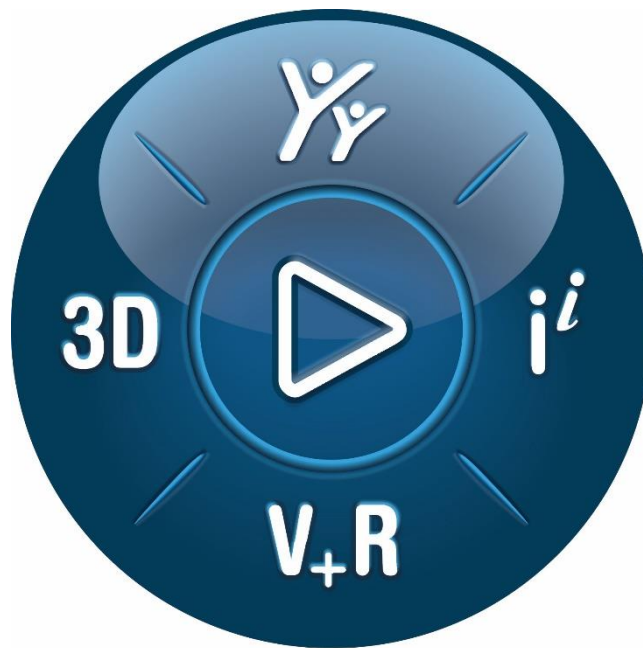


SolidPractice: Bolt Connectors Technical Definition, Tips and Tricks

SOLIDWORKS® Simulation

Last Update: March 2021

Revision 1.1



3DEXPERIENCE®

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Revision History

Rev #	Date	Description
1.0	Mar 2019	Document created.
1.1	Mar 2021	Document reviewed. Verified for current software release. Expanded the topic 6b 'Von Mises stress for a bolt connector'.

Note

All SolidPractices are written as guidelines. It is a strong recommendation to use these documents only after properly evaluating your requirements. Distribution of this document is limited to Dassault Systèmes SolidWorks employees, VARs and customers that are on active subscription. You may not post this document on blogs or any internal or external forums without prior written authorization from Dassault Systèmes SolidWorks Corporation.

This document was updated using version SOLIDWORKS 2021 SP02. If you have questions or need assistance in understanding the content, please get in touch with your designated reseller.

1) Preface

If you have ever used SOLIDWORKS® Simulation to analyze assemblies or multibody parts, you most likely know that mate definitions in the SOLIDWORKS assembly do not translate into contact definitions in SOLIDWORKS Simulation. Therefore, from the point of view of SOLIDWORKS Simulation, the components of the assemblies are not attached until a proper contact condition or connector describing interactions between the assembly components is defined.

Among those simulation connectors is the *bolt connector*. Introduced with the release of SOLIDWORKS 2005, this type of connector allows a semi-automatic procedure where you can define the bolt to be used in a simulation study, specify the bolt's preload, and list the force in the bolt after the analysis is run.

SOLIDWORKS 2014 introduced the **Automatic Conversion of Toolbox Fasteners to Bolts** feature. The main purpose of this feature is to avoid having users duplicate efforts when defining a toolbox component during the design stage in SOLIDWORKS, and then need to redefine a bolt connector setting inside SOLIDWORKS Simulation during the analysis stage. With this new feature, SOLIDWORKS Simulation takes advantage of the robust Toolbox add-in.

The objective of this SolidPractice document is to share tips and best practices for setting up a simulation bolt connector, provide an in-depth technical definition, and provide information that relates to the **Automatic Conversion of Toolbox Fasteners** option.

Your Feedback Requested

We would like to hear your feedback and also suggestions for new topics. After reviewing this document, please take a few minutes to fill out a [brief survey](#). Your feedback will help us create the content that directly addresses your challenges.

2) Overview

A connector is a mechanism that defines how one entity (vertex, edge, face) connects to another entity or to the ground. SOLIDWORKS Simulation offers sets of mathematical connectors instead of actual physical models of the connectors to connect multiple parts to each other with pins, bolts, springs, bearings, links, spot welds, edge welds, rigid, or elastic supports. With this semi-automatic procedure, users have the ability to specify the parameters for a connector (such as a bolt's preload), and list the force in the bolts after running the analysis. The use of these connectors can speed up the analysis process due to a reduction of the mesh and contacts. Therefore, the solution can be found more quickly.

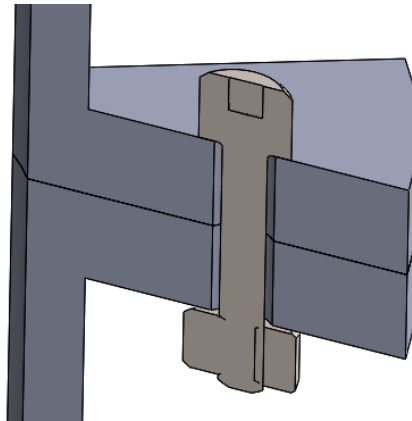
In general, bolt connectors are the most common connector type used by SOLIDWORKS users. Their application is very important as it covers several industries that benefit from the use of this type of connector. By understanding how the simulation bolt connectors are constructed, you can better judge when and where to use them.

