



Connecting Beams and Solids

Introduction

The selection of element types for modeling different parts of a structure depends on a variety of factors. Even though solid elements have the advantage of representing the behavior of any structure in detail, their use increases the number of degrees of freedom compared to other structural elements, which often results in significantly higher computational efforts. Under such circumstances, instead of modeling the entire structure using solid elements, you can use a combination of different elements by employing certain engineering assumptions. In order to model slender structures with significant bending and torsional stiffness, use of beam elements is a good alternative. In a structure having solid and beam elements, it is essential to couple these two element types accurately.

This example demonstrates the use of the **Solid-Beam Connection** multiphysics coupling in order to create a transition between a domain modeled with solid elements and an edge modeled with beam elements. Two different connection types are discussed, and a comparison of the stress distribution at the interface is performed.

Model Definition

The model consists of an I-section beam with a circular hole through its flange. The beam is fixed at one end and subjected to different point loads at the free end. In this example, you model the beams using two different structural elements. While the presence of a circular hole in the first beam necessitates the use of solid elements, the outer part of the beam can be modeled using beam elements, as shown in [Figure 1](#).

The transition between the two parts of the beam is created using the **Solid-Beam Connection** multiphysics coupling. In order to compare the two different solid-beam connection types, two instances of the solid-beam assembly with different types of couplings are used. The **Solid boundaries to beam points, transition** connection type is used to model the transition in the first instance, and the **Solid boundaries to beam points, general** connection type is used in the second one.

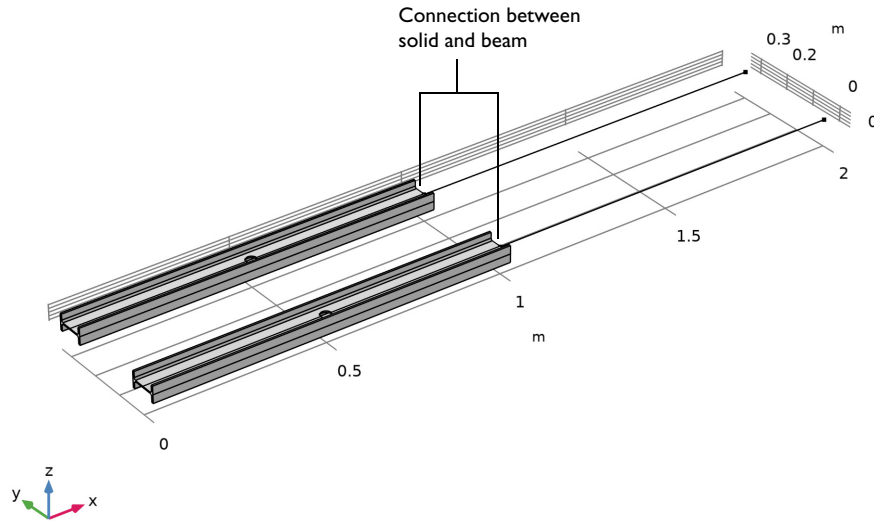


Figure 1: The geometry used for demonstrating two different solid-beam connections.

GEOMETRY

- Length of each beam: 2 m. The transition is at the midpoint.
- Cross section of the beam: European standard I-section beam (IPE 80) of 80-by-46 mm with 3.8 mm web thickness and 5.2 mm flange thickness.
- Radius of the circular hole: 20 mm.

MATERIAL

The material is Structural Steel with the following data at room temperature:

- Young's modulus, $E = 200$ GPa.
- Poisson's ratio, $\nu = 0.30$.

CONSTRAINTS

The inner end of the solid modeled beam is fixed.

LOAD

In order to compare the behavior of structure under various loading conditions, six different load cases are analyzed separately. A unit point load (as force or moment) is applied at the free end of the beam in three different directions.

Results and Discussion

The von Mises stress distribution for the load case with moment about the X -axis (the “twisting moment” load case) is plotted and compared for both connection types. As shown in Figure 2, the stress distribution seems to be comparable for both cases except near the solid-beam connections. Note that the von Mises stress variable in the Beam interface provides an upper bound. Since in this case it is known that the stress state is due to pure torsion, the maximum torsional shear stress is used for comparison.

Twisting Moment Volume: von Mises stress (N/m²) Line: if(group.lgMx,beam.tmax*sqrt(3),beam.mises)
(N/m²)

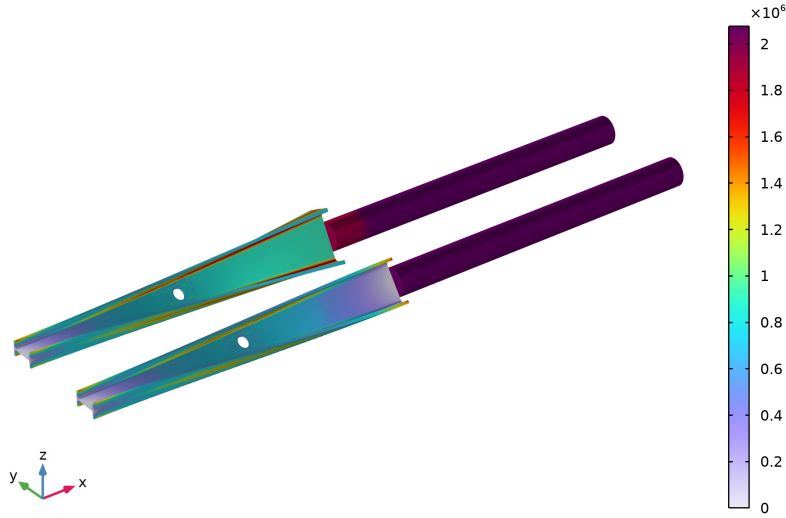


Figure 2: The von Mises stress distribution of the Twisting Moment load case.

