coordinate	0. mm
Mobile Z Coordinate	10. mm
Mobile Location	Click to Change
Behavior	Rigid
Pinball Region	All

Beam Connections for Bolts (cont.)

- Advantages:
  - Very little effort in pre-processing
  - Automation of creating beams using Object Generator
  - Simple drag-and-drop actions for defining bolt pretension object
- Limitations over line bodies:
  - Not applicable when preload cannot be defined using the pretension object.

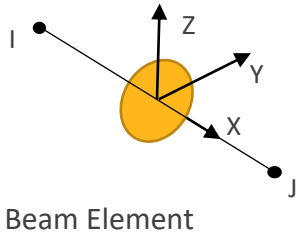
Beam connections are the recommended way of modeling bolts as line bodies.

What Is a Remote Point?

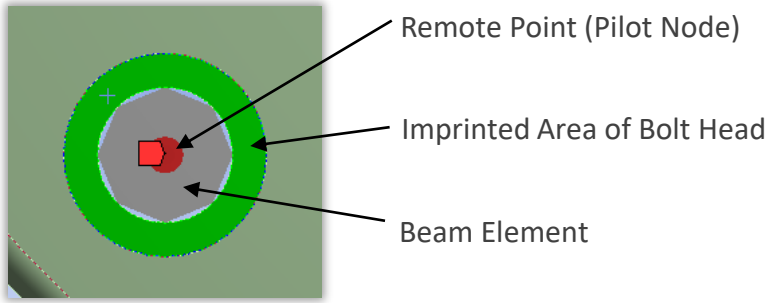
- Remote Points are a way to connect a vertex to a solid model (edge, face). Beam Connections make use of Remote Points to connect the vertex of the line body (bolt) to the mating part (area in contact with washer/bolt head/nut).
- The vertex is also called a "Pilot Node" that is "Scoped" to geometry.
- The solver uses Multipoint Constraint (**MPC**) equations to make these connections.

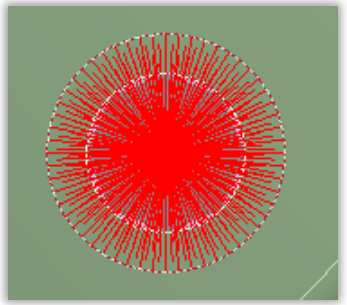
What is a Remote Point (cont.)

- The cross section of the beam connection needs to be defined in order to mesh with the beam elements. The beam element has 2 nodes (I and J) and 6 Degrees of Freedom (DOFs). The vertex representing the cross section needs to be connected to the edge/area. How do we connect the vertex/point to an edge or area? The answer is – **By Remote Point (Pilot Node) and MPCs**.



Beam Element




MPC Equations

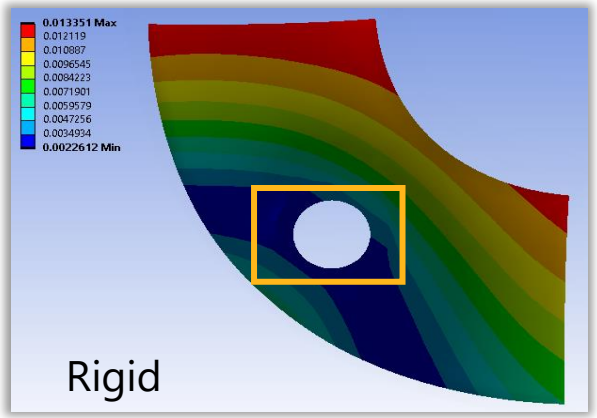
- When the beam connection is created, the Remote Points at each end of the beam are created automatically. The Remote Points are used to connect the beam to the scoped geometry (imprinted area of the bolt head/washer/nut).
- The pilot node has 6 DOFs - 3 translations and 3 rotations.
- The nodes on the scoped geometry generally have 3 translational DOFs "tied" with the motion of the pilot node.