3) Fastener and Bolts Differences and Definitions

From a technical perspective, it is important to note the difference between a SOLIDWORKS Toolbox fastener and a SOLIDWORKS Simulation bolt connector.

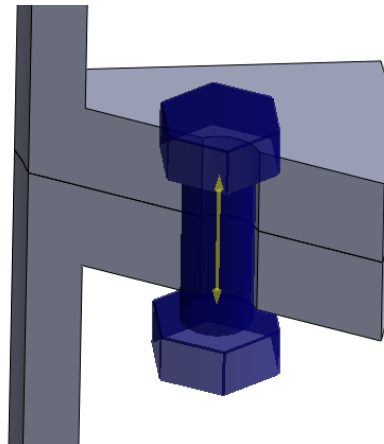
a) SOLIDWORKS Toolbox fastener

A SOLIDWORKS Toolbox fastener is a geometric representation of an actual fastener, which is meant to physically represent the fastener in the model, for spatial and mass property considerations, and for inclusion in the Bill of Materials (BOM).

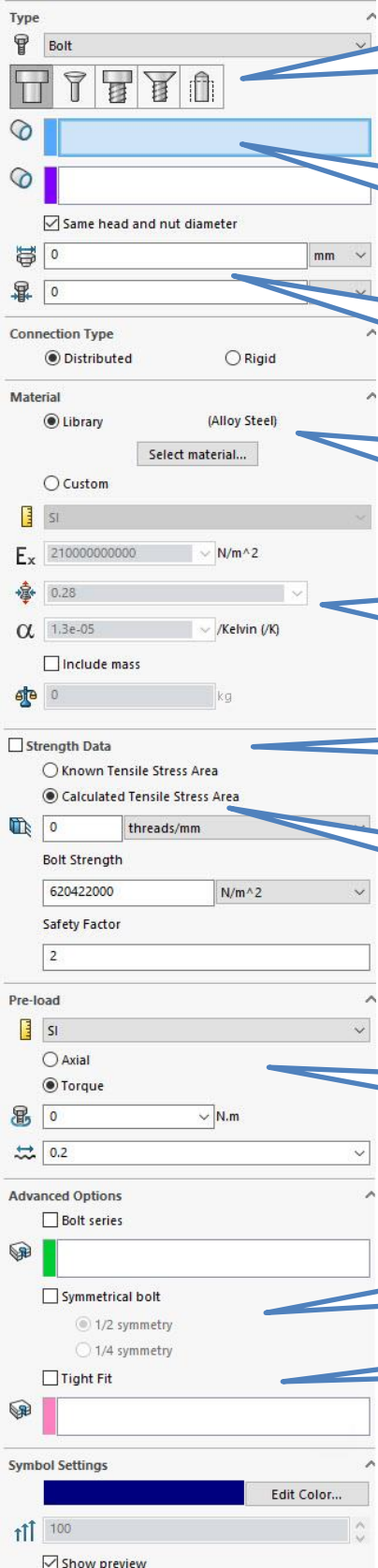


b) SOLIDWORKS Simulation bolt connector

A SOLIDWORKS Simulation bolt connector is a simulation abstraction that makes it possible to model the effect of bolting components together without the need to mesh and solve the actual geometry. A bolt connector not only helps to connect parts, it also helps to transfer loads between parts, resist and take on preloads or external loads, and avoids using actual geometry. Perhaps most importantly, the bolt connector reports several different results such as axial force, shear force, bending moment, etc., to help you with a better understanding to determine bolt sizing.



The definition for a SOLIDWORKS Simulation bolt connector is as follows:



Type

☒ Bolt

☐ Countersink
☐ Counter bore
☐ Nut
☐ Screw

☒ Same head and nut diameter

☐ Different head and nut diameter

Connection Type

☒ Distributed ☐ Rigid

Material

☒ Library (Alloy Steel) ☐ Custom

Select material...

SI

E_x 210000000000 N/m²

ν 0.28

α 1.3e-05 /Kelvin (°K)

☐ Include mass

0 kg

☐ Strength Data

☐ Known Tensile Stress Area

☒ Calculated Tensile Stress Area

0 threads/mm

Bolt Strength

620422000 N/m²

Safety Factor

2

Pre-load

SI

☐ Axial

☒ Torque

0 N.m

0.2

Advanced Options

☐ Bolt series

☒ Symmetrical bolt

☒ 1/2 symmetry

☐ 1/4 symmetry

☐ Tight Fit

Symbol Settings

100

☒ Show preview

In this first area, you define whether the fastener is a countersink or a counter bore type fastener. You also specify whether it is a bolt (that threads into a nut) or a screw (that threads into a tapped hole).

For a bolt, you must select a circular edge at the intersection of the hole and the planar face secured by the bolt head. You must select a similar circular edge for a nut. It could be from same or different part, but it must be concentric.

In this area, you must define the diameter of the washer or bolt head that is in contact with the face secured by the bolt head. You must define a similar diameter on the nut side and define the shank diameter of the bolt.

You must define a material (the default selection is alloy steel). The program does not maintain a link to the selected library. If you edit the library, the bolt does not reflect your changes.