To compare the behavior of both connection types, the von Mises stress distribution for the load case with moment about the Z axis (the “bending moment Z ” load case) is plotted, along with the difference in von Mises distribution between the two. In Figure 3, the left hand side plot is the difference in the von Mises stress distribution between two solid structures, while the right hand side plot is von Mises stress distribution in one solid structure. The von Mises stress distribution is comparable throughout the structure except near the solid-beam interface.

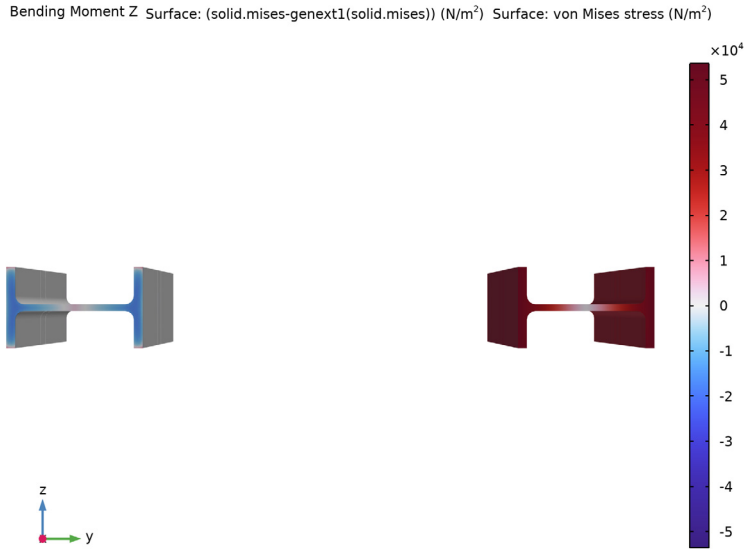


Figure 3: Comparison of von Mises stress distribution under Bending Moment Z load case.

To compare the performance of the two connection types, the traction distribution at the solid-beam interface for different load cases are plotted as shown in [Figure 4](#) and [Figure 5](#). For the load case with twisting moment, the transition connection type shows an in-plane distribution of traction, while the traction in the second case is predominantly out of plane. Similarly, for the load case with moment about the Z-axis, a uniform distribution of traction across the cross section is observed for the first type compared to the general connection type in the second case.

Twisting Moment Surface: von Mises stress (N/m^2) Arrow Surface: Traction (force/area) (spatial frame)

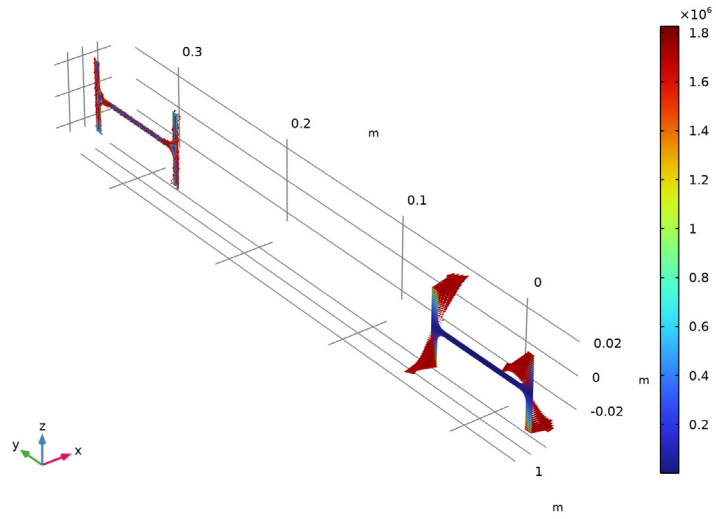


Figure 4: Traction distribution at the solid-beam interface for the twisting moment load case.

Bending Moment Z Surface: von Mises stress (N/m^2) Arrow Surface: Traction (force/area) (spatial frame)

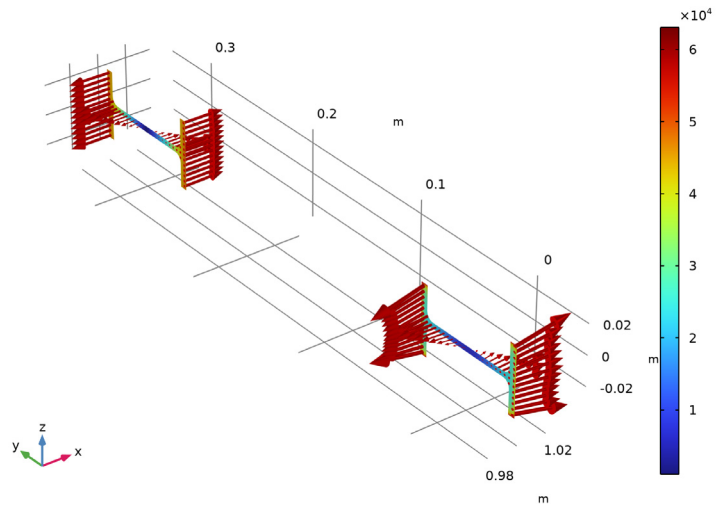


Figure 5: Traction distribution at solid-beam interface for bending moment Z load case.

Notes About the COMSOL Implementation

The built-in multiphysics coupling **Solid-Beam Connection** is used to connect the Solid and Beam interfaces in this model. The connection type **Solid boundaries to beam points, transition** includes warping of the cross section. The variables of warping are separately solved for in a stationary step, by clearing the selection of all other physics interfaces except the **Solid-Beam Connection** multiphysics coupling. In the subsequent study steps, these variables are manually suppressed to solve for the other variables of the study. If warping is insignificant for a certain connection, then you can choose to ignore it, thus simplifying the solver setup.


