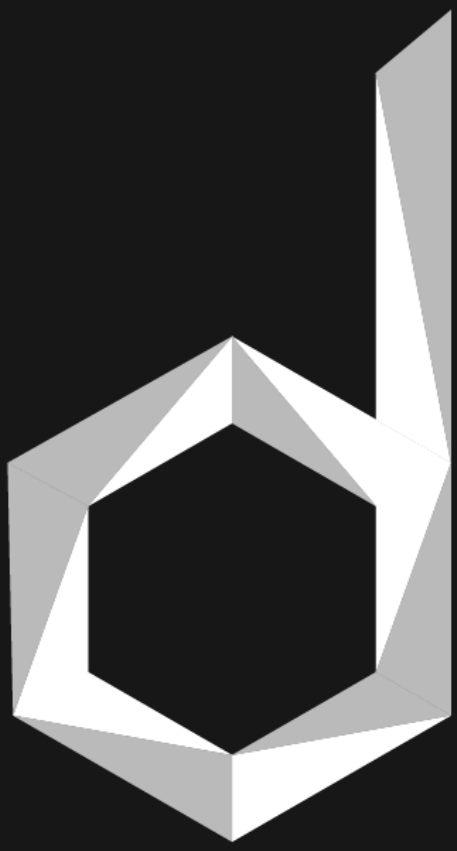
INGENIERÍA MECATRÓNICA



DI_CERO

DIEGO CERVANTES RODRÍGUEZ

INGENIERÍA ASISTIDA POR COMPUTADORA

COMSOL MULTIPHYSICS 5.6

16: Pandeo en Columnas

Contenido

DESCRIPCIÓN DEL PROBLEMA:

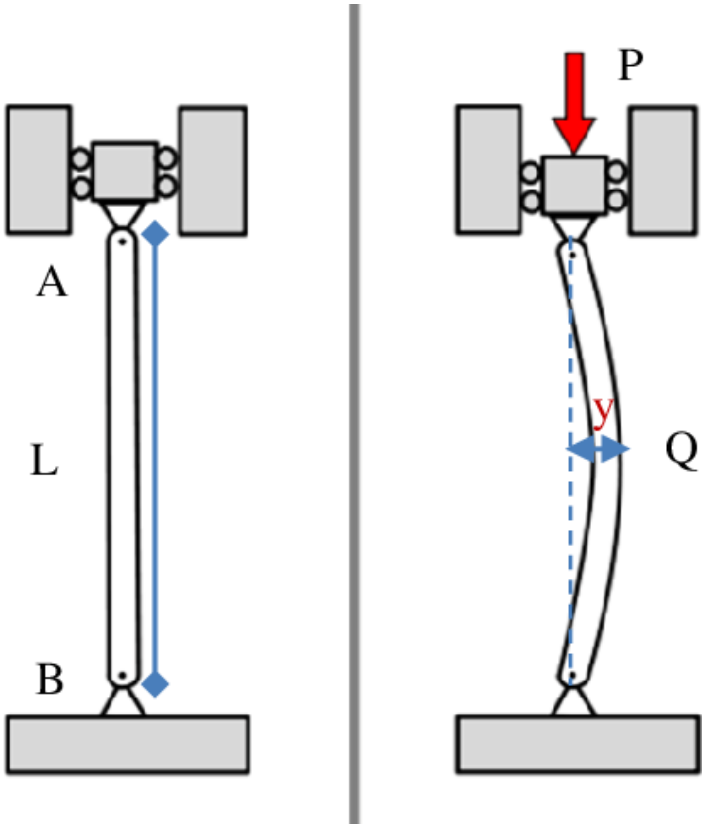
Presión crítica:

$$Pcr \ = \ Factor\ de\ carga\ crítica \ * \ presión\ en\ la\ columna \ = \ 1.686x106\ (100\ N/m2)$$

$$Pcr \ = \ 168.6x106\ Pa \ = \ 168.6\ MPa$$

$$Fcr \ = \ Pcr \ * \ Área\ de\ la\ sección\ transversal\ de\ la\ columna$$

$$Fcr \ = \ Pcr \ * \ A \ = \ (168.6x106\ N/m2)\ (\ 0.033755\ m2) \ = \ 5691093\ N \ = \ 5.7\ MN$$



Cálculo analítico usando la fórmula de Euler para condiciones de frontera en la columna empotrado – libre:

$$F_{cr} = \frac{C\pi^2 EA}{\left(\frac{L}{k_x}\right)^2}$$

$$C \ = \ Constante\ que\ depende\ de\ las\ condiciones\ de\ frontera, en\ este\ caso\ C \ = \ 1/4 \ = \ 0.25$$

$$Fcr \ = \ Carga\ crítica \ = ¿\ ?$$

$$E \ = \ Módulo\ de\ elasticidad \ = \ 69x109\ Pa$$

$$A \ = \ 0.033755\ m2$$

$$L \ = \ 2\ m$$

$$k = \sqrt{\frac{I}{A}}$$

***I* = el menor momento de inercia de *Ix, Iy*.**

$$I_x = \left(\frac{bh^3}{36}\right) = \left[\frac{(0.3\ m)(0.2598\ m)^3}{36}\right] = 1.46129x10^{-4}\ m^4$$

$$I_y = \left(\frac{hb^3}{48}\right) = \left[\frac{(0.2598\ m)(0.3\ m)^3}{48}\right] = 1.461375x10^{-4}\ m^4$$

$$I_{círculo} = \frac{\pi}{64}d^4 = \frac{\pi}{64}(0.08)^4 = 2x10^{-6}m^4$$

$$I = I_x - I_{círculo} = 1.46129x10^{-4}\ m^4 - 2x10^{-6}m^4 = 1.4411x10^{-4}\ m^4$$

$$k_x = \sqrt{\frac{I}{A}} = \sqrt{\frac{1.4411x10^{-4}}{0.033755}} = 0.06534\ m$$

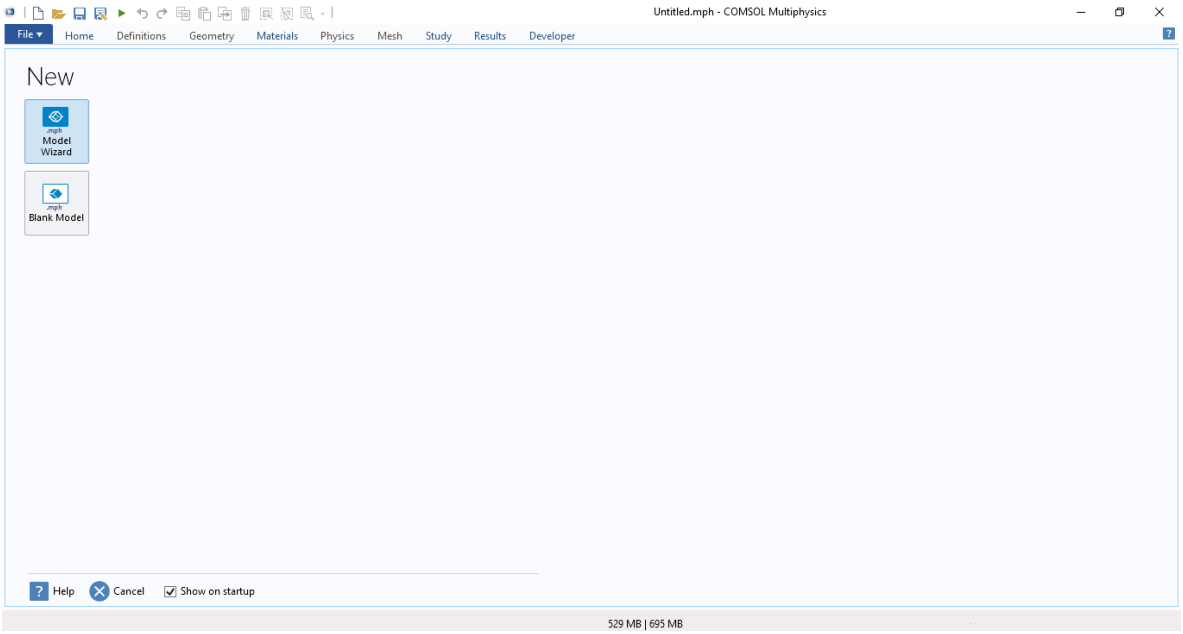
$$F_{cr} = \frac{C\pi^2 EA}{\left(\frac{L}{k_x}\right)^2} = \frac{(0.25)\pi^2(69x10^9)(0.033755)}{\left(\frac{2}{0.06534}\right)^2} = 6.13\ MN$$

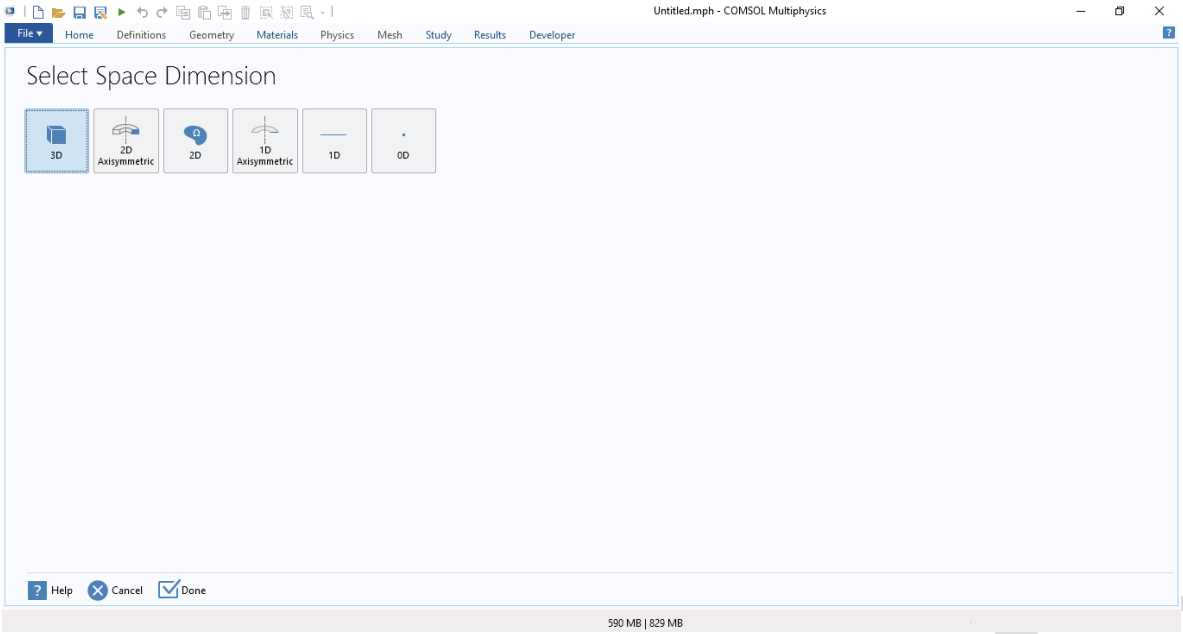
Cálculo del error relativo:

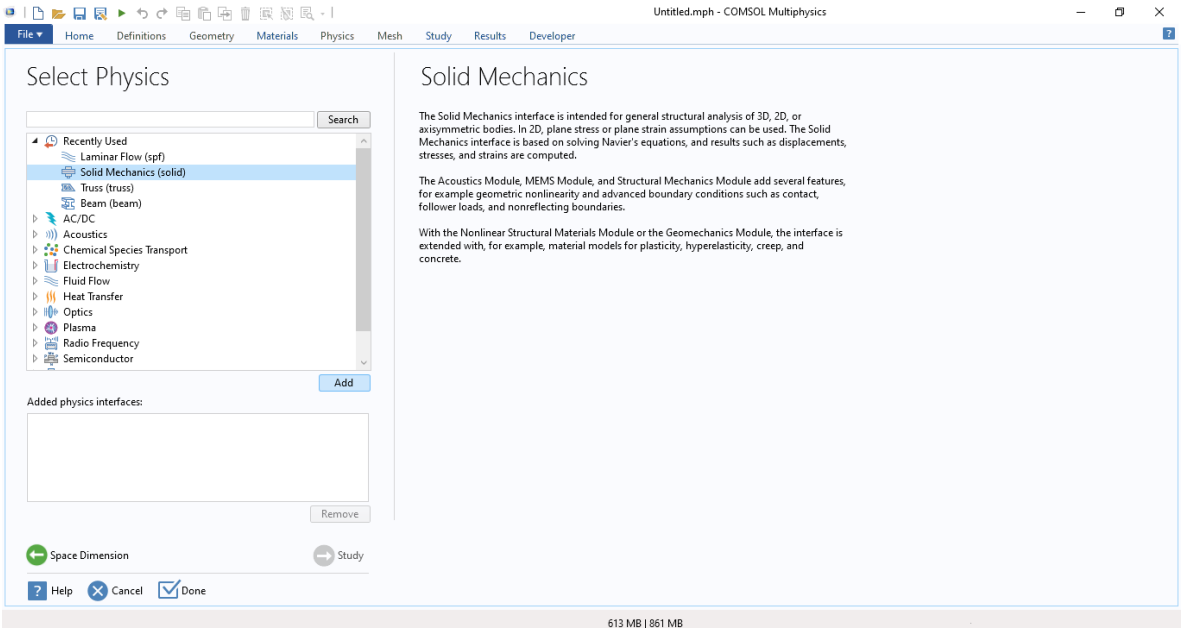
$$\epsilon = \frac{|F_{cr}^{Analítica} - F_{cr}^{Numérica}|}{F_{cr}^{Analítica}} x100 = \frac{|6.13-5.7|}{6.13} x100 = 7\ \% < 11\ \%$$

An important ingredient of a finite element analysis is the calculation of error estimates, that is, estimates of how closely the finite element solution approximates the exact solution of the mathematical model (see Section 4.3.6). These estimates indicate whether a specific finite element discretization has indeed yielded an accurate response prediction, and a designer can then rationally decide whether the given results should be used. In the case that unacceptable results have been obtained using unreliable finite element methods, the difficulty is of course *how* to obtain accurate results.

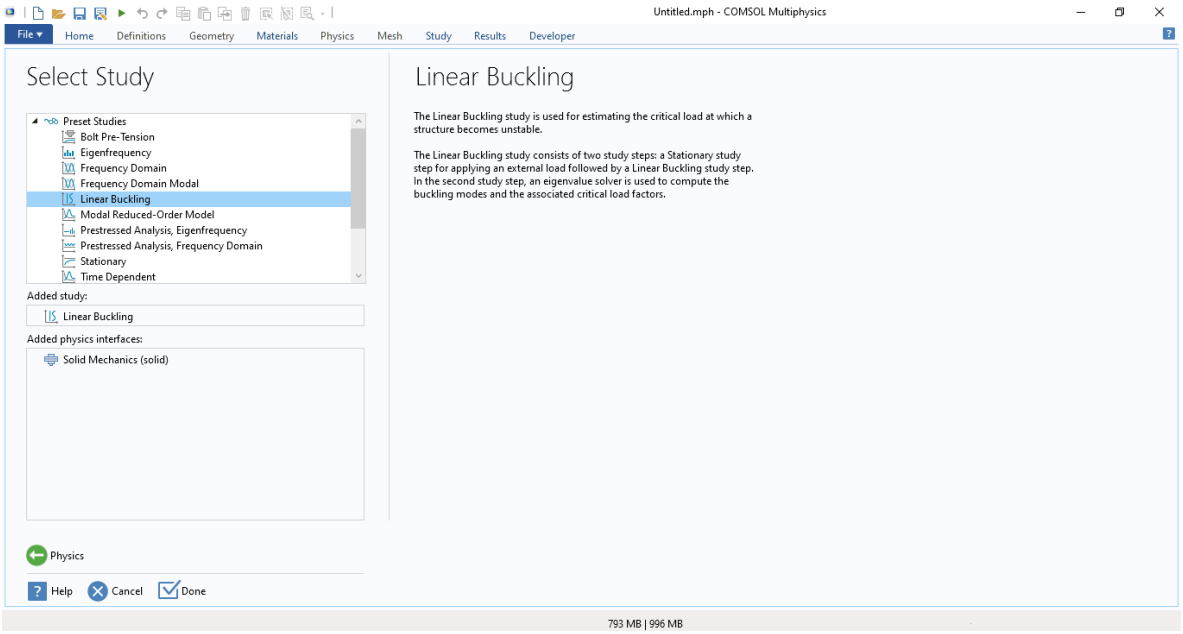
CREACIÓN DE LA PIEZA EN COMSOL:

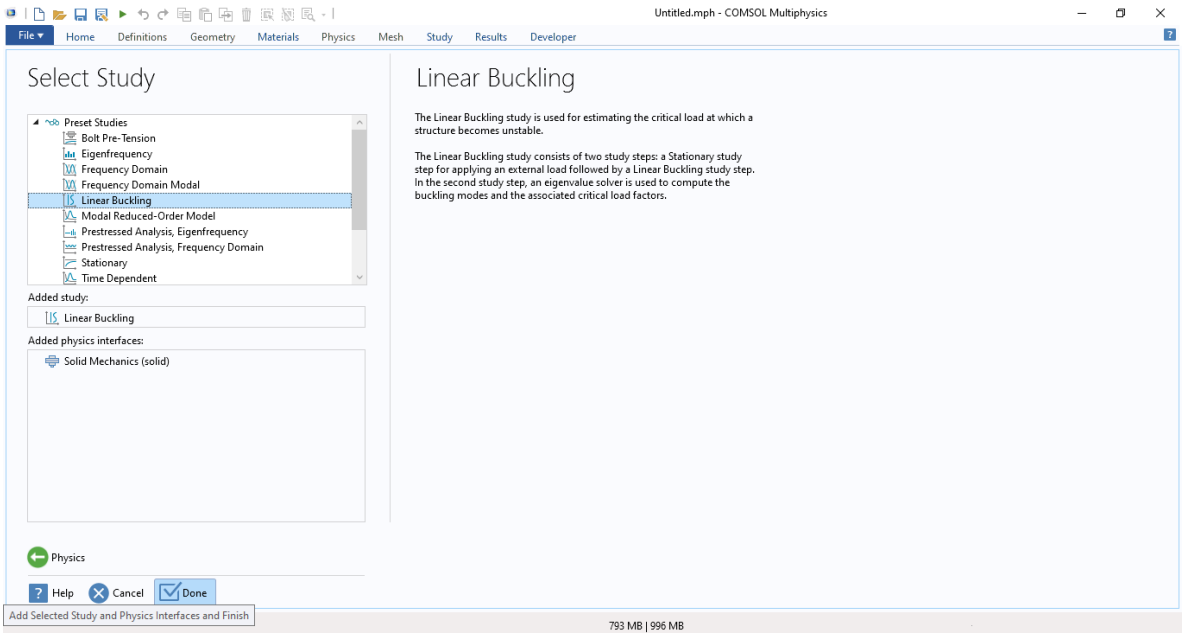






Este es el cálculo elegido para el análisis mecánico de columnas.

