

Solid Mechanics (beam)

Computational Design Laboratory
Department of Automotive Engineering
Hanyang University, Seoul, Korea



Computational
Design
Lab

CONTENTS

- Beam model: 2D
 - ✓ Textbook of “Solid Mechanics”
- Beam model: 3D
- Assignment

STRUCTURAL MECHANICS MODULE

PHYSICS	DEFAULT NAME	DEPENDENT VARIABLES	GEOMETRY LEVEL			
			POINTS	EDGES	BOUNDARIES	DOMAINS
STRUCTURAL MECHANICS						
Solid Mechanics	solid	$\mathbf{u}, (p)$	✓	✓	✓	✓
Shell	shell	$\mathbf{u}, a_x, a_y, a_z$	✓	✓	✓	
Plate	plate	\mathbf{u}, a_x, a_y	✓		✓	✓
Beam	beam	\mathbf{u}, θ	✓	✓		
Truss	truss	\mathbf{u}	✓	✓		
Membrane	mem	\mathbf{u}	✓	✓	✓	
Thermal Stress	ts	$\mathbf{u}, (p), T$	✓	✓	✓	✓
Joule Heating and Thermal Expansion	tem	$\mathbf{u}, (p), T, V$	✓	✓	✓	✓
Piezoelectric Devices	pzd	\mathbf{u}, V	✓	✓	✓	✓
Fluid Flow						
Fluid-Structure Interaction	fsi	$\mathbf{u}_{\text{solid}}, \mathbf{u}_{\text{fluid}}, p$	✓	✓	✓	✓

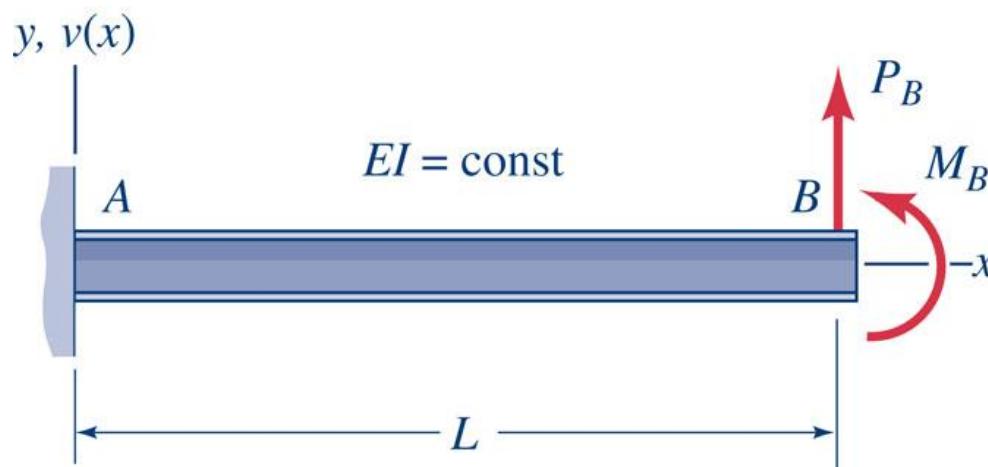
- **Beam model: 2D**
 - ✓ **Textbook of “Solid Mechanics”**
- **Beam model: 3D**
- **Assignment**

BEAMS

BEAMS

The Beam interface (Beam icon) is intended for the modeling of slender structures (beams) that can be fully described by cross-section properties, such as area and moments of inertia. The Beam interface defines stresses and strains using Hermitian elements and Euler-Bernoulli theory. Beam elements are used to model frame structures, both planar and three-dimensional. It is also suitable for modeling reinforcements of solid and shell structures. The Beam interface includes a library for rectangular, box, circular, pipe, H-profile, U-profile, and T-profile beam sections. Additional features include damping, thermal expansion, and initial stresses and strains. The preset studies for this physics interface are almost the same as for the Solid Mechanics interface, with two exceptions—it does not include the Linear Buckling or Prestressed study types.

EXAMPLE 7.1 (PP.471)



Analytical solution

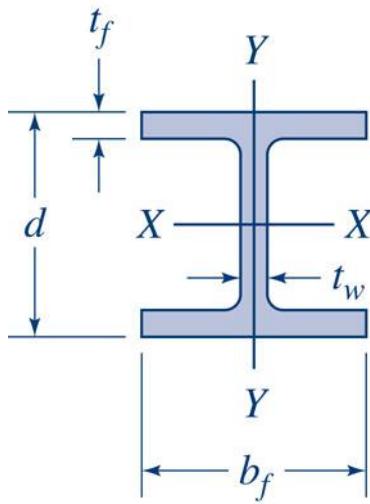
- Geometry
 - $L = 10 \text{ ft}$
 - $P_B = 4.5 \text{ kips}$
 - $M_B = 50 \text{ kips-in}$
- Material Properties
 - A-36 steel
 - $E = 29 \times 10^3 \text{ ksi}$
- Element Properties
 - Wide-flange beam
 - W10x30
 - $I = 170 \text{ in}^4$

kips: kilo pounds

ksi: kilo pounds per square inch

$$\begin{cases} \delta_B = \frac{1}{EI} \left[M_B \left(\frac{L^2}{2} \right) + P_B \left(\frac{L^3}{3} \right) \right] = 0.0730 + 0.526 = 0.599 \text{ in} \\ \theta_B = \frac{1}{EI} \left[M_B (L) + P_B \left(\frac{L^2}{2} \right) \right] = 0.00122 + 0.00657 = 0.00779 \text{ rad} \end{cases}$$