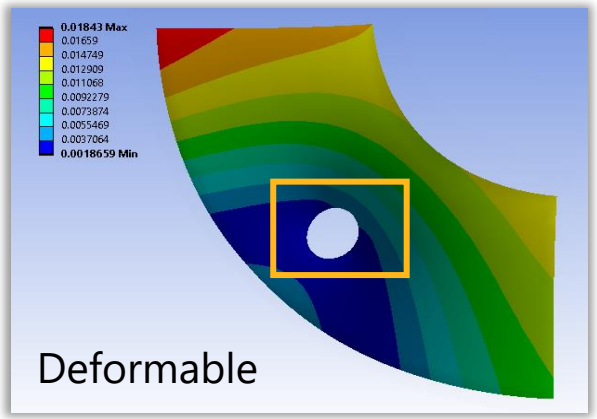
MPC Equations

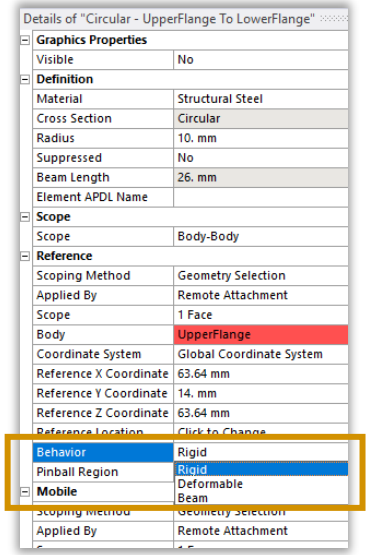
- The solver uses multipoint constraint (MPC) equations to make the connections between remote points and scoped geometry. MPC equations are complex equations that relate various DOFs to each other. MPCs are extra equations that are added to the structural matrix equation (equation of motion).
- How do the MPC equations work?
  - If we have 3 unknowns ‘A’, ‘B’ and ‘C’ that will solve in the set of equations and if there is the additional constraint of ‘A=B+C’ that must be satisfied. Because this is an extra constraint, we can’t impose this after solving for “A”, “B”,and “C” separately with our original set of equations.
  - We need to make ‘A’ a dependent variable and substitute A with B+C in the original equations.
  - We can solve for B and C since they are independent variables first and then calculate A by using the constraint equation A=B+C.
- MPCs have "independent" and "dependent" DOFs. Dependent DOFs are removed from the matrix equation by processing them in [K] first.
- The dependent DOFs are removed from the set of equations while the independent DOFs are retained. We solve for the independent DOFs and then calculate the values of the dependent DOFs by processing the MPCs.

Remote Points – Behavior

- When modeling bolt as a beam connection, the stiffness of the bolt head is not captured perfectly. However, modeling a bolt as a beam connection is easier to model and computationally more efficient than modeling a bolt as a solid body.
- Remote Point Behavior can be Rigid or Deformable. The Behavior option dictates the behavior of the attached geometry.
  - Rigid: The geometry will not deform (maintains the initial shape). The remote point has independent DOF, and how the remote point is moving the scoped geometry has to follow (dependent DOF). You can imagine that there is a material between the emote point and the scoped geometry that is infinitely stiff in behavior. This option adds stiffness to the model and doesn't distribute bolt load evenly on the surface.
  - Deformable: The geometry is free to deform. In this case the remote point has dependent DOF which means that the remote point follows the deformation of the scoped geometry which has independent DOF. The remote point has the "average" movement of the scoped geometry. This represents another extreme case where the region between remote point and scoped geometry is not infinitely stiff, but behavior is related to the average movement of the scoped geometry.