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Physics
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Results
Developer
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Bolt Pre-Tension
Eigenfrequency
Frequency Domain
Frequency Domain Modal
Linear Buckling
Modal Reduced-Order Model
Prestressed Analysis, Eigenfrequency
Prestressed Analysis, Frequency Domain
Stationary
Time Dependent
Added study:
Linear Buckling
Added physics interfaces:
Solid Mechanics (solid)
Linear Buckling
The Linear Buckling study is used for estimating the critical load at which a structure becomes unstable.
The Linear Buckling study consists of two study steps: a Stationary study step for applying an external load followed by a Linear Buckling study step. In the second study step, an eigenvalue solver is used to compute the buckling modes and the associated critical load factors.
Physics
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Add Selected Study and Physics Interfaces and Finish
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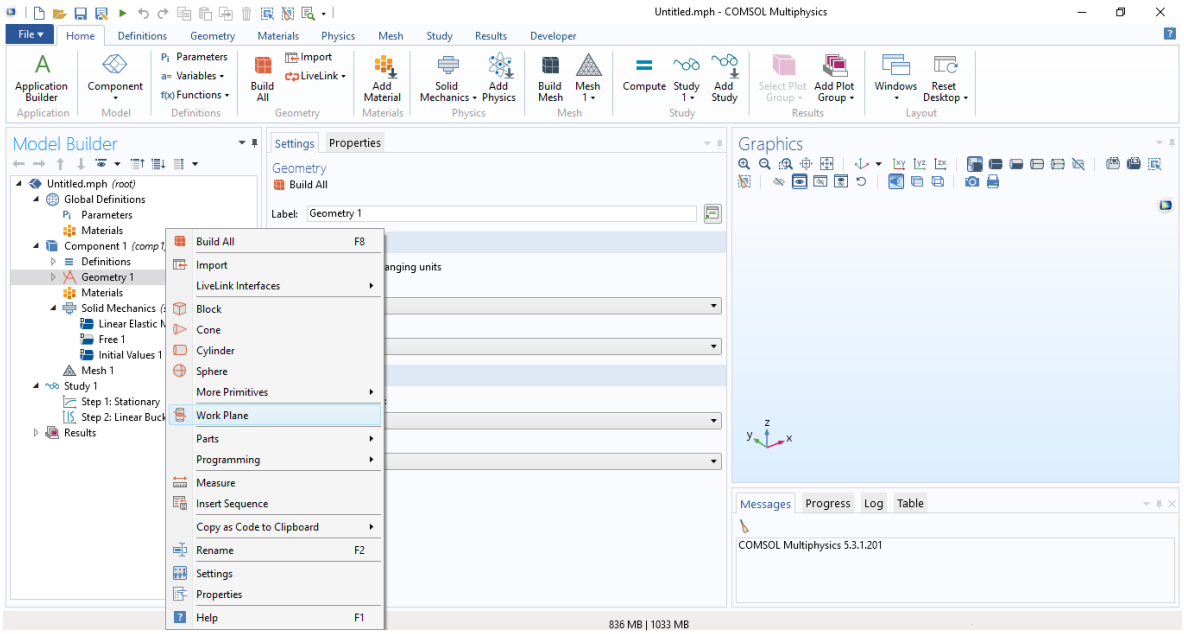
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Linear Elastic
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Study 1
Step 1: Stationary
Step 2: Linear Buck
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Label: Geometry 1
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Cylinder
Sphere
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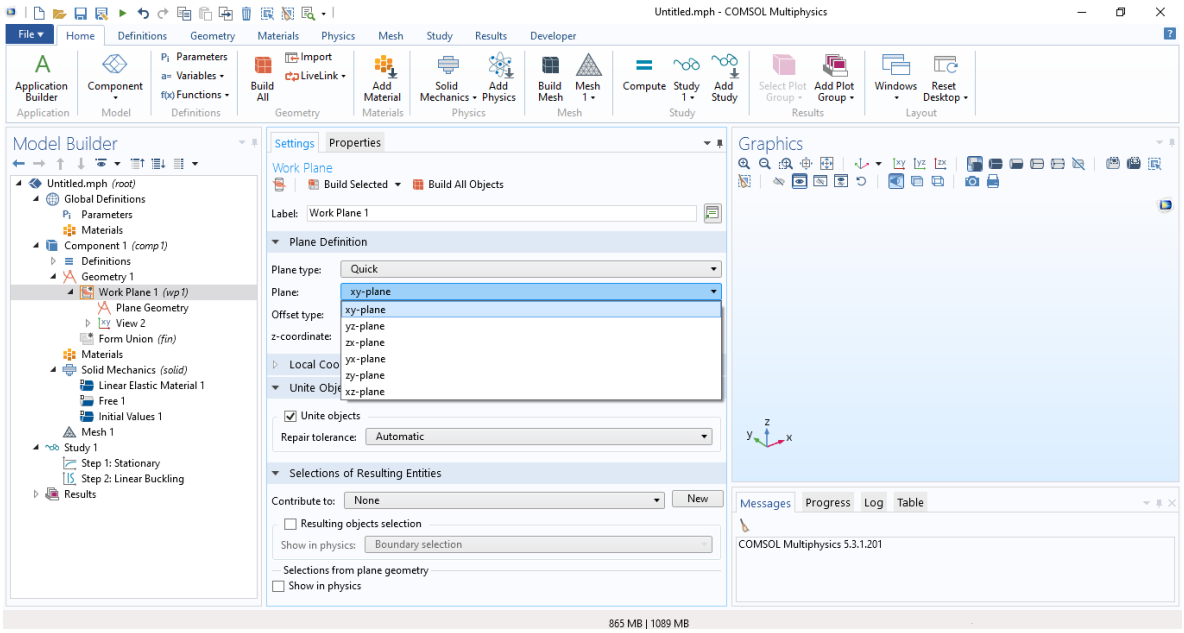
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Build All Objects
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xy-plane
yz-plane
zx-plane
yx-plane
zy-plane
xz-plane
Offset type:
z-coordinate:
Unite objects
Repair tolerance: Automatic
Selections of Resulting Entities
Contribute to: None
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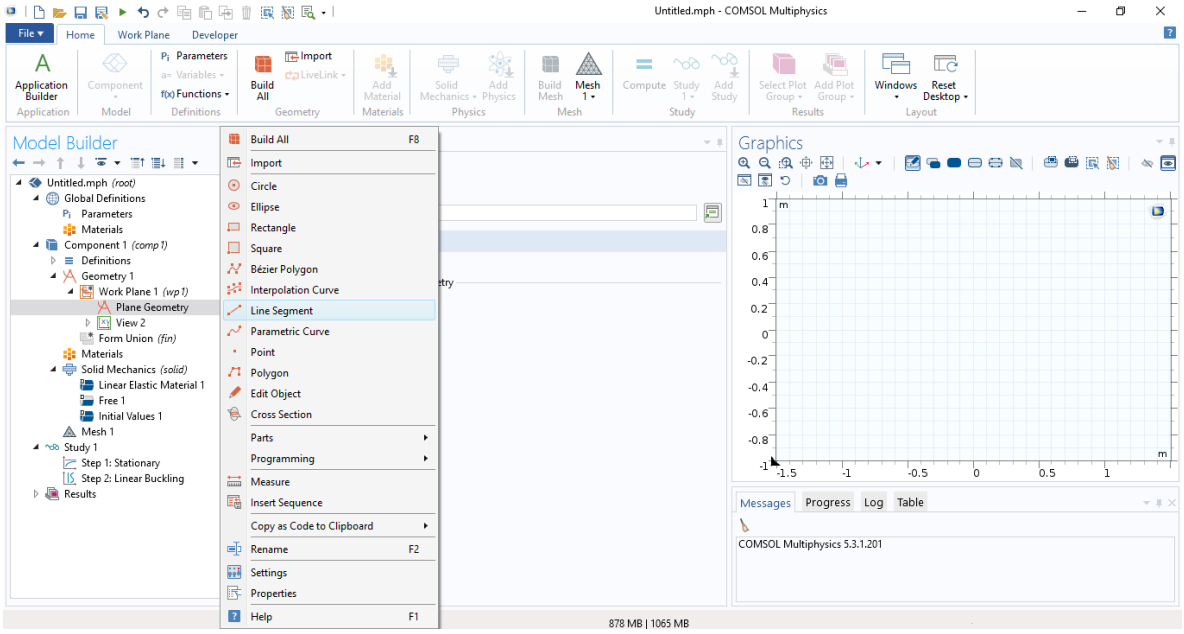
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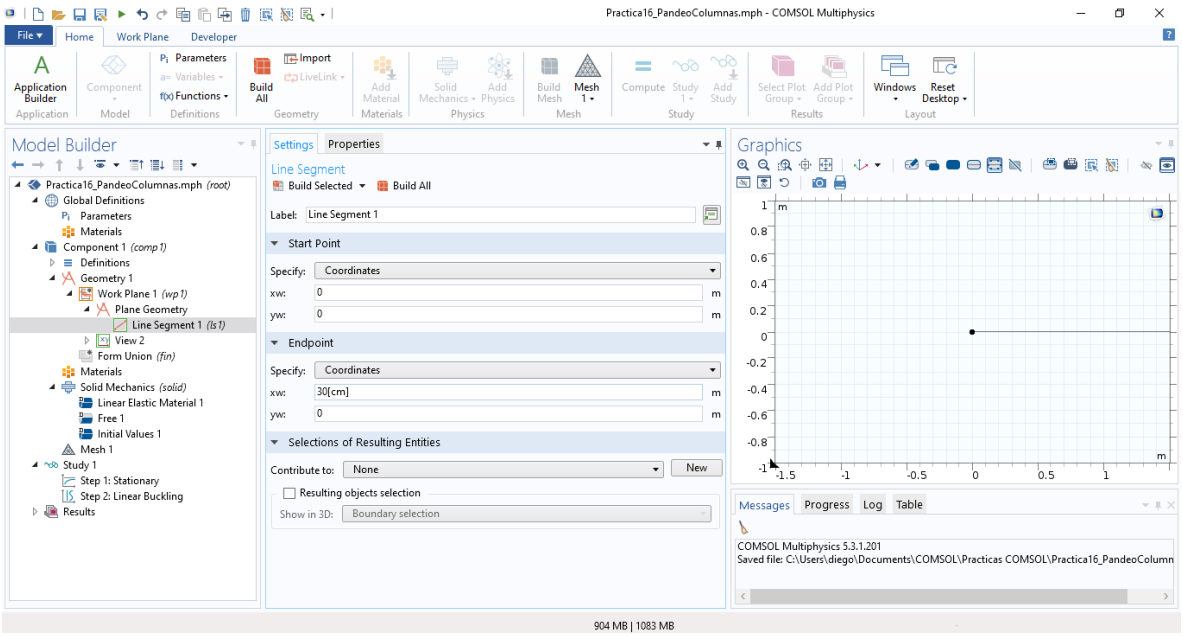
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Step 2: Linear Buckling
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Build Selected
Build All
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Start Point
Specify: Coordinates
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yw: 0 m
Endpoint
Specify: Coordinates
xw: 30[cm] m
yw: 0 m
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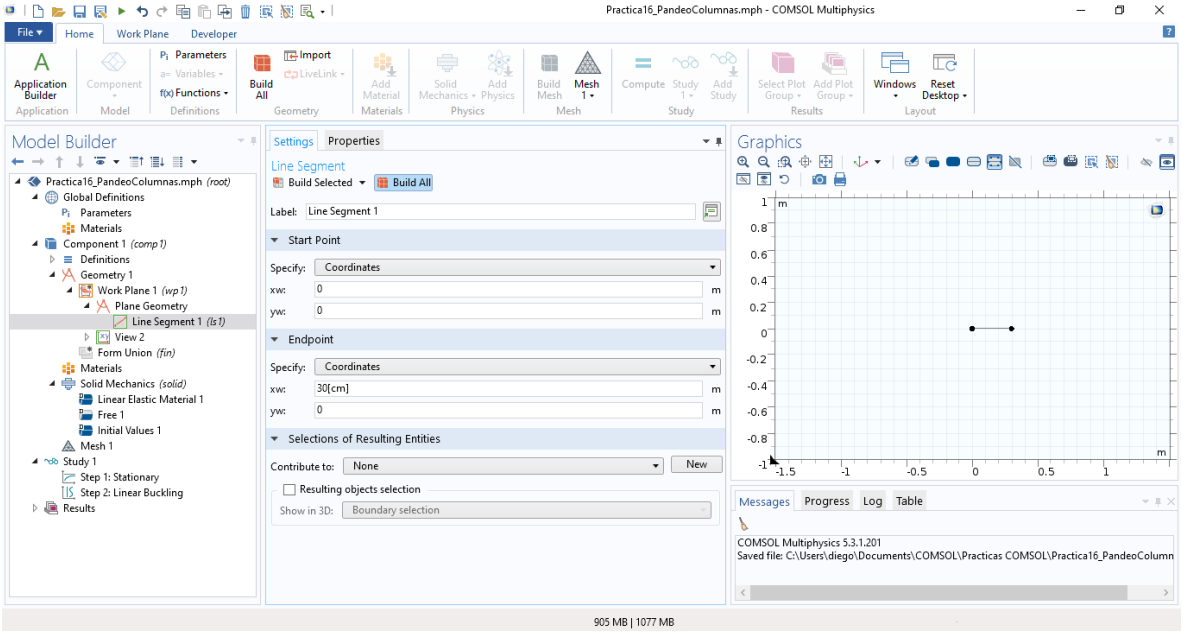
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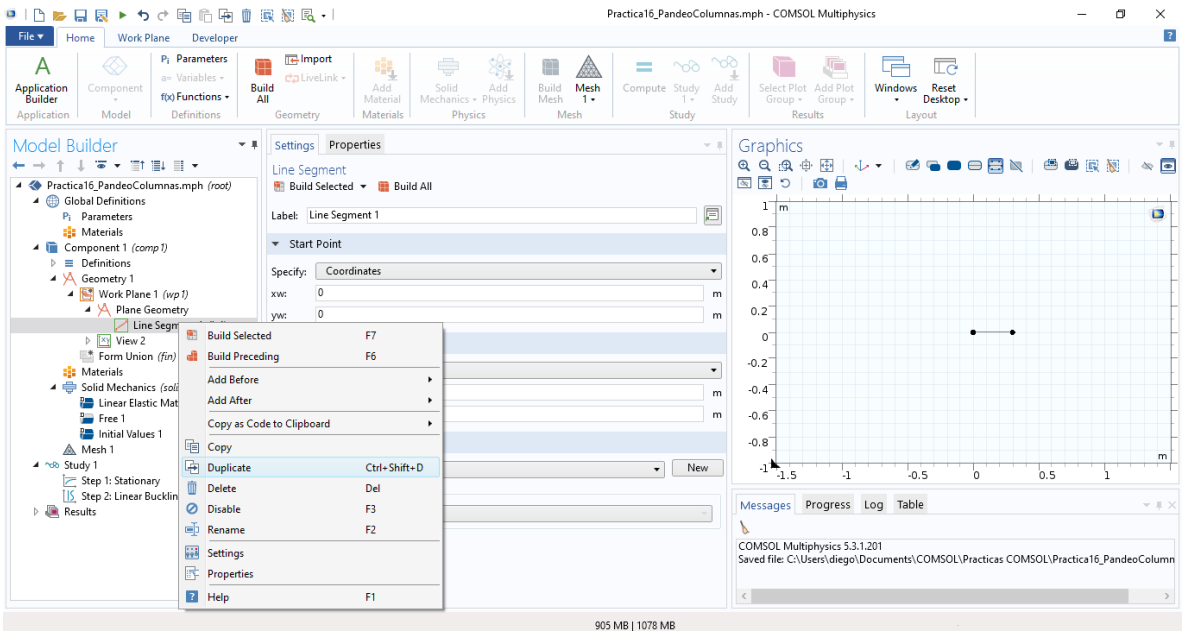
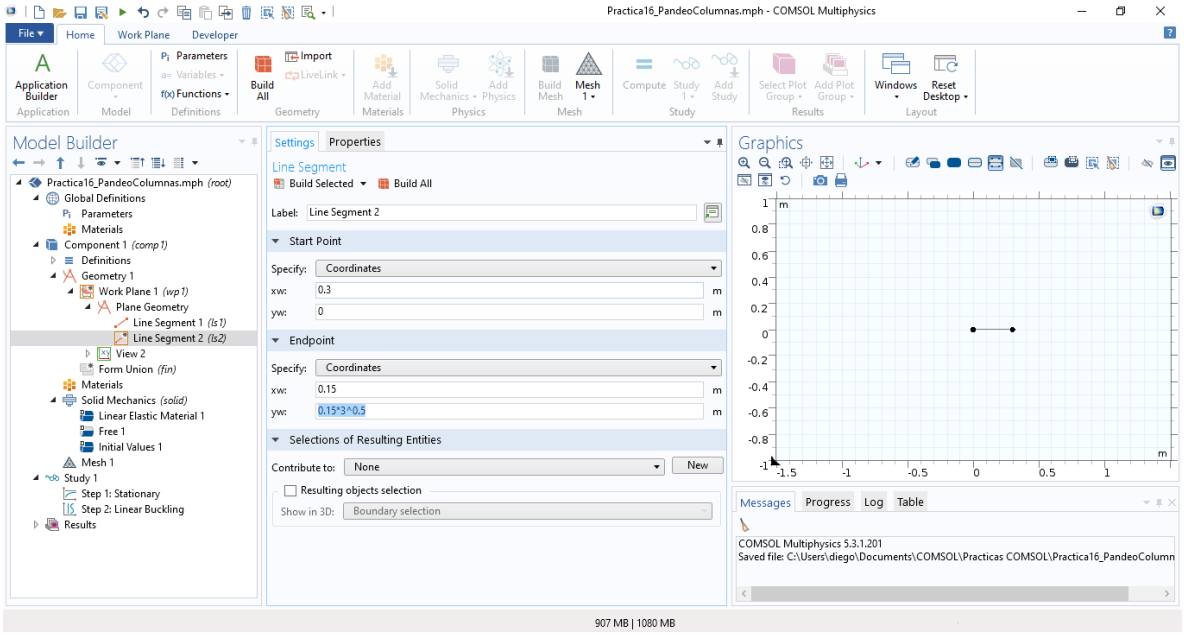
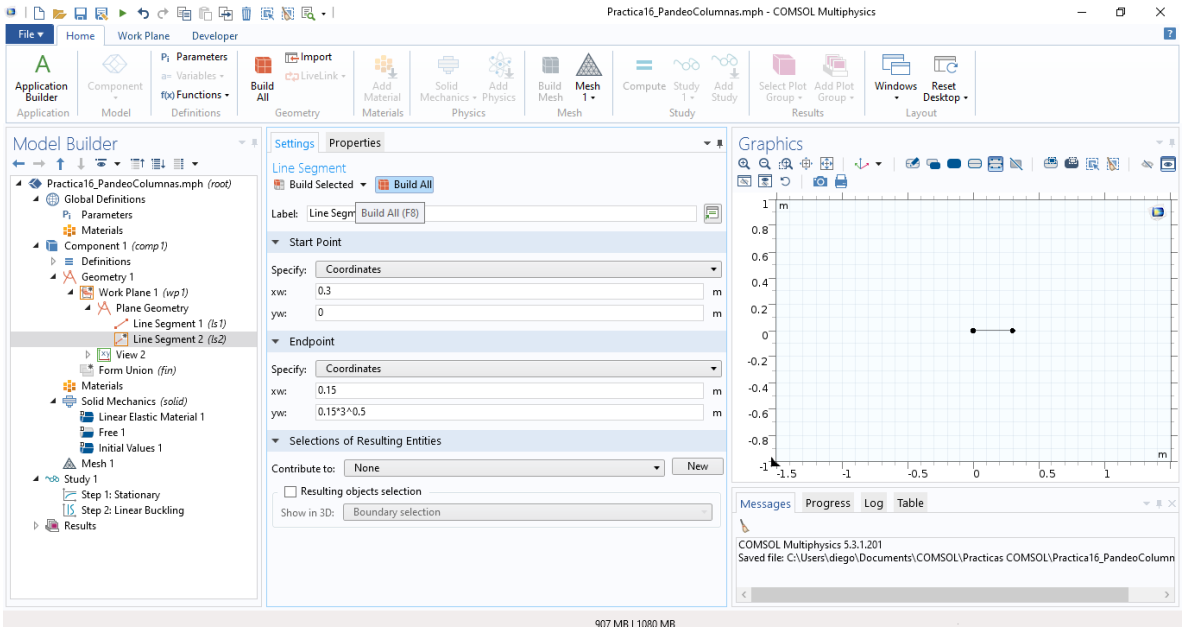


$0.15 * 3^{0.5}$ Es la ecuación del seno para que se cree un triángulo que es la base de la columna.