WIDE-FLANGE BEAM

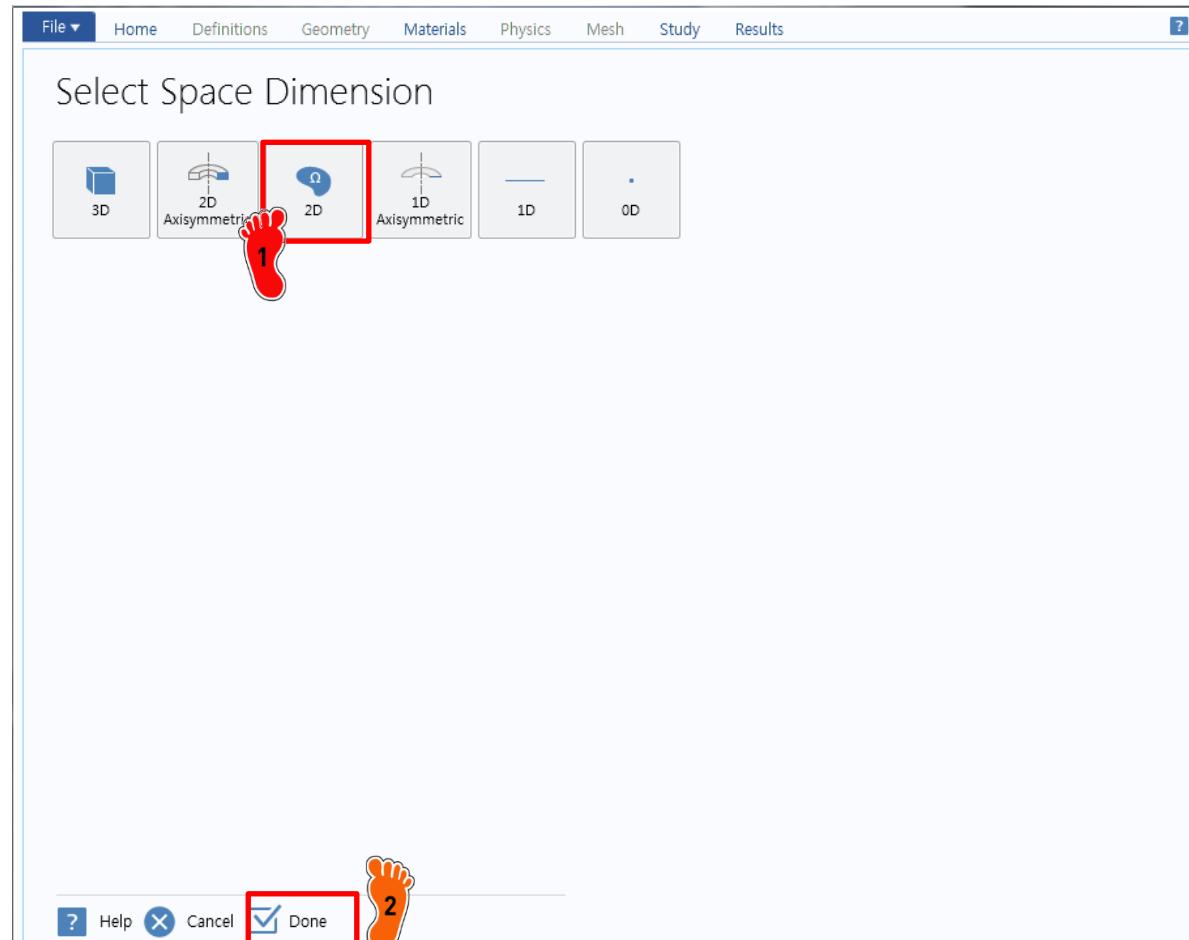


D.1. Properties of Steel Wide-Flange (W) Shapes (U.S. Customary Units)

