



Model created in COMSOL Multiphysics 6.4

Scordelis–Lo Roof Shell Benchmark

Introduction

In the following example you build and solve a 3D shell model using the Shell interface. This example is a widely used benchmark model called the Scordelis–Lo roof. The computed maximum z -deformation is compared with the value given in [Ref. 1](#).

Model Definition

GEOMETRY

The geometry consists of a curved face as shown in [Figure 1](#). Only one quarter is analyzed due to symmetry.

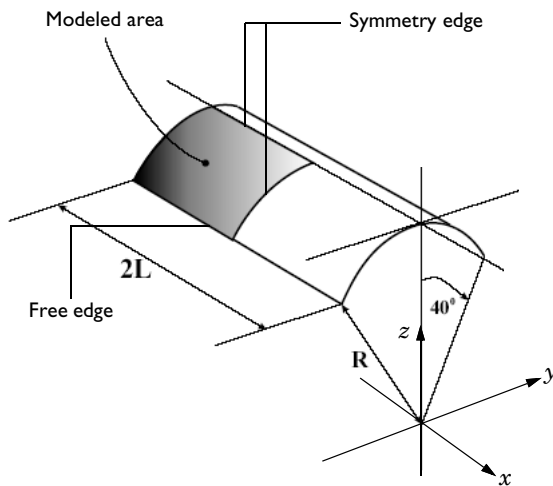


Figure 1: The Scordelis-Lo roof shell benchmark geometry.

- Roof length $2L = 50$ m
- Roof radius $R = 25$ m.

MATERIAL

- Isotropic material with Young's modulus set to $E = 4.32 \cdot 10^8$ N/m².
- Poisson's ratio set to $\nu = 0.0$.

CONSTRAINTS

- The outer straight edge is free.
- The outer curved edge is constrained against translation in the y and z directions.
- The straight edge on the top of the roof has symmetry edge constraints.
- The curved inner edge also has symmetry constraints.

LOAD

A force per area unit of -90 N/m^2 in the z direction is applied on the surface.

Results and Discussion

The maximum deformation in the global z direction with the default mesh settings is shown in [Figure 2](#). The computed value is -0.303 m .

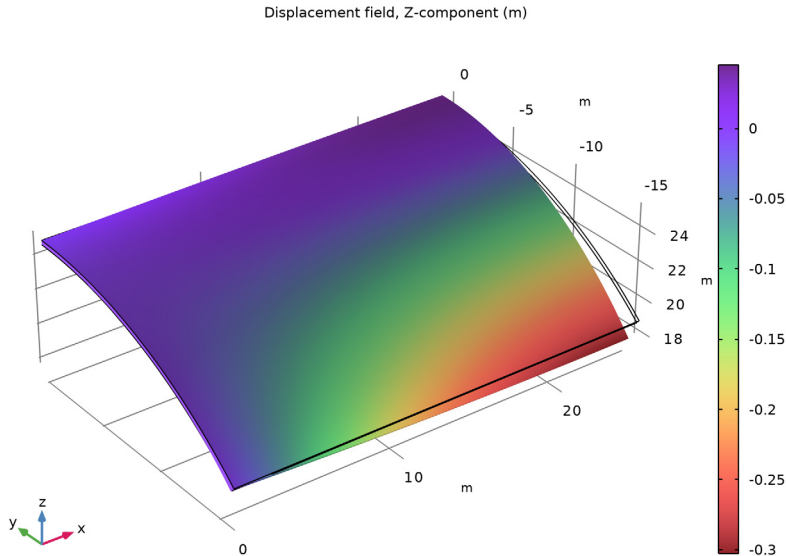


Figure 2: z-displacement with 176 triangular elements.

When changing to a mapped mesh, the more efficient quadrilateral elements are used. The result is -0.301 m as shown in [Figure 3](#). With a very fine mesh, the value converges to -0.302 m , [Figure 4](#). The reference solution quoted in [Ref. 1](#) for the midside vertical displacement is -0.3086 m . The value -0.302 m is in fact observed in other published benchmark results treating this problem as the value that this problem converges toward.

A summary of the performance for different element types and mesh densities is given in [Table 1](#). As can be seen, the results are good even with rather coarse meshes.