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Endpoint
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Coordinates
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0.15
yw:
0.15*3^0.5
Selections of Resulting Entities
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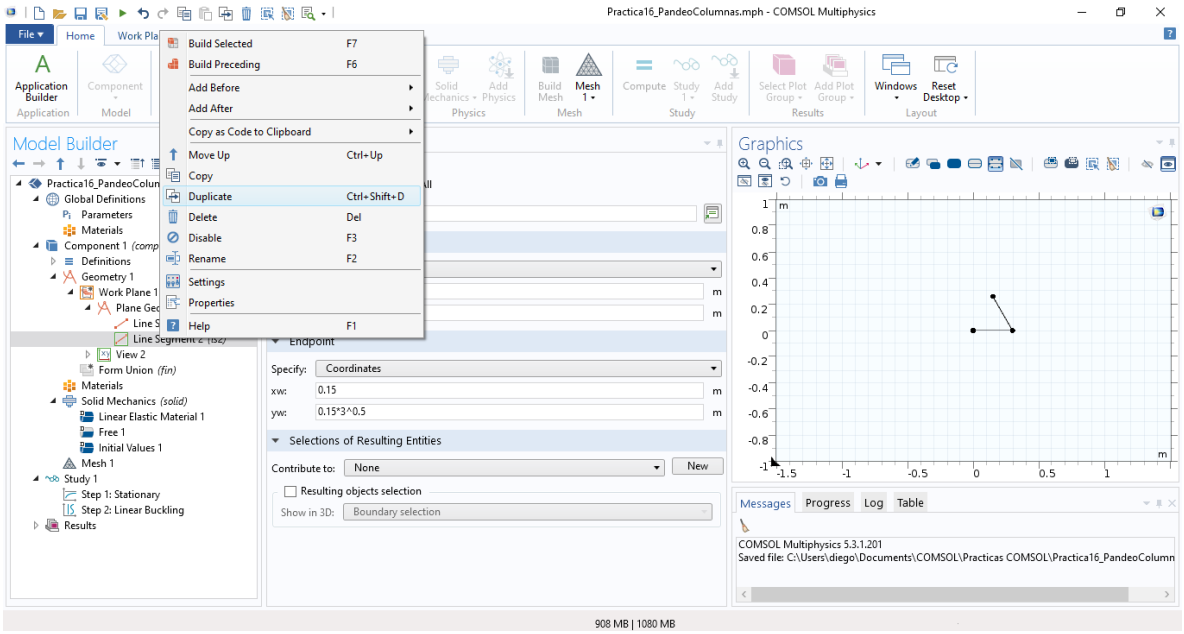
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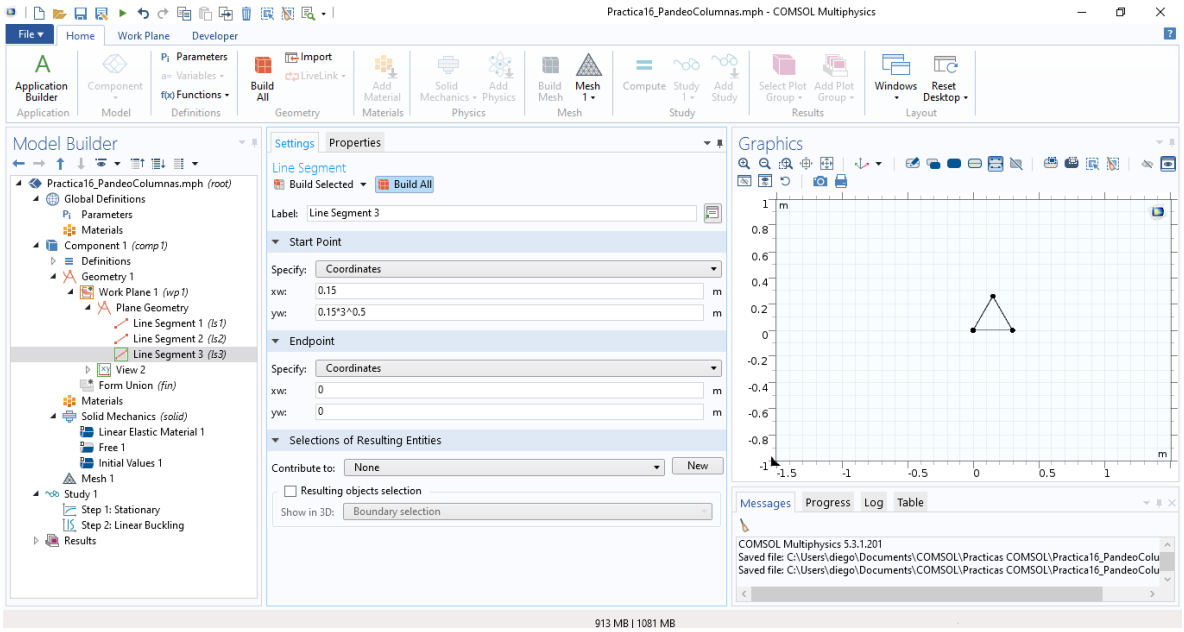
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Mesh 1
Study 1
Step 1: Stationary
Step 2: Linear Buckling
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Build Selected
Build All
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yw: 0.15*3^0.5 m
Endpoint
Specify: Coordinates
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yw: 0 m
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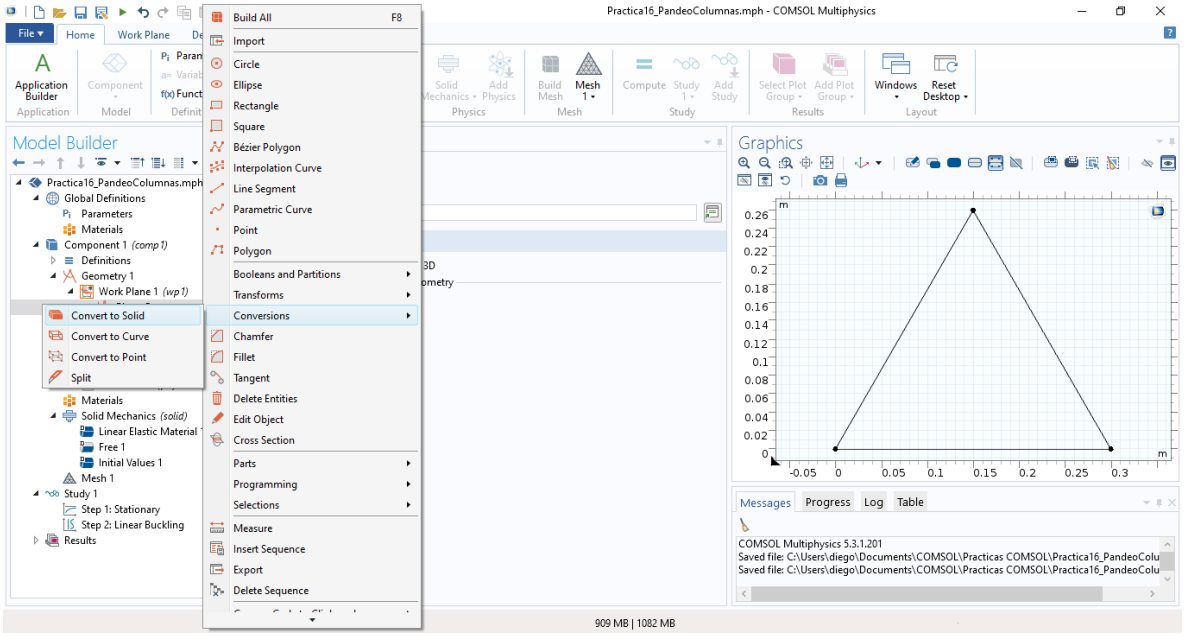
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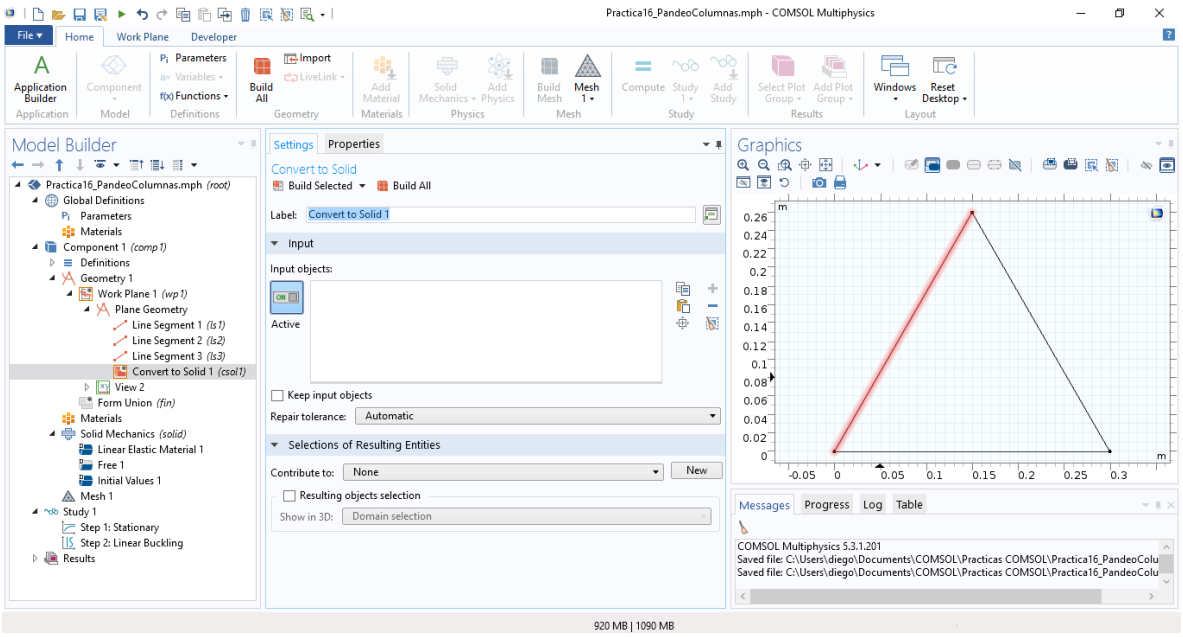
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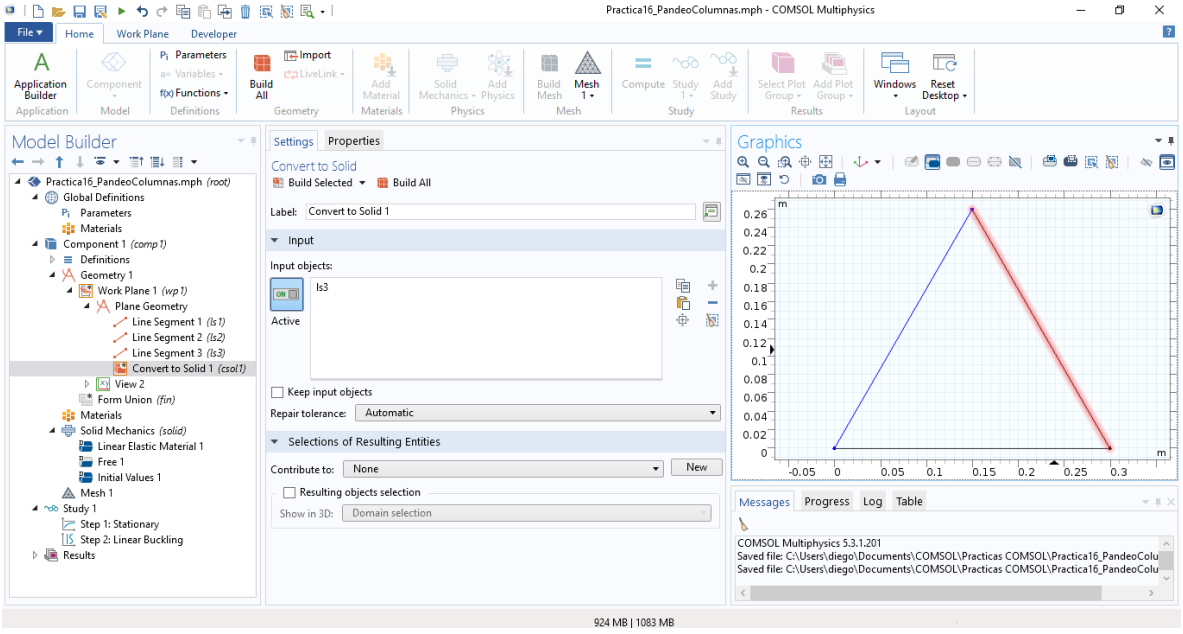
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Step 2: Linear Buckling
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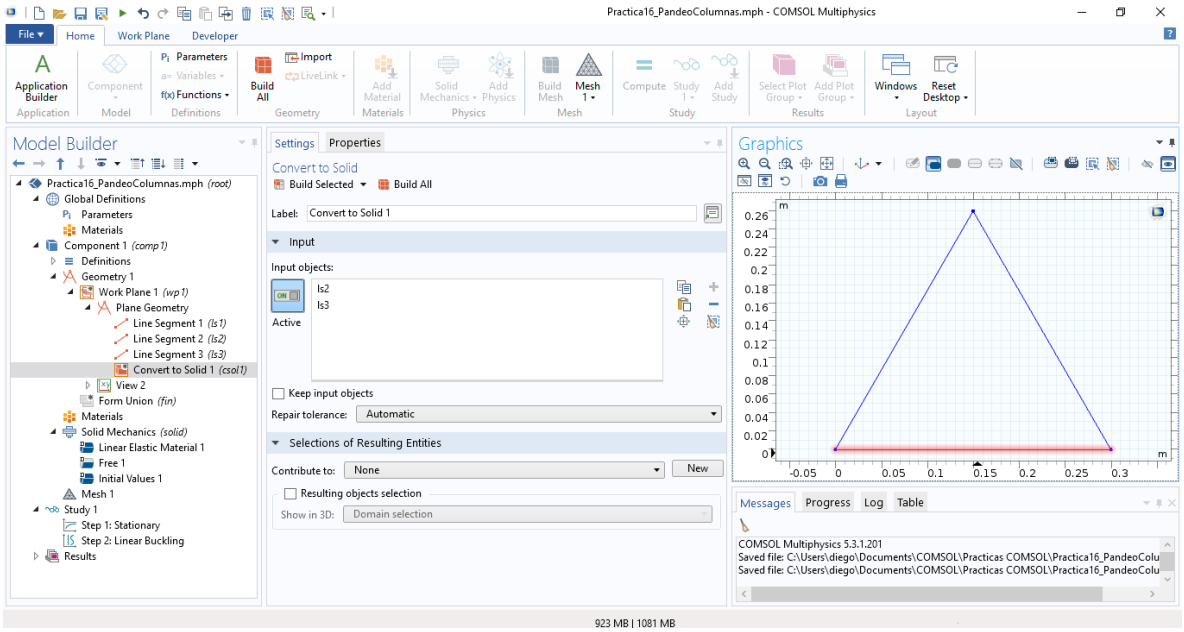
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Label: Convert to Solid 1
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Input objects:
ls2
ls3
Active
Keep input objects
Repair tolerance: Automatic
Selections of Resulting Entities
Contribute to: None
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Show in 3D: Domain selection
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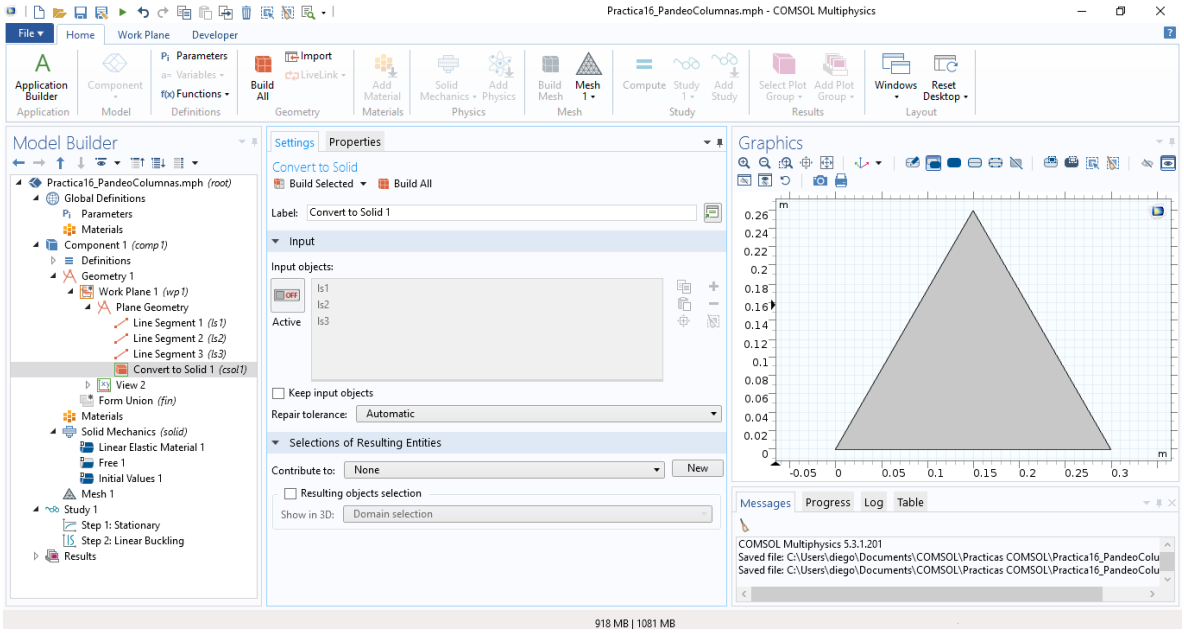
COMSOL Multiphysics 5.3.1.201
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
923 MB | 1081 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
File
Home
Work Plane
Developer
Application Builder
Parameters
Variables
Functions
Import
LiveLink
Build All
Add Material
Solid Mechanics
Add Physics
Build Mesh
Mesh 1
Compute
Study 1
Add Study
Select Plot Group
Add Plot Group
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Physics
Mesh
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Model Builder
Practica16_PandeoColumnas.mph (root)
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Geometry 1
Work Plane 1 (wp 1)
Plane Geometry
Line Segment 1 (ls1)
Line Segment 2 (ls2)
Line Segment 3 (ls3)
Convert to Solid 1 (csol1)
View 2
Form Union (fin)
Materials
Solid Mechanics (solid)
Linear Elastic Material 1
Free 1
Initial Values 1
Mesh 1
Study 1
Step 1: Stationary
Step 2: Linear Buckling
Results
Settings
Properties
Convert to Solid
Build Selected
Build All
Label: Convert to Solid 1
Input
Input objects:
ls1
ls2
ls3
Active
Keep input objects
Repair tolerance: Automatic
Selections of Resulting Entities
Contribute to: None
New
Resulting objects selection
Show in 3D: Domain selection
Graphics
Messages
Progress
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Table
COMSOL Multiphysics 5.3.1.201
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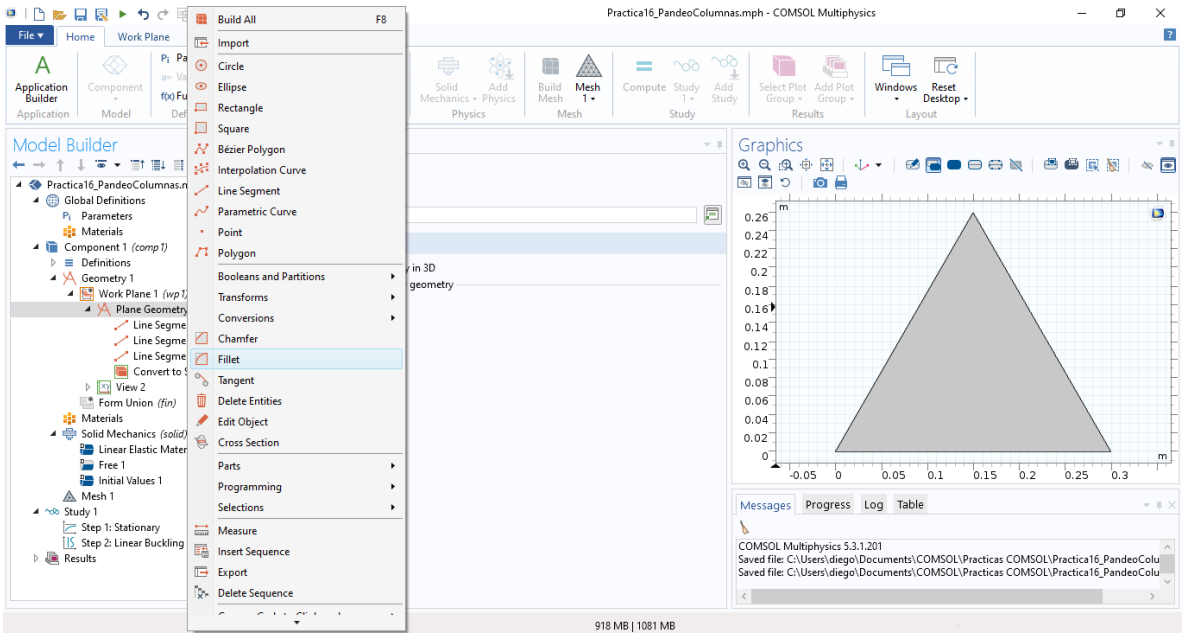
918 MB | 1081 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
File
Home
Work Plane
Model Builder
Graphics
Build All F8
Import
Circle
Ellipse
Rectangle
Square
Bézier Polygon
Interpolation Curve
Line Segment
Parametric Curve
Point
Polygon
Booleans and Partitions
Transforms
Conversions
Chamfer
Fillet
Tangent
Delete Entities
Edit Object
Cross Section
Parts
Programming
Selections
Measure
Insert Sequence
Export
Delete Sequence
Messages
Progress
Log
Table
COMSOL Multiphysics 5.3.1.201
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Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
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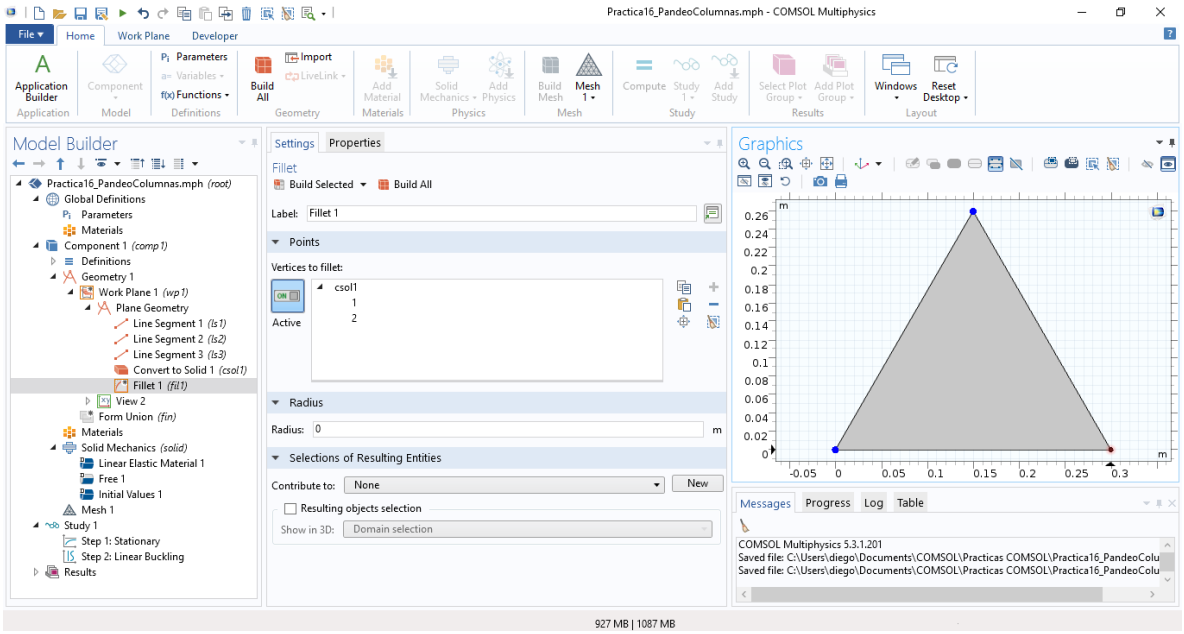
Practica16_PandeoColumnas.mph - COMSOL Multiphysics
File
Home
Work Plane
Developer
Model Builder
Settings
Properties
Fillet
Build Selected
Build All
Label: Fillet 1
Points
Vertices to fillet:
Active
csol1
1
2
Radius
Radius: 0 m
Selections of Resulting Entities
Contribute to: None
New
Resulting objects selection
Show in 3D: Domain selection
Graphics
Messages
Progress
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Table
COMSOL Multiphysics 5.3.1.201
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
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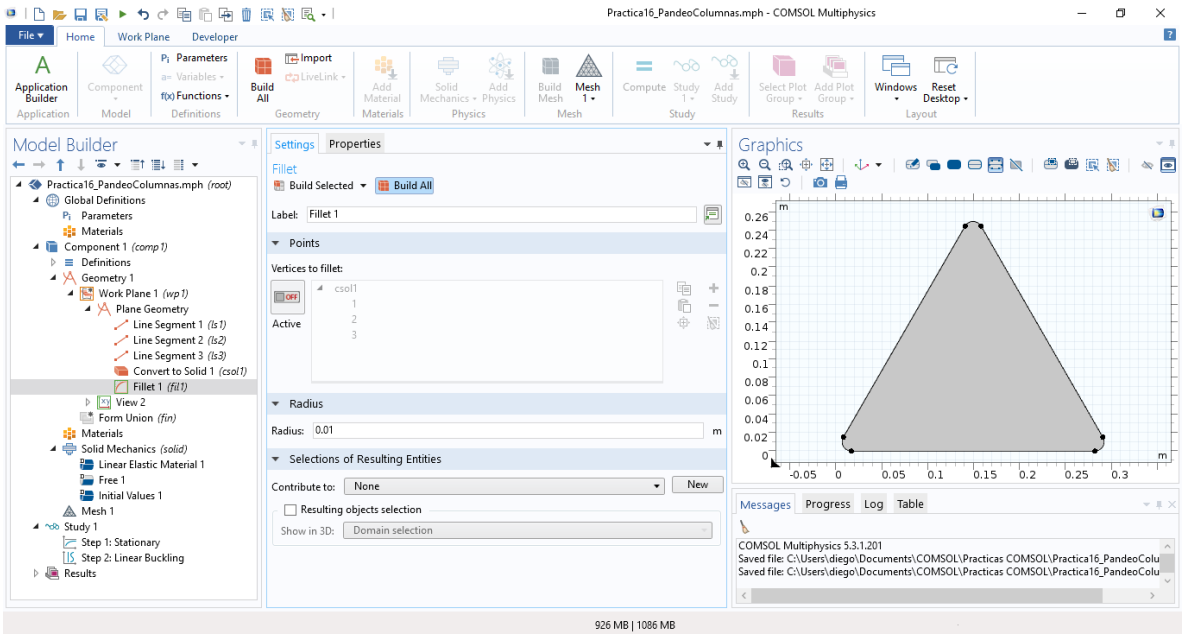
927 MB | 1087 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
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Practica16_PandeoColumnas.mph (root)
Global Definitions
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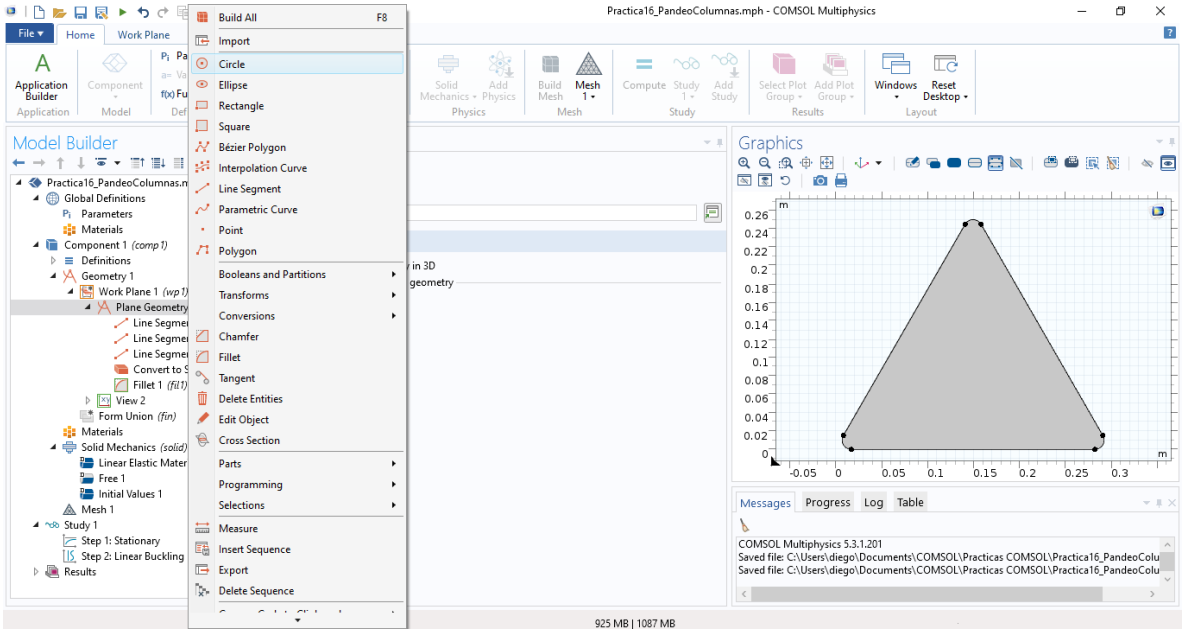
Line Segment 2 (ls2)
Line Segment 3 (ls3)
Convert to Solid 1 (csol1)
Fillet 1 (fil1)
View 2
Form Union (fin)
Materials
Solid Mechanics (solid)
Linear Elastic Material 1
Free 1
Initial Values 1
Mesh 1
Study 1
Step 1: Stationary
Step 2: Linear Buckling
Results
Settings
Properties
Fillet
Build Selected
Build All
Label: Fillet 1
Points
Vertices to fillet:
Active
Radius
Radius: 0.01
m
Selections of Resulting Entities
Contribute to: None
New
Resulting objects selection
Show in 3D:
Domain selection
Graphics
Messages
Progress
Log
Table
COMSOL Multiphysics 5.3.1.201
926 MB | 1086 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Build All F8
Import
Circle
Ellipse
Rectangle
Square
Bézier Polygon
Interpolation Curve
Line Segment
Parametric Curve
Point
Polygon
Booleans and Partitions
Transforms
Conversions
Chamfer
Fillet
Tangent
Delete Entities
Edit Object
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Insert Sequence
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Delete Sequence
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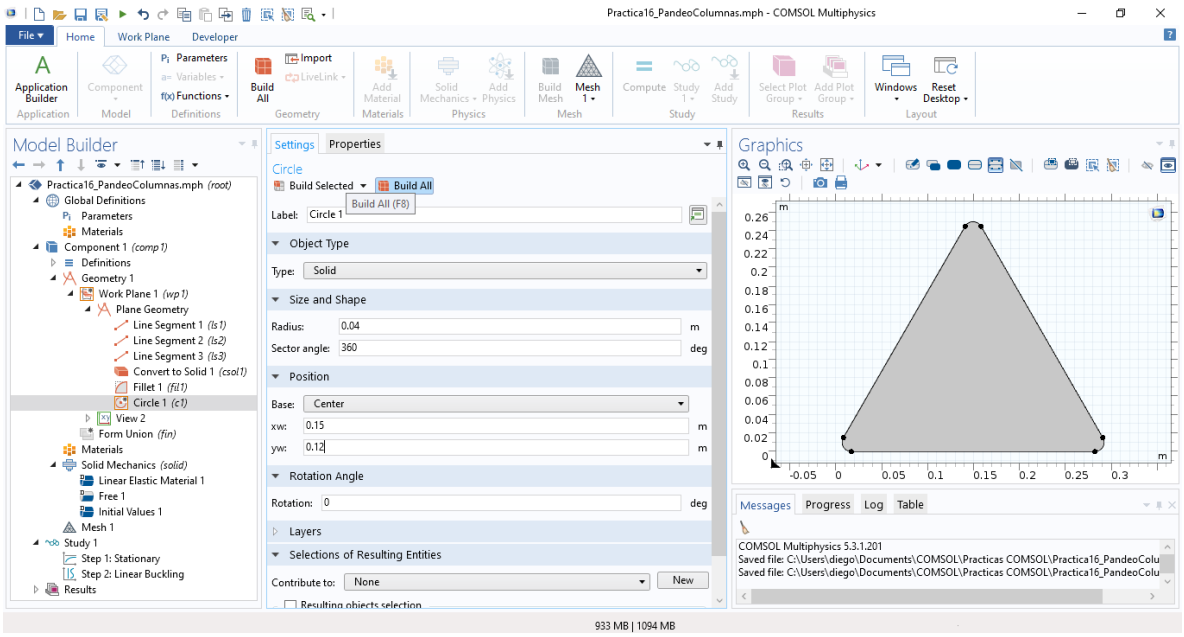
Table
COMSOL Multiphysics 5.3.1.201
925 MB | 1087 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
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Build All
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Line Segment 2 (ls2)
Line Segment 3 (ls3)
Convert to Solid 1 (csol1)
Fillet 1 (fil1)
Circle 1 (c1)
View 2
Form Union (fin)
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Linear Elastic Material 1
Free 1
Initial Values 1
Mesh 1
Study 1
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Step 2: Linear Buckling
Results
Settings
Properties
Circle
Build Selected
Build All
Build All (F8)
Label: Circle 1
Object Type
Type: Solid
Size and Shape
Radius: 0.04 m
Sector angle: 360 deg
Position
Base: Center
xw: 0.15 m
yw: 0.12 m
Rotation Angle
Rotation: 0 deg
Layers
Selections of Resulting Entities
Contribute to: None
New
Resulting objects selection
Graphics
Messages
Progress
Log
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COMSOL Multiphysics 5.3.1.201
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
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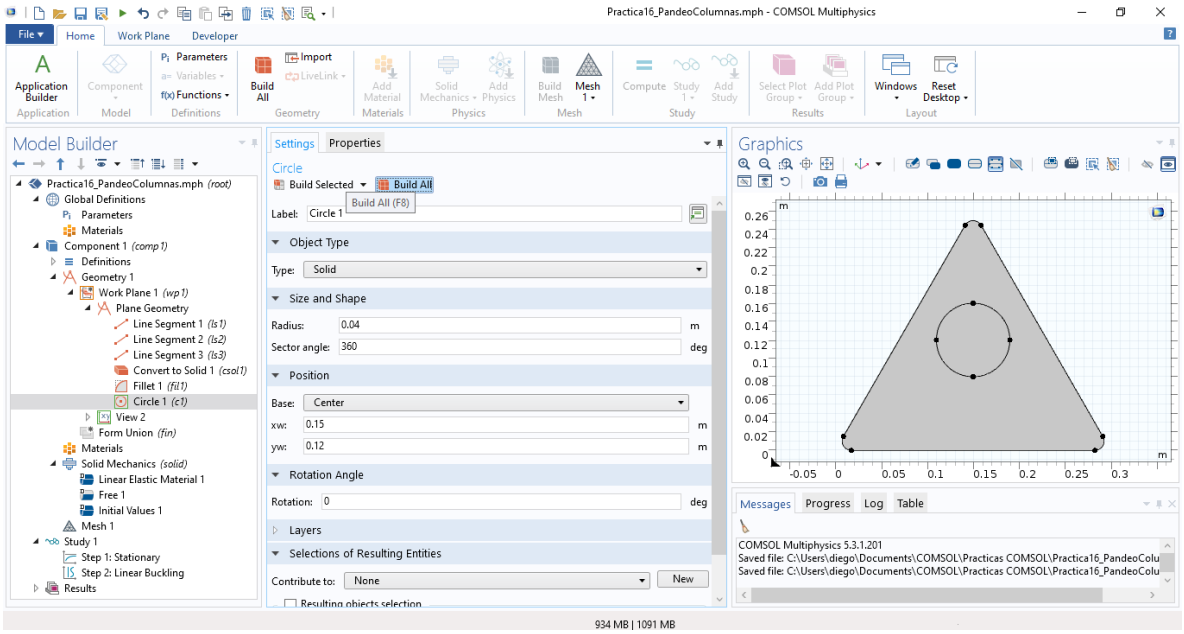
933 MB | 1094 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
File
Home
Work Plane
Developer
Application Builder
Parameters
Variables
Functions
Import
LiveLink
Build All
Add Material
Solid Mechanics
Add Physics
Build Mesh
Mesh 1
Compute
Study 1
Add Study
Select Plot Group
Add Plot Group
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Line Segment 3 (ls3)
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Fillet 1 (fil1)
Circle 1 (c1)
View 2
Form Union (fin)
Materials
Solid Mechanics (solid)
Linear Elastic Material 1
Free 1
Initial Values 1
Mesh 1
Study 1
Step 1: Stationary
Step 2: Linear Buckling
Results
Settings
Properties
Circle
Build Selected
Build All
Build All (F8)
Label: Circle 1
Object Type
Type: Solid
Size and Shape
Radius: 0.04 m
Sector angle: 360 deg
Position
Base: Center
xw: 0.15 m
yw: 0.12 m
Rotation Angle
Rotation: 0 deg
Layers
Selections of Resulting Entities
Contribute to: None
New
Resulting objects selection
Graphics
Messages
Progress
Log
Table
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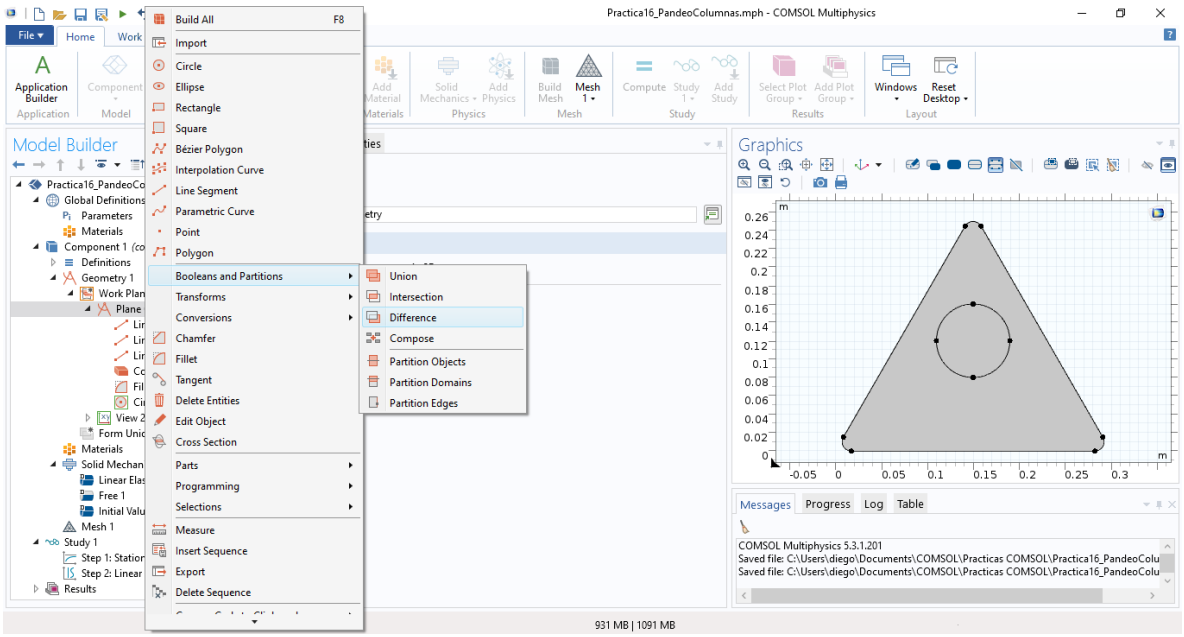
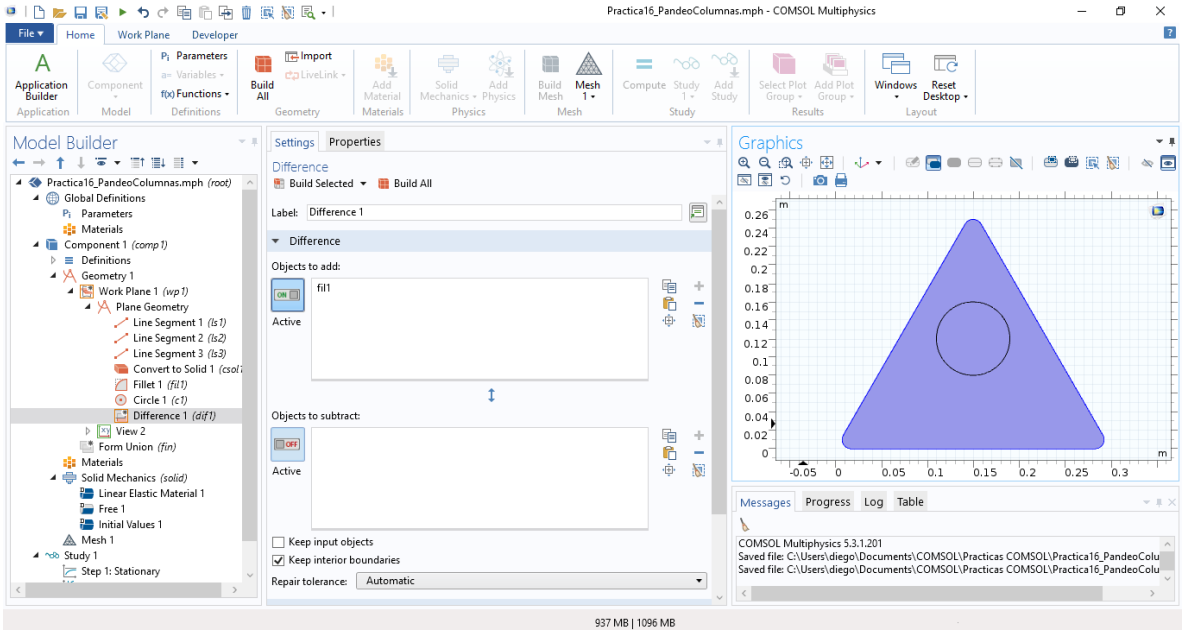
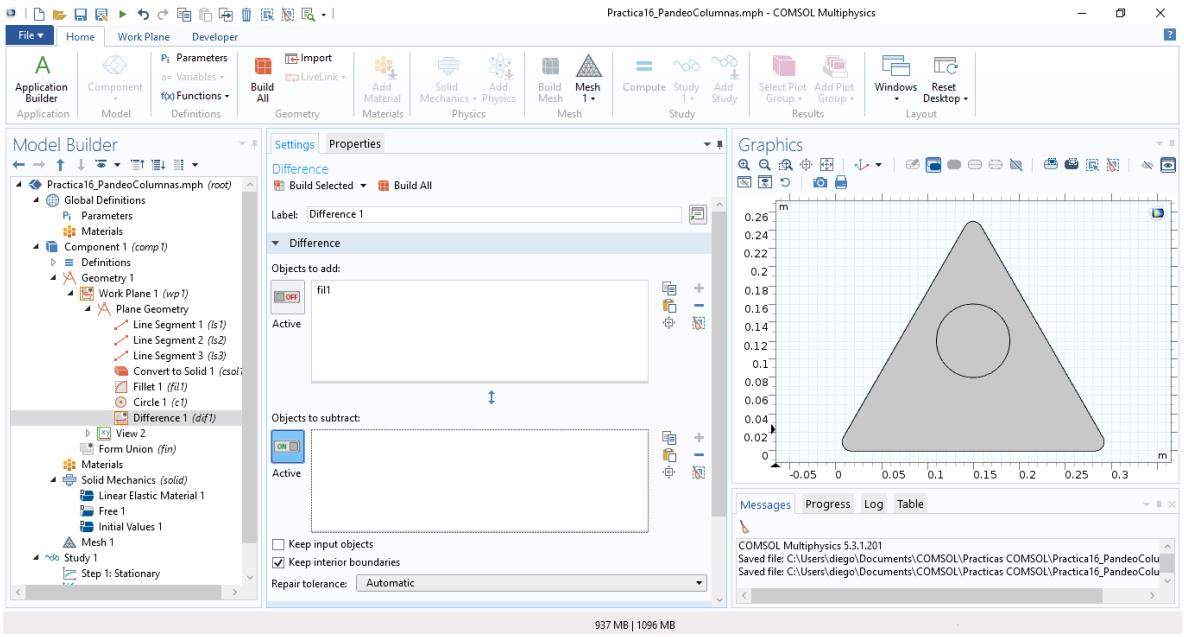
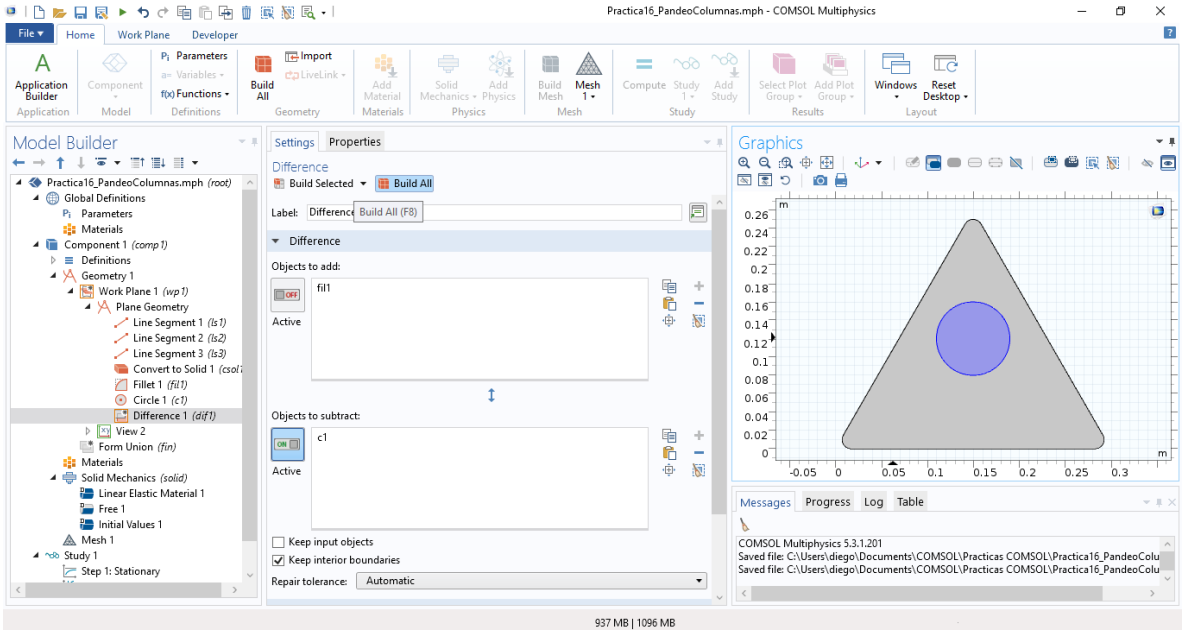
934 MB | 1091 MB