Designation*	Area A in. ²	Depth d in.	Flange		Web Thickness t_w in.	Elastic Properties						Plastic Modulus Z_x in. ³
			Width b_f in.	Thickness t_f in.		I_x in. ⁴	S_x in. ³	r_x in.	I_y in. ⁴	S_y in. ³	r_y in.	
W36×230	67.6	35.90	16.470	1.260	0.760	15000	837	14.9	940	114	3.73	943
× 150	44.2	35.85	11.975	0.940	0.625	9040	504	14.3	270	45.1	2.47	581
W33×201	59.1	33.68	15.745	1.150	0.715	11500	684	14.0	749	95.2	3.56	772
× 130	38.3	33.09	11.510	0.855	0.580	6710	406	13.2	218	37.9	2.39	467
W30×173	50.8	30.44	14.985	1.065	0.655	8200	539	12.7	598	79.8	3.43	605
× 90	26.4	29.53	10.400	0.610	0.470	3620	245	11.7	115	22.1	2.09	283
W27×146	42.9	27.38	13.965	0.975	0.605	5630	411	11.4	443	63.5	3.21	461
× 84	24.8	26.71	9.960	0.640	0.460	2850	213	10.7	106	21.2	2.07	244
W24× 94	27.7	24.31	9.065	0.875	0.515	2700	222	9.87	109	24.0	1.98	254
× 62	18.2	23.74	7.040	0.590	0.430	1550	131	9.23	34.5	9.80	1.38	153
W21×101	29.8	21.36	12.290	0.800	0.500	2420	227	9.02	248	40.3	2.89	253
× 73	21.5	21.24	8.295	0.740	0.455	1600	151	8.64	70.6	17.0	1.81	172
× 50	14.7	20.83	6.530	0.535	0.380	984	94.5	8.18	24.9	7.64	1.30	110
W18×130	38.2	19.25	11.160	1.200	0.670	2460	256	8.03	278	49.9	2.70	291
× 76	22.3	18.21	11.035	0.680	0.425	1330	146	7.73	152	27.6	2.61	163
W18× 60	17.6	18.24	7.555	0.695	0.415	984	108	7.47	50.1	13.3	1.69	123
× 50	14.7	17.99	7.495	0.570	0.355	800	88.9	7.38	40.1	10.7	1.65	101
W16×100	29.4	16.97	10.425	0.985	0.585	1490	175	7.10	186	35.7	2.51	198
× 67	19.7	16.33	10.235	0.665	0.395	954	117	6.96	119	23.2	2.46	130
× 50	14.7	16.26	7.070	0.630	0.380	659	81.0	6.68	37.2	10.5	1.59	92.0
× 40	11.8	16.01	6.995	0.505	0.305	518	64.7	6.63	28.9	8.25	1.57	72.9
W14×176	51.8	15.22	15.650	1.310	0.830	2140	281	6.43	838	107	4.02	320
× 120	35.3	14.48	14.670	0.940	0.590	1380	190	6.24	495	65.7	3.74	212
× 82	24.1	14.31	10.130	0.855	0.510	882	123	6.05	148	29.3	2.48	139
× 53	15.6	13.92	8.060	0.660	0.370	541	77.8	5.89	57.7	14.3	1.92	87.1
× 26	7.69	13.91	5.025	0.420	0.255	245	35.3	5.65	8.91	3.54	1.08	40.2
W12×152	44.7	13.71	12.480	1.400	0.870	1430	209	5.66	454	72.8	3.19	243
× 96	28.2	12.71	12.160	0.900	0.550	833	131	5.44	270	44.4	3.09	147
× 65	19.1	12.12	12.000	0.605	0.390	533	87.9	5.28	174	29.1	3.02	96.8
× 50	14.7	12.19	8.080	0.640	0.370	394	64.7	5.18	56.3	13.9	1.96	72.4
× 35	10.3	12.50	6.560	0.520	0.300	285	45.6	5.25	24.5	7.47	1.54	51.2
× 22	6.48	12.31	4.030	0.425	0.260	156	25.4	4.91	4.66	2.31	0.847	29.3
W10× 60	17.6	10.22	10.080	0.680	0.420	341	66.7	4.39	116	23.0	2.57	74.6
× 45	13.3	10.10	8.020	0.620	0.350	248	49.1	4.32	53.4	13.3	2.01	54.9
× 30	8.84	10.47	5.810	0.510	0.300	170	32.4	4.38	16.7	5.75	1.37	36.6
× 12	3.54	9.87	3.960	0.210	0.190	53.8	10.9	3.90	2.18	1.10	0.785	12.6
W 8× 48	14.1	8.50	8.110	0.685	0.400	184	43.3	3.61	60.9	15.0	2.08	49.0
× 40	11.7	8.25	8.070	0.560	0.360	146	35.5	3.53	49.1	12.2	2.04	39.8
× 35	10.3	8.12	8.020	0.495	0.310	127	31.2	3.51	42.6	10.6	2.03	34.7
× 21	6.16	8.28	5.270	0.400	0.250	75.3	18.2	3.49	9.77	3.71	1.26	20.4
× 15	4.44	8.11	4.015	0.315	0.245	48.0	11.8	3.29	3.41	1.70	0.876	13.6
W 6× 25	7.34	6.38	6.080	0.455	0.320	53.4	16.7	2.70	17.1	5.61	1.52	18.9
× 20	5.87	6.20	6.020	0.365	0.260	41.1	13.4	2.66	13.3	4.41	1.50	14.9
× 16	4.74	6.28	4.030	0.405	0.260	32.1	10.2	2.60	4.43	2.20	0.966	11.7
× 15	4.43	5.99	5.990	0.260	0.230	29.1	9.72	2.56	9.32	3.11	1.46	10.8

*W(nominal depth in inches) × (weight in pounds per foot)