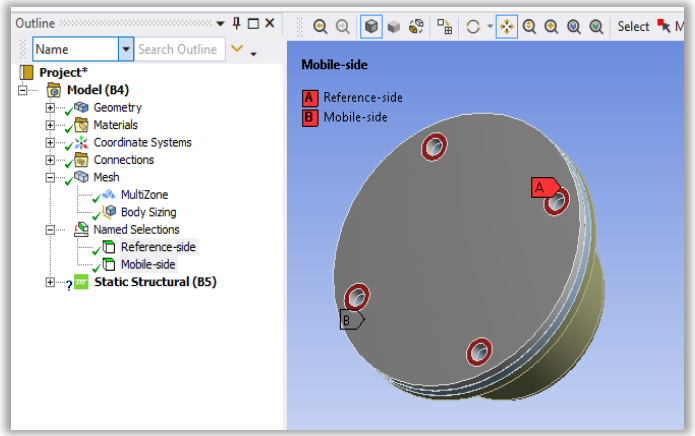


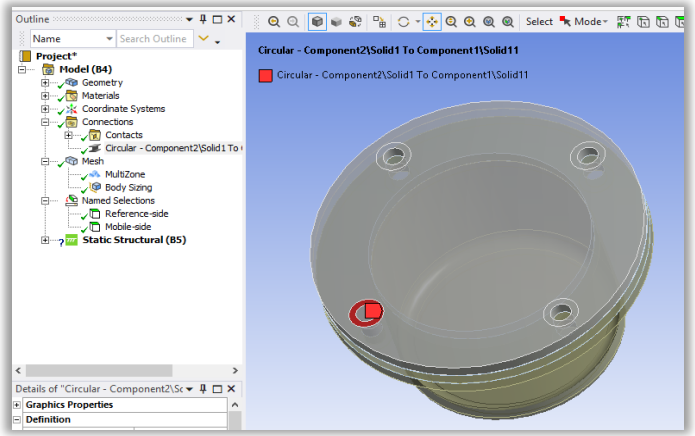


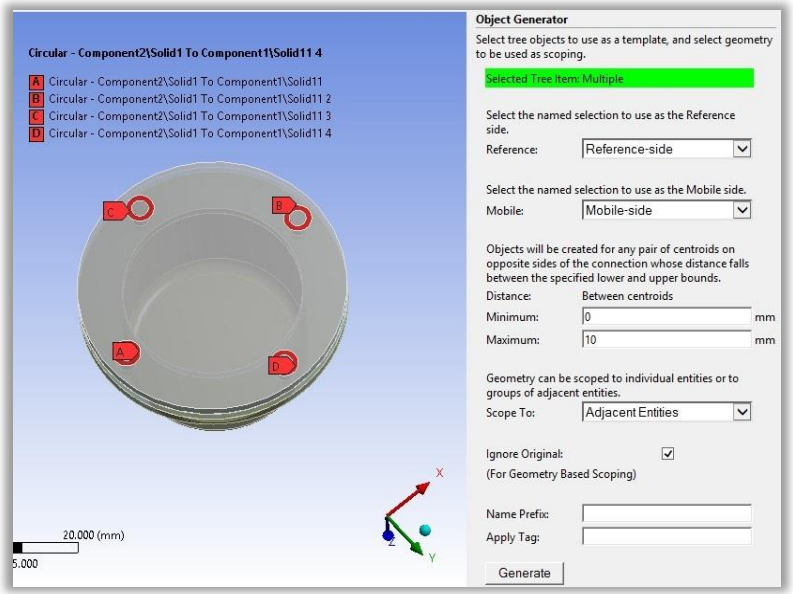


Ease-of-Use

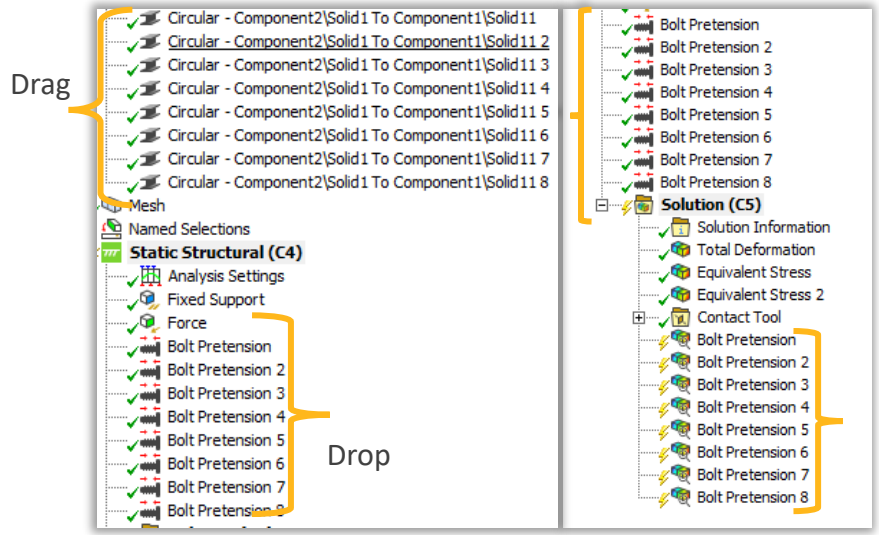
- Object Generator and Named Selections can be used to make copies of the beam connection for more efficient preprocessing.