If selecting a **Custom** material, you must define the material properties such as **Young's Modulus**, **Poisson's Ratio**, **Thermal Expansion Coefficient**, and whether or not to include **Mass**.

If **Factor of Safety** is a concern, you must define the **Strength Data**

You input a known tensile stress area or you could let the program calculate this value by using the shank bolt diameter and thread pitch.

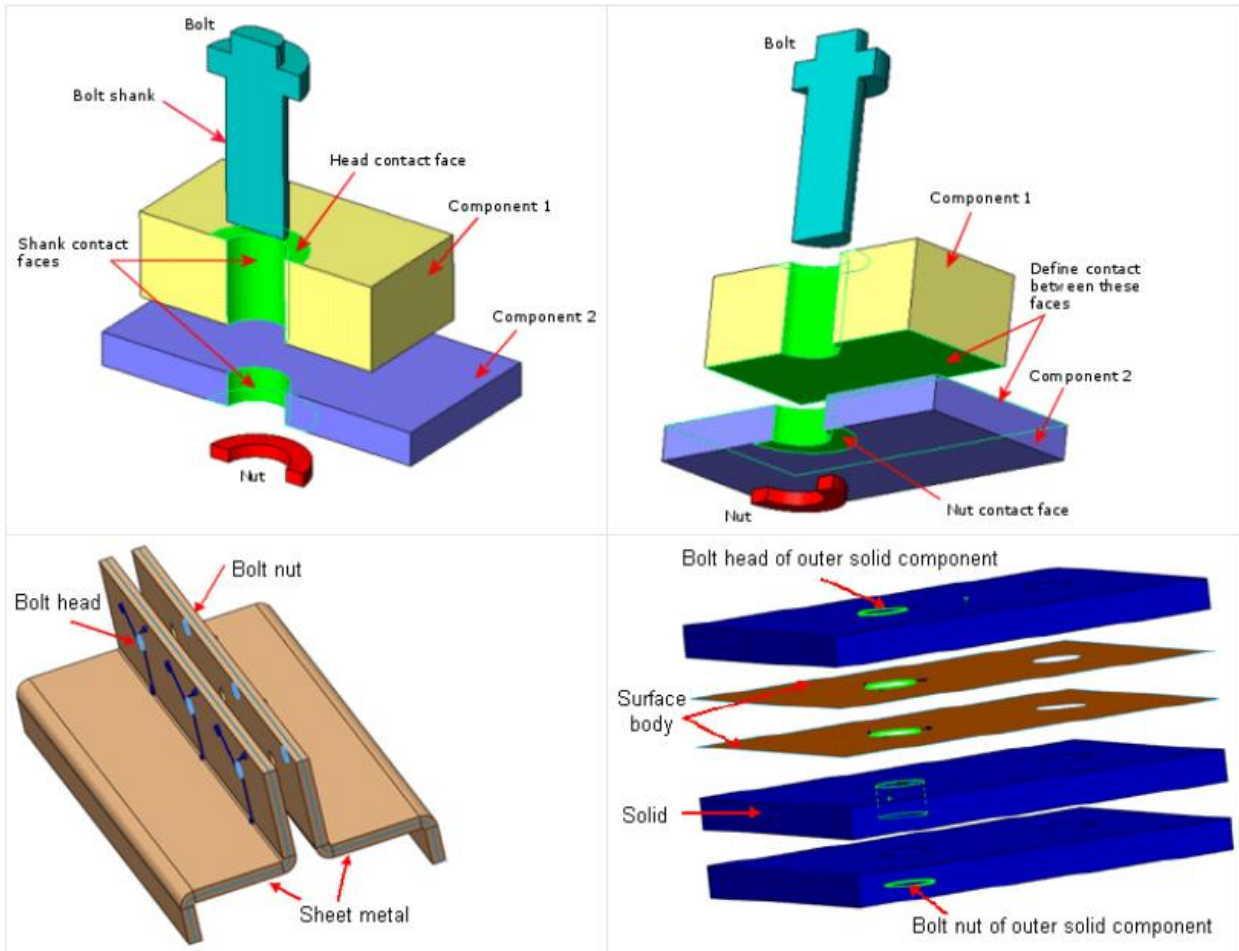
Define the preload in this area. The applied preload (clamp force) provides the frictional force necessary to resist slippage between the connecting parts.

Use the **Symmetrical bolt** option when is possible to cut the model in quarter or half.

If selecting the **Tight Fit** option, the holes must be coaxial.