DIMENSION SELECTION



PHYSICS SELECTION

Search

- Recently Used
- AC/DC
- Acoustics
- Chemical Species Transport
- Electrochemistry
- Fluid Flow
- Heat Transfer
- Optics
- Plasma
- Radio Frequency
- Semiconductor
- Structural Mechanics
 - Solid Mechanics (solid)
 - Plate (plate)
 - Beam (beam)** 
 - Truss (truss)
 - Multibody Dynamics (mbd)
 - Thermal Stress
 - Thermoelasticity (te)
 - Joule Heating and Thermal Expansion
 - Piezoelectric Devices
 - Electromechanics (emi)
 - Porcelasticity (poro)
 - Fatigue (ftg)
 - Beam Cross Section (bcs)
- Mathematics

Add

Added physics interfaces:

Remove

 Space Dimension  Study 

? Help  Cancel  Done

652 MB | 863 MB

-  1 Structural Mechanics 의 Beam 추가
-  2 Study 클릭

STUDY TYPE SELECTION

File ▾ Home Definitions Geometry Materials Physics Mesh Study Results

Select Study

Preset Studies

- Eigenfrequency
- Frequency Domain
- Frequency-Domain Modal
- Modal Reduction Model
- Stationary** 
- Time Dependent
- Time-Dependent Modal

Custom Studies

Empty Study

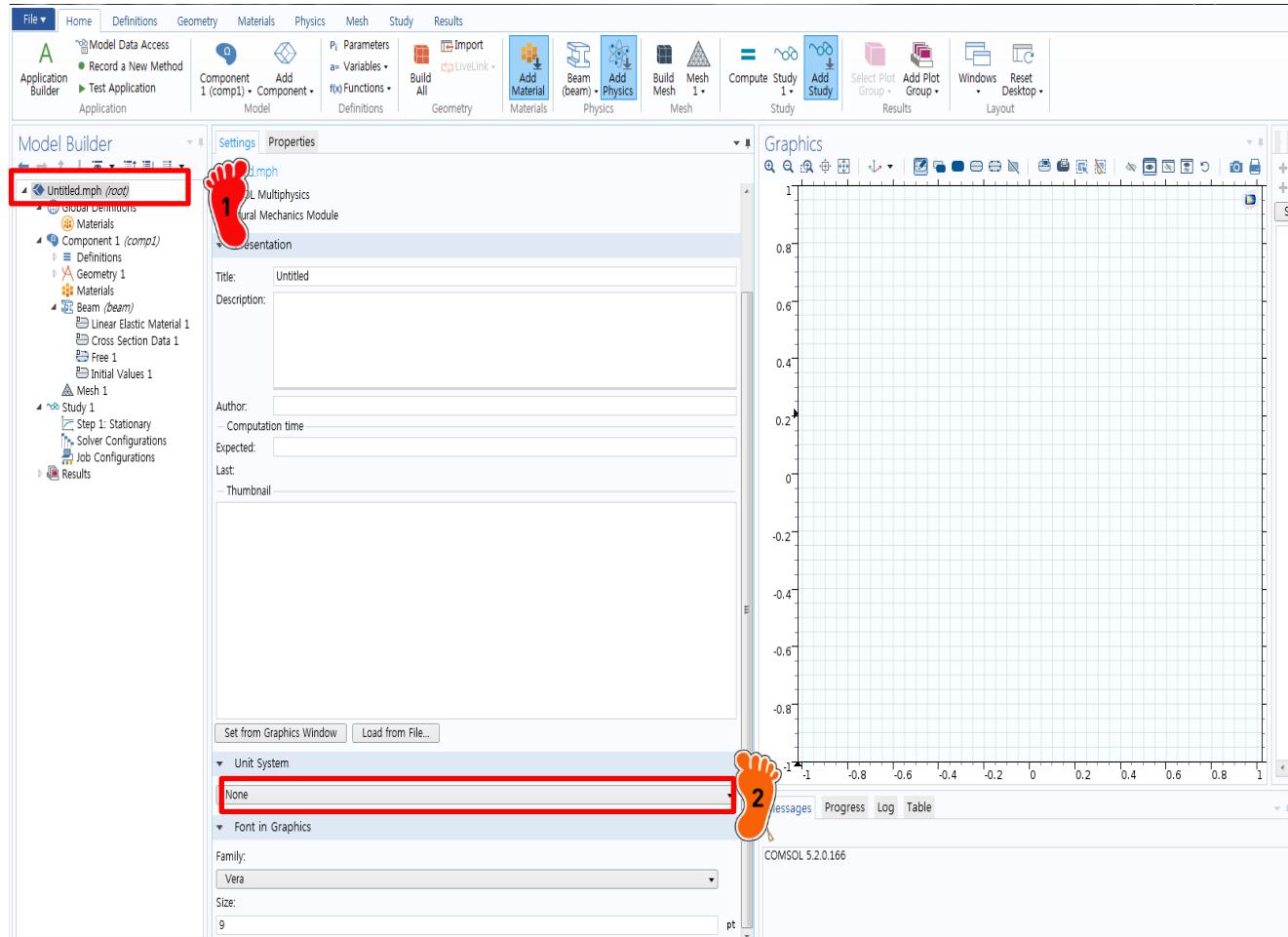
Added study: Stationary

Added physics interfaces: Beam (beam)