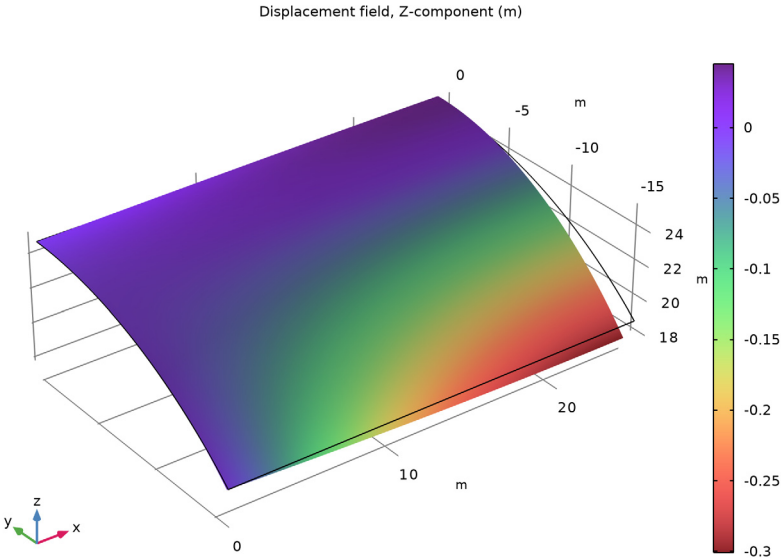


Figure 3: z-displacement with 70 quadrilateral elements.

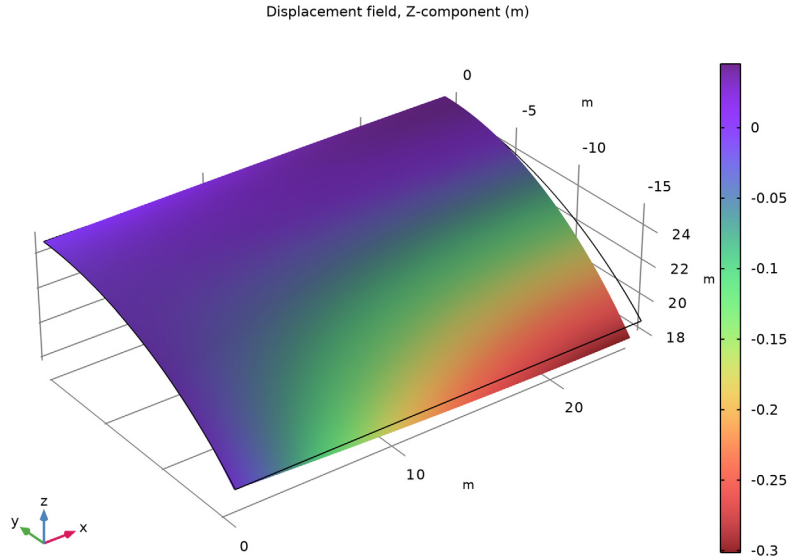


Figure 4: z-displacement with 580 quadrilateral elements.

TABLE I: CONVERGENCE OF MIDPOINT VERTICAL DISPLACEMENT.

MESH SIZE SETTING	ELEMENT TYPE	NUMBER OF ELEMENTS	MIDPOINT DISPLACEMENT
Coarser	Triangle	64	-0.304
Coarser	Quadrilateral	24	-0.300
Normal	Triangle	176	-0.303
Normal	Quadrilateral	70	-0.301
Extra fine	Triangle	1384	-0.302
Extra fine	Quadrilateral	580	-0.301

Reference


1. R.H. MacNeal and R.L. Harder, *Proposed Standard Set of Problems to Test Finite Element Accuracy*, Finite Elements in Analysis and Design, 1, 1985.

Application Library path: Structural_Mechanics_Module/
Verification_Examples/scordelis_lo_roof




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 > Shell (shell)**.
- 3 Click **Add**.
- 4 Click  **Study**.
- 5 In the **Select Study** tree, select **General Studies > Stationary**.
- 6 Click  **Done**.

GEOMETRY I


Work Plane 1 (wp1)

- 1 In the **Geometry** toolbar, click  **Work Plane**.
- 2 In the **Settings** window for **Work Plane**, click  **Go to Plane Geometry**.