- Drag and Drop Beam Connections to Analysis branch to create Bolt Pretension object.
- Drag and Drop Bolt Pretension to Solution branch to get Bolt Pretension Probe.
- Drag and Drop Beam Connections under Solution branch to get Beam Probe.

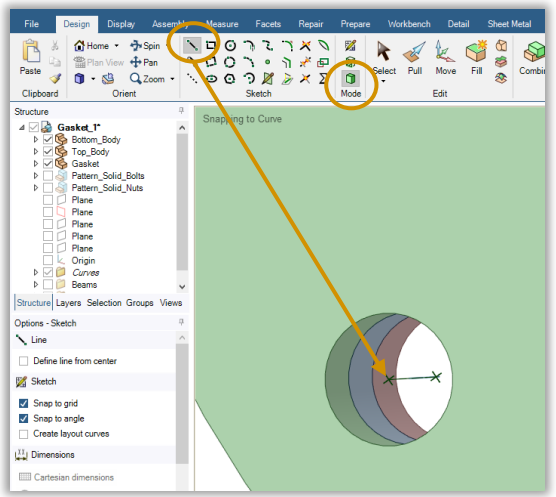


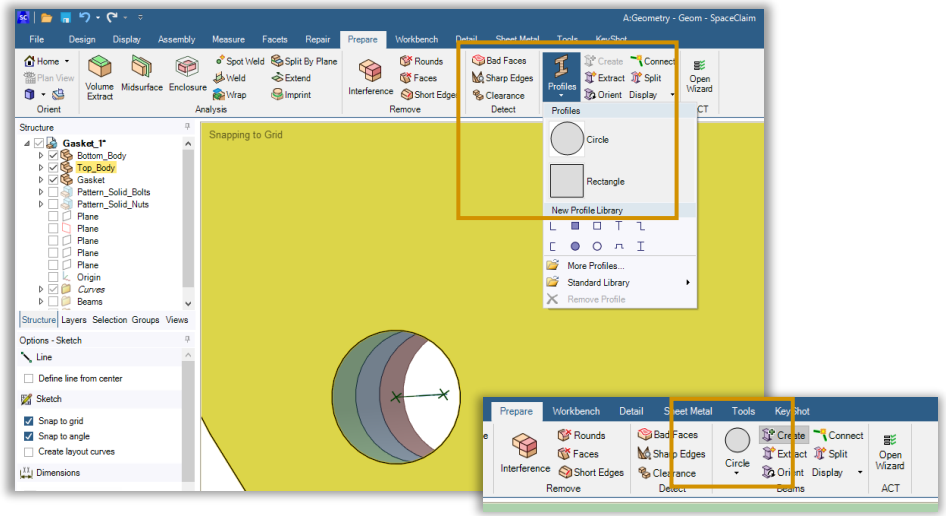
Manually Connecting Line Body

- If you inherit model/analysis from a colleague that already has line bodies, manual connection is necessary.
- There are some restrictions for Beam Connections
  - Doesn’t update with geometry if geometric changes are made.
  - Bolt tool to review multiple bolt results at once is not supported.

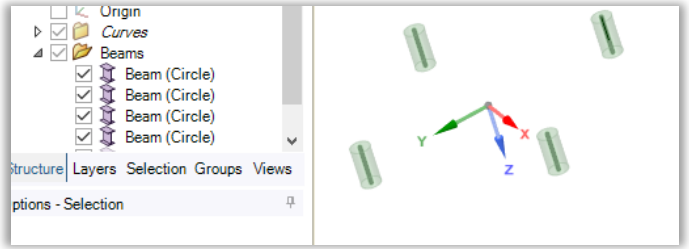
Preparing Geometry – Line Body

- In SpaceClaim, the line body can be created by using the "Line" feature and "3D Mode." The cross section of the beam can be defined using the "Profile" feature, select the profile and "Create."