The **Solid boundaries to beam points, general** connection type does not consider warping of the cross section. Additional details about these connection types can be found in the documentation for *Couplings Between Structural Mechanics Interfaces* in the *Structural Mechanics Module User's Guide*.

Application Library path: Structural_Mechanics_Module/Beams_and_Shells/
beam_solid_connection




Modeling Instructions

From the **File** menu, choose **New**.

NEW


In the **New** window, click  **Model Wizard**.

MODEL WIZARD

- 1 In the **Model Wizard** window, click  **3D**.
- 2 In the **Select Physics** tree, select **Structural Mechanics>Solid Mechanics (solid)**.
- 3 Click **Add**.
- 4 In the **Select Physics** tree, select **Structural Mechanics>Beam (beam)**.
- 5 Click **Add**.
- 6 Click  **Study**.
- 7 In the **Select Study** tree, select **General Studies>Stationary**.
- 8 Click  **Done**.

GLOBAL DEFINITIONS

Parameters I

- 1 In the **Model Builder** window, under **Global Definitions** click **Parameters I**.
- 2 In the **Settings** window for **Parameters**, locate the **Parameters** section.
- 3 Click  **Load from File**.
- 4 Browse to the model's Application Libraries folder and double-click the file `beam_solid_connection_parameters.txt`.

Load Group Mx

- 1 In the **Model Builder** window, right-click **Global Definitions** and choose **Load and Constraint Groups>Load Group**.
- 2 In the **Settings** window for **Load Group**, type Load Group Mx in the **Label** text field.
- 3 In the **Parameter name** text field, type lgMx.

Load Group My

- 1 In the **Model Builder** window, right-click **Load and Constraint Groups** and choose **Load Group**.
- 2 In the **Settings** window for **Load Group**, type Load Group My in the **Label** text field.
- 3 In the **Parameter name** text field, type lgMy.

Load Group Mz

- 1 Right-click **Load and Constraint Groups** and choose **Load Group**.
- 2 In the **Settings** window for **Load Group**, type Load Group Mz in the **Label** text field.
- 3 In the **Parameter name** text field, type lgMz.

Load Group Fx

- 1 Right-click **Load and Constraint Groups** and choose **Load Group**.
- 2 In the **Settings** window for **Load Group**, type Load Group Fx in the **Label** text field.
- 3 In the **Parameter name** text field, type lgFx.

Load Group Fy

- 1 Right-click **Load and Constraint Groups** and choose **Load Group**.
- 2 In the **Settings** window for **Load Group**, type Load Group Fy in the **Label** text field.
- 3 In the **Parameter name** text field, type lgFy.

Load Group Fz

- 1 Right-click **Load and Constraint Groups** and choose **Load Group**.




- 2 In the **Settings** window for **Load Group**, type Load Group Fz in the **Label** text field.
- 3 In the **Parameter name** text field, type 1gFz.

The following section provides step by step instructions to create the geometry from scratch. If you do not want to build the geometry yourself, you can load the geometry sequence from the stored model. In the **Model Builder** window, under **Component 1 (comp1)** right-click **Geometry 1** and choose **Insert Sequence**. Browse to the model's Application Libraries folder and double-click the file `beam_solid_connection.mph`.



You can then skip the section about creating **Geometry 1** and continue to the **Definitions** section.

GEOMETRY 1

Polygon 1 (pol1)

- 1 In the **Geometry** toolbar, click  **More Primitives** and choose **Polygon**.
- 2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.
- 3 From the **Data source** list, choose **Vectors**.
- 4 In the **x** text field, type $L/2 \times L$.
- 5 In the **y** text field, type 0 0.
- 6 In the **z** text field, type 0 0.
- 7 Click  **Build Selected**.
- 8 Click the  **Zoom Extents** button in the **Graphics** toolbar.


Work Plane 1 (wp1)

- 1 In the **Geometry** toolbar, click  **Work Plane**.
- 2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.
- 3 From the **Plane** list, choose **zy-plane**.
- 4 Click  **Build Selected**.

Work Plane 1 (wp1)>Plane Geometry

In the **Model Builder** window, click **Plane Geometry**.

PART LIBRARIES

- 1 In the **Home** toolbar, click  **Windows** and choose **Part Libraries**.
- 2 In the **Part Libraries** window, select **Structural Mechanics Module>Beams>European Standard>IPE_beam** in the tree.

3 Click  **Add to Geometry**.

GEOMETRY I

Work Plane 1 (wp1)>European IPE-beam 1 (pil)

1 In the **Model Builder** window, under **Component 1 (comp1)>Geometry 1>Work Plane 1 (wp1)>Plane Geometry** click **European IPE-beam 1 (pil)**.

2 In the **Settings** window for **Part Instance**, click  **Build Selected**.

Extrude 1 (ext1)

1 In the **Model Builder** window, right-click **Geometry 1** and choose **Extrude**.

2 In the **Settings** window for **Extrude**, locate the **Distances** section.


3 In the table, enter the following settings:

Distances (m)
L

4 Select the **Reverse direction** check box.

5 Click  **Build Selected**.

Cylinder 1 (cyl1)

1 In the **Geometry** toolbar, click  **Cylinder**.

2 In the **Settings** window for **Cylinder**, locate the **Size and Shape** section.

3 In the **Radius** text field, type R.

4 In the **Height** text field, type L.

5 Locate the **Position** section. In the **x** text field, type L/2.

6 In the **z** text field, type -L/2.

7 Click  **Build Selected**.

Difference 1 (dif1)

1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Difference**.