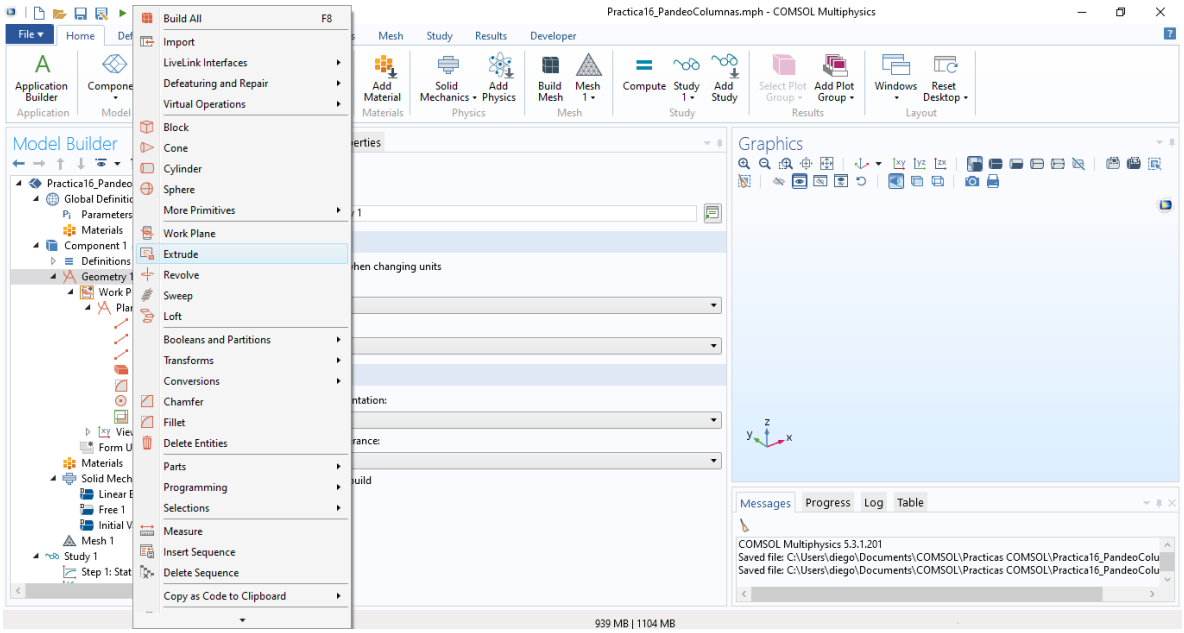

Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Build All F8
Import
Circle
Ellipse
Rectangle
Square
Bézier Polygon
Interpolation Curve
Line Segment
Parametric Curve
Point
Polygon
Booleans and Partitions
Transforms
Conversions
Chamfer
Fillet
Tangent
Delete Entities
Edit Object
Cross Section
Parts
Programming
Selections
Measure
Insert Sequence
Export
Delete Sequence
Union
Intersection
Difference
Compose
Partition Objects
Partition Domains
Partition Edges
Model Builder
Graphics
Messages
Progress
Log
Table
COMSOL Multiphysics 5.3.1.201
931 MB | 1091 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Model Builder
Settings
Properties
Difference
Build Selected
Build All
Label: Difference 1
Objects to add:
fil1
Active
Objects to subtract:
Keep input objects
Keep interior boundaries
Repair tolerance: Automatic
Graphics
Messages
Progress
Log
Table
COMSOL Multiphysics 5.3.1.201
937 MB | 1096 MB





Ya no voy a estar en Plane Geometry porque ya no voy a hacer nada en este plano, ahora lo voy a extruir, por eso me voy a Geometry 1 que hace referencia al 3D.