Work Plane 1 (wp1) > Plane Geometry

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



Work Plane 1 (wp1) > Polygon 1 (pol1)

- 1 In the **Work Plane** toolbar, click  **Polygon**.
- 2 In the **Settings** window for **Polygon**, locate the **Coordinates** section.
- 3 In the table, enter the following settings:


xw (m)	yw (m)
0	25
25	25

4 Right-click **Polygon 1 (pol1)** and choose **Build All Objects**.

Revolve 1 (rev1)

- 1 In the **Model Builder** window, under **Component 1 (comp1)** > **Geometry 1** right-click **Work Plane 1 (wp1)** and choose **Revolve**.
- 2 In the **Settings** window for **Revolve**, locate the **Revolution Angles** section.
- 3 Click the **Angles** button.
- 4 In the **Start angle** text field, type 90.
- 5 In the **End angle** text field, type 90+40.
- 6 Locate the **Revolution Axis** section. Find the **Direction of revolution axis** subsection. In the **xw** text field, type 1.
- 7 In the **yw** text field, type 0.
- 8 Click  **Build Selected**.
- 9 Click the  **Zoom Extents** button in the **Graphics** toolbar.

Form Union (fin)


- 1 In the **Model Builder** window, click **Form Union (fin)**.
- 2 In the **Settings** window for **Form Union/Assembly**, click  **Build Selected**.

SHELL (SHELL)


Thickness and Offset 1

- 1 In the **Model Builder** window, under **Component 1 (comp1)** > **Shell (shell)** click **Thickness and Offset 1**.
- 2 In the **Settings** window for **Thickness and Offset**, locate the **Thickness and Offset** section.
- 3 In the d_0 text field, type 0.25.

Symmetry 1

- 1 In the **Physics** toolbar, click  **Edges** and choose **Symmetry**.
- 2 Select Edges 3 and 4 only.

Prescribed Displacement/Rotation 1

- 1 In the **Physics** toolbar, click  **Edges** and choose **Prescribed Displacement/Rotation**.
- 2 Select Edge 1 only.
- 3 In the **Settings** window for **Prescribed Displacement/Rotation**, locate the **Prescribed Displacement** section.
- 4 From the **Displacement in y direction** list, choose **Prescribed**.

5 From the **Displacement in z direction** list, choose **Prescribed**.

Face Load 1

1 In the **Physics** toolbar, click  **Boundaries** and choose **Face Load**.

2 Select Boundary 1 only.

3 In the **Settings** window for **Face Load**, locate the **Force** section.

4 Specify the \mathbf{f}_A vector as

0	x
0	y
-90	z

MATERIALS

Material 1 (mat1)

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

2 In the **Settings** window for **Material**, locate the **Material Contents** section.

3 In the table, enter the following settings:

Property	Variable	Value	Unit	Property group
Young's modulus	E	4.32e8	Pa	Young's modulus and Poisson's ratio
Poisson's ratio	nu	0		Young's modulus and Poisson's ratio
Density	rho	1	kg/m ³	Basic

MESH 1

First, compute the results with the default triangular mesh.

Free Triangular 1

1 In the **Mesh** toolbar, click  **More Generators** and choose **Free Triangular**.


2 In the **Settings** window for **Free Triangular**, locate the **Boundary Selection** section.

3 From the **Selection** list, choose **All boundaries**.

4 Click  **Build All**.

STUDY 1: TRI NORMAL

1 In the **Model Builder** window, click **Study 1**.

- 2 In the **Settings** window for **Study**, type Study 1: Tri Normal in the **Label** text field.
- 3 In the **Study** toolbar, click  **Compute**.