2 Select the object **ext1** only.




3 In the **Settings** window for **Difference**, locate the **Difference** section.

4 Click to select the  **Activate Selection** toggle button for **Objects to subtract**.



5 Select the object **cyl1** only.

6 Click  **Build Selected**.


Copy 1 (copy1)

- 1 In the **Geometry** toolbar, click  **Transforms** and choose **Copy**.
- 2 Click in the **Graphics** window and then press Ctrl+A to select both objects.
- 3 In the **Settings** window for **Copy**, locate the **Displacement** section.
- 4 In the **y** text field, type $0.3 \cdot L$.
- 5 Click  **Build Selected**.
- 6 Click the  **Zoom Extents** button in the **Graphics** toolbar.



Work Plane 2 (wp2)

- 1 In the **Geometry** toolbar, click  **Work Plane**.
- 2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.
- 3 From the **Plane** list, choose **zy-plane**.
- 4 In the **x-coordinate** text field, type $0.45 \cdot L$.
- 5 Click  **Build Selected**.
- 6 Right-click **Work Plane 2 (wp2)** and choose **Duplicate**.

Work Plane 3 (wp3)

- 1 In the **Model Builder** window, click **Work Plane 3 (wp3)**.
- 2 In the **Settings** window for **Work Plane**, locate the **Plane Definition** section.
- 3 In the **x-coordinate** text field, type $0.55 \cdot L$.
- 4 Click  **Build Selected**.

Partition Objects 1 (par1)

- 1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Partition Objects**.
- 2 Select the objects **copy1(1)** and **dif1** only.
- 3 In the **Settings** window for **Partition Objects**, locate the **Partition Objects** section.
- 4 From the **Partition with** list, choose **Work plane**.
- 5 From the **Work plane** list, choose **Work Plane 2 (wp2)**.
- 6 Click  **Build Selected**.
- 7 Right-click **Partition Objects 1 (par1)** and choose **Duplicate**.

Partition Objects 2 (par2)

- 1 In the **Model Builder** window, click **Partition Objects 2 (par2)**.
- 2 Select the objects **par1(1)** and **par1(2)** only.
- 3 In the **Settings** window for **Partition Objects**, locate the **Partition Objects** section.


4 From the **Work plane** list, choose **Work Plane 3 (wp3)**.

5 Click  **Build Selected**.

Union 1 (uni1)

1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Union**.


2 Select the object **par2(2)** only.

3 In the **Settings** window for **Union**, click  **Build Selected**.

Union 2 (uni2)

1 In the **Geometry** toolbar, click  **Booleans and Partitions** and choose **Union**.

2 Select the object **par2(1)** only.


3 In the **Settings** window for **Union**, click  **Build Selected**.

Form Union (fin)

1 In the **Model Builder** window, under **Component 1 (comp1)>Geometry 1** click **Form Union (fin)**.

2 In the **Settings** window for **Form Union/Assembly**, locate the **Form Union/Assembly** section.

3 From the **Action** list, choose **Form an assembly**.

4 In the **Geometry** toolbar, click  **Build All**.

Fixed End

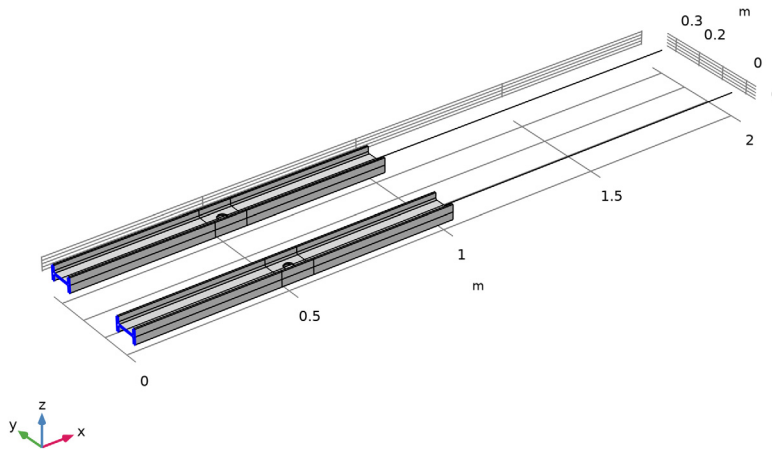
1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.

2 In the **Settings** window for **Explicit Selection**, type **Fixed End** in the **Label** text field.


3 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.

- 4 On the object **fin**, select Boundaries 1 and 69 only.


It might be easier to select the boundaries by using the **Selection List** window. To open this window, in the **Home** toolbar click **Windows** and choose **Selection List**. (If you are running the cross-platform desktop, you find **Windows** in the main menu.)



Solid Beam Interface


- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type Solid Beam Interface in the **Label** text field.
- 3 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Boundary**.
- 4 On the object **fin**, select Boundaries 68 and 136 only.

Free End

- 1 In the **Geometry** toolbar, click  **Selections** and choose **Explicit Selection**.
- 2 In the **Settings** window for **Explicit Selection**, type Free End in the **Label** text field.
- 3 Locate the **Entities to Select** section. From the **Geometric entity level** list, choose **Point**.
- 4 On the object **fin**, select Points 178 and 180 only.



DEFINITIONS

General Extrusion 1 (genext1)

- 1 In the **Definitions** toolbar, click  **Nonlocal Couplings** and choose **General Extrusion**.
- 2 Select Domains 4–6 only.
- 3 In the **Settings** window for **General Extrusion**, locate the **Destination Map** section.
- 4 In the **x-expression** text field, type X .
- 5 In the **y-expression** text field, type $Y+0.3*L$.
- 6 In the **z-expression** text field, type Z .
- 7 Locate the **Source** section. From the **Source frame** list, choose **Material (X, Y, Z)**.

ADD MATERIAL

Structural steel is used for all the components of the structure, and thus it can be added as a **Global Material** in the model. Using the **Material Link** node, you can assign the **Global Material** to different domains, boundaries, and edges of the structure.