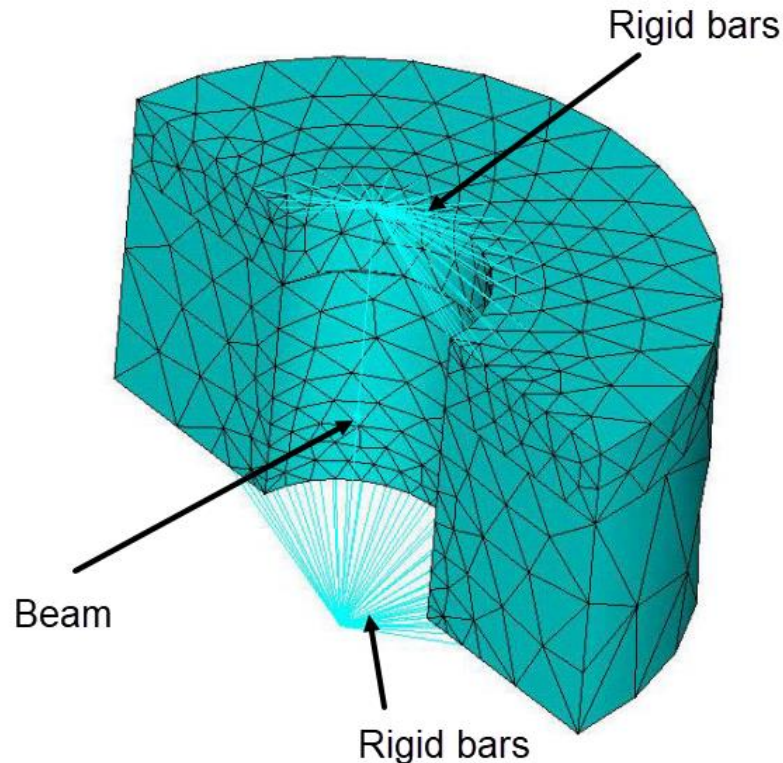
4) Bolt Connector – Technical Definition

It is possible to define bolt connectors through a mixed stack of solids, shells, and sheet metal bodies. It is also possible to define bolt connectors by selecting entities of the same component.



a) SOLIDWORKS Simulation bolt connector method

SOLIDWORKS Simulation uses its own bolt connector method. This method is similar to the spider bolt method as explained in “Methods for Modeling Bolts in the Bolted Joint” by Jerome Montgomery, Siemens Westinghouse Power Corporation, Orlando, FL. In reality, SOLIDWORKS Simulation uses a beam element to represent the bolt shank and uses rigid bar elements to connect the beam to the flanges. The software simulates the bolt preload by using thermal expansion and contraction. For example, to generate the preload force, it contracts the axial length by an appropriate amount. This calculation of the thermal expansion and contraction is done automatically by the solver. The method used comes from “Modeling Pretensions in Bolted Connections”, by J.M. Stallings and D.Y. Hwang, Computers & Structures, Vol. 45, No.4, pp 801-803, 1992.



This is defined by a beam element, which does not have any resistance to torque because axial rotational degree of freedom is released. This is consistent with the physical model. In reality, the slippage between the connecting parts is resisted by the frictional force provided by the clamp force (preload).

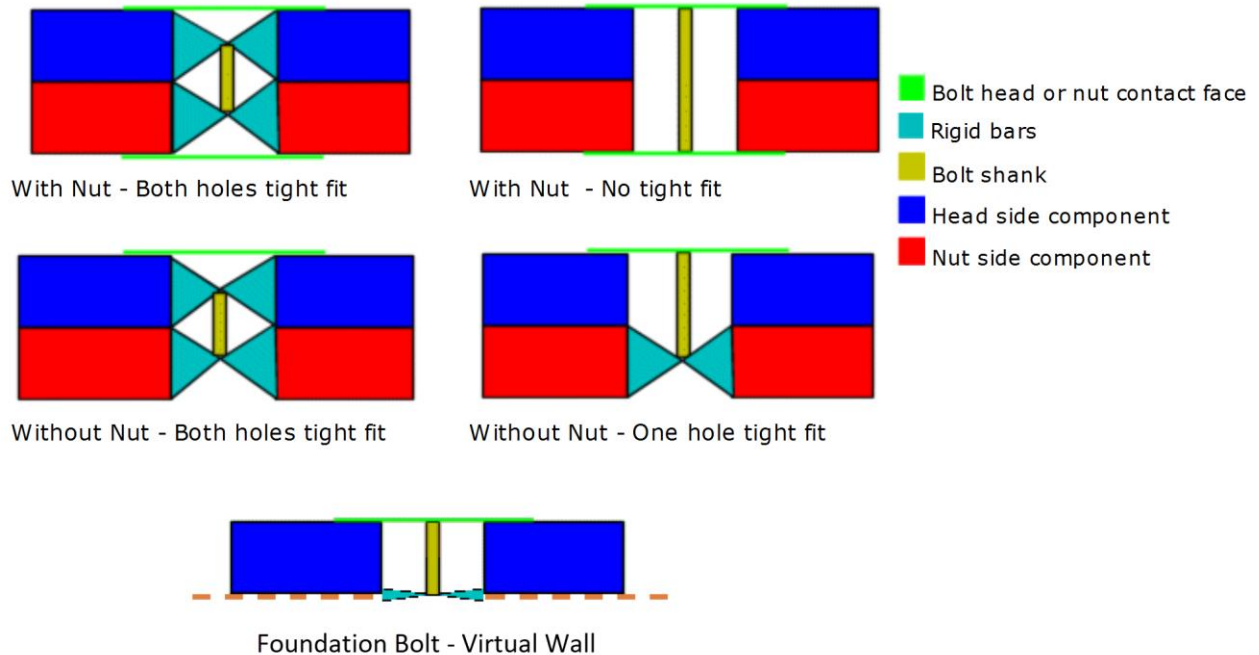
In addition, it is important to note that the beam used between the two ends is tension-resistant only (no resistance to compressive force). In fact, this feature is the reason for the problem to become nonlinear (in the absence of any other nonlinearity), and simulate a contact behavior (but in opposite direction to no-penetration contact due to the tension-resistance feature of it). That is why the problem must go through iterations and subsequently becomes slower (in the absence of any other nonlinearity such as actual contacts defined between the parts).