Physics  Help  Cancel  Done 

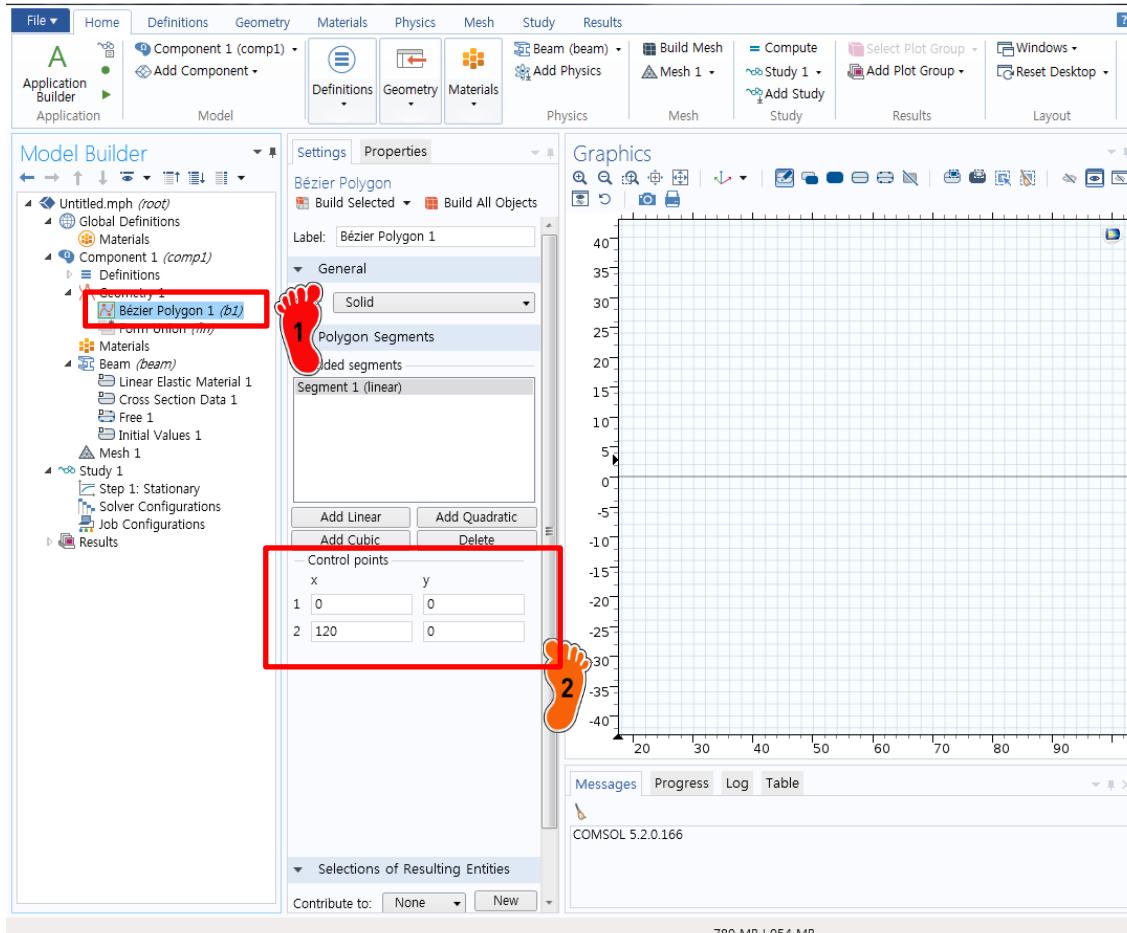


DIMENSIONLESS UNIT



- 1 Untitled.mph 클릭
2 Unit System 을 None 으로 변경

GEOMETRY CREATION

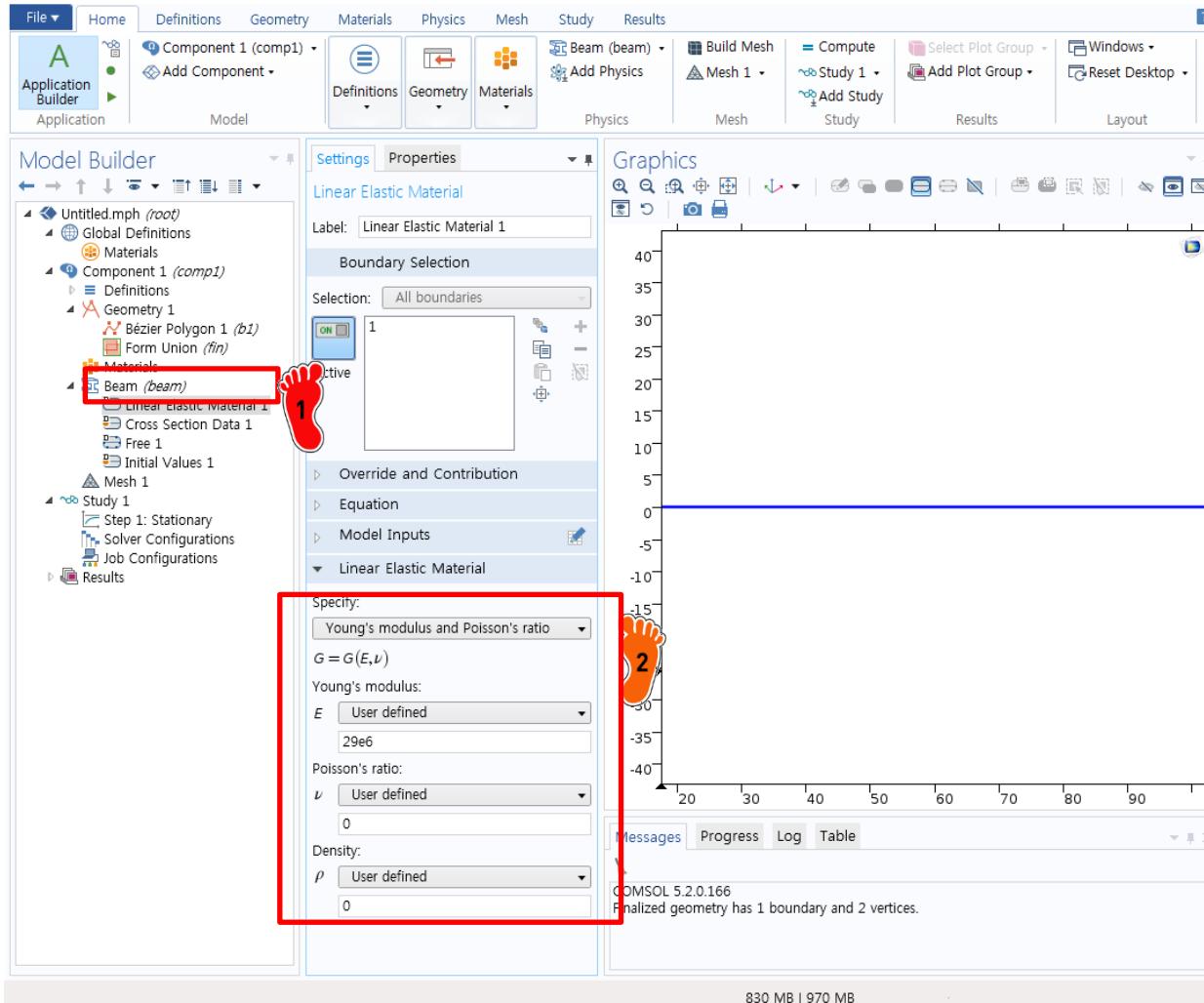