RESULTS


Vertical displacement

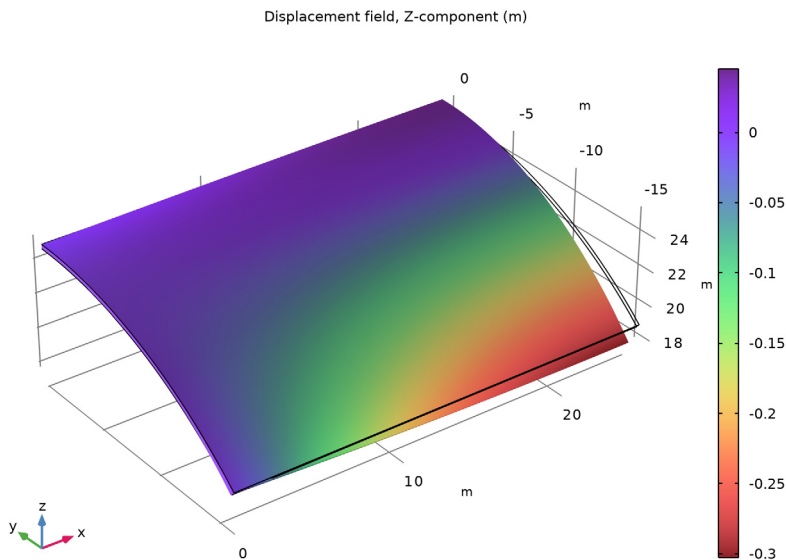
In the **Settings** window for **3D Plot Group**, type Vertical displacement in the **Label** text field.

Surface 1

- 1 In the **Model Builder** window, expand the **Vertical displacement** node, then click **Surface 1**.
- 2 In the **Settings** window for **Surface**, click **Replace Expression** in the upper-right corner of the **Expression** section. From the menu, choose **Component 1 (comp 1) > Shell > Displacement > Displacement field - m > w - Displacement field, Z-component**.
- 3 Locate the **Coloring and Style** section. From the **Color table** list, choose **SpectrumLight**.
- 4 From the **Color table transformation** list, choose **Reverse**.

Vertical displacement

- 1 In the **Model Builder** window, click **Vertical displacement**.
- 2 In the **Vertical displacement** toolbar, click  **Plot**.



Tri Normal

- 1 In the **Model Builder** window, expand the **Results > Datasets** node, then click **Study 1: Tri Normal/Solution 1 (sol1)**.
- 2 In the **Settings** window for **Solution**, type **Tri Normal** in the **Label** text field. Switch to the more effective quadrilateral mesh elements.



TRI NORMAL

- 1 In the **Model Builder** window, under **Component 1 (comp1)** click **Mesh 1**.
- 2 In the **Settings** window for **Mesh**, type **Tri Normal** in the **Label** text field.



QUAD NORMAL

- 1 In the **Mesh** toolbar, click **Add Mesh** and choose **Add Mesh**.
- 2 In the **Settings** window for **Mesh**, type **Quad Normal** in the **Label** text field.


Mapped 1

- 1 In the **Mesh** toolbar, click  **More Generators** and choose **Mapped**.
- 2 In the **Settings** window for **Mapped**, locate the **Boundary Selection** section.
- 3 From the **Geometric entity level** list, choose **Remaining**.
- 4 Click  **Build All**.

ADD STUDY

- 1 In the **Home** toolbar, click  **Add Study** to open the **Add Study** window.
- 2 Go to the **Add Study** window.
- 3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies > Stationary**.
- 4 Click the **Add Study** button in the window toolbar.
- 5 In the **Home** toolbar, click  **Add Study** to close the **Add Study** window.


STUDY 2: QUAD NORMAL

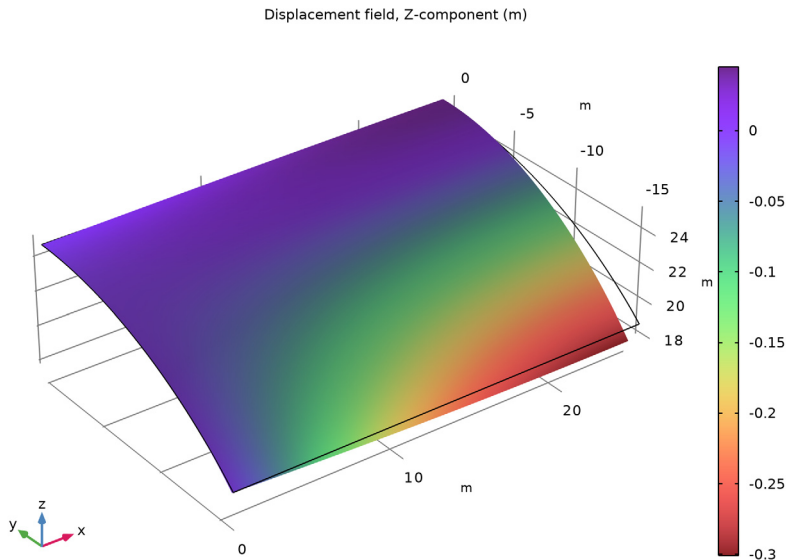
- 1 In the **Settings** window for **Study**, type **Study 2: Quad Normal** in the **Label** text field.
- 2 Locate the **Study Settings** section. Clear the **Generate default plots** checkbox.
- 3 In the **Study** toolbar, click  **Compute**.