b) Rigid bars implementation for solids

Depending on the type of bolt connector used, the number of rigid bar elements depends directly on the type of mesh created. There are two types of fit options:

Loose fit bolt: On each side of the modeled bolt, the number of rigid bars is equal to the number of nodes on the face that are in contact with the nut and the screw head respectively. Therefore, it can only be determined after meshing the model.

Tight fit bolt: In addition to the rigid bar elements as generated for a loose fit bolt, SOLIDWORKS Simulation generates the rigid bar elements between the nodes on the cylindrical surfaces that are in contact with the screw shank and the node from where the spider arrangement originates.



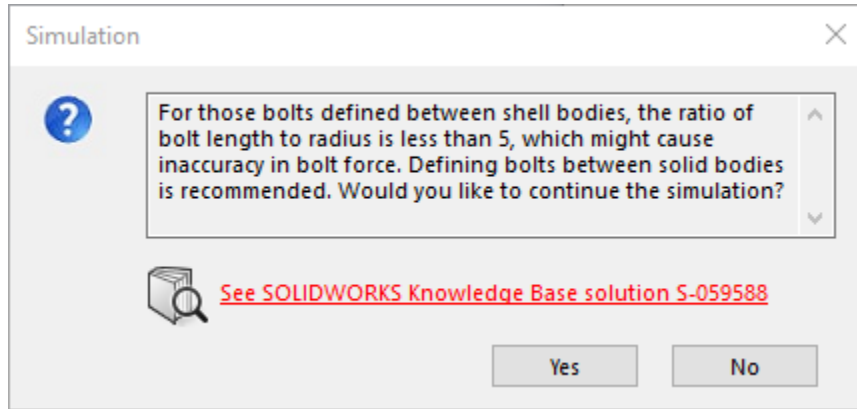
Overall, for loose fit bolts, the number of rigid bars is equal to the number of nodes on the head and nut surfaces. For tight fit bolts, the number of rigid bar elements is equal to the total sum of the nodes on the dead, nut and cylindrical surfaces of the bolt.

There is no need to use split lines at bolt head and nut diameters because SOLIDWORKS Simulation will internally do some imprinting to get the head and nut area and mesh it. The mesh data is transferred to the analysis. The number of rigid bars is still equal to the number of nodes on the head or nut area for loose fit bolts and for tight fit, and the number of rigid bar elements is equal to the total sum of the nodes on the head, nut and cylindrical surfaces of the bolt. In more recent versions, the options to select the split surface have been removed.

c) Rigid bars implementation for shells

It has been determined that the result forces on bolt connectors defined between shell surfaces were not sufficiently accurate when the bolt shank was too bulky. A message will appear only when the ratio of bolt length to the shank radius is lower than 5. The user is then advised to define the bolt between the solid bodies.

For bolt connectors defined between shells, the following warning message appears at the beginning of the simulation:



The bolt shank length is taken as the sum of the thickness of all the plates. The bolt length is usually not equal to the distance between the modeled shells.

The bolt radius is taken as half the Nominal Shank Diameter entered in the **Bolt Connector** PropertyManager.

The rigid bars construction for bolt connectors defined between shells is in the following manner:



5) Automatic Conversion of Toolbox Fasteners to Bolts Connectors

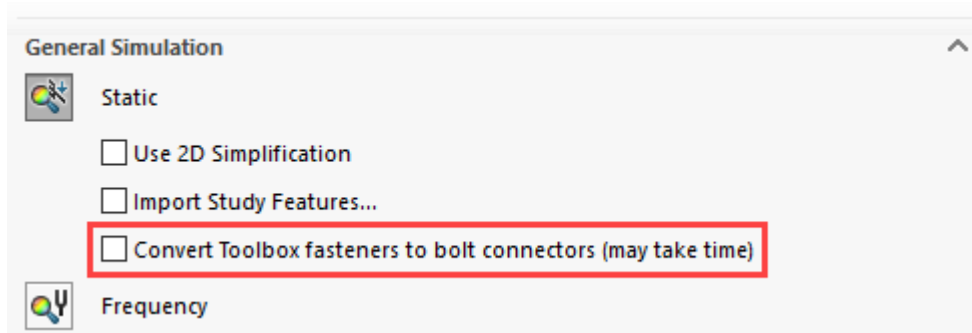
Prior to the release of SOLIDWORKS 2014, it was often necessary to repeat what you had done in the “CAD” side of SOLIDWORKS to set up your study in SOLIDWORKS Simulation. One example is that you had to exclude toolbox fasteners in the simulation study and then add a series of simulation connectors. With the introduction of the **Automatic Conversion of Toolbox Fasteners to Bolts** feature in the SOLIDWORKS 2014 release, you were no longer forced to embark in this repetitive task. Now, the conversion tool will detect all of the Toolbox fasteners and use this information to add simulation bolt connectors of the same size and location as the previously excluded Toolbox fasteners. Additionally, if the material was defined for the Toolbox fastener, this material is used in SOLIDWORKS Simulation for the bolt connector along with calculate values of preload, tensile stress area, and bolt strength.