- 1 In the **Home** toolbar, click  **Add Material** to open the **Add Material** window.
- 2 Go to the **Add Material** window.
- 3 In the tree, select **Built-in>Structural steel**.
- 4 Click the right end of the **Add to Component** split button in the window toolbar.
- 5 From the menu, choose **Add to Global Materials**.
- 6 In the **Home** toolbar, click  **Add Material** to close the **Add Material** window.

MATERIALS

Material Link 1 (matlnk1)

In the **Model Builder** window, under **Component 1 (comp1)** right-click **Materials** and choose **More Materials>Material Link**.

Material Link 2 (matlnk2)


- 1 Right-click **Materials** and choose **More Materials>Material Link**.
- 2 In the **Settings** window for **Material Link**, locate the **Geometric Entity Selection** section.
- 3 From the **Geometric entity level** list, choose **Edge**.
- 4 Select Edges 309 and 310 only.

SOLID MECHANICS (SOLID)


- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Solid Mechanics (solid)**.

- 2 In the **Settings** window for **Solid Mechanics**, click to expand the **Discretization** section.
- 3 From the **Displacement field** list, choose **Linear**.

Fixed Constraint I

- 1 In the **Physics** toolbar, click  **Boundaries** and choose **Fixed Constraint**.
- 2 In the **Settings** window for **Fixed Constraint**, locate the **Boundary Selection** section.
- 3 From the **Selection** list, choose **Fixed End**.

BEAM (BEAM)

- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Beam (beam)**.
- 2 In the **Settings** window for **Beam**, locate the **Edge Selection** section.
- 3 Click  **Clear Selection**.
- 4 Select Edges 309 and 310 only.

Cross-Section Data I

- 1 In the **Model Builder** window, under **Component 1 (comp1)>Beam (beam)** click **Cross-Section Data 1**.
- 2 In the **Settings** window for **Cross-Section Data**, locate the **Cross-Section Definition** section.
- 3 In the **A** text field, type **A**.
- 4 In the I_{zz} text field, type **Izz**.
- 5 In the e_z text field, type **ez**.
- 6 In the I_{yy} text field, type **Iyy**.
- 7 In the e_y text field, type **ey**.
- 8 In the **J** text field, type **J**.
- 9 Click to expand the **Stress Evaluation Properties** section. In the h_y text field, type **hy**.
- 10 In the h_z text field, type **hz**.
- 11 In the w_t text field, type **Wt**.
- 12 In the μ_y text field, type **muy**.
- 13 In the μ_z text field, type **muz**.


Section Orientation I

- 1 In the **Model Builder** window, click **Section Orientation 1**.
- 2 In the **Settings** window for **Section Orientation**, locate the **Section Orientation** section.
- 3 From the **Orientation method** list, choose **Orientation vector**.


4 Specify the V vector as

0	X
1	Y
0	Z


Point Load, M_x

- 1 In the **Physics** toolbar, click  **Points** and choose **Point Load**.
- 2 In the **Settings** window for **Point Load**, type Point Load, M_x in the **Label** text field.
- 3 Locate the **Point Selection** section. From the **Selection** list, choose **Free End**.
- 4 Locate the **Moment** section. Specify the M_P vector as


1	x
0	y
0	z

- 5 In the **Physics** toolbar, click  **Load Group** and choose **Load Group M_x** .


Point Load, M_y

- 1 In the **Physics** toolbar, click  **Points** and choose **Point Load**.
- 2 In the **Settings** window for **Point Load**, type Point Load, M_y in the **Label** text field.
- 3 Locate the **Point Selection** section. From the **Selection** list, choose **Free End**.
- 4 Locate the **Moment** section. Specify the M_P vector as

0	x
1	y
0	z

- 5 In the **Physics** toolbar, click  **Load Group** and choose **Load Group M_y** .

Point Load, M_z

- 1 In the **Physics** toolbar, click  **Points** and choose **Point Load**.
- 2 In the **Settings** window for **Point Load**, locate the **Point Selection** section.
- 3 From the **Selection** list, choose **Free End**.
- 4 In the **Label** text field, type Point Load, M_z .

5 Locate the **Moment** section. Specify the \mathbf{M}_P vector as

0	x
0	y
1	z

6 In the **Physics** toolbar, click  **Load Group** and choose **Load Group Mz**.

Point Load, Fx

1 In the **Physics** toolbar, click  **Points** and choose **Point Load**.

2 In the **Settings** window for **Point Load**, type Point Load, Fx in the **Label** text field.

3 Locate the **Point Selection** section. From the **Selection** list, choose **Free End**.

4 Locate the **Force** section. Specify the \mathbf{F}_P vector as

1	x
0	y
0	z

5 In the **Physics** toolbar, click  **Load Group** and choose **Load Group Fx**.

Point Load, Fy

1 In the **Physics** toolbar, click  **Points** and choose **Point Load**.

2 In the **Settings** window for **Point Load**, type Point Load, Fy in the **Label** text field.

3 Locate the **Point Selection** section. From the **Selection** list, choose **Free End**.

4 Locate the **Force** section. Specify the \mathbf{F}_P vector as

0	x
1	y
0	z

5 In the **Physics** toolbar, click  **Load Group** and choose **Load Group Fy**.

Point Load, Fz

1 In the **Physics** toolbar, click  **Points** and choose **Point Load**.

2 In the **Settings** window for **Point Load**, type Point Load, Fz in the **Label** text field.

3 Locate the **Point Selection** section. From the **Selection** list, choose **Free End**.

4 Locate the **Force** section. Specify the $\mathbf{F_P}$ vector as




0	x
0	y
1	z

5 In the **Physics** toolbar, click  **Load Group** and choose **Load Group Fz**.



Add couplings between the solid and the beam elements.