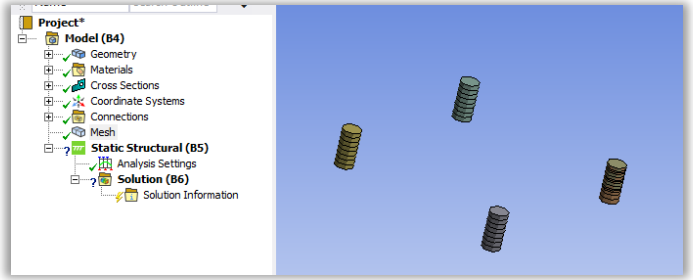




SpaceClaim

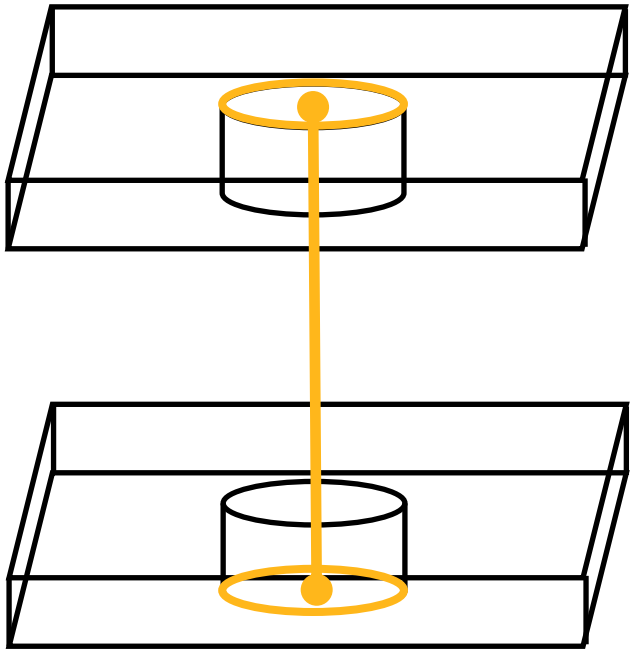


Mechanical



Line Bodies for Bolts

- In case of line bodies, only the bolt shank is represented.
- Two ends of the shank are connected to holes on mating parts.
- Vertex to Edge/Face connections are used.
- Two ways of defining these connections:
  - Fixed joints
  - MPC bonded contacts

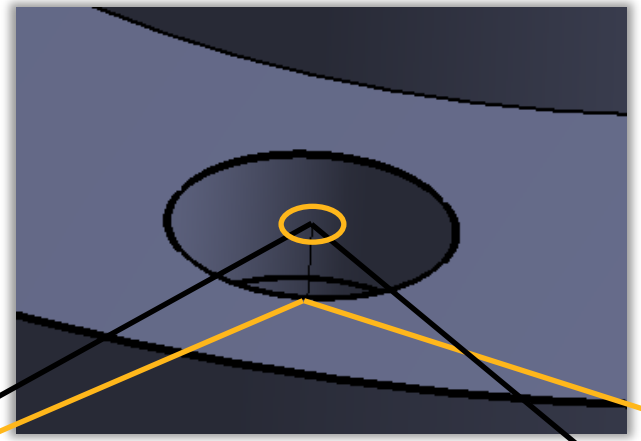


Connecting Line Body with Solid Model

- Prescribed settings for defining the MPC contact or the fixed joint for connecting bolt to the holes when the bolt is modeled as a line body.

MPC Bonded Contact

Details of "Bonded - SYS\Extracted Beam (Extracted Profile1) To SYS\Sc	
Scope	
Scoping Method	Geometry Selection
Contact	1 Vertex
Target	1 Edge
Contact Bodies	SYS\Extracted Beam (Extracted Profile1)
Target Bodies	SYS\Solid211
Protected	No
Definition	
Type	Bonded
Scope Mode	Manual
Trim Contact	Off
Suppressed	No
Advanced	
Formulation	MPC
Constraint Type	Distributed, Anywhere Inside Pinball
Pinball Region	Radius
Pinball Radius	6. mm