RESULTS

Vertical displacement

- 1 In the **Model Builder** window, under **Results** click **Vertical displacement**.
- 2 In the **Settings** window for **3D Plot Group**, locate the **Data** section.

- 3 From the **Dataset** list, choose **Study 2: Quad Normal/Solution 2 (sol2)**.
- 4 In the **Vertical displacement** toolbar, click  **Plot**.



Quad Normal

- 1 In the **Model Builder** window, under **Results > Datasets** click **Study 2: Quad Normal/Solution 2 (sol2)**.
- 2 In the **Settings** window for **Solution**, type Quad Normal in the **Label** text field.
Examine a well converged result with a fine quadrilateral mesh.

QUAD NORMAL

In the **Model Builder** window, under **Component 1 (comp1) > Meshes** right-click **Quad Normal** and choose **Duplicate**.

QUAD EXTRA FINE



In the **Settings** window for **Mesh**, type Quad Extra fine in the **Label** text field.

Size


- 1 In the **Model Builder** window, expand the **Quad Extra fine** node, then click **Size**.
- 2 In the **Settings** window for **Size**, locate the **Element Size** section.
- 3 From the **Predefined** list, choose **Extra fine**.

4 Click  **Build All**.

ADD STUDY

- 1 In the **Home** toolbar, click  **Add Study** to open the **Add Study** window.
- 2 Go to the **Add Study** window.
- 3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies > Stationary**.
- 4 Click the **Add Study** button in the window toolbar.
- 5 In the **Home** toolbar, click  **Add Study** to close the **Add Study** window.

STUDY 3: QUAD EXTRA FINE

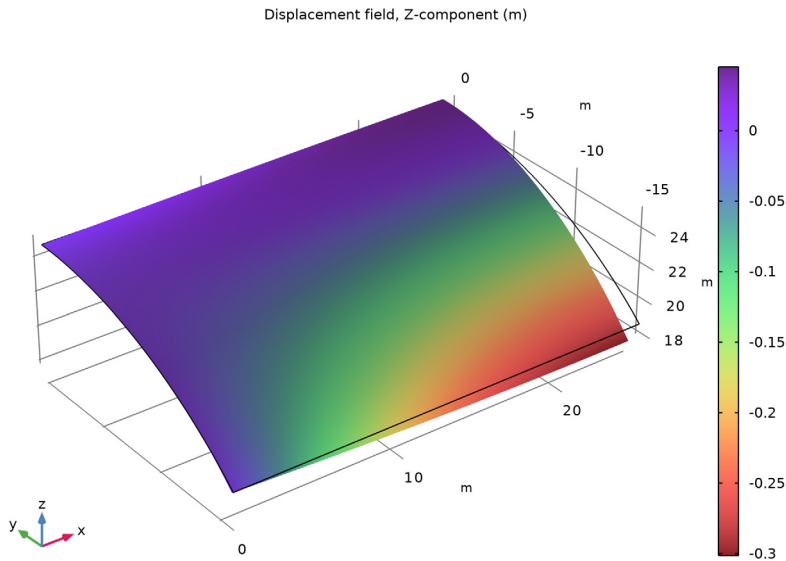
- 1 In the **Settings** window for **Study**, type Study 3: Quad Extra fine in the **Label** text field.
- 2 Locate the **Study Settings** section. Clear the **Generate default plots** checkbox.
- 3 In the **Study** toolbar, click  **Compute**.

RESULTS

Vertical displacement

- 1 In the **Model Builder** window, under **Results** click **Vertical displacement**.
- 2 In the **Settings** window for **3D Plot Group**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Study 3: Quad Extra fine/Solution 3 (sol3)**.

- 4 In the **Vertical displacement** toolbar, click  **Plot**.



Quad Extra fine

- 1 In the **Model Builder** window, under **Results** > **Datasets** click **Study 3: Quad Extra fine/ Solution 3 (sol3)**.
- 2 In the **Settings** window for **Solution**, type Quad Extra fine in the **Label** text field.
Examine a well converged result with a triangular mesh.