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Build All F8
Import
LiveLink Interfaces
Defeaturing and Repair
Virtual Operations
Block
Cone
Cylinder
Sphere
More Primitives
Work Plane
Extrude
Revolve
Sweep
Loft
Booleans and Partitions
Transforms
Conversions
Chamfer
Fillet
Delete Entities
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Measure
Insert Sequence
Delete Sequence
Copy as Code to Clipboard
Model Builder
Graphics
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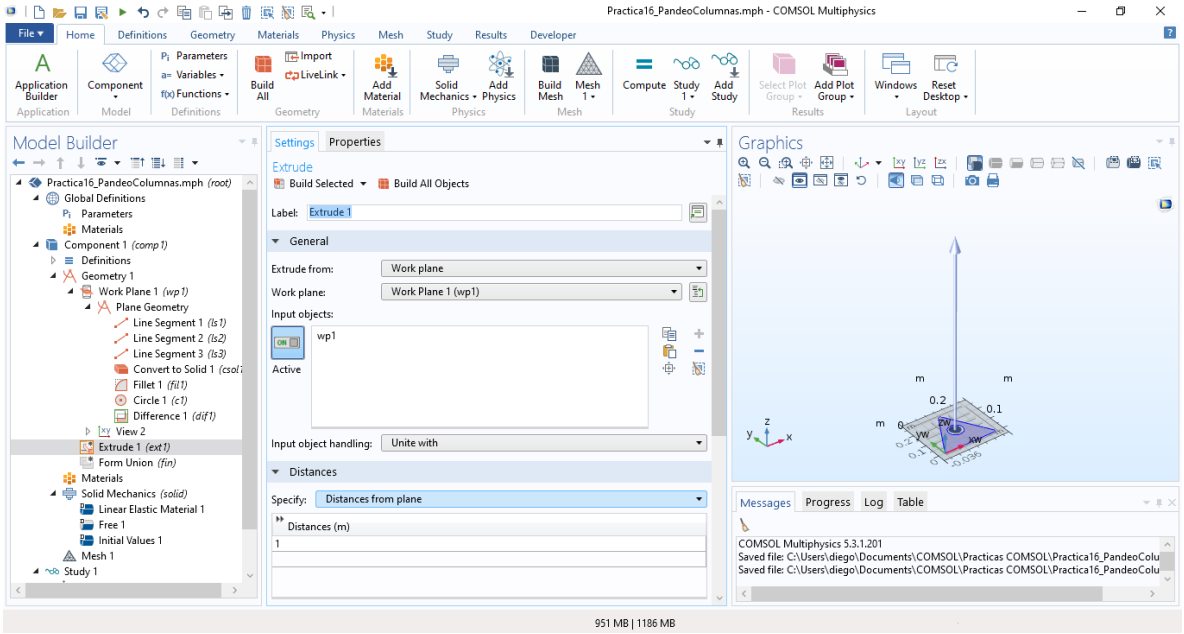
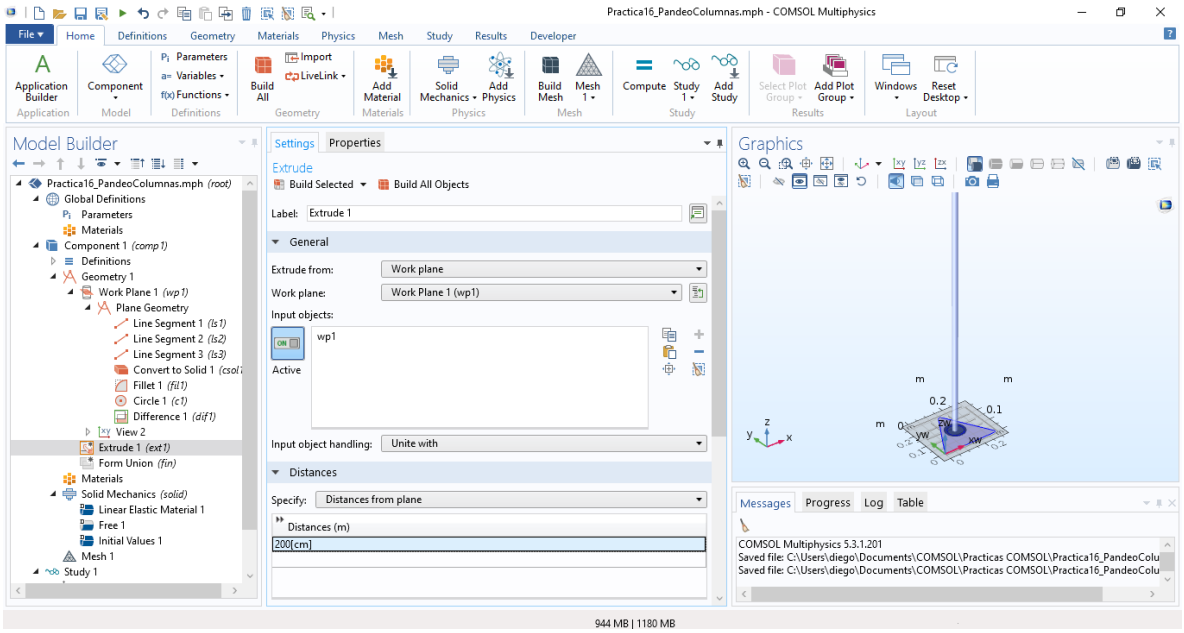
Table
COMSOL Multiphysics 5.3.1.201
939 MB | 1104 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Model Builder
Settings
Properties
Extrude
Build Selected
Build All Objects
Label: Extrude 1
General
Extrude from: Work plane
Work plane: Work Plane 1 (wp1)
Input objects:
wp1
Active
Input object handling: Unite with
Distances
Specify: Distances from plane
Distances (m)
Graphics
Messages
Progress
Log
Table
COMSOL Multiphysics 5.3.1.201
951 MB | 1186 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Model Builder
Practica16_PandeoColumnas.mph (root)
Global Definitions
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Component 1 (comp 1)
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Plane Geometry
Line Segment 1 (ls 1)
Line Segment 2 (ls2)
Line Segment 3 (ls3)
Convert to Solid 1 (csol1)
Fillet 1 (fil1)
Circle 1 (c1)
Difference 1 (dif1)
View 2
Extrude 1 (ext1)
Form Union (fin)
Materials
Solid Mechanics (solid)
Linear Elastic Material 1
Free 1
Initial Values 1
Mesh 1
Study 1
Settings
Properties
Extrude
Build Selected
Build All Objects
Label: Extrude 1
General
Extrude from: Work plane
Work plane: Work Plane 1 (wp1)
Input objects:
wp1
Active
Input object handling: Unite with
Distances
Specify: Distances from plane
Distances (m)
200[cm]
Graphics
Messages
Progress
Log
Table
COMSOL Multiphysics 5.3.1.201
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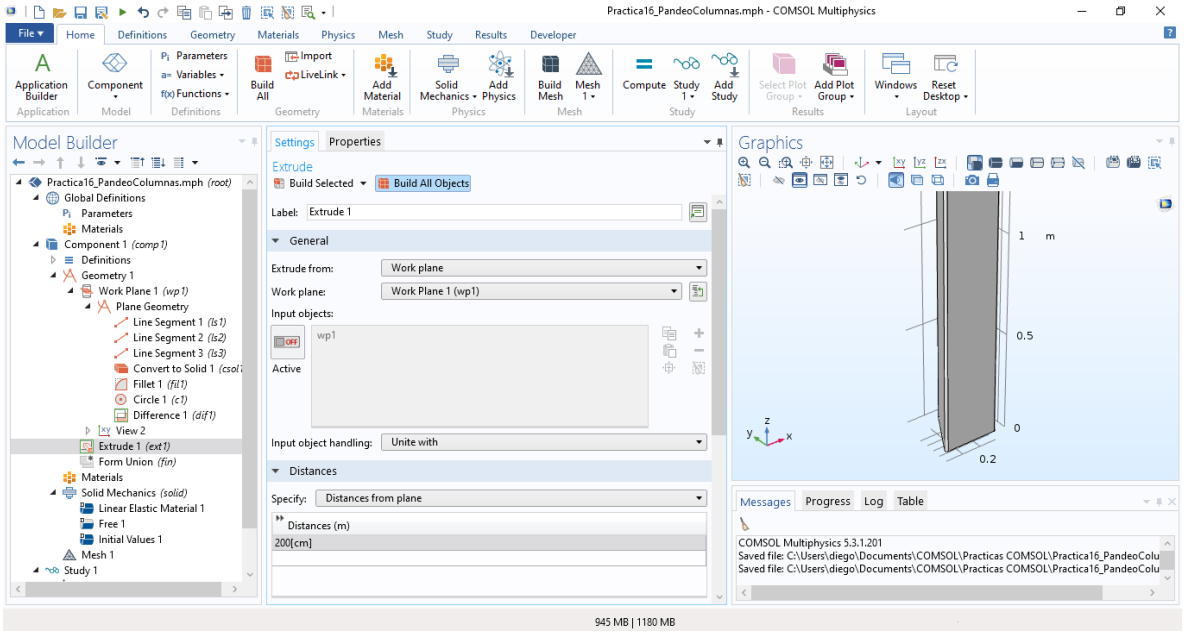
944 MB | 1180 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Model Builder
Practica16_PandeoColumnas.mph (root)
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Line Segment 3 (ls3)
Convert to Solid 1 (csol1)
Fillet 1 (fil1)
Circle 1 (c1)
Difference 1 (dif1)
View 2
Extrude 1 (ext1)
Form Union (fin)
Materials
Solid Mechanics (solid)
Linear Elastic Material 1
Free 1
Initial Values 1
Mesh 1
Study 1
Settings
Properties
Extrude
Build Selected
Build All Objects
Label: Extrude 1
General
Extrude from: Work plane
Work plane: Work Plane 1 (wp1)
Input objects:
wp1
Active
Input object handling: Unite with
Distances
Specify: Distances from plane
Distances (m)
200[cm]
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Messages
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Log
Table
COMSOL Multiphysics 5.3.1.201
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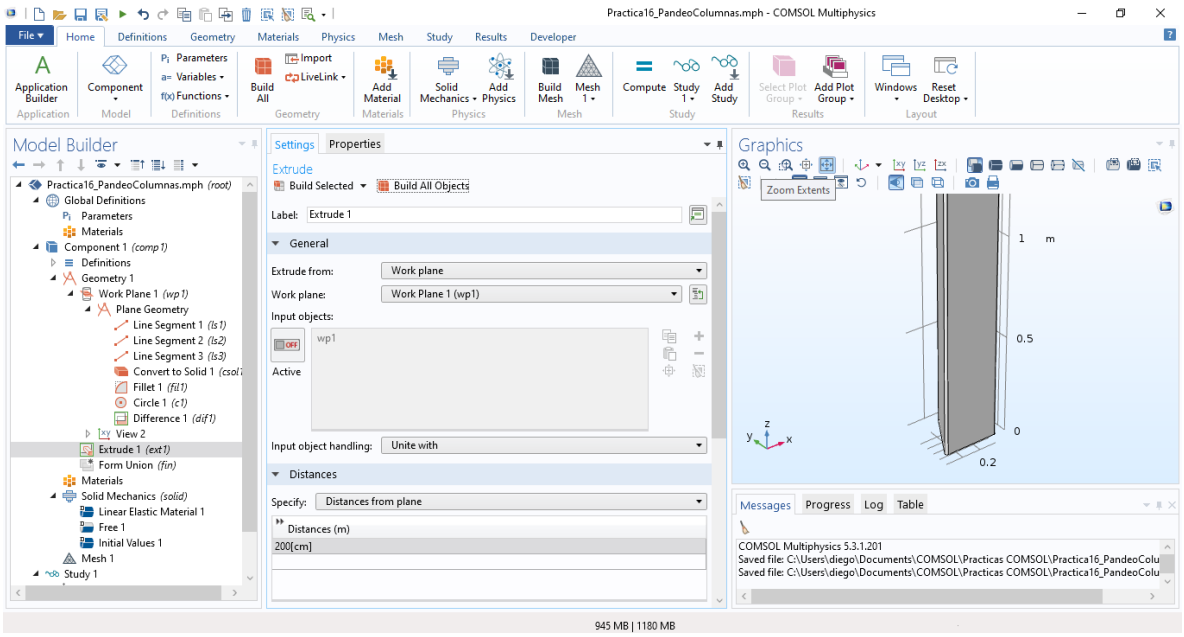
945 MB | 1180 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
File
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Add Physics
Build Mesh
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Study 1
Add Study
Select Plot Group
Add Plot Group
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Reset Desktop
Model Builder
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Line Segment 2 (ls2)
Line Segment 3 (ls3)
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Fillet 1 (fil1)
Circle 1 (c1)
Difference 1 (dif1)
View 2
Extrude 1 (ext1)
Form Union (fin)
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Linear Elastic Material 1
Free 1
Initial Values 1
Mesh 1
Study 1
Settings
Properties
Extrude
Build Selected
Build All Objects
Label: Extrude 1
General
Extrude from: Work plane
Work plane: Work Plane 1 (wp1)
Input objects:
wp1
Active
Input object handling: Unite with
Distances
Specify: Distances from plane
Distances (m)
200[cm]
Graphics
Zoom Extents
1
m
0.5
0
0.2
Messages
Progress
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Table
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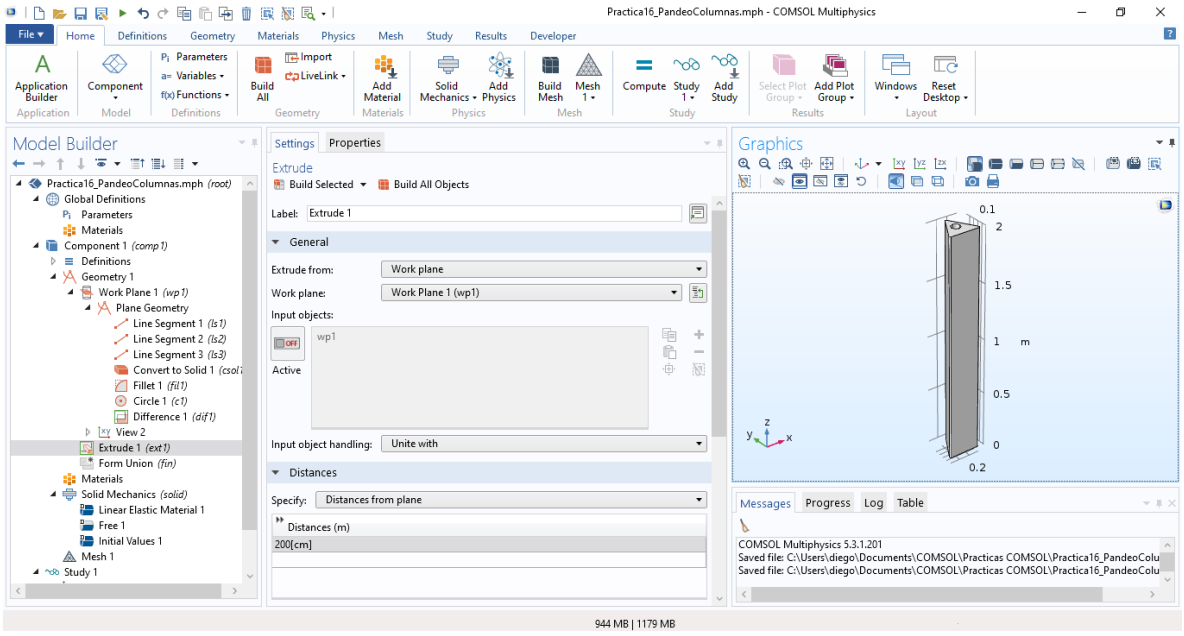
945 MB | 1180 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
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Materials
Physics
Mesh
Study
Results
Developer
Application Builder
Component
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Line Segment 3 (ls3)
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Fillet 1 (fil1)
Circle 1 (c1)
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Extrude
Build Selected
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Label: Extrude 1
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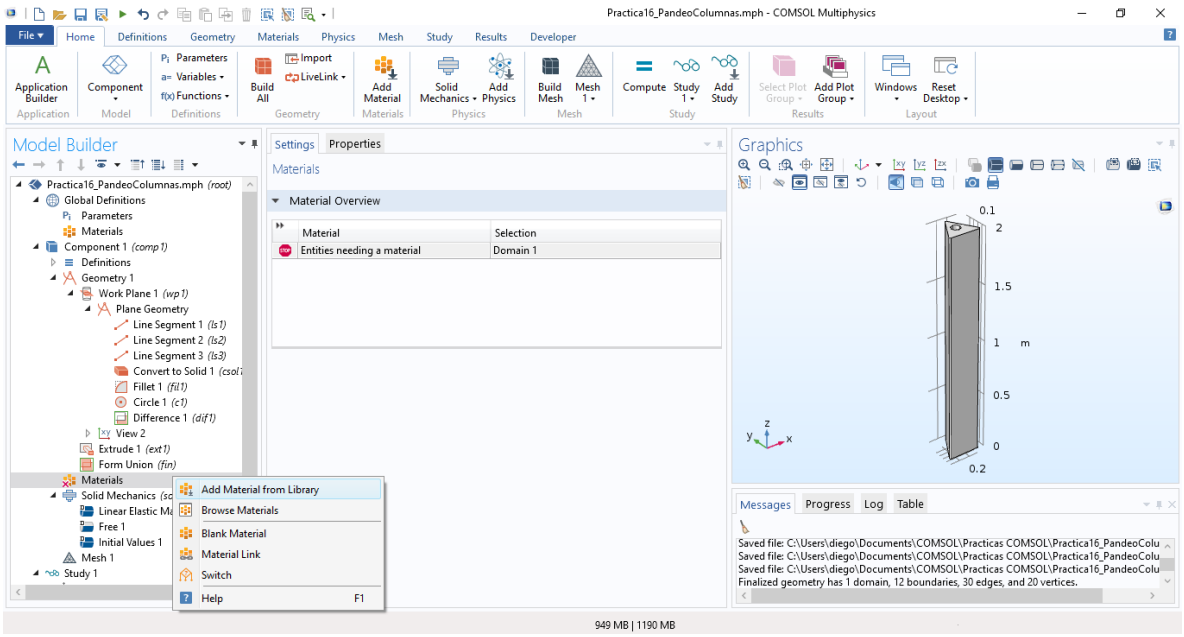
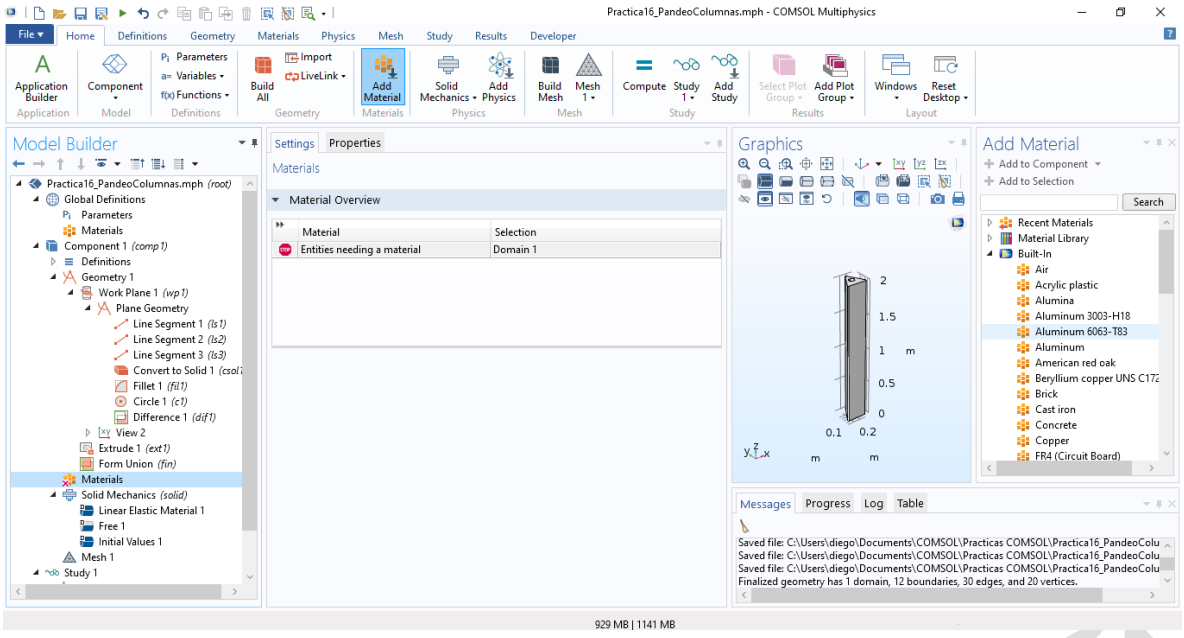
Extrude from: Work plane
Work plane: Work Plane 1 (wp1)
Input objects:
wp1
Active
Input object handling: Unite with
Distances
Specify: Distances from plane
Distances (m)
200[cm]
Graphics
0.1
2
1.5
1
m
0.5
0
0.2
Messages
Progress
Log
Table
COMSOL Multiphysics 5.3.1.201
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
944 MB | 1179 MB

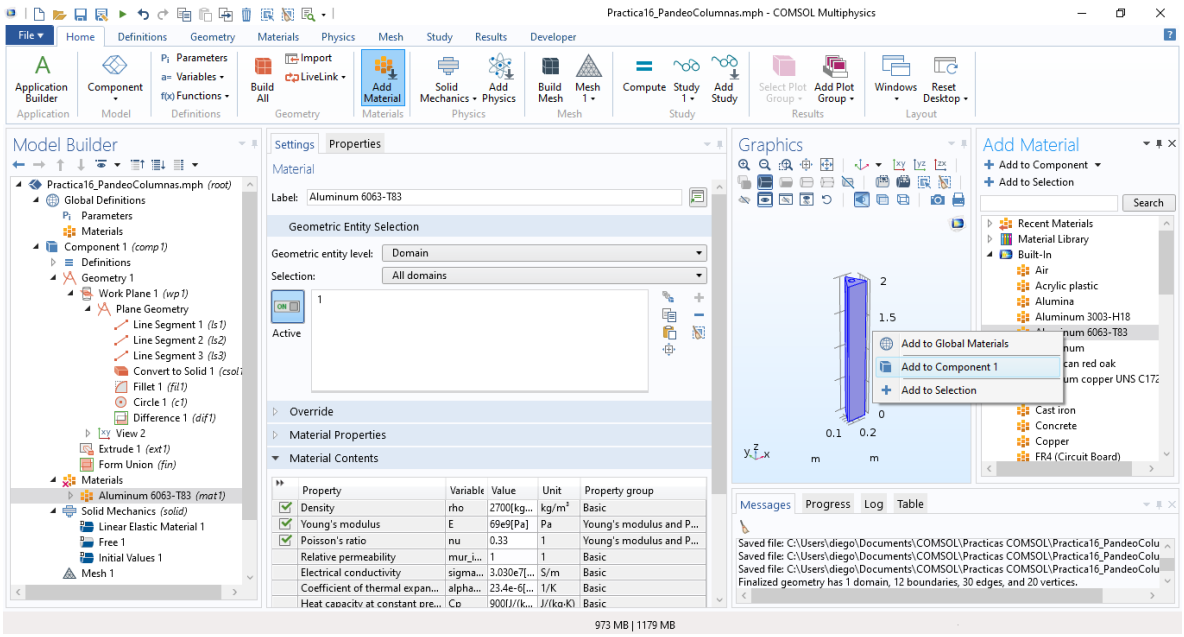
ANÁLISIS MECÁNICO EN COMSOL:

El material debe ser aluminio con tratamiento térmico y debe tener 100 Pascales de presión en la parte de arriba y la parte de abajo debe estar fija.

- El aluminio 6063 (se refiere a que es de aluminio).
- T83 (se refiere a que tiene un tratamiento térmico).






Practica16_PandeoColumnas.mph - COMSOL Multiphysics
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Materials
Physics
Mesh
Study
Results
Developer
Model Builder
Practica16_PandeoColumnas.mph (root)
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Line Segment 2 (ls2)
Line Segment 3 (ls3)
Convert to Solid 1 (csol1)
Fillet 1 (fil1)
Circle 1 (c1)
Difference 1 (dif1)
View 2
Extrude 1 (ext1)
Form Union (fin)
Materials
Aluminum 6063-T83 (mat1)
Solid Mechanics (solid)
Linear Elastic Material 1
Free 1
Initial Values 1
Mesh 1
Settings
Properties
Material
Label: Aluminum 6063-T83
Geometric Entity Selection
Geometric entity level: Domain
Selection: All domains
Active
Override
Material Properties
Material Contents
Property
Variable
Value
Unit
Property group
Density
rho
2700[kg...
kg/m³
Basic
Young's modulus
E
69e9[Pa]
Pa
Young's modulus and P...
Poisson's ratio
nu
0.33
1
Young's modulus and P...
Relative permeability
mur_i...
1
1
Basic
Electrical conductivity
sigma...
3.030e7[...
S/m
Basic
Coefficient of thermal expan...
alpha...
23.4e-6[...
1/K
Basic
Heat capacity at constant pre...
Cp
900[J/(k...
J/(kg·K)
Basic
Graphics
Add to Global Materials
Add to Component 1
Add to Selection
Add Material
Add to Component
Add to Selection
Search
Recent Materials
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Built-In
Air
Acrylic plastic
Alumina
Aluminum 3003-H18
Aluminum 6063-T83
American red oak
Cast iron
Concrete
Copper
FR4 (Circuit Board)
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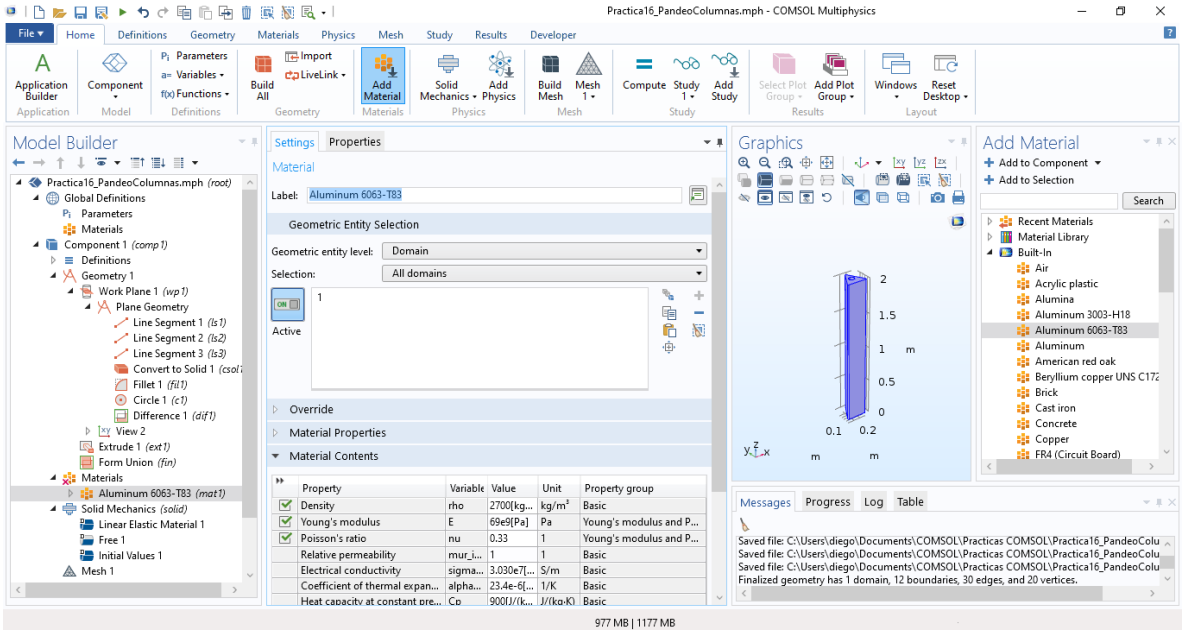
Table
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
Finalized geometry has 1 domain, 12 boundaries, 30 edges, and 20 vertices.
973 MB | 1179 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
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Practica16_PandeoColumnas.mph (root)
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Line Segment 3 (ls3)
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Fillet 1 (fil1)
Circle 1 (c1)
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Aluminum 6063-T83 (mat1)
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Linear Elastic Material 1
Free 1
Initial Values 1
Mesh 1
Settings
Properties
Material
Label: Aluminum 6063-T83
Geometric Entity Selection
Geometric entity level: Domain
Selection: All domains
Active
Override
Material Properties
Material Contents
Property
Variable
Value
Unit
Property group
Density
rho
2700[kg...
kg/m³
Basic
Young's modulus
E
69e9[Pa]
Pa
Young's modulus and P...
Poisson's ratio
nu
0.33
1
Young's modulus and P...
Relative permeability
mur_i...
1
1
Basic
Electrical conductivity
sigma...
3.030e7[...
S/m
Basic
Coefficient of thermal expan...
alpha...
23.4e-6[...
1/K
Basic
Heat capacity at constant pre...
Cp
900[J/(k...
J/(kg·K)
Basic
Graphics
Add Material
Add to Component
Add to Selection
Search
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Alumina
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Aluminum 6063-T83
Aluminum
American red oak
Beryllium copper UNS C17
Brick
Cast iron
Concrete
Copper
FR4 (Circuit Board)
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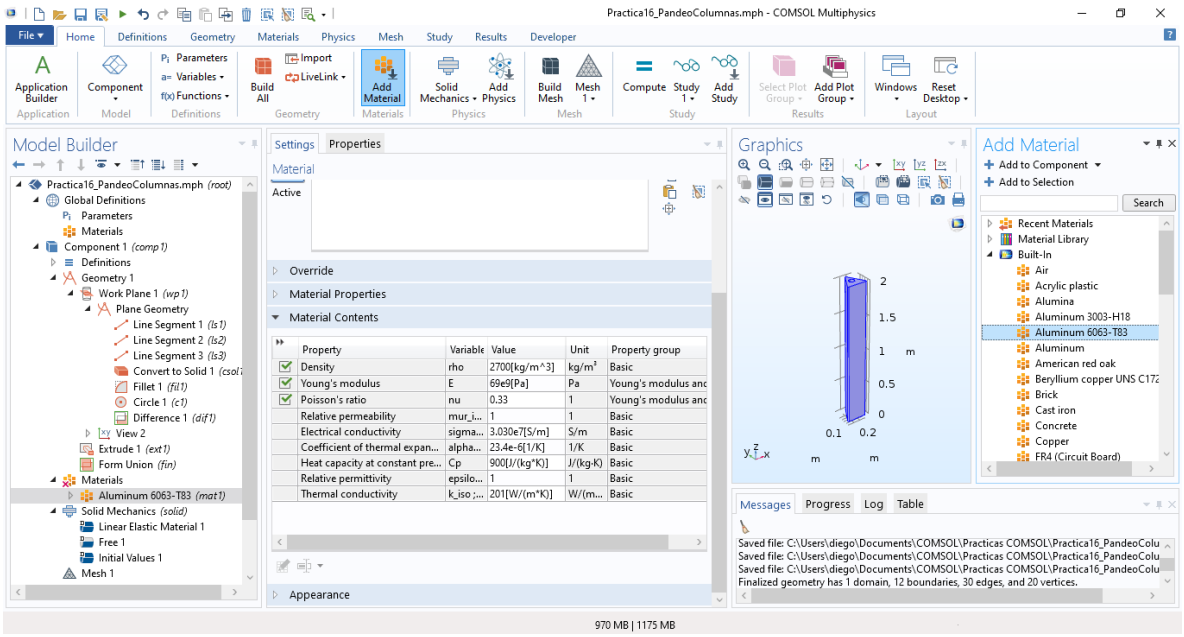
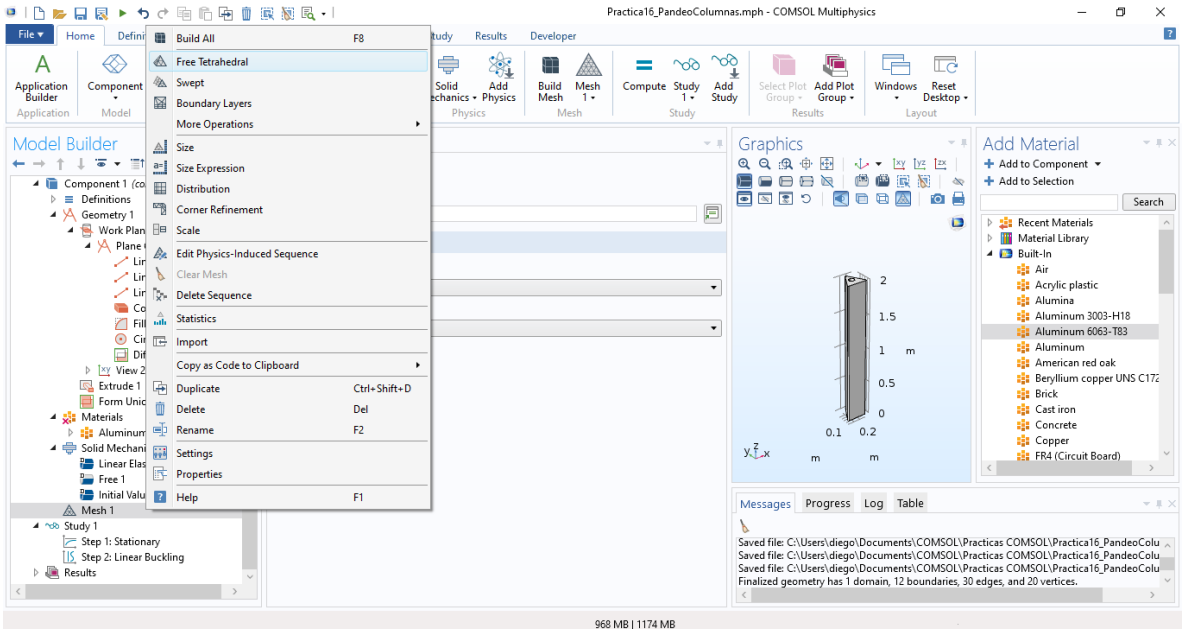
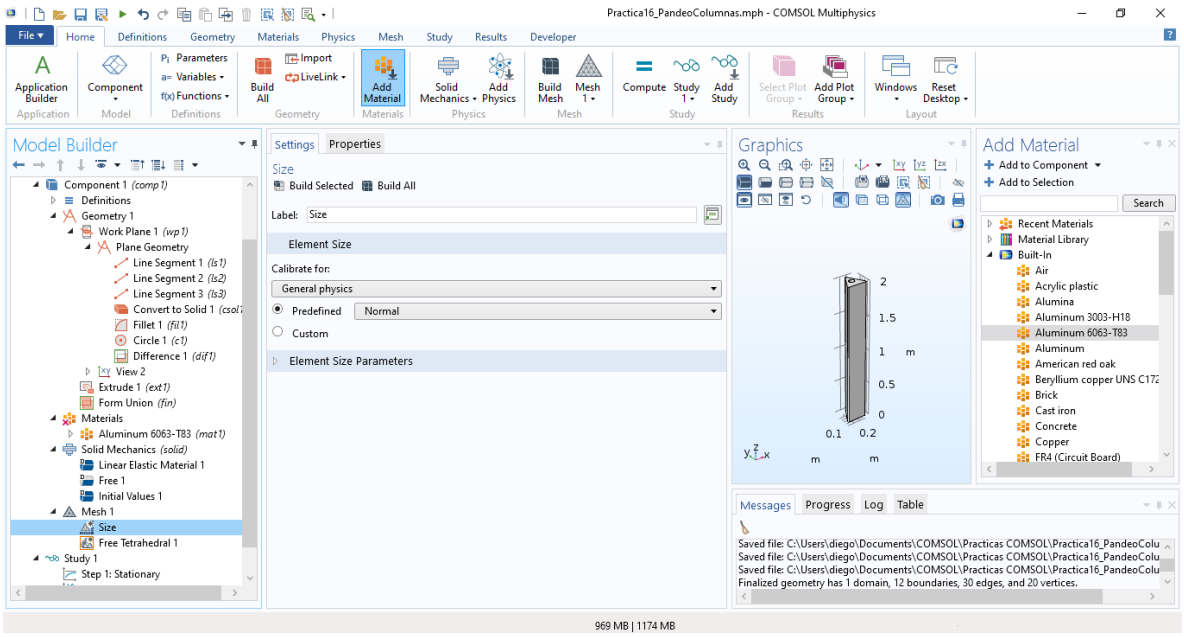
Table
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
Finalized geometry has 1 domain, 12 boundaries, 30 edges, and 20 vertices.
977 MB | 1177 MB



Si no se encuentra el material en la biblioteca, solo debo saber su coeficiente de elasticidad (E), su número de poisson y densidad.