MULTIPHYSICS

Solid-Beam Connection Transition


- 1 In the **Physics** toolbar, click  **Multiphysics Couplings** and choose **Global>Solid-Beam Connection**.
- 2 In the **Settings** window for **Solid-Beam Connection**, type Solid-Beam Connection Transition in the **Label** text field.
- 3 Locate the **Connection Settings** section. From the **Connection type** list, choose **Solid boundaries to beam points, transition**.
- 4 Select the **Manual control of selections** check box.
- 5 Locate the **Boundary Selection, Solid** section. Click to select the  **Activate Selection** toggle button.
- 6 Select Boundary 136 only.
- 7 Locate the **Point Selection, Beam** section. Click to select the  **Activate Selection** toggle button.
- 8 Select Point 179 only.

Solid-Beam Connection General


- 1 In the **Physics** toolbar, click  **Multiphysics Couplings** and choose **Global>Solid-Beam Connection**.
- 2 In the **Settings** window for **Solid-Beam Connection**, type Solid-Beam Connection General in the **Label** text field.
- 3 Locate the **Connection Settings** section. Select the **Manual control of selections** check box.
- 4 Select Boundary 68 only.
- 5 Locate the **Point Selection, Beam** section. Click to select the  **Activate Selection** toggle button.
- 6 Select Point 177 only.

MESH I


Free Triangular I

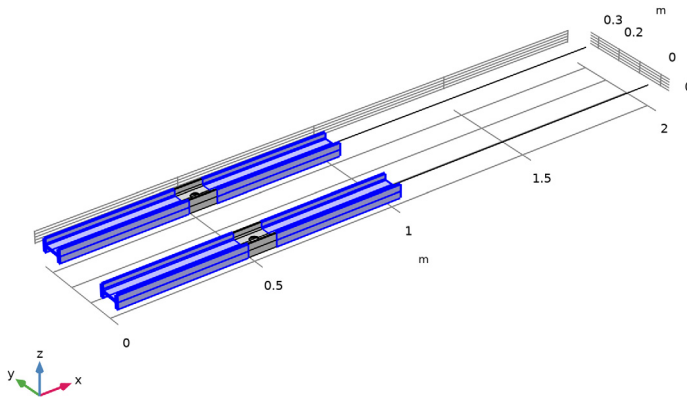
- 1 In the **Mesh** toolbar, click  **More Generators** and choose **Free Triangular**.
- 2 Select Boundaries 1, 68, 69, and 136 only.

Size I

- 1 Right-click **Free Triangular I** and choose **Size**.
- 2 In the **Settings** window for **Size**, locate the **Element Size** section.
- 3 Click the **Custom** button.
- 4 Locate the **Element Size Parameters** section.
- 5 Select the **Maximum element size** check box. In the associated text field, type 0.002.
- 6 Click  **Build Selected**.



Swept I

- 1 In the **Mesh** toolbar, click  **Swept**.
- 2 In the **Settings** window for **Swept**, locate the **Domain Selection** section.
- 3 From the **Geometric entity level** list, choose **Domain**.
- 4 Select Domains 1, 3, 4, and 6 only.





Distribution I


- 1 Right-click **Swept I** and choose **Distribution**.

- 2 In the **Settings** window for **Distribution**, locate the **Domain Selection** section.
- 3 In the list, choose **3** and **6**.
- 4 Click  **Remove from Selection**.
- 5 Select Domains 1 and 4 only.
- 6 Locate the **Distribution** section. From the **Distribution type** list, choose **Explicit**.
- 7 In the **Relative placement of vertices along edge** text field, type $\text{range}(0, 0.015, 1)$.
- 8 Click  **Build Selected**.


Distribution 2

- 1 In the **Model Builder** window, right-click **Swept 1** and choose **Distribution**.
- 2 In the **Settings** window for **Distribution**, locate the **Domain Selection** section.
- 3 In the list, choose **1** and **4**.
- 4 Click  **Remove from Selection**.
- 5 Select Domains 3 and 6 only.
- 6 Locate the **Distribution** section. From the **Distribution type** list, choose **Explicit**.
- 7 In the **Relative placement of vertices along edge** text field, type $\text{range}(0, 0.015, 0.92)$
 $\text{range}(0.92, 0.005, 1)$.
- 8 Select the **Reverse direction** check box.
- 9 Click  **Build Selected**.


Free Tetrahedral 1

- 1 In the **Mesh** toolbar, click  **Free Tetrahedral**.
- 2 In the **Settings** window for **Free Tetrahedral**, locate the **Domain Selection** section.
- 3 From the **Geometric entity level** list, choose **Domain**.
- 4 Select Domains 2 and 5 only.


Size 1

- 1 Right-click **Free Tetrahedral 1** and choose **Size**.
- 2 In the **Settings** window for **Size**, locate the **Element Size** section.
- 3 Click the **Custom** button.
- 4 Locate the **Element Size Parameters** section.
- 5 Select the **Maximum element size** check box. In the associated text field, type 0.002.
- 6 Click  **Build Selected**.

Edge 1

- 1 In the **Mesh** toolbar, click  **More Generators** and choose **Edge**.
- 2 Select Edges 309 and 310 only.

Distribution 1

- 1 Right-click **Edge 1** and choose **Distribution**.
- 2 In the **Settings** window for **Distribution**, locate the **Distribution** section.
- 3 In the **Number of elements** text field, type 10.
- 4 Click  **Build All**.