TRI NORMAL

In the **Model Builder** window, under **Component 1 (comp1)** > **Meshes** right-click **Tri Normal** and choose **Duplicate**.



TRI EXTRA FINE

In the **Settings** window for **Mesh**, type Tri Extra Fine in the **Label** text field.


Size

- 1 In the **Model Builder** window, expand the **Tri Extra Fine** node, then click **Size**.
- 2 In the **Settings** window for **Size**, locate the **Element Size** section.
- 3 From the **Predefined** list, choose **Extra fine**.
- 4 Click  **Build All**.

ADD STUDY


- 1 In the **Home** toolbar, click  **Add Study** to open the **Add Study** window.
- 2 Go to the **Add Study** window.
- 3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies > Stationary**.
- 4 Click the **Add Study** button in the window toolbar.
- 5 In the **Home** toolbar, click  **Add Study** to close the **Add Study** window.

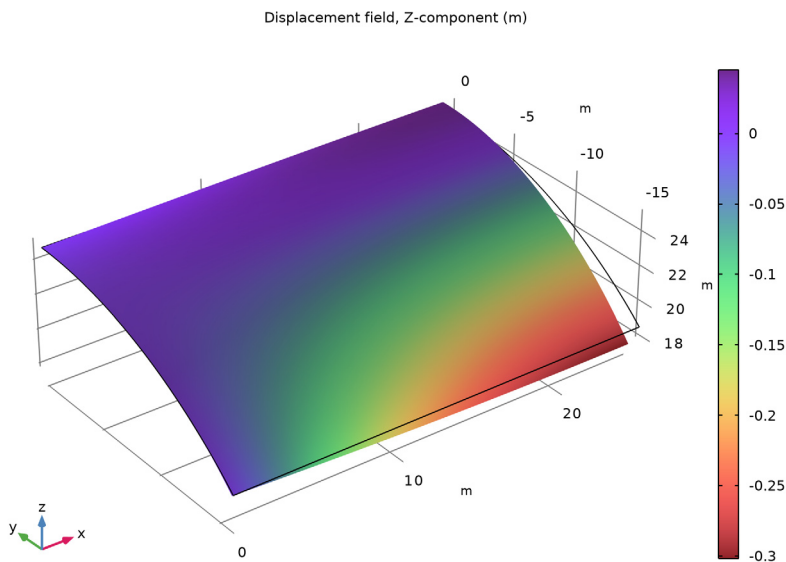
STUDY 4: TRI EXTRA FINE

- 1 In the **Settings** window for **Study**, type Study 4: Tri Extra fine in the **Label** text field.
- 2 Locate the **Study Settings** section. Clear the **Generate default plots** checkbox.
- 3 In the **Study** toolbar, click  **Compute**.

RESULTS

Vertical displacement

- 1 In the **Model Builder** window, under **Results** click **Vertical displacement**.
- 2 In the **Settings** window for **3D Plot Group**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Study 4: Tri Extra fine/Solution 4 (sol4)**.
- 4 In the **Vertical displacement** toolbar, click  **Plot**.



Tri Extra fine

- 1 In the **Model Builder** window, under **Results** > **Datasets** click **Study 4: Tri Extra fine/Solution 4 (sol4)**.
- 2 In the **Settings** window for **Solution**, type *Tri Extra fine* in the **Label** text field.
Investigate how well the elements perform with a very coarse mesh.


TRI NORMAL

In the **Model Builder** window, under **Component 1 (comp1)** > **Meshes** right-click **Tri Normal** and choose **Duplicate**.



TRI COARSER

In the **Settings** window for **Mesh**, type *Tri Coarser* in the **Label** text field.


Size

- 1 In the **Model Builder** window, expand the **Tri Coarser** node, then click **Size**.
- 2 In the **Settings** window for **Size**, locate the **Element Size** section.
- 3 From the **Predefined** list, choose **Coarser**.
- 4 Click  **Build All**.

ADD STUDY

- 1 In the **Home** toolbar, click  **Add Study** to open the **Add Study** window.
- 2 Go to the **Add Study** window.
- 3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies** > **Stationary**.
- 4 Click the **Add Study** button in the window toolbar.
- 5 In the **Home** toolbar, click  **Add Study** to close the **Add Study** window.