a) Methods to Convert Toolbox Fasteners to Bolt Connectors

There are three main methods of converting Toolbox fasteners to bolt connectors:

i) During study creation

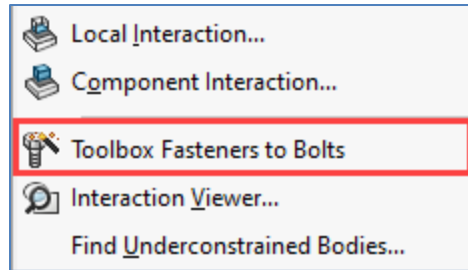
The **Convert Toolbox fasteners to Bolt Connectors (may take time option)** is only available for linear static, nonlinear static, and nonlinear dynamic studies. During the conversion process, all information related to the location, geometric features, and material of the Toolbox fasteners is mapped internally to the formulation of the corresponding bolt connectors.



Please note that this option is only available if the current model contains Toolbox fasteners. In addition, the **Use 2D Simplification** and **Convert Toolbox fasteners to Bolt Connectors** options are mutually exclusive. Upon selection of one option, the other option becomes inactive.

ii) Context menu of the Connections folder

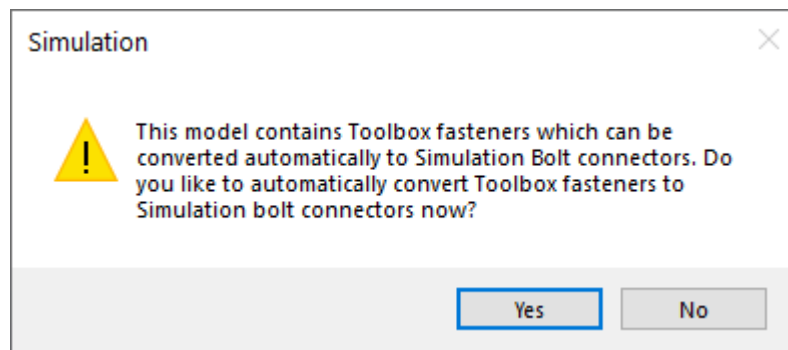
If you do not set the **Convert Toolbox fasteners to Bolt Connectors (may take time)** option during study creation, you can still choose to run the option from the right-click context menu of the **Connections** folder.



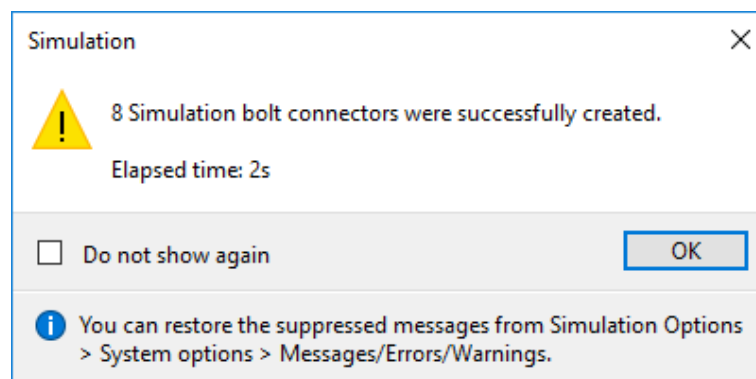
This option is only available if there are Toolbox fasteners in the SOLIDWORKS model that have not been excluded in the current simulation study.

iii) First time you define a simulation bolt connector

If there are Toolbox fasteners in the SOLIDWORKS model that have not been excluded in the current simulation study, the following message will appear the first time a user defines a simulation bolt connector.



After the completing the analysis, a dialog box reports the number of simulation bolt connectors that were successfully created as well as the number of toolbox fasteners that could not be converted to simulation bolt connectors.



6) Tips and Best Practices

When defining or using bolt connectors inside a SOLIDWORKS Simulation study, keep in mind the following considerations:

a) External Custom Fasteners

External fasteners that were created outside of the SOLIDWORKS Toolbox environment and simply added the fastener flag using the **sldsetdocprop** utility will not automatically convert in SOLIDWORKS Simulation. One way to determine if the Toolbox component is associated correctly with the Toolbox Configure environment is to right-click on the component and confirm that the **Edit Toolbox Component** option is available in the context menu after enabling the Toolbox add-in.

If this option is not available, you will need to add the custom part to the SOLIDWORKS Toolbox database. Follow these steps:

1. Go to **Tools > Toolbox > Configure > 2. Customize your hardware**.
2. Right-click on **Toolbox Standards** and create a new folder. This folder is used to create a new standard that could be customizable.
3. Copy a representative standard and paste it into the new folder.
4. Select the correct category and add your custom part.
5. After adding the custom part, remember to save your changes and close the Toolbox dialog box.