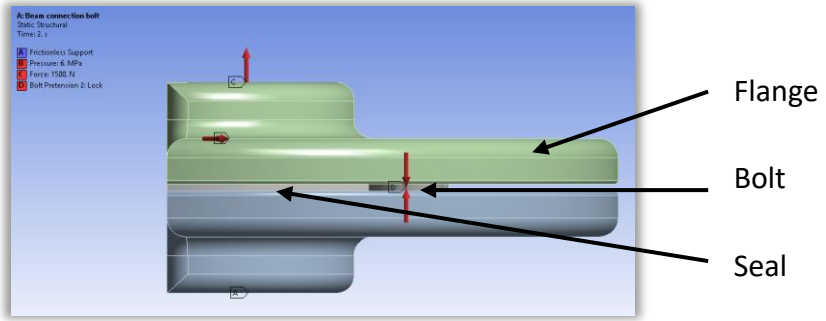


Fixed Joint

Details of "Fixed - SYS\Solid211 To SYS\Extracted Beam (Extracted Pr	
Definition	
Connection Type	Body-Body
Type	Fixed
Solver Element Type	Program Controlled
Suppressed	No
Element APDL Name	
Reference	
Scoping Method	Geometry Selection
Applied By	Remote Attachment
Scope	1 Edge
Body	SYS\Solid211
Coordinate System	Reference Coordinate System
Behavior	Rigid
Pinball Region	All
Mobile	
Scoping Method	Geometry Selection
Applied By	Remote Attachment
Scope	1 Vertex
Body	SYS\Extracted Beam (Extracted Profile1)
Initial Position	Unchanged
Pinball Region	All