STUDY 1

Step 1: Stationary

- 1 In the **Model Builder** window, under **Study 1** click **Step 1: Stationary**.
- 2 In the **Settings** window for **Stationary**, locate the **Physics and Variables Selection** section.
- 3 In the table, enter the following settings:



Physics interface	Solve for	Equation form
Solid Mechanics (solid)		Automatic (Stationary)
Beam (beam)		Automatic (Stationary)

- 4 In the table, enter the following settings:

Multiphysics couplings	Solve for	Equation form
Solid-Beam Connection General (sbc2)		Automatic (Stationary)

- 5 Click to expand the **Values of Dependent Variables** section. Find the **Initial values of variables solved for** subsection. From the **Settings** list, choose **User controlled**.


Step 2: Stationary 2


- 1 In the **Study** toolbar, click  **Study Steps** and choose **Stationary>Stationary**.
- 2 In the **Settings** window for **Stationary**, click to expand the **Study Extensions** section.
- 3 Select the **Define load cases** check box.
- 4 Click  **Add** six times.

5 In the table, leave all weights unchanged and modify the other columns as follows:

Load case	IgMx	IgMy	IgMz	IgFx	IgFy	IgFz
Twisting Moment	√					
Bending Moment Y		√				
Bending Moment Z			√			
Axial Force				√		
Transverse Force Y					√	
Transverse Force Z						√

Solution I (sol1)

- 1 In the **Study** toolbar, click  **Show Default Solver**.
- 2 In the **Model Builder** window, expand the **Solution I (sol1)** node, then click **Dependent Variables 1**.
- 3 In the **Settings** window for **Dependent Variables**, locate the **General** section.
- 4 From the **Defined by study step** list, choose **User defined**.
- 5 In the **Model Builder** window, expand the **Study 1>Solver Configurations>Solution I (sol1)>Dependent Variables 1** node, then click **Displacement field (comp1.u)**.
- 6 In the **Settings** window for **Field**, locate the **General** section.
- 7 Clear the **Solve for this field** check box.
- 8 In the **Model Builder** window, under **Study 1>Solver Configurations>Solution I (sol1)** click **Dependent Variables 2**.
- 9 In the **Settings** window for **Dependent Variables**, locate the **General** section.
- 10 From the **Defined by study step** list, choose **User defined**.
- 11 In the **Model Builder** window, expand the **Study 1>Solver Configurations>Solution I (sol1)>Dependent Variables 2** node, then click **Displacement field (comp1.u2)**.
- 12 In the **Settings** window for **Field**, locate the **Scaling** section.
- 13 From the **Method** list, choose **Manual**.
- 14 In the **Scale** text field, type $1.0e-10$.
- 15 In the **Model Builder** window, under **Study 1>Solver Configurations>Solution I (sol1)>Dependent Variables 2** click **Displacement field (comp1.u2)**.

- 16 In the **Settings** window for **Field**, locate the **Scaling** section.
- 17 From the **Method** list, choose **Manual**.
- 18 In the **Scale** text field, type $1.0e-10$.
- 19 In the **Model Builder** window, under **Study 1>Solver Configurations>Solution 1 (sol1)>Dependent Variables 2** click **Warping function (comp1.sbcl.wv)**.
- 20 In the **Settings** window for **Field**, locate the **General** section.
- 21 Clear the **Solve for this field** check box.
- 22 In the **Model Builder** window, under **Study 1>Solver Configurations>Solution 1 (sol1)>Dependent Variables 2** click **Warping constant (comp1.sbcl.C0)**.
- 23 In the **Settings** window for **State**, locate the **General** section.
- 24 Clear the **Solve for this state** check box.
- 25 In the **Model Builder** window, under **Study 1>Solver Configurations>Solution 1 (sol1)>Dependent Variables 2** click **Warping constant (comp1.sbcl.C1)**.
- 26 In the **Settings** window for **State**, locate the **General** section.
- 27 Clear the **Solve for this state** check box.
- 28 In the **Model Builder** window, under **Study 1>Solver Configurations>Solution 1 (sol1)>Dependent Variables 2** click **Warping constant (comp1.sbcl.C2)**.
- 29 In the **Settings** window for **State**, locate the **General** section.
- 30 Clear the **Solve for this state** check box.
- 31 In the **Study** toolbar, click  **Compute**.

DEFINITIONS

View 1

- 1 In the **Model Builder** window, under **Component 1 (comp1)>Definitions** click **View 1**.
- 2 In the **Settings** window for **View**, locate the **View** section.
- 3 Clear the **Show grid** check box.

Use the following instructions to plot the von Mises stress distribution shown in [Figure 2](#).

RESULTS

Stress, Solid and Beam

- 1 In the **Model Builder** window, under **Results** click **Stress (solid)**.
- 2 In the **Settings** window for **3D Plot Group**, type **Stress, Solid and Beam** in the **Label** text field.

- 3 Locate the **Data** section. From the **Load case** list, choose **Twisting Moment**.
- 4 Locate the **Plot Settings** section. Clear the **Plot dataset edges** check box.



Line 1

- 1 In the **Model Builder** window, expand the **Stress (beam)** node.
- 2 Right-click **Line 1** and choose **Copy**.



Stress, Solid and Beam

In the **Model Builder** window, under **Results** right-click **Stress, Solid and Beam** and choose **Paste Line**.

Line 1


- 1 In the **Model Builder** window, click **Line 1**.
- 2 In the **Settings** window for **Line**, locate the **Expression** section.
- 3 In the **Expression** text field, type `if(group.lgMx,beam.ttmax*sqrt(3), beam.mises)`.
- 4 Click to expand the **Inherit Style** section. From the **Plot** list, choose **Volume 1**.
- 5 In the **Stress, Solid and Beam** toolbar, click  **Plot**.
- 6 Click the  **Zoom Extents** button in the **Graphics** toolbar.