1 Bezier Polygon 생성

2 120 길이의 선분 생성

lb-inch 단위로 계산할 예정
따라서 10 ft = 120 in.

MATERIAL PROPERTY



Linear Elastic Material 클릭

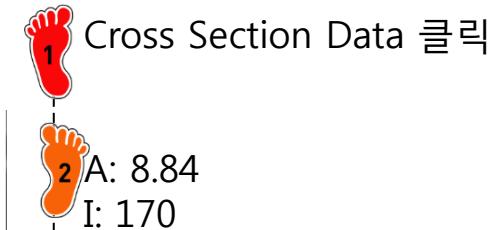
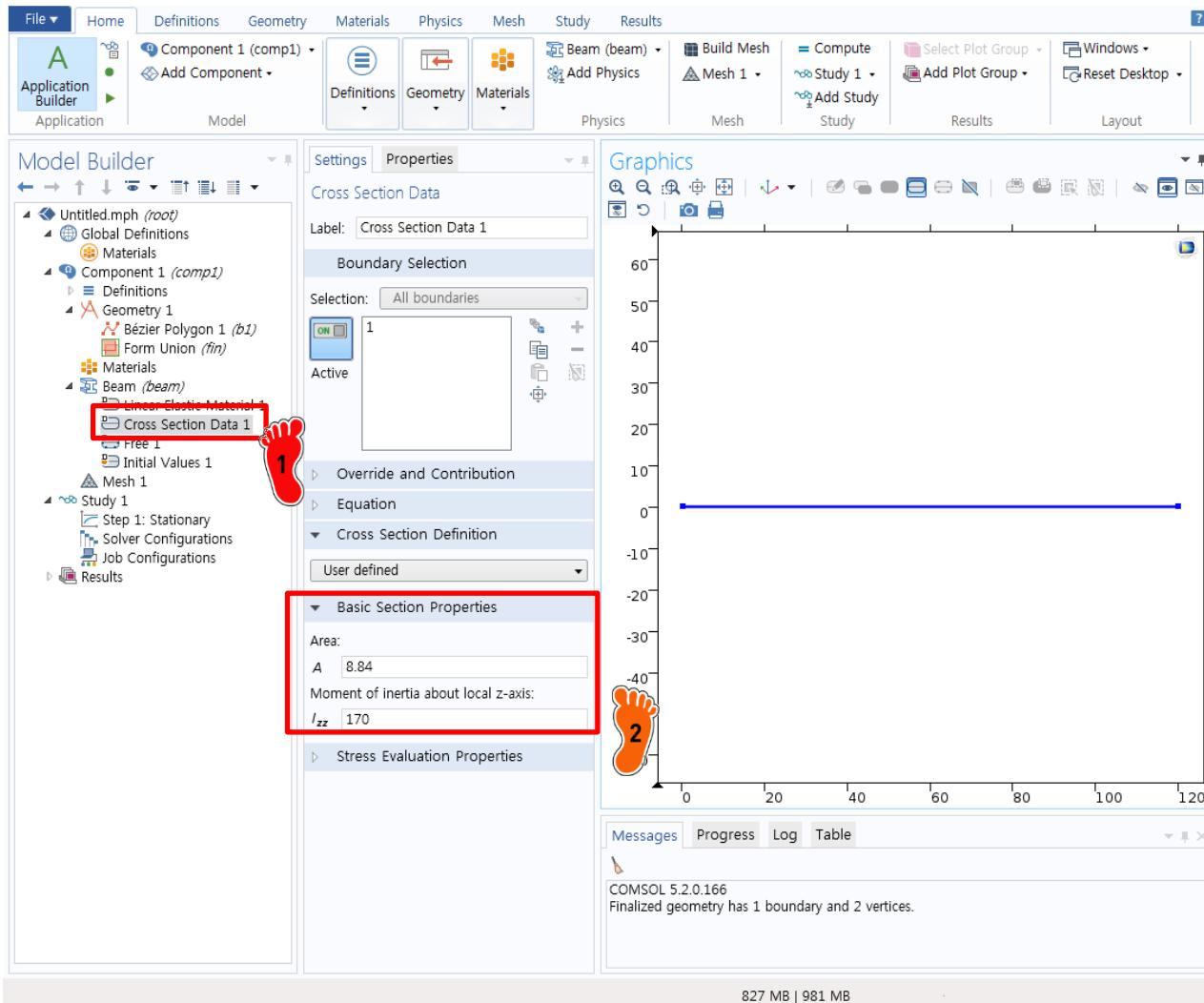