After completing these steps, the **Edit Toolbox Component** option should be available and SOLIDWORKS Simulation should be able to convert the fasteners successfully.

b) Von Mises Stress for a Bolt Connector

The **Bolt Connector** formulation approximates the behavior of a real bolt and works by calculating resultant forces, not stress distributions. Therefore, SOLIDWORKS Simulation does not provide von Mises stress results for bolt connectors.

However, you could still manually calculate the stress within a bolt by first calculating the axial, shear, and bending stresses. Then, calculating the principal stresses. Finally, you can combine the principal stresses into von Mises stress.

Be aware that this method of calculation will only return a single value of von Mises stress for the bolt, which is based on the equivalent bolt forces. To obtain a detailed distribution of stress throughout the bolt, you need to model the bolt as a solid body.

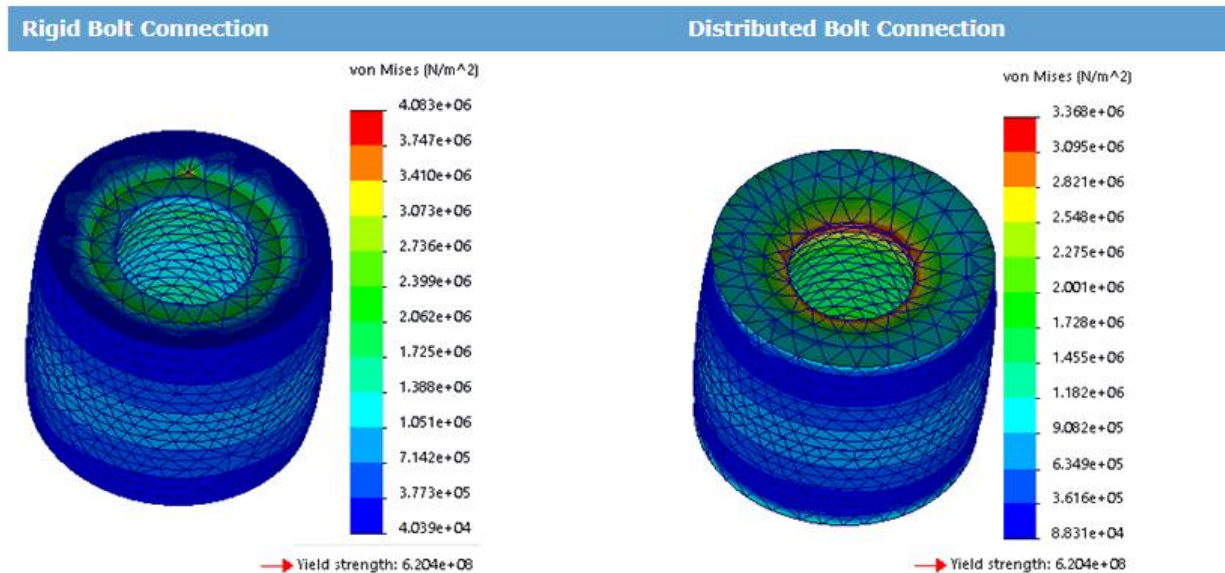
For more information, refer to the following documentation about the stress calculations:

- <http://www.faculty.fairfield.edu/wdornfeld/ME311/BasicStressEqns-DBWallace.pdf>
- http://en.wikipedia.org/wiki/Principal_stress#Principal_stresses_and_stress_invariants
- http://en.wikipedia.org/wiki/Von_Mises_stress

Starting in SOLIDWORKS 2020, the introduction of distributed coupling enhanced the formulation of the bolt connectors. Distributed coupling allows the faces attached to bolt connectors to deform, which delivers a more realistic representation of a connector's behavior.

When you set the **Connection Type** to **Distributed**, a distributed coupling formulation connects a reference node (beam element node of a bolt shank) to a group of coupling nodes inside the imprint regions of a bolt's head and nut. Distributing coupling constrains the motion of the coupling nodes to the translation and rotation of the reference node. Nodes located inside the head and nut imprint areas can deform relative to each other.

This constraint is enforced in an average sense in a way that enables control of the transmission of loads through weight factors at the coupling nodes. For example, the constraint distributes a bolt's pre-load such that the sum of the forces at the coupling nodes is equivalent to the total pre-load at the reference node. Uniform weight factors are applied in this case.



As shown in the previous image, the von Mises stress plot shows a hot spot at the head imprint region when using Rigid Bolt Connection. In contrast, the von Mises stress plot shows smoother gradients at the head imprint region when using Distributed Bolt Connection.

c) Stress Distribution Around Bolt Connectors

When you define a bolt connector, a message in the **Bolt Connector** PropertyManager displays the warning: **Reported stress in the 1-diameter vicinity of the bolt will usually be higher than the actual stress**. It is always an expectation that stresses in the close vicinity of bolts are not to be taken at face value. The close vicinity can be understood as the region closer than one bolt diameter away from the edge selected to define the bolt connector. Typically, the stresses in this region will be overestimated by the simulation results. This is a drawback of the technology in use to represent the actual bolts with bolt connectors.

Please note that the accuracy of stress in the close vicinity of a bolt connector is lower when the bolt connects shell elements as opposed to solid elements.