Practica16_PandeoColumnas.mph - COMSOL Multiphysics
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Linear Elastic Material 1
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Build Selected
Build All
Label: Size
Element Size
Calibrate for:
General physics
Predefined
Normal
Custom
Element Size Parameters
Graphics
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Add to Selection
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Air
Acrylic plastic
Alumina
Aluminum 3003-H18
Aluminum 6063-T83
Aluminum
American red oak
Beryllium copper UNS C17
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Cast iron
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FR4 (Circuit Board)
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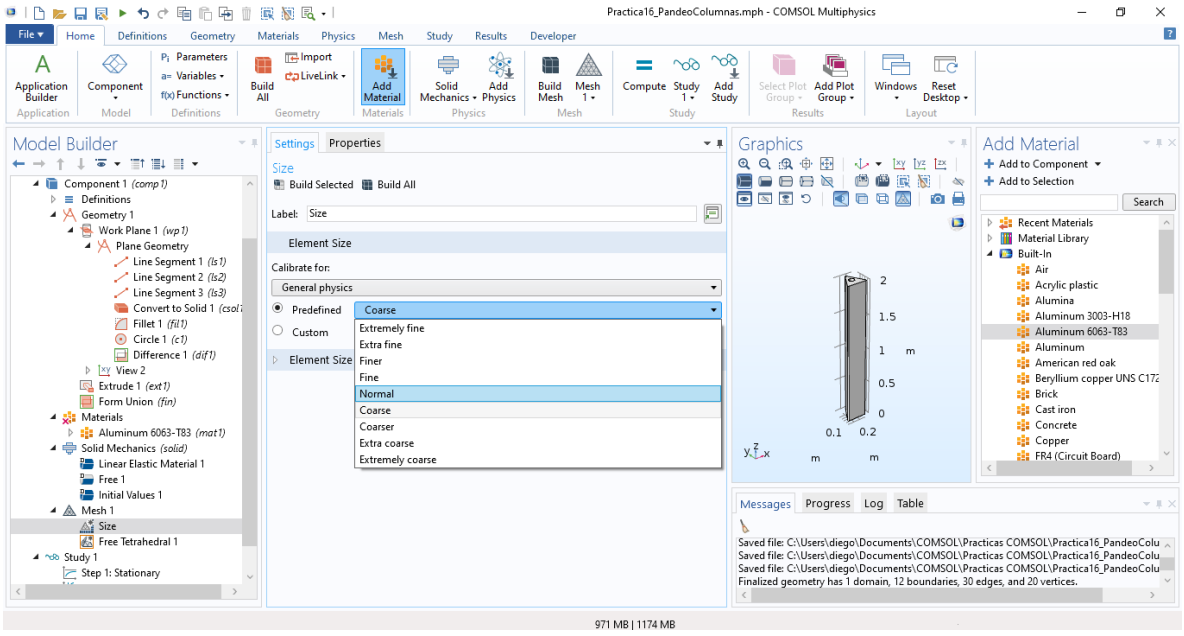
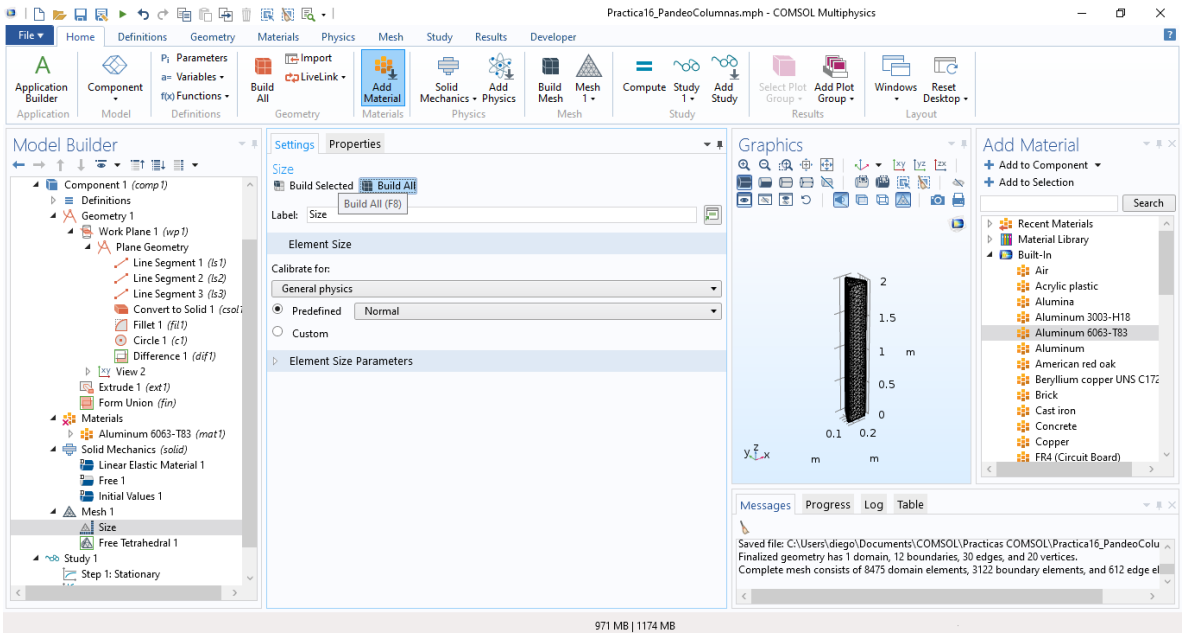
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
Finalized geometry has 1 domain, 12 boundaries, 30 edges, and 20 vertices.
969 MB | 1174 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Model Builder
Settings
Properties
Size
Build Selected
Build All
Label: Size
Element Size
Calibrate for:
General physics
Predefined
Coarse
Custom
Extremely fine
Extra fine
Finer
Fine
Normal
Coarse
Coarser
Extra coarse
Extremely coarse
Graphics
Add Material
Messages
Progress
Log
Table
Finalized geometry has 1 domain, 12 boundaries, 30 edges, and 20 vertices.
971 MB | 1174 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
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Circle 1 (c1)
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Form Union (fin)
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Aluminum 6063-T83 (mat1)
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Initial Values 1
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Size
Build Selected
Build All
Build All (F8)
Label: Size
Element Size
Calibrate for:
General physics
Predefined
Normal
Custom
Element Size Parameters
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Add to Selection
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Recent Materials
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Acrylic plastic
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Aluminum 3003-H18
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Aluminum
American red oak
Beryllium copper UNS C17
Brick
Cast iron
Concrete
Copper
FR4 (Circuit Board)
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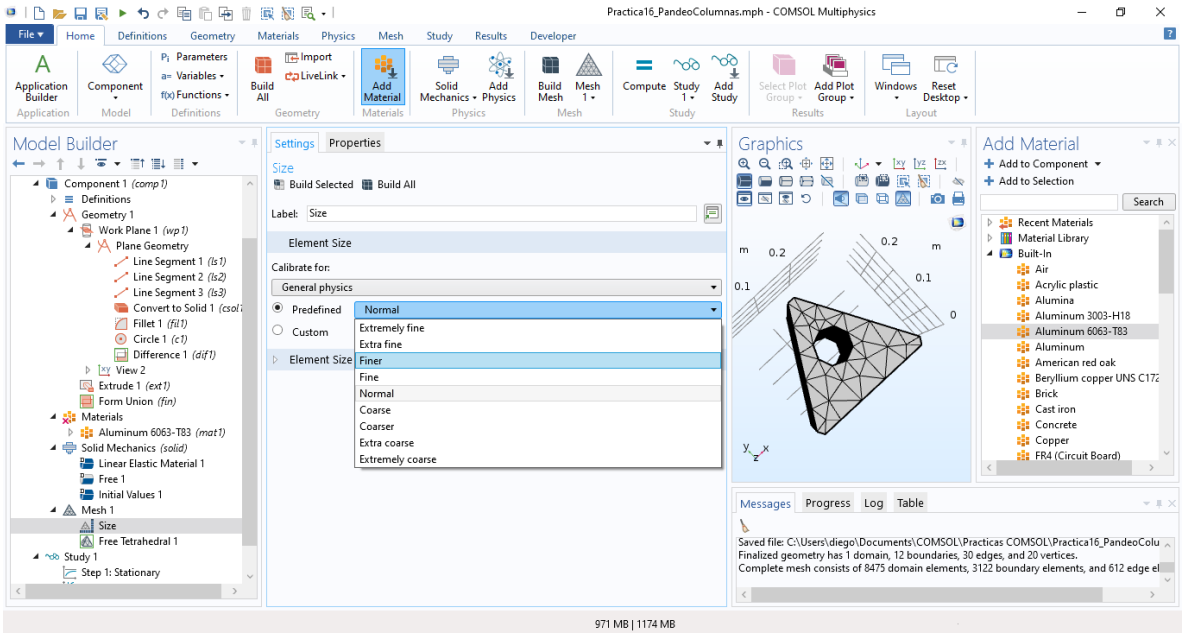
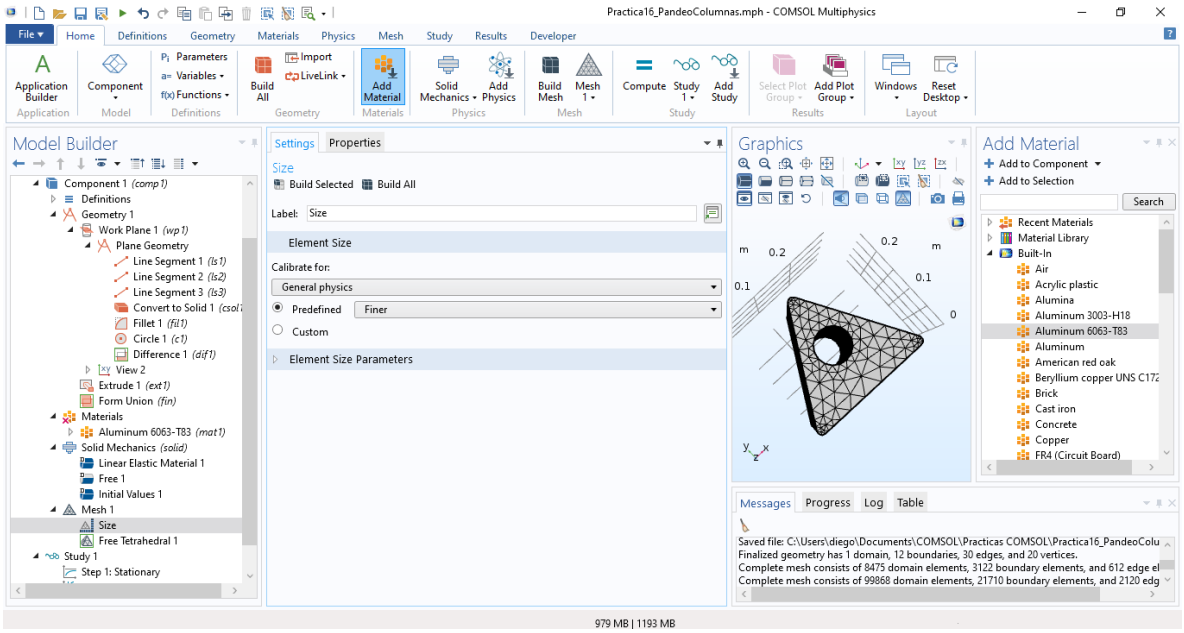
Table
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
Finalized geometry has 1 domain, 12 boundaries, 30 edges, and 20 vertices.
Complete mesh consists of 8475 domain elements, 3122 boundary elements, and 612 edge el
971 MB | 1174 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Normal
Extremely fine
Extra fine
Finer
Fine
Normal
Coarse
Coarser
Extra coarse
Extremely coarse
971 MB | 1174 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
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Beryllium copper UNS C17
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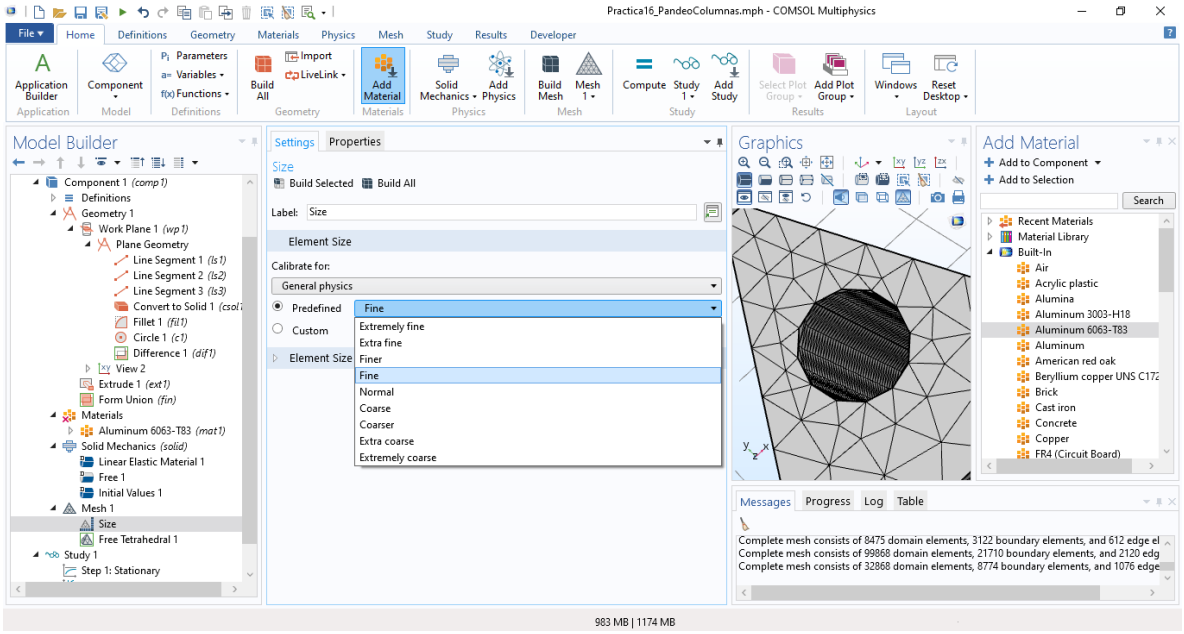
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
Finalized geometry has 1 domain, 12 boundaries, 30 edges, and 20 vertices.
Complete mesh consists of 8475 domain elements, 3122 boundary elements, and 612 edge el
Complete mesh consists of 99868 domain elements, 21710 boundary elements, and 2120 edg
979 MB | 1193 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Model Builder
Settings
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Build Selected
Build All
Label: Size
Element Size
Calibrate for:
General physics
Predefined
Fine
Custom
Extremely fine
Extra fine
Finer
Fine
Normal
Coarse
Coarser
Extra coarse
Extremely coarse
Graphics
Add Material
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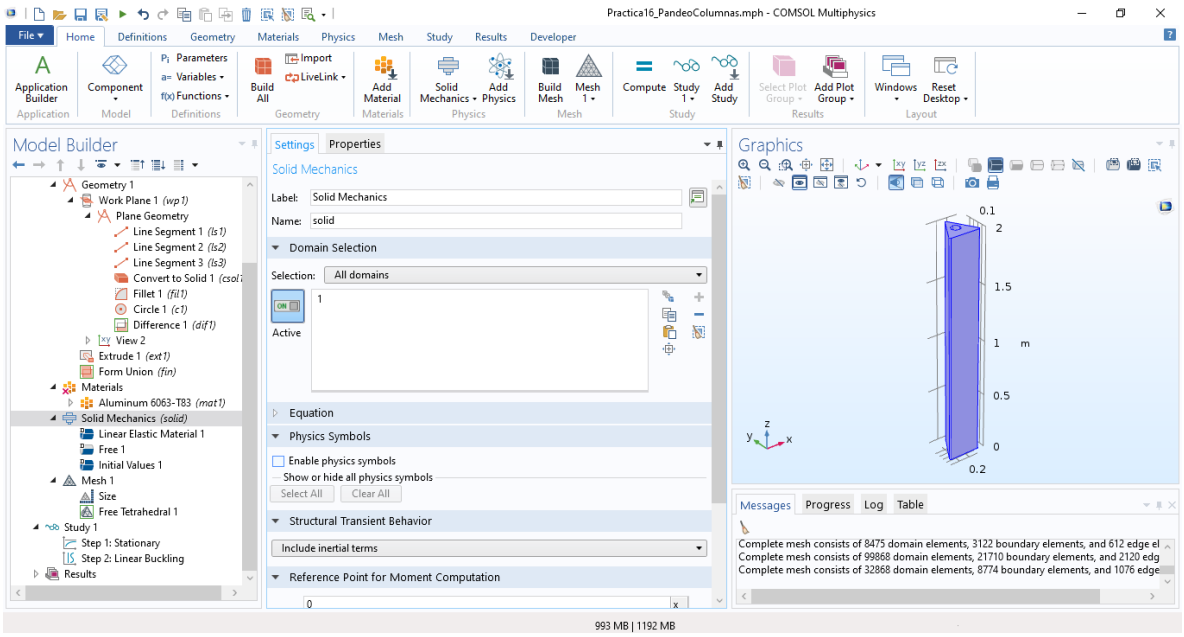
Table
Complete mesh consists of 8475 domain elements, 3122 boundary elements, and 612 edge el
Complete mesh consists of 99868 domain elements, 21710 boundary elements, and 2120 edg
Complete mesh consists of 32868 domain elements, 8774 boundary elements, and 1076 edge
983 MB | 1174 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
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Aluminum 6063-T83 (mat1)
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Linear Elastic Material 1
Free 1
Initial Values 1
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Free Tetrahedral 1
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Step 1: Stationary
Step 2: Linear Buckling
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Settings
Properties
Solid Mechanics
Label: Solid Mechanics
Name: solid
Domain Selection
Selection: All domains
Active
Equation
Physics Symbols
Enable physics symbols
Show or hide all physics symbols
Select All
Clear All
Structural Transient Behavior
Include inertial terms
Reference Point for Moment Computation
Graphics
Messages
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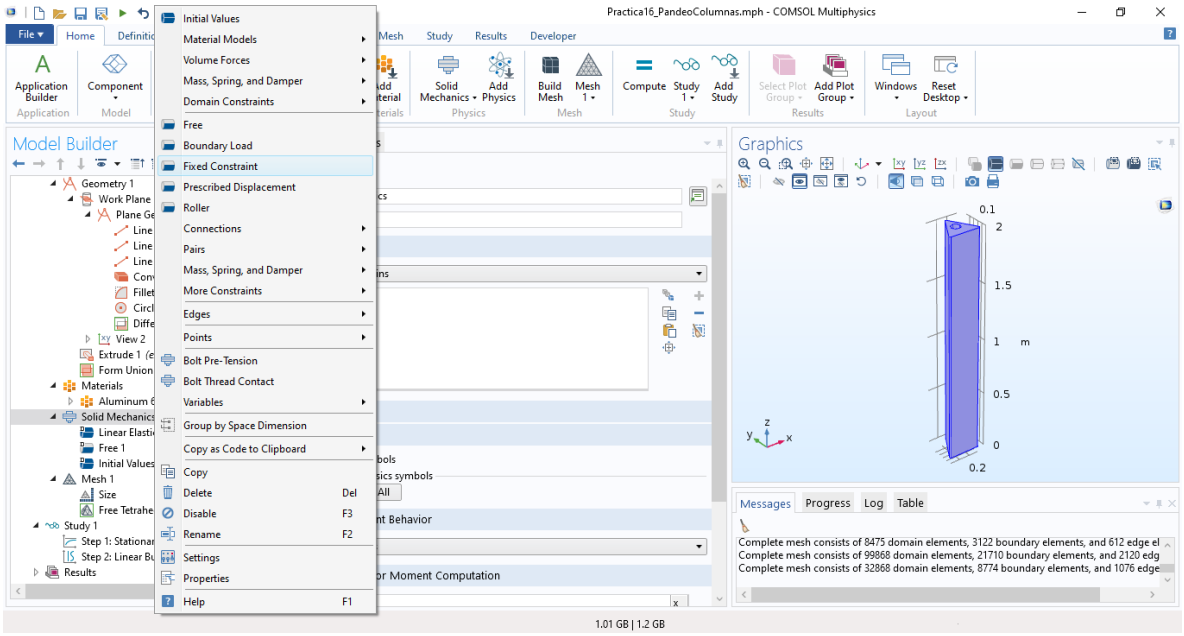
Table
Complete mesh consists of 8475 domain elements, 3122 boundary elements, and 612 edge el
Complete mesh consists of 99868 domain elements, 21710 boundary elements, and 2120 edg
Complete mesh consists of 32868 domain elements, 8774 boundary elements, and 1076 edge
993 MB | 1192 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Initial Values
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Domain Constraints
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Boundary Load
Fixed Constraint
Prescribed Displacement
Roller
Connections
Pairs
Mass, Spring, and Damper
More Constraints
Edges
Points
Bolt Pre-Tension
Bolt Thread Contact
Variables
Group by Space Dimension
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Delete Del
Disable F3
Rename F2
Settings
Properties
Help F1
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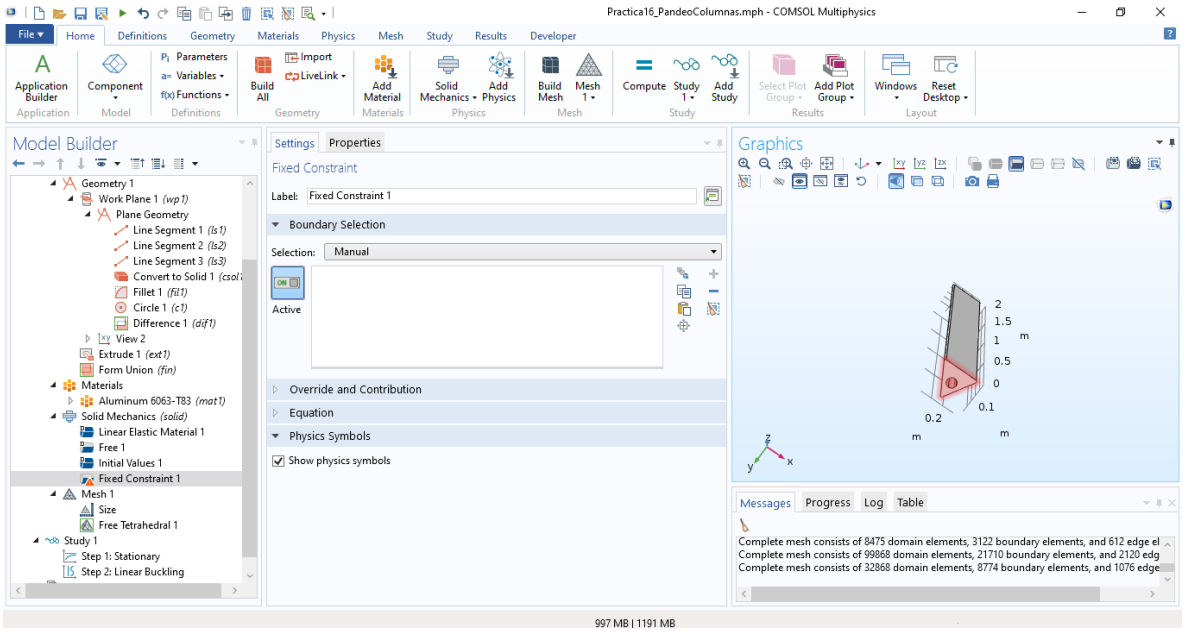
Table
Complete mesh consists of 8475 domain elements, 3122 boundary elements, and 612 edge el
Complete mesh consists of 99868 domain elements, 21710 boundary elements, and 2120 edg
Complete mesh consists of 32868 domain elements, 8774 boundary elements, and 1076 edge
1.01 GB | 1.2 GB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
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Line Segment 3 (ls3)
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Circle 1 (c1)
Difference 1 (dif1)
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Extrude 1 (ext1)
Form Union (fin)
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Fixed Constraint 1
Mesh 1
Size
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Study 1
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Step 2: Linear Buckling
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Properties
Fixed Constraint
Label: Fixed Constraint 1
Boundary Selection
Selection: Manual
Active
Override and Contribution
Equation
Physics Symbols
Show physics symbols
Graphics
2
1.5
1
0.5
0
0.1
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m
Messages
Progress
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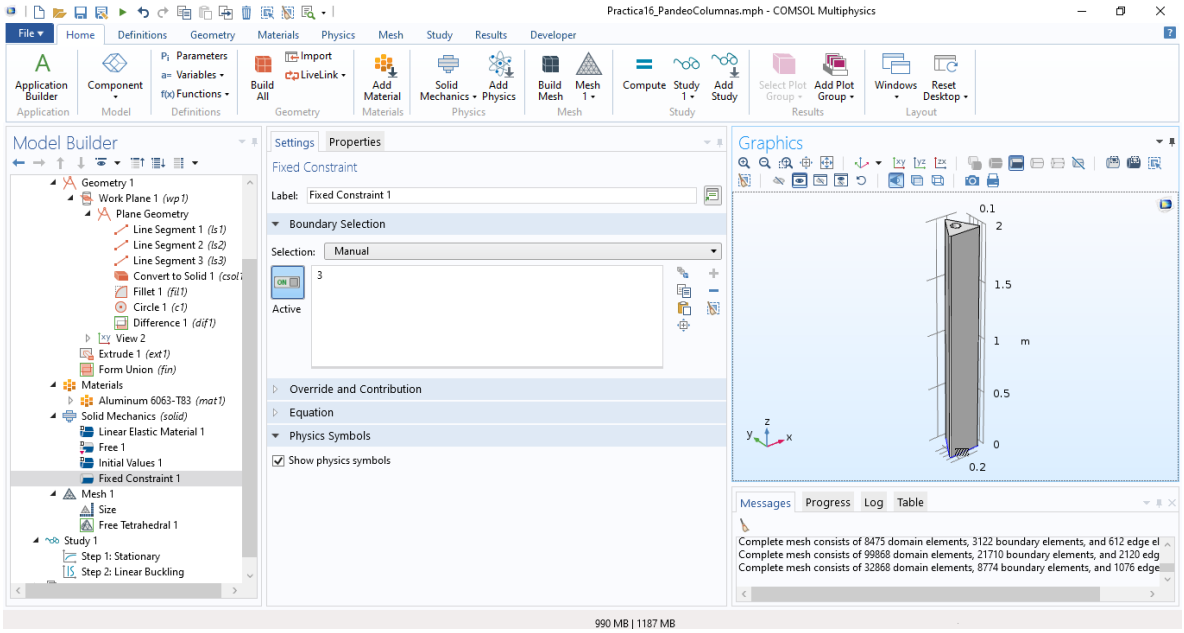
Table
Complete mesh consists of 8475 domain elements, 3122 boundary elements, and 612 edge el
Complete mesh consists of 99868 domain elements, 21710 boundary elements, and 2120 edg
Complete mesh consists of 32868 domain elements, 8774 boundary elements, and 1076 edge
997 MB | 1191 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
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Physics
Mesh
Study
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Add Plot Group
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Line Segment 2 (ls2)
Line Segment 3 (ls3)
Convert to Solid 1
Fillet 1 (fil1)
Circle 1 (c1)
Difference 1 (dif1)
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Extrude 1 (ext1)
Form Union (fin)
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Aluminum 6063-T83 (mat1)
Solid Mechanics (solid)
Linear Elastic Material 1
Free 1
Initial Values 1
Fixed Constraint 1
Mesh 1
Size
Free Tetrahedral 1
Study 1
Step 1: Stationary
Step 2: Linear Buckling
Settings
Properties
Fixed Constraint
Label: Fixed Constraint 1
Boundary Selection
Selection: Manual
3
Active
Override and Contribution
Equation
Physics Symbols
Show physics symbols
Graphics
0.1
2
1.5
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m
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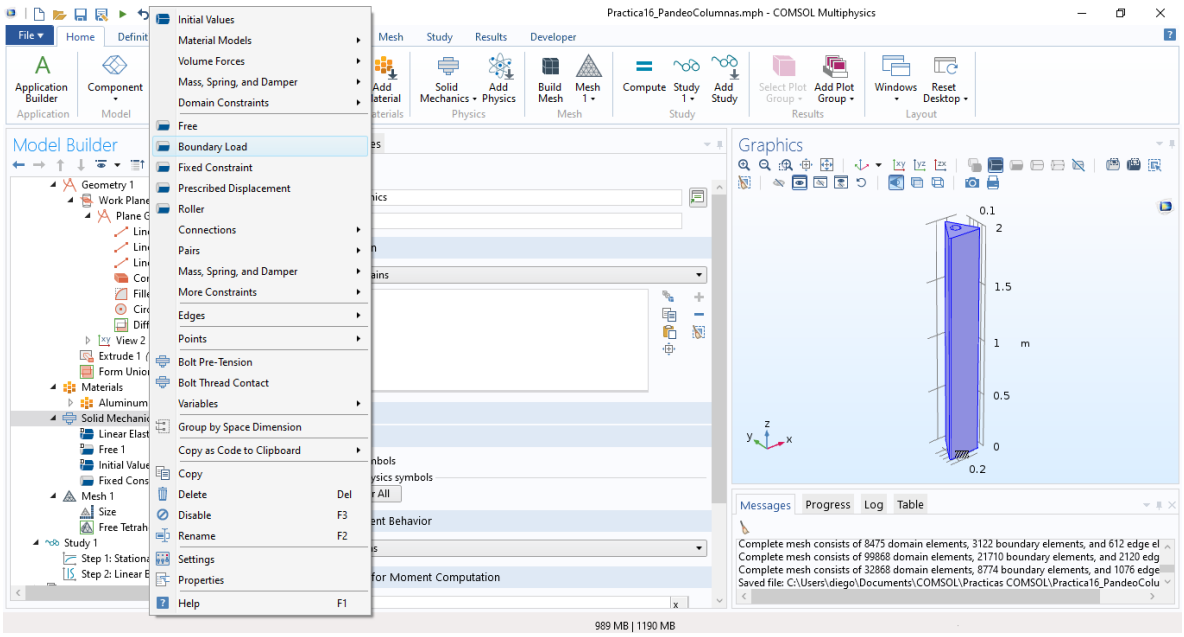
0.2
Messages
Progress
Log
Table
Complete mesh consists of 8475 domain elements, 3122 boundary elements, and 612 edge el
Complete mesh consists of 99868 domain elements, 21710 boundary elements, and 2120 edg
Complete mesh consists of 32868 domain elements, 8774 boundary elements, and 1076 edge
990 MB | 1187 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Model Builder
Graphics
Initial Values
Material Models
Volume Forces
Mass, Spring, and Damper
Domain Constraints
Free
Boundary Load
Fixed Constraint
Prescribed Displacement
Roller
Connections
Pairs
Mass, Spring, and Damper
More Constraints
Edges
Points
Bolt Pre-Tension
Bolt Thread Contact
Variables
Group by Space Dimension
Copy as Code to Clipboard
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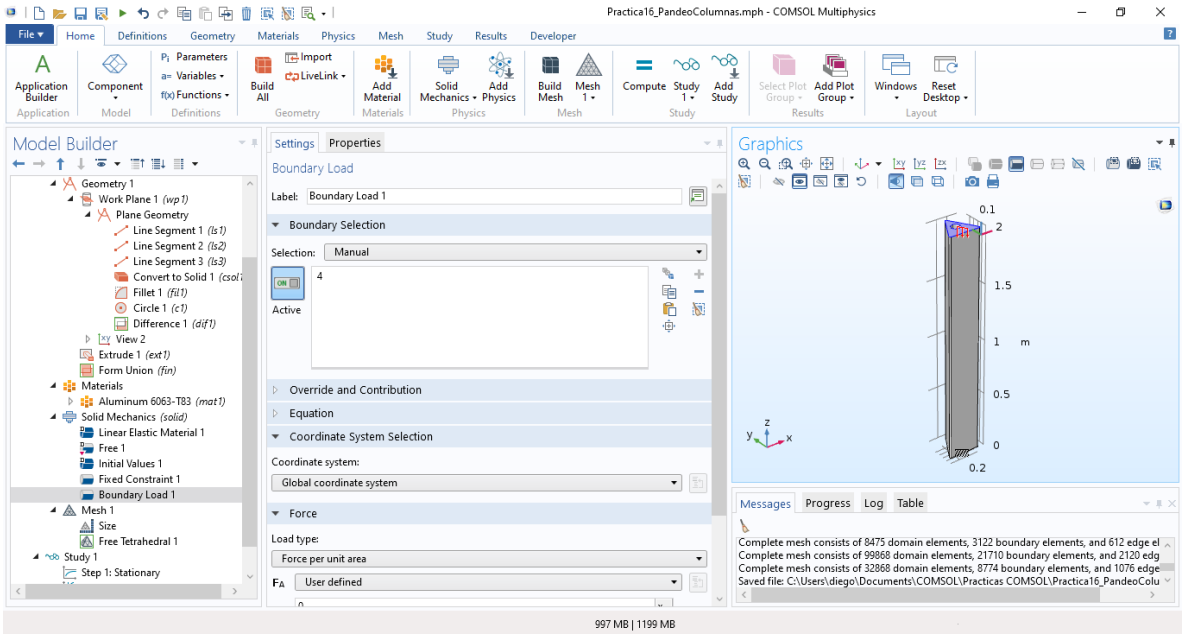
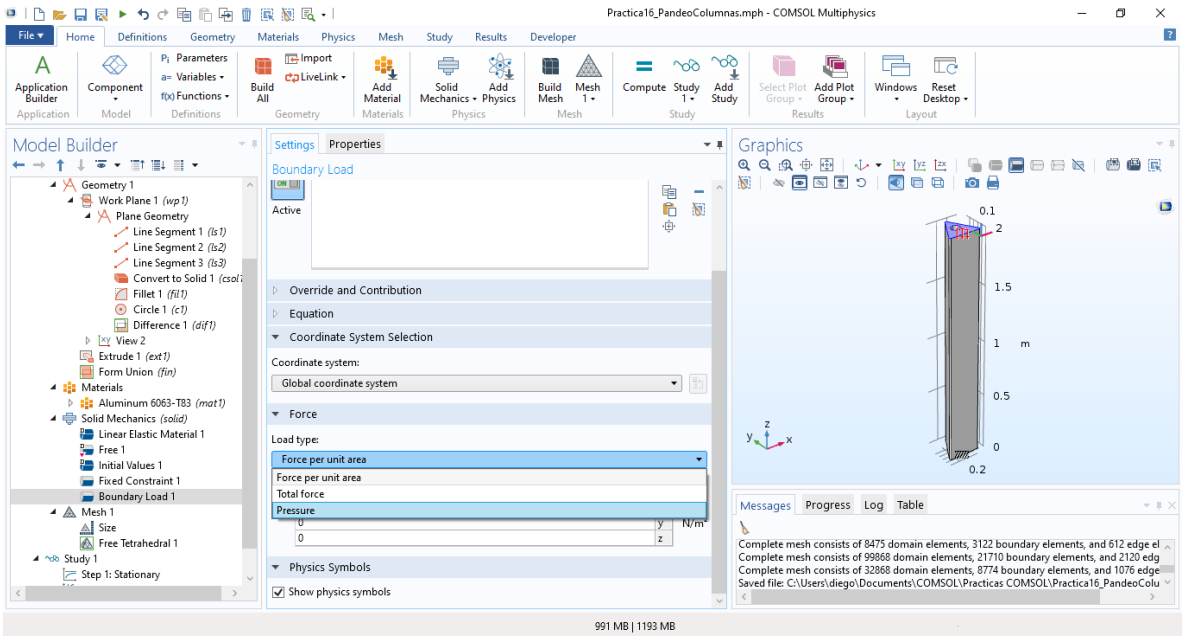
Delete Del
Disable F3
Rename F2
Settings
Properties
Help F1
Messages
Progress
Log
Table
989 MB | 1190 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Model Builder
Settings
Properties
Boundary Load
Label: Boundary Load 1
Boundary Selection
Selection: Manual
Active
Override and Contribution
Equation
Coordinate System Selection
Coordinate system:
Global coordinate system
Force
Load type:
Force per unit area
User defined
Graphics
Messages
Progress
Log
Table
997 MB | 1199 MB


Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Model Builder
Settings
Properties
Boundary Load
Active
Override and Contribution
Equation
Coordinate System Selection
Coordinate system:
Global coordinate system
Force
Load type:
Force per unit area
Force per unit area
Total force
Pressure
N/m
Physics Symbols
Show physics symbols
Graphics
Messages
Progress
Log
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Complete mesh consists of 8475 domain elements, 3122 boundary elements, and 612 edge el
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Complete mesh consists of 32868 domain elements, 8774 boundary elements, and 1076 edge
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
991 MB | 1193 MB

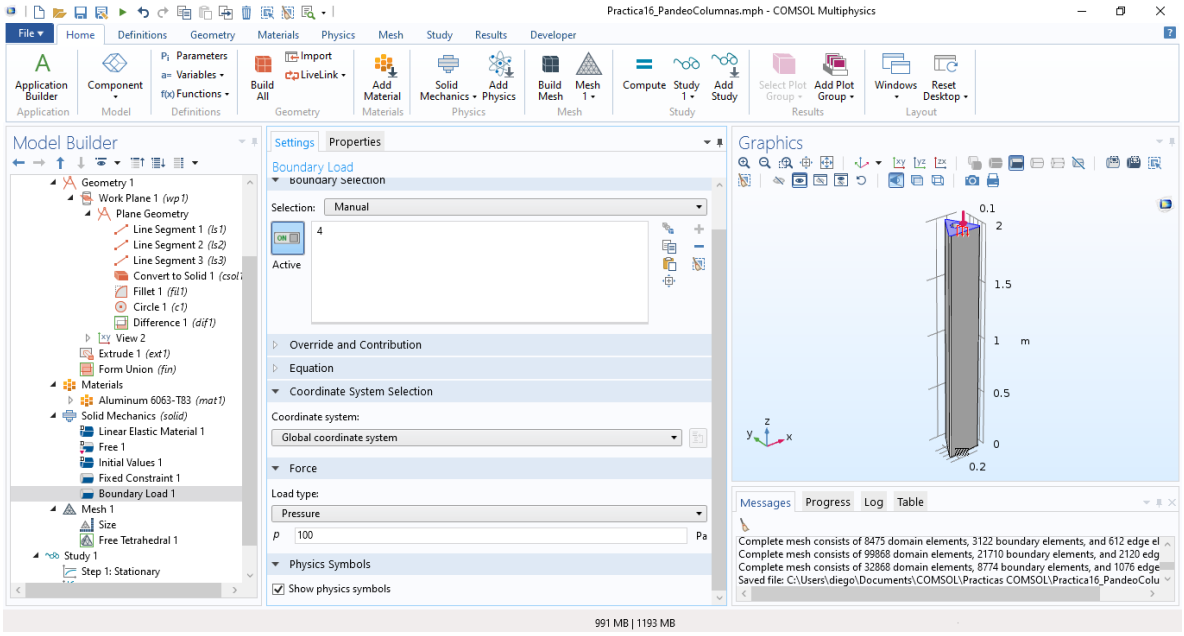
Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Model Builder
Settings
Properties
Boundary Load
Boundary Selection
Selection:
Manual
4
Active
Override and Contribution
Equation
Coordinate System Selection
Coordinate system:
Global coordinate system
Force
Load type:
Pressure
p
100
Pa
Physics Symbols
Show physics symbols
Graphics
Messages
Progress
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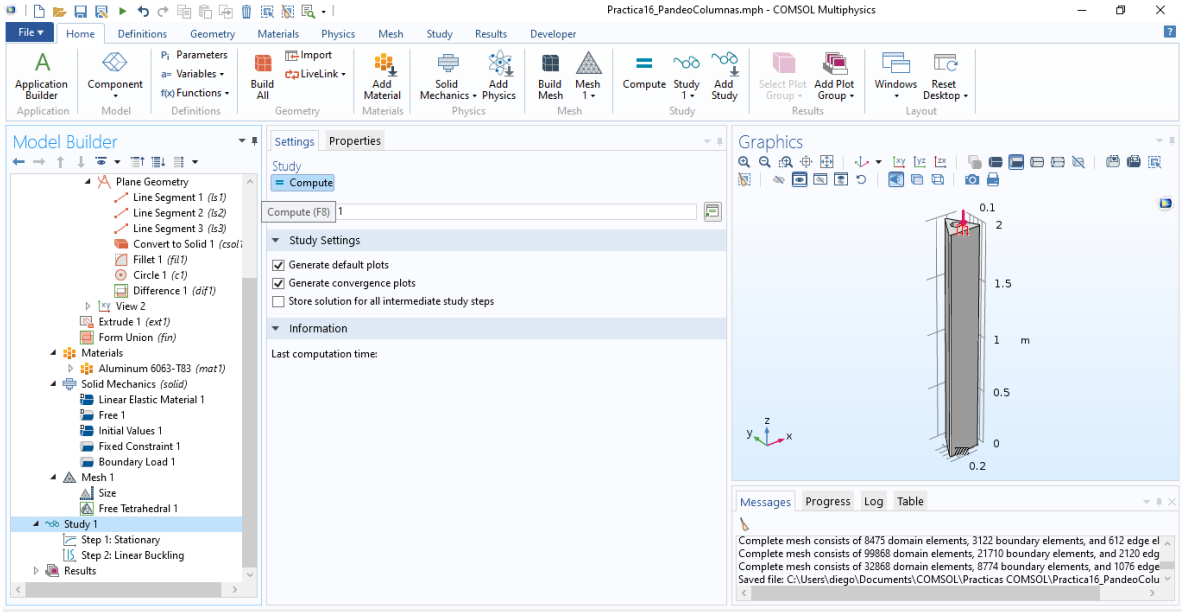
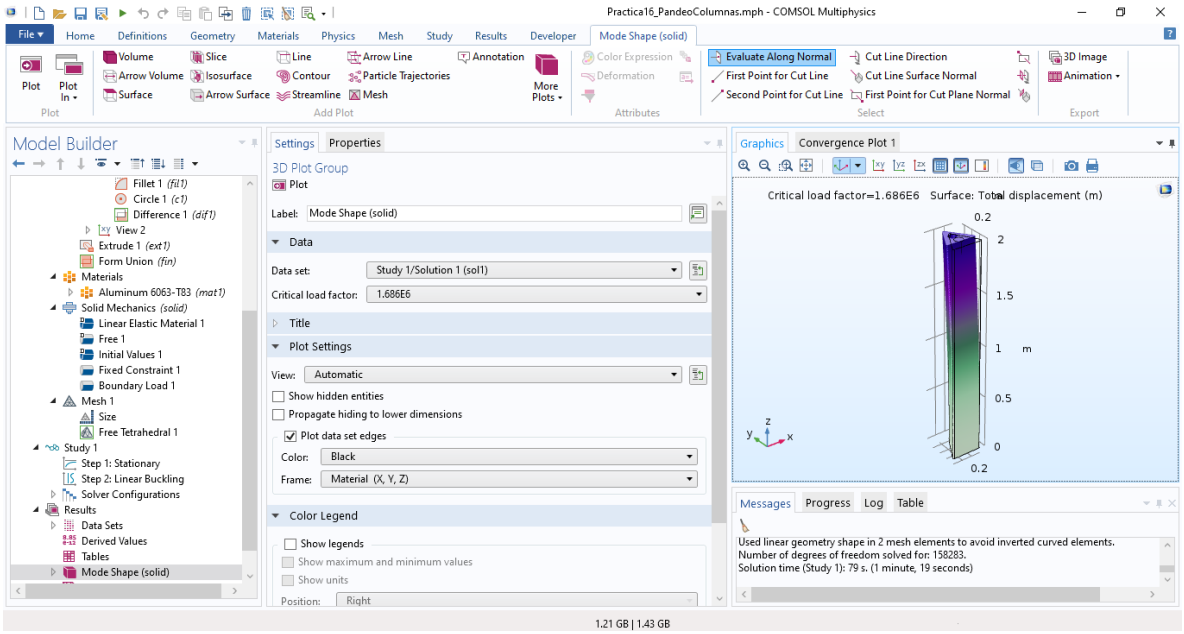
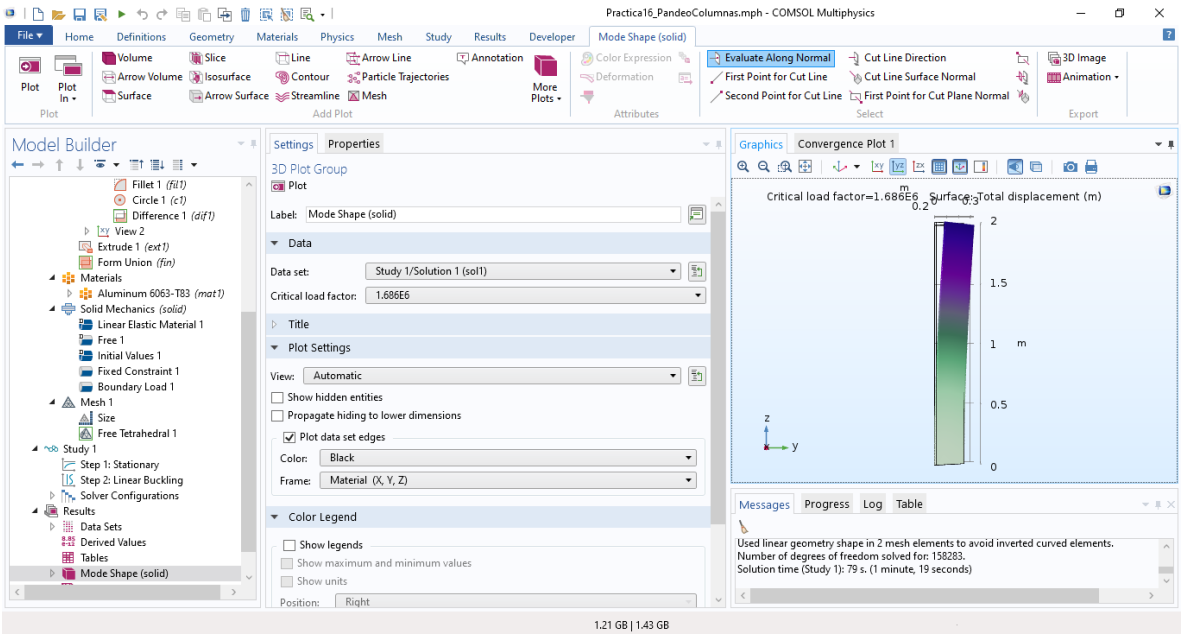
Table
Complete mesh consists of 8475 domain elements, 3122 boundary elements, and 612 edge el
Complete mesh consists of 99868 domain elements, 21710 boundary elements, and 2120 edg
Complete mesh consists of 32868 domain elements, 8774 boundary elements, and 1076 edge
Saved file: C:\Users\diego\Documents\COMSOL\Practicas COMSOL\Practica16_PandeoColu
991 MB | 1193 MB