STUDY 5: TRI COARSER

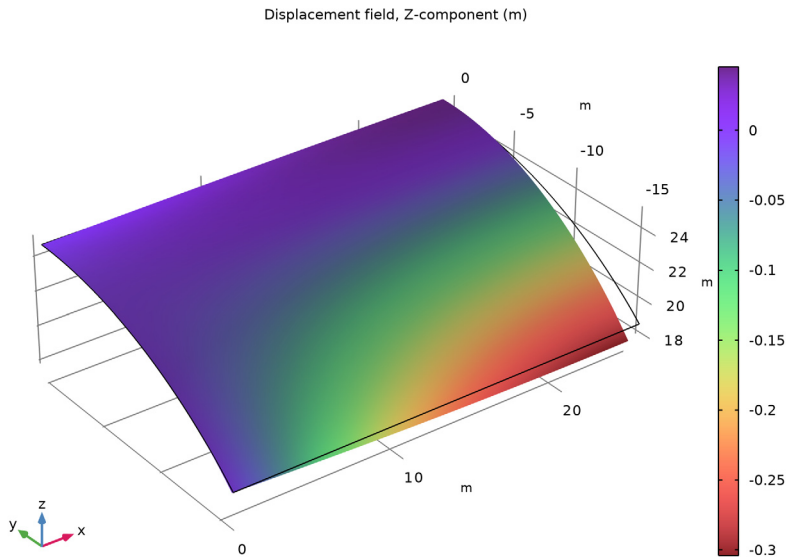
- 1 In the **Settings** window for **Study**, type *Study 5: Tri Coarser* in the **Label** text field.
- 2 Locate the **Study Settings** section. Clear the **Generate default plots** checkbox.
- 3 In the **Study** toolbar, click  **Compute**.

RESULTS

Vertical displacement

- 1 In the **Model Builder** window, under **Results** click **Vertical displacement**.
- 2 In the **Settings** window for **3D Plot Group**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Study 5: Tri Coarser/Solution 5 (sol5)**.

- 4 In the **Vertical displacement** toolbar, click  **Plot**.



Tri Coarser

- 1 In the **Model Builder** window, under **Results** > **Datasets** click **Study 5: Tri Coarser/ Solution 5 (sol5)**.
- 2 In the **Settings** window for **Solution**, type Tri Coarser in the **Label** text field.

QUAD NORMAL

In the **Model Builder** window, under **Component 1 (comp1)** > **Meshes** right-click **Quad Normal** and choose **Duplicate**.

QUAD COARSER


In the **Settings** window for **Mesh**, type Quad Coarser in the **Label** text field.

Size


- 1 In the **Model Builder** window, expand the **Quad Coarser** node, then click **Size**.
- 2 In the **Settings** window for **Size**, locate the **Element Size** section.
- 3 From the **Predefined** list, choose **Coarser**.

ADD STUDY

- 1 In the **Home** toolbar, click  **Add Study** to open the **Add Study** window.


- 2 Go to the **Add Study** window.
- 3 Find the **Studies** subsection. In the **Select Study** tree, select **General Studies > Stationary**.
- 4 Click the **Add Study** button in the window toolbar.
- 5 In the **Home** toolbar, click  **Add Study** to close the **Add Study** window.