E: 29e6
mu: 0
rho : 0

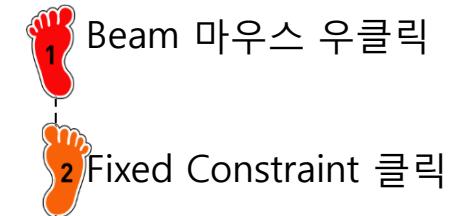
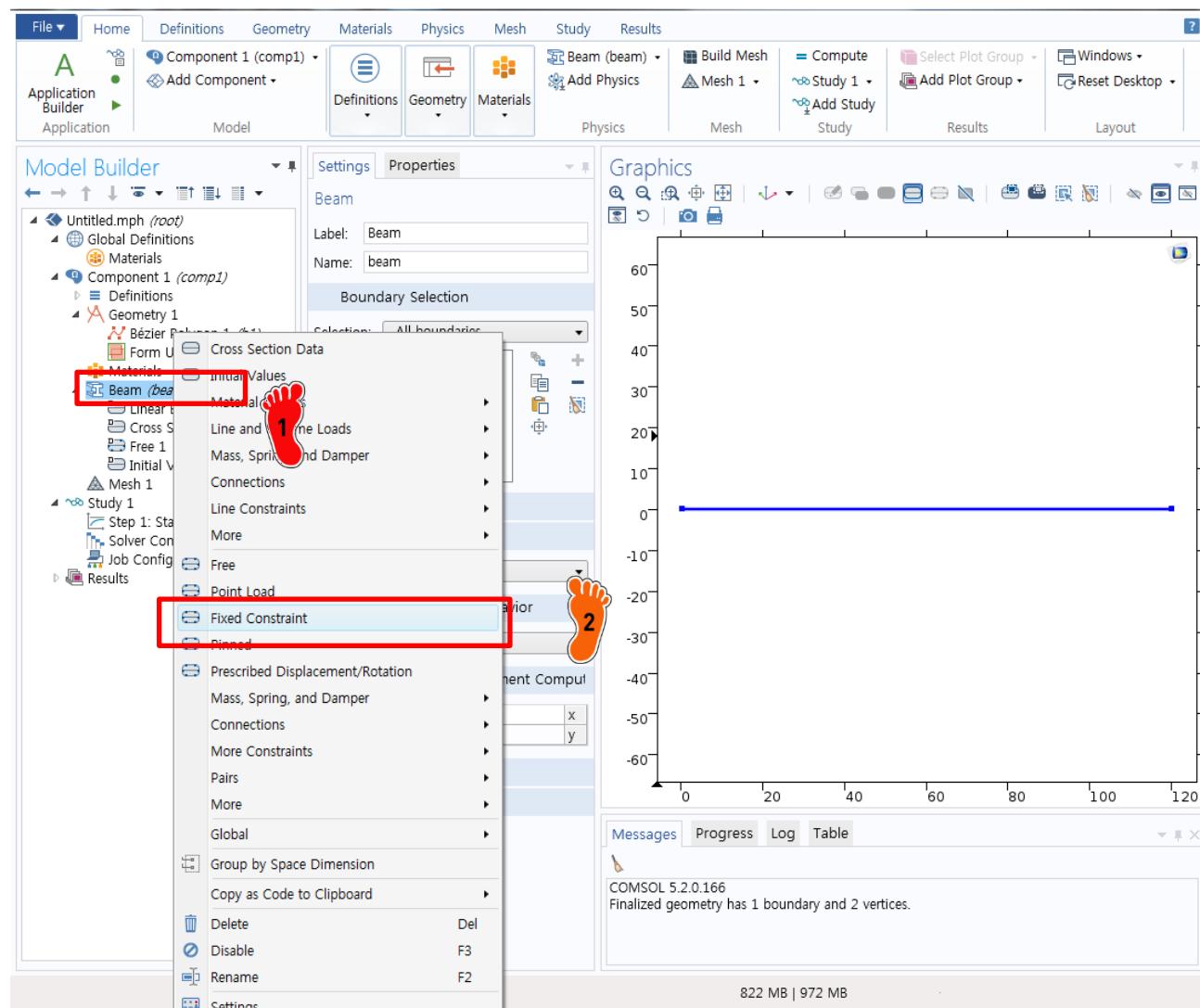
입력