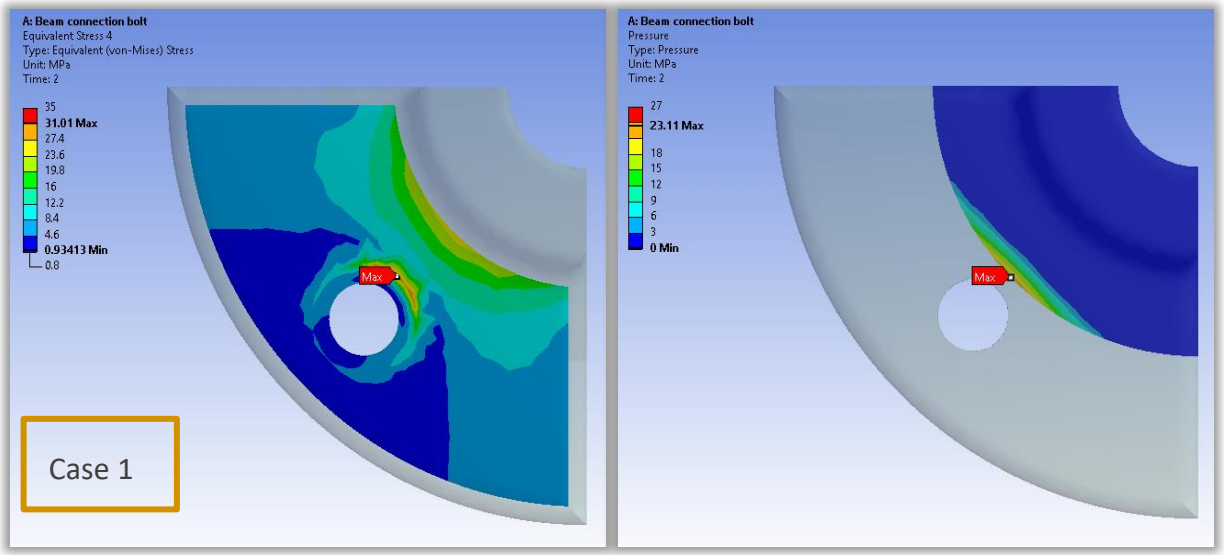
Case Study

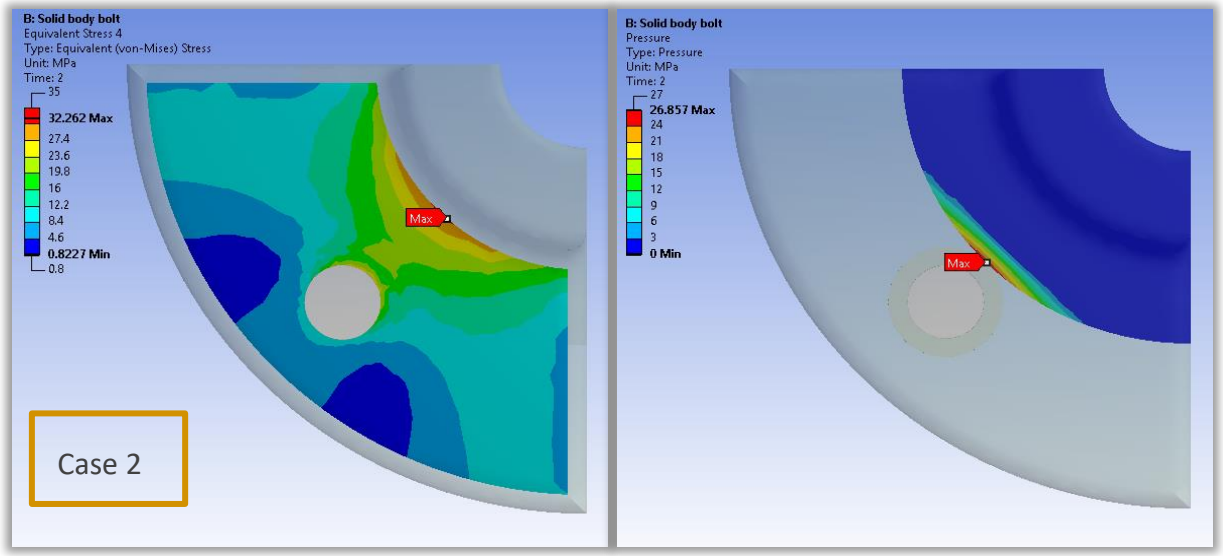
- This model represents part of the flange-seal assembly.
- Bolt represented by the beam connection is just a cylinder, there no bolt head or nut.



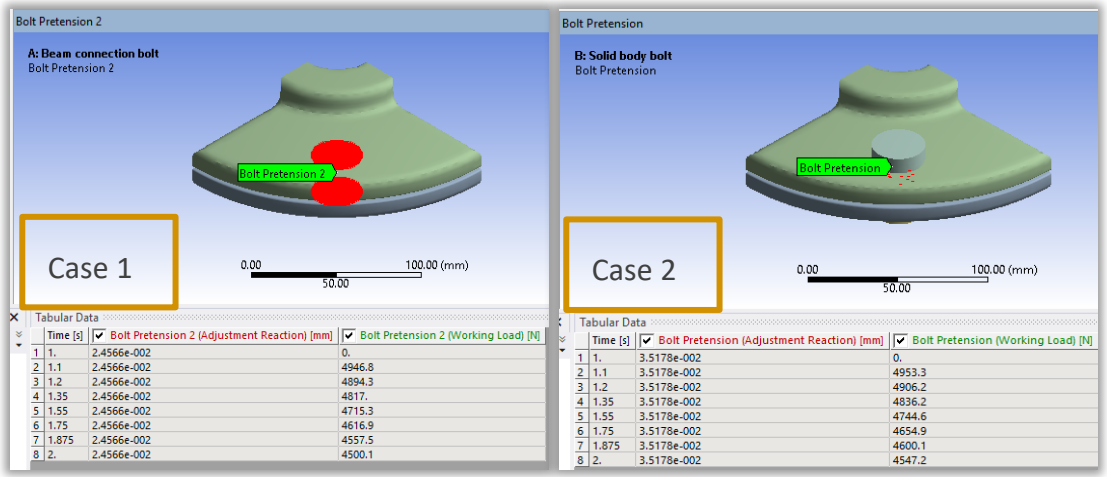
- The stiffness of the bolted joint is different between line body (shank only) and solid body (shank, bolt head, nut, etc.).
- Local results (stresses, deformations) near bolt hole may differ between these two approaches, and if the user is interested in the stress/deformation near the bolt hole the user should model the bolt with solid bodies and frictional contact.
- If the user is interested in bolt load history or overall assembly performance (e.g., seals), the Line Body or Beam Connection way of modeling the bolt is perfectly fine.

Case Study (cont.)





- Case 1 – Bolt is modeled as beam connection.
- Case 2 – Bolt is modeled as solid body with bolt head and nut.
- Results are comparable between line vs. solid body bolt.




Ansys