Use your best judgement when deciding to dismiss these spots. Currently, it is not possible for post-processing features to dismiss the spots.

As workaround, you can use the **ISO Clipping** view, together with mesh refinement on this area. Then you can remove the area that has extremely high stress, and manually set the max stress to a lower value to avoid these hotspots.

d) Partial Cylindrical Faces

Avoid selecting partial cylindrical faces (less than a full 360 degrees) unless you are using the **Symmetrical bolt** option. Although the user interface may allow you to make this selection, the solver will not be able to handle it in a majority of cases. In the few specific cases that it solves, you may receive unexpected results.

e) Tight Fit Option

The **Tight Fit** option used in the bolt connector requires the selection of a set of cylindrical faces that the shank of the bolt comes in contact with in a through hole. Holes must be coaxial and they could be from different parts and have different radii. However, keep in mind that if through holes are from the same part, the radii values must be the same.

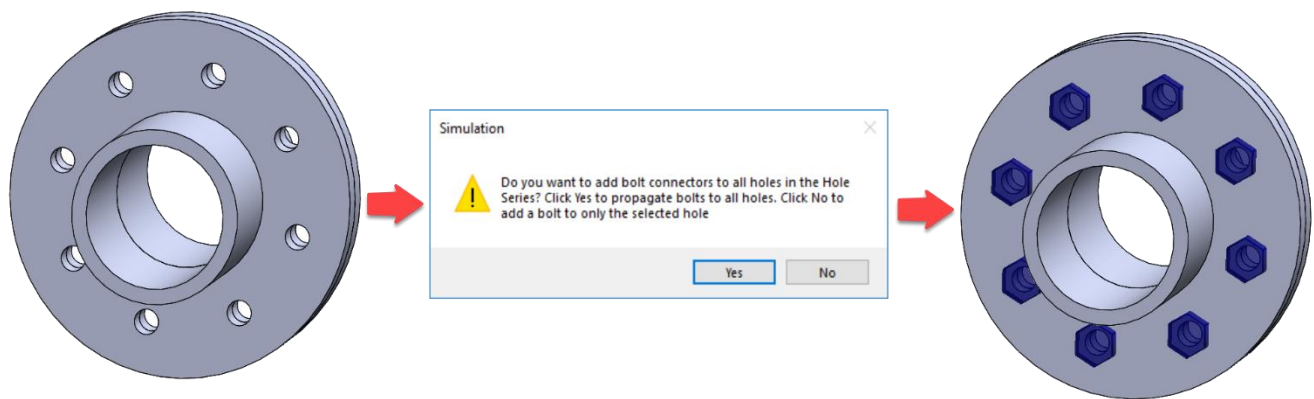
f) Torque Coefficient

The bolt connector torque coefficient is a difficult value to calculate. The calculation involves thread diameters, thread lead angle, friction coefficients, and thread angles. Friction coefficients are difficult to estimate in a real-world application and could vary and be unpredictable. The SOLIDWORKS recommendation is to start with initial well-published k

values, and then adjust those values based on testing. If you do not have any better information in your design, choose the default of **0.20** for initial analyses.

g) Propagating Bolt Connectors to Other Holes

There are a lot of automation tools that leverage smart intelligent data from SOLIDWORKS to save you a lot of time. This is especially true when dealing with many bolt connectors in your assembly. For example, the **Hole Series** feature in SOLIDWORKS allows you to create a series of holes through the individual parts of an assembly. Using this feature in SOLIDWORKS allows the option to propagate the bolt connector to be available at your disposal and fast track your productivity when defining a bolt connector.



h) Symmetrical Bolt

You can often analyze either half or a quarter geometry of your assembly part for simulation purposes. This reduces meshing and simulation solve time. The good news is that if the plane of symmetry cuts through the actual bolt as well, then the symmetrical bolt connector could be used in the bolt connector definition.

A few things to keep in mind while using this option is that the total preload values input is divided by a half or quarter of the total preload of the bolt according to the selected symmetry type. Similarly, when the program reports bolt force results, the load will be either one-half or one quarter of the total force. Lastly, if the **Strength Data** option is used whether you use **Calculated Tensile Stress Area** or **Known Tensile Stress Area**, the tensile area scales automatically based on the symmetry type.

i) Strength Data from Converted Fasteners

An additional advantage of the automated mapping of the Toolbox data is that the tensile stress area is calculated using the ISO and ANSI Bolt threads as per the following formulas:

- **ISO Bolt threads:** $A_t = 0.7854 * [d - (0.9382 / n)]^2$, where d is given in mm, and n is given in threads/mm.
- **ANSI threads:** $A_t = 0.7854 * [d - (0.9743 / n)]^2$, where d is given in inches, and n is given in threads/inch.

Reference: Machinery's Handbook published by Industrial Press.

Because d is nominal diameter of the bolt taken from the Toolbox fastener data, and n is number of threads per inch (mm) also taken from the Toolbox fastener data; the **Pitch** and **Diameter** values found in the Toolbox database are the two key inputs that the simulation bolt connector takes into consideration. Keep this in mind, especially when creating custom bolts.