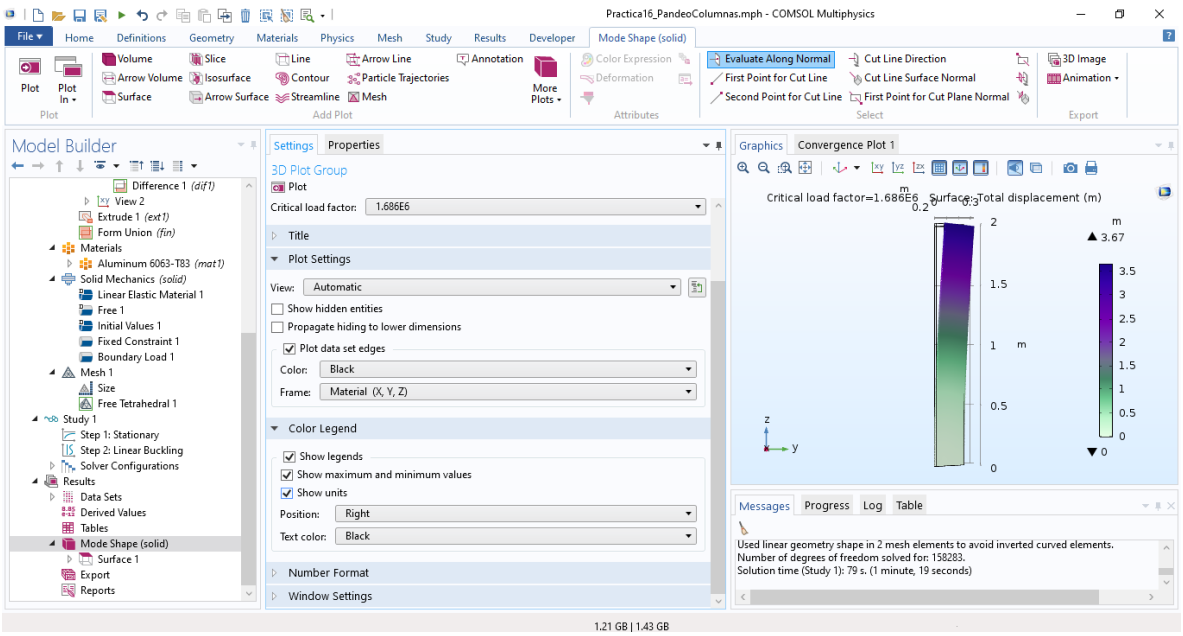
RESULTADO DEL ELEMENTO FINITO EN COMSOL:

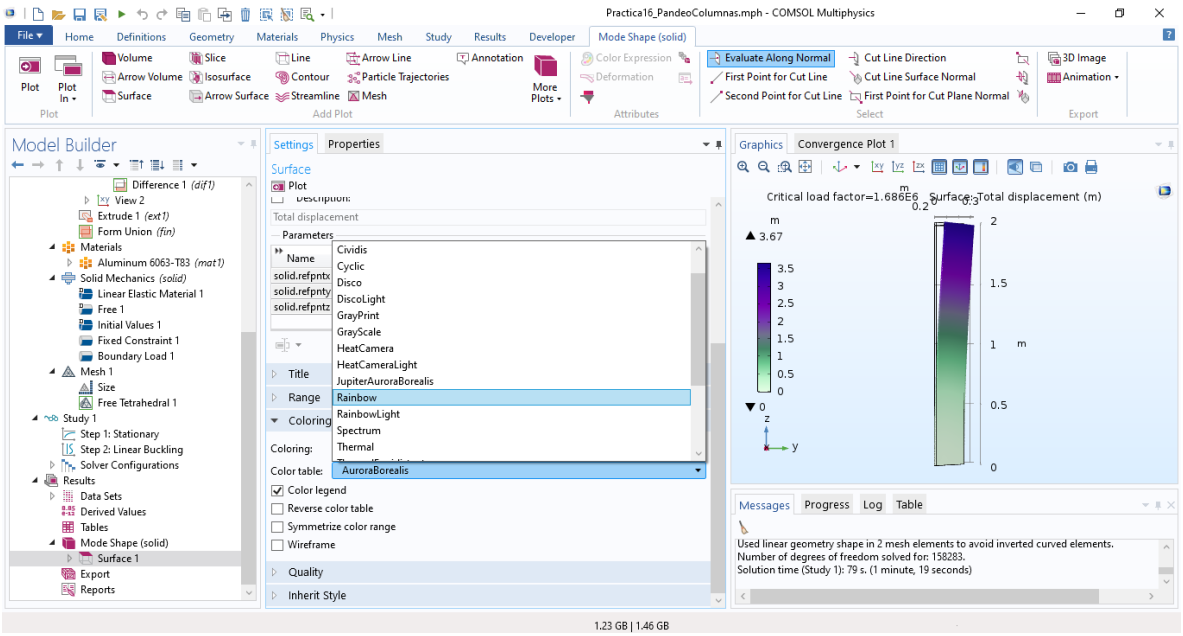


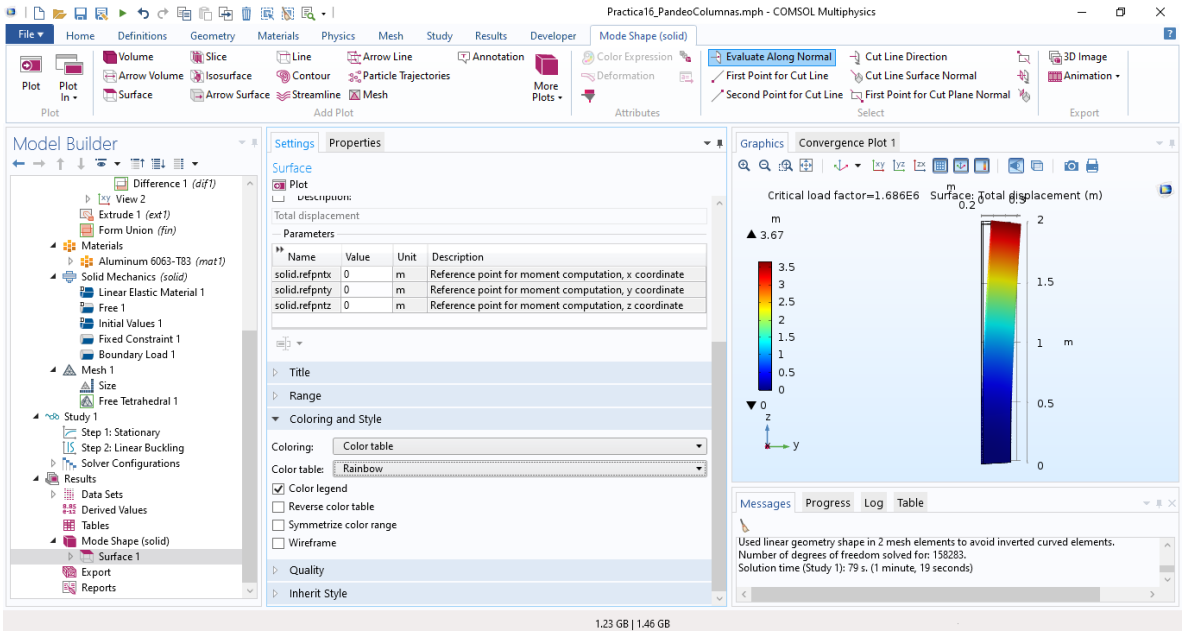




El problema de pandeo en columnas es de eigenvalores, por eso sale el resultado de Mode Shape en el programa.




Practica16_PandeoColumnas.mph - COMSOL Multiphysics
Model Builder
Settings
Properties
Surface
Graphics
Convergence Plot 1
Critical load factor=1.686E6 Surface: Total displacement (m)
Messages
Progress
Log
Table
Used linear geometry shape in 2 mesh elements to avoid inverted curved elements.
Number of degrees of freedom solved for: 158283.
Solution time (Study 1): 79 s. (1 minute, 19 seconds)
1.23 GB | 1.46 GB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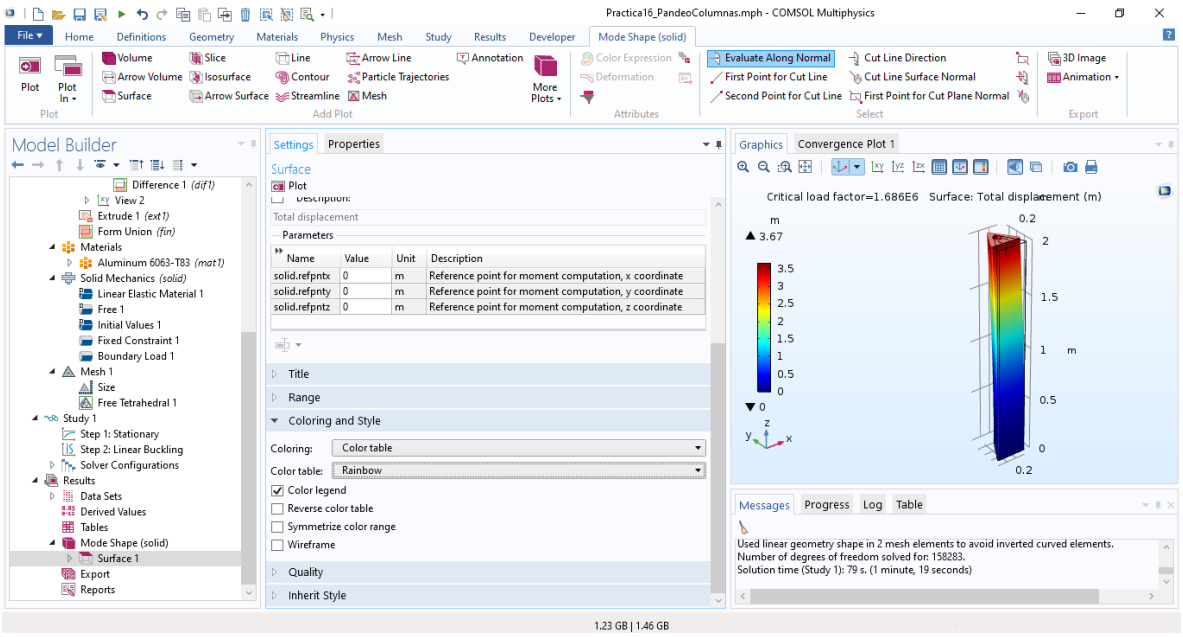
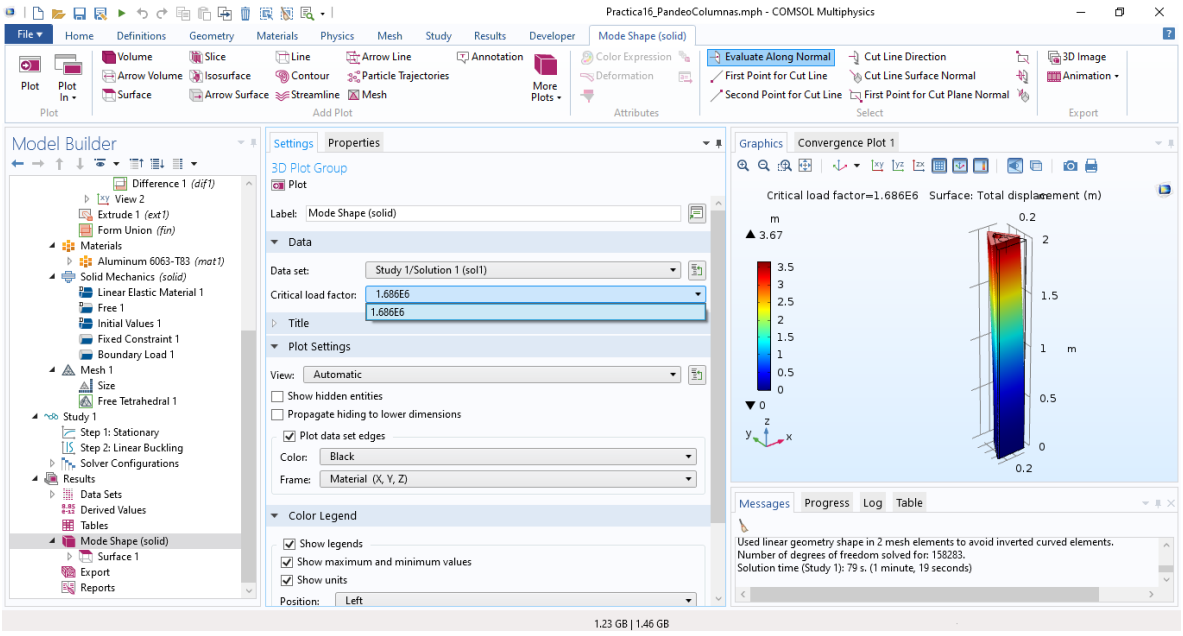


Los valores de pandeo están exagerados, no puede ser que la barra sea de 2 metros y el pandeo sea de 3.67 metros



El factor de carga crítico es de 1.686e6 = $1.686X10^6$, esto lo uso para multiplicarlo por la carga que está soportando la columna.

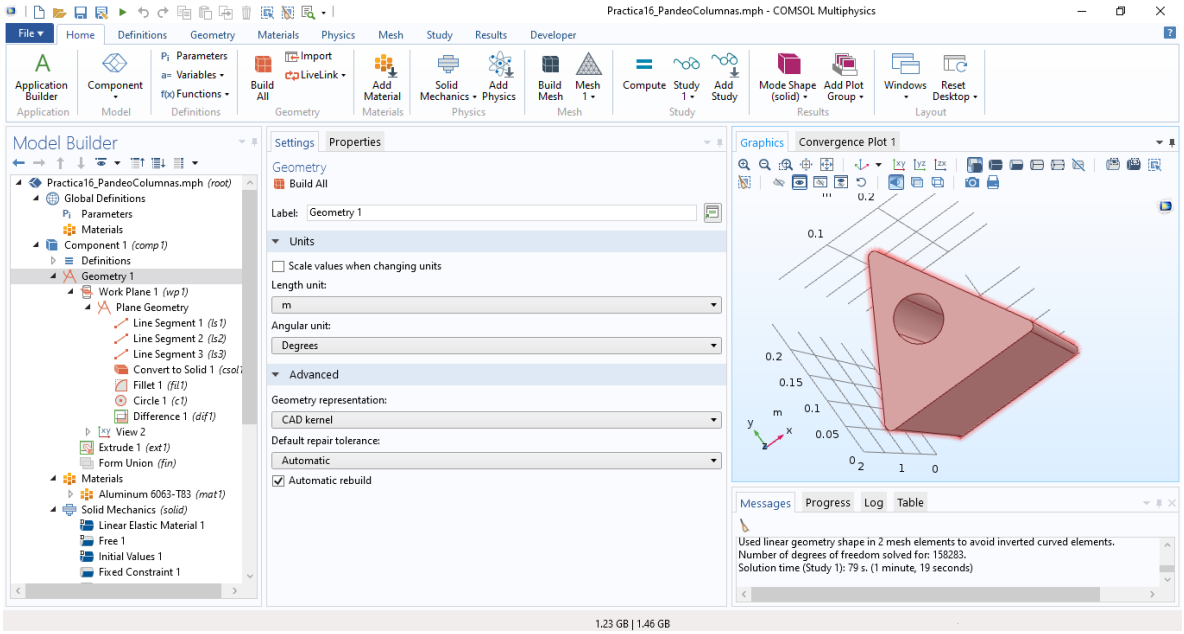
Presión crítica = Factor de carga crítica * carga en la columna = 100Pa*1.686e6 = 168.6 MPa.

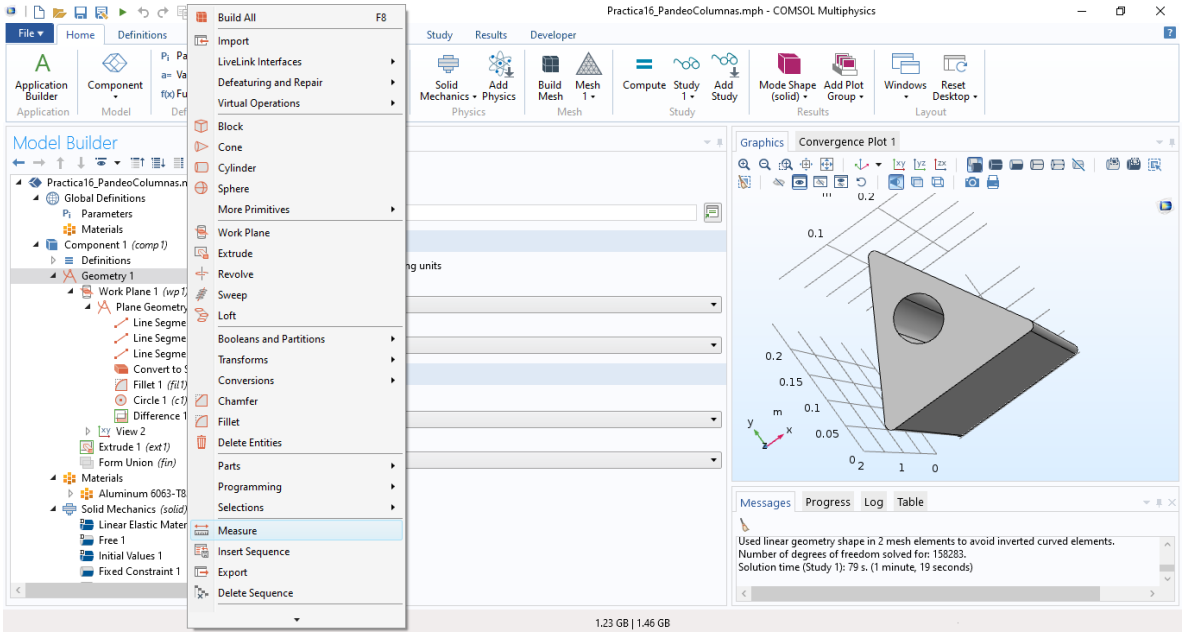
Pero como es una presión lo que tengo, lo obtenido es Presión Crítica.

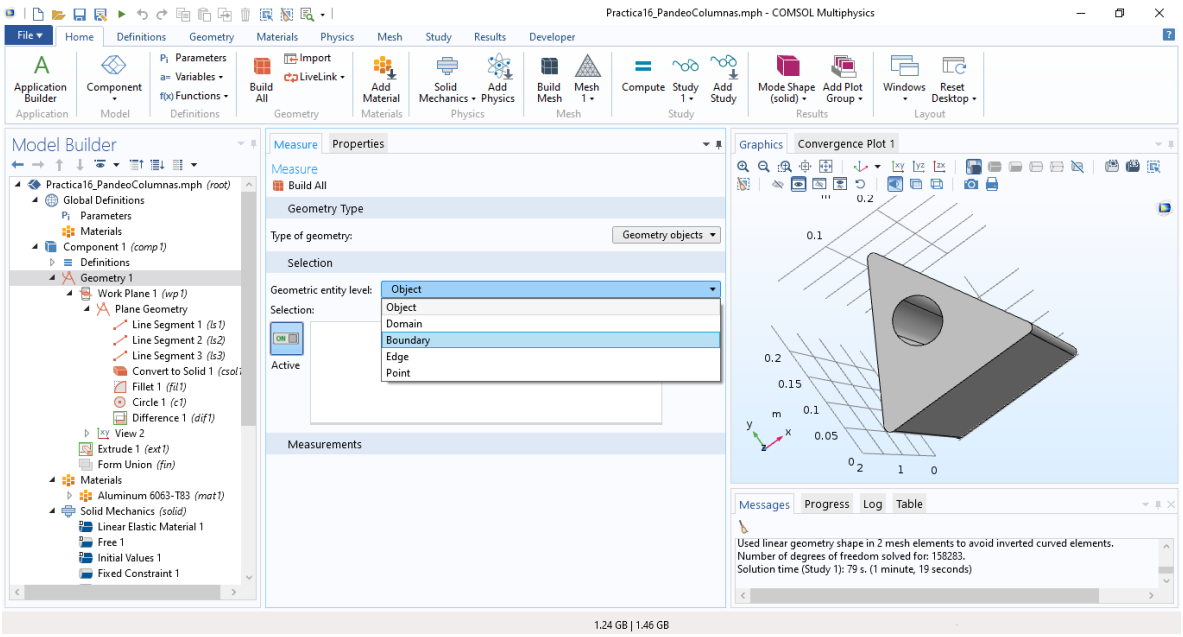
Pc = 168.6MPa.

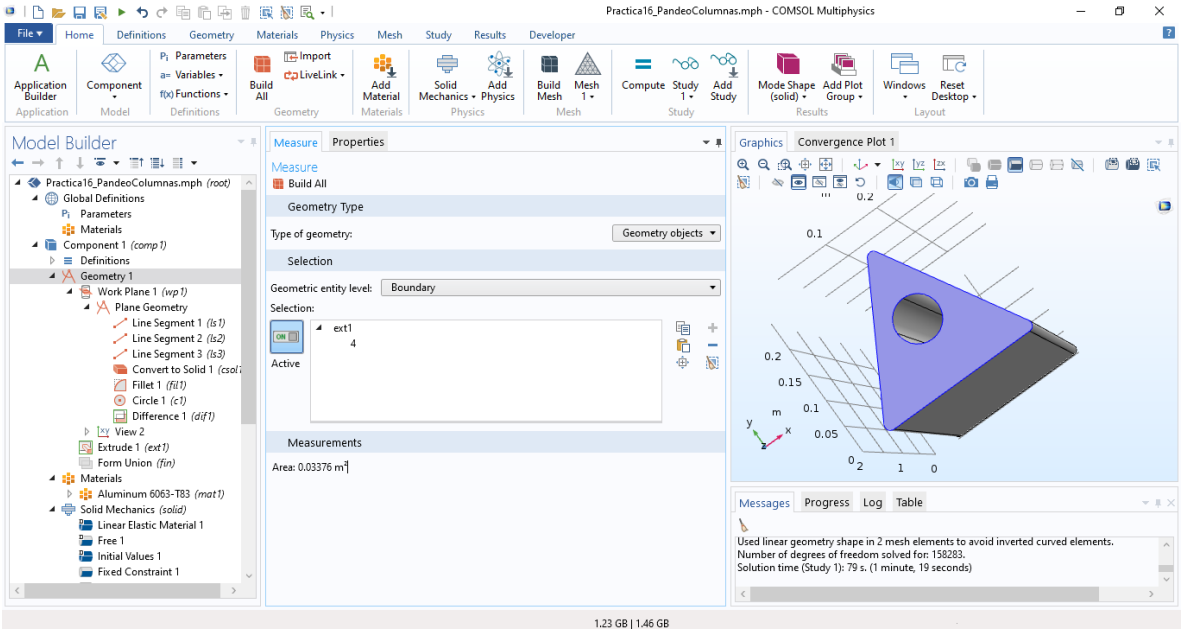
Carga crítica = Cc = P (Área de sección transversal) = 168.6e6/A

Para medir el área puedo usar el programa.









BIBLIOGRAFÍA:

INGENIERÍA MECÁNICA ESTÁTICA (12VA EDICIÓN) – RUSSELL C. HIBBELER.

CONCLUSIÓN:

Área que se busca = 0.03376 m²

Carga crítica = Cc = P (Área de sección transversal) = 168.6e6 $\left[\frac{N}{m^2}\right]$*0.03376 [m²] = 5.691936 e6 [N]

No es un hecho que esta sea la carga crítica, para que esto salga es mejor. Para que se pandee críticamente se debe aplicar la siguiente carga a la columna.

Fórmula de Euler:

$$Fcr = \frac{\pi^2}{L^2} * E * I$$

$$Fcrx = \frac{\pi^2}{L^2} * E * Ix = \frac{\pi^2}{L^2} * E * \frac{b * h^3}{36}$$

$$Fcrx = \frac{\pi^2}{2[m]^2} * 69e9\left[\frac{N}{m^2}\right] * \frac{0.3[m] * 0.2598[m]^3}{36} = 24.87\ [Mega\ Newtons]$$

$$Fcry = \frac{\pi^2}{L^2} * E * Iy = \frac{\pi^2}{L^2} * E * \frac{h * b^3}{48}$$

$$Fcry = \frac{\pi^2}{2[m]^2} * 69e9\left[\frac{N}{m^2}\right] * \frac{0.2598[m] * 0.3[m]^3}{48} = 24.88\ [Mega\ Newtons]$$