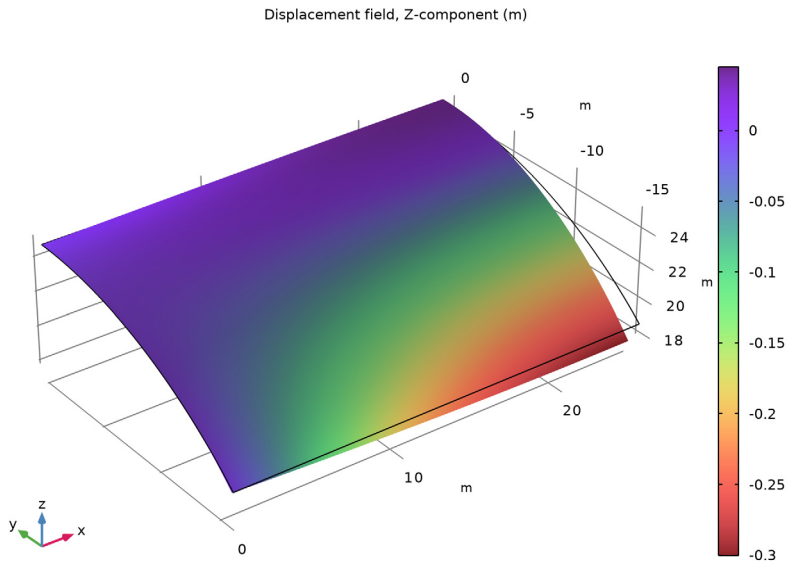
STUDY 6: QUAD COARSER

- 1 In the **Settings** window for **Study**, type Study 6: Quad Coarser in the **Label** text field.
- 2 Locate the **Study Settings** section. Clear the **Generate default plots** checkbox.
- 3 In the **Study** toolbar, click  **Compute**.

RESULTS

Vertical displacement

- 1 In the **Model Builder** window, under **Results** click **Vertical displacement**.
- 2 In the **Settings** window for **3D Plot Group**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Study 6: Quad Coarser/Solution 6 (sol6)**.
- 4 In the **Vertical displacement** toolbar, click  **Plot**.



Quad Coarser

- 1 In the **Model Builder** window, under **Results** > **Datasets** click **Study 6: Quad Coarser/ Solution 6 (sol6)**.
- 2 In the **Settings** window for **Solution**, type Quad Coarser in the **Label** text field.
The following section compares the maximum deformation of the midpoint, in the vertical direction, for different element types and mesh densities.

Point Evaluation 1

- 1 In the **Results** toolbar, click 8.85×10^{-12} **Point Evaluation**.
- 2 Select Point 3 only.
- 3 In the **Settings** window for **Point Evaluation**, locate the **Expressions** section.
- 4 In the table, enter the following settings:

Expression	Unit	Description
w	m	Midpoint displacement, Tri Normal

- 5 Click  **Evaluate**.

Point Evaluation 2

- 1 Right-click **Point Evaluation 1** and choose **Duplicate**.
- 2 In the **Settings** window for **Point Evaluation**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Quad Normal (sol2)**.
- 4 Locate the **Expressions** section. In the table, enter the following settings:

Expression	Unit	Description
w	m	Midpoint displacement, Quad Normal

- 5 Click  next to  **Evaluate**, then choose **Table 1 - Point Evaluation 1**.

Point Evaluation 3

- 1 Right-click **Point Evaluation 2** and choose **Duplicate**.
- 2 In the **Settings** window for **Point Evaluation**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Quad Extra fine (sol3)**.
- 4 Locate the **Expressions** section. In the table, enter the following settings:

Expression	Unit	Description
w	m	Midpoint displacement, Quad Extra fine

- 5 Click  next to  **Evaluate**, then choose **Table 1 - Point Evaluation 1**.

Point Evaluation 4

- 1 Right-click **Point Evaluation 3** and choose **Duplicate**.
- 2 In the **Settings** window for **Point Evaluation**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Tri Extra fine (sol4)**.
- 4 Locate the **Expressions** section. In the table, enter the following settings:

Expression	Unit	Description
w	m	Midpoint displacement, Tri Extra fine

- 5 Click ▼ next to **Evaluate**, then choose **Table I - Point Evaluation I**.

Point Evaluation 5

- 1 Right-click **Point Evaluation 4** and choose **Duplicate**.
- 2 In the **Settings** window for **Point Evaluation**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Tri Coarser (sol5)**.
- 4 Locate the **Expressions** section. In the table, enter the following settings:

Expression	Unit	Description
w	m	Midpoint displacement, Tri Coarser

- 5 Click ▼ next to **Evaluate**, then choose **Table I - Point Evaluation I**.

Point Evaluation 6

- 1 Right-click **Point Evaluation 5** and choose **Duplicate**.
- 2 In the **Settings** window for **Point Evaluation**, locate the **Data** section.
- 3 From the **Dataset** list, choose **Quad Coarser (sol6)**.
- 4 Locate the **Expressions** section. In the table, enter the following settings:

Expression	Unit	Description
w	m	Midpoint displacement, Quad Coarser

- 5 Click ▼ next to **Evaluate**, then choose **Table I - Point Evaluation I**.