Stress, Beam

- 1 In the **Model Builder** window, under **Results** click **Stress (beam)**.
- 2 In the **Settings** window for **3D Plot Group**, type **Stress, Beam** in the **Label** text field.
- 3 Click to expand the **Selection** section. From the **Geometric entity level** list, choose **Edge**.
- 4 Select Edges 309 and 310 only.
- 5 Select the **Apply to dataset edges** check box.
- 6 In the **Stress, Beam** toolbar, click  **Plot**.
- 7 Click the  **Zoom Extents** button in the **Graphics** toolbar.


Use the following instructions to plot the comparison of von Mises stress distribution shown in [Figure 3](#).

Stress Comparison, Solid

- 1 In the **Home** toolbar, click  **Add Plot Group** and choose **3D Plot Group**.
- 2 In the **Settings** window for **3D Plot Group**, type **Stress Comparison, Solid** in the **Label** text field.
- 3 Locate the **Data** section. From the **Load case** list, choose **Bending Moment Z**.

- 4 Locate the **Plot Settings** section. Clear the **Plot dataset edges** check box.

Surface 1

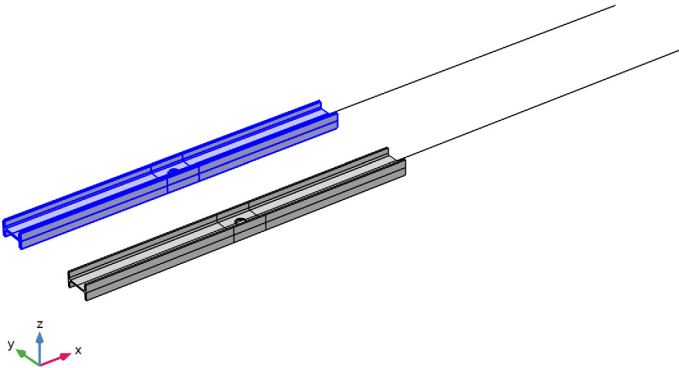
- 1 Right-click **Stress Comparison, Solid** and choose **Surface**.
- 2 In the **Settings** window for **Surface**, locate the **Expression** section.
- 3 In the **Expression** text field, type `(solid.mises-genext1(solid.mises))`.
- 4 Locate the **Coloring and Style** section. Click  **Change Color Table**.
- 5 In the **Color Table** dialog box, select **Wave>Wave** in the tree.
- 6 Click **OK**.
- 7 In the **Settings** window for **Surface**, locate the **Coloring and Style** section.
- 8 From the **Scale** list, choose **Linear symmetric**.


Surface 2

- 1 In the **Model Builder** window, right-click **Stress Comparison, Solid** and choose **Surface**.
- 2 In the **Settings** window for **Surface**, locate the **Expression** section.
- 3 In the **Expression** text field, type `solid.mises`.
- 4 Click to expand the **Inherit Style** section. From the **Plot** list, choose **Surface 1**.


Selection 1

- 1 Right-click **Surface 2** and choose **Selection**.
- 2 Select Boundaries 69–136 only.



3 In the **Stress Comparison, Solid** toolbar, click  **Plot**.

To see the stress distribution at the solid-beam interface, select the **YZ View**.

4 Click the  **Go to YZ View** button in the **Graphics** toolbar.

For different load cases, the traction at the solid-beam interface is compared for both Solid-Beam Connection types as shown in [Figure 4](#) and [Figure 5](#).


Study 1/Solution 1 (3) (sol1)

In the **Results** toolbar, click  **More Datasets** and choose **Solution**.

Selection

- 1 Right-click **Study 1/Solution 1 (3) (sol1)** and choose **Selection**.
- 2 In the **Settings** window for **Selection**, locate the **Geometric Entity Selection** section.
- 3 From the **Geometric entity level** list, choose **Boundary**.
- 4 From the **Selection** list, choose **Solid Beam Interface**.

Traction

- 1 In the **Results** toolbar, click  **3D Plot Group**.
- 2 In the **Settings** window for **3D Plot Group**, type Traction in the **Label** text field.
- 3 Locate the **Data** section. From the **Dataset** list, choose **Study 1/Solution 1 (3) (sol1)**.
- 4 From the **Load case** list, choose **Twisting Moment**.
- 5 Locate the **Plot Settings** section. Clear the **Plot dataset edges** check box.

Surface 1



- 1 Right-click **Traction** and choose **Surface**.
- 2 In the **Settings** window for **Surface**, locate the **Expression** section.
- 3 In the **Expression** text field, type `solid.mises`.

Arrow Surface 1


- 1 In the **Model Builder** window, right-click **Traction** and choose **Arrow Surface**.
- 2 In the **Settings** window for **Arrow Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp1)>Solid Mechanics>Stress>solid.Tax,...,solid.Taz - Traction (force/area) (spatial frame)**.
- 3 Locate the **Arrow Positioning** section. In the **Number of arrows** text field, type 1000.
- 4 Click to expand the **Inherit Style** section. From the **Plot** list, choose **Surface 1**.

Traction

- 1 In the **Model Builder** window, click **Traction**.

- 2 In the **Settings** window for **3D Plot Group**, locate the **Plot Settings** section.
- 3 From the **View** list, choose **New view**.
- 4 Click the  **Zoom Extents** button in the **Graphics** toolbar.
- 5 In the **Traction** toolbar, click  **Plot**.
- 6 Locate the **Data** section. From the **Load case** list, choose **Bending Moment Z**.

Arrow Surface 1

- 1 In the **Model Builder** window, click **Arrow Surface 1**.
- 2 In the **Settings** window for **Arrow Surface**, locate the **Arrow Positioning** section.
- 3 In the **Number of arrows** text field, type 120.
- 4 In the **Traction** toolbar, click  **Plot**.