lb-inch 단위
 $E = 29e3 \text{ ksi} = 29e6 \text{ psi}$
 $= 29e6 \text{ lb/in.}^2$

CROSS SECTION



BOUNDARY CONDITION



BOUNDARY CONDITION

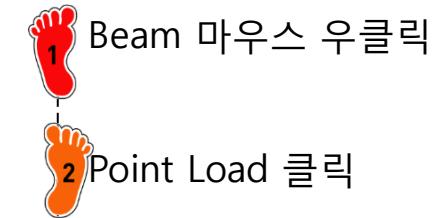
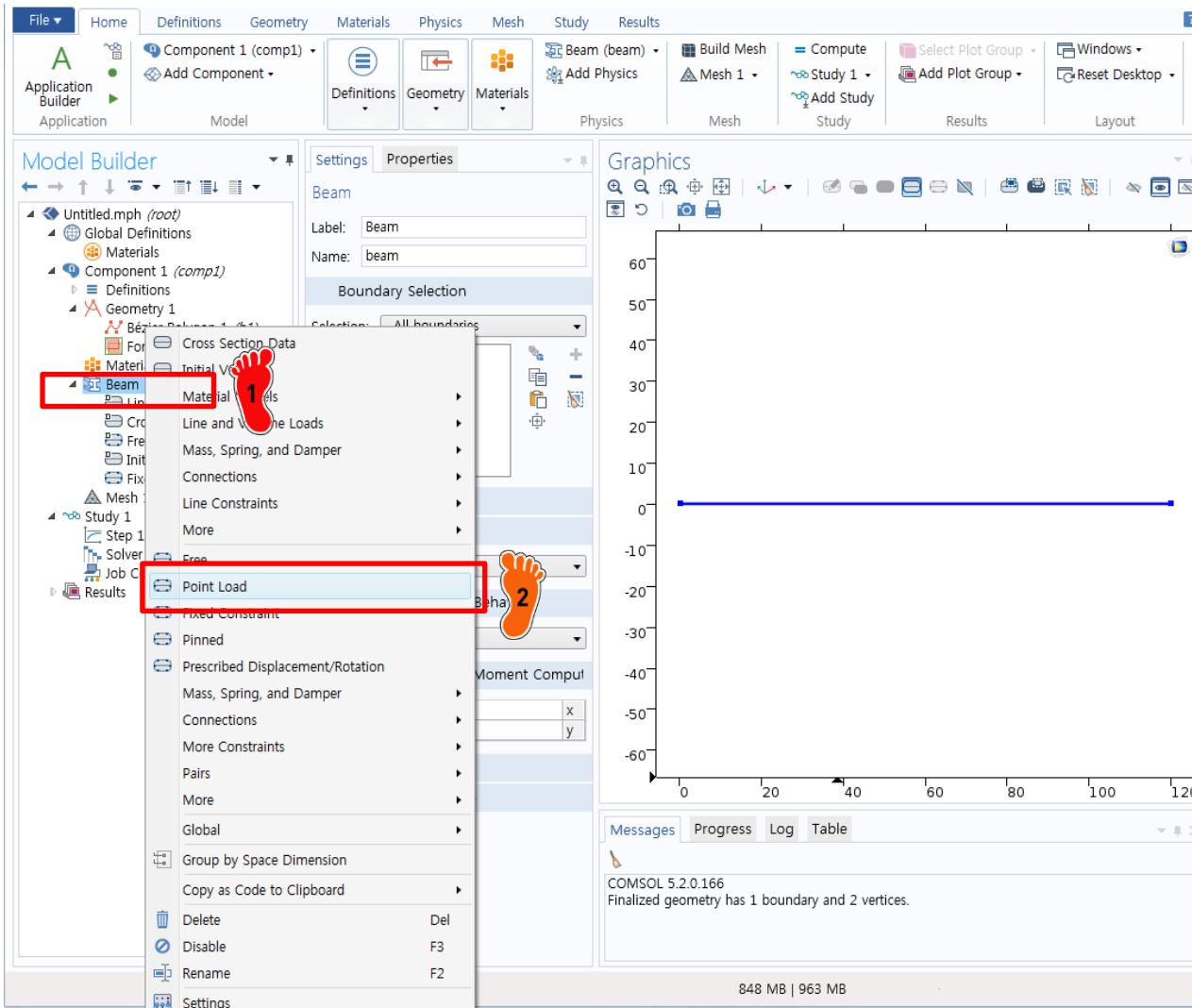


왼쪽 절점 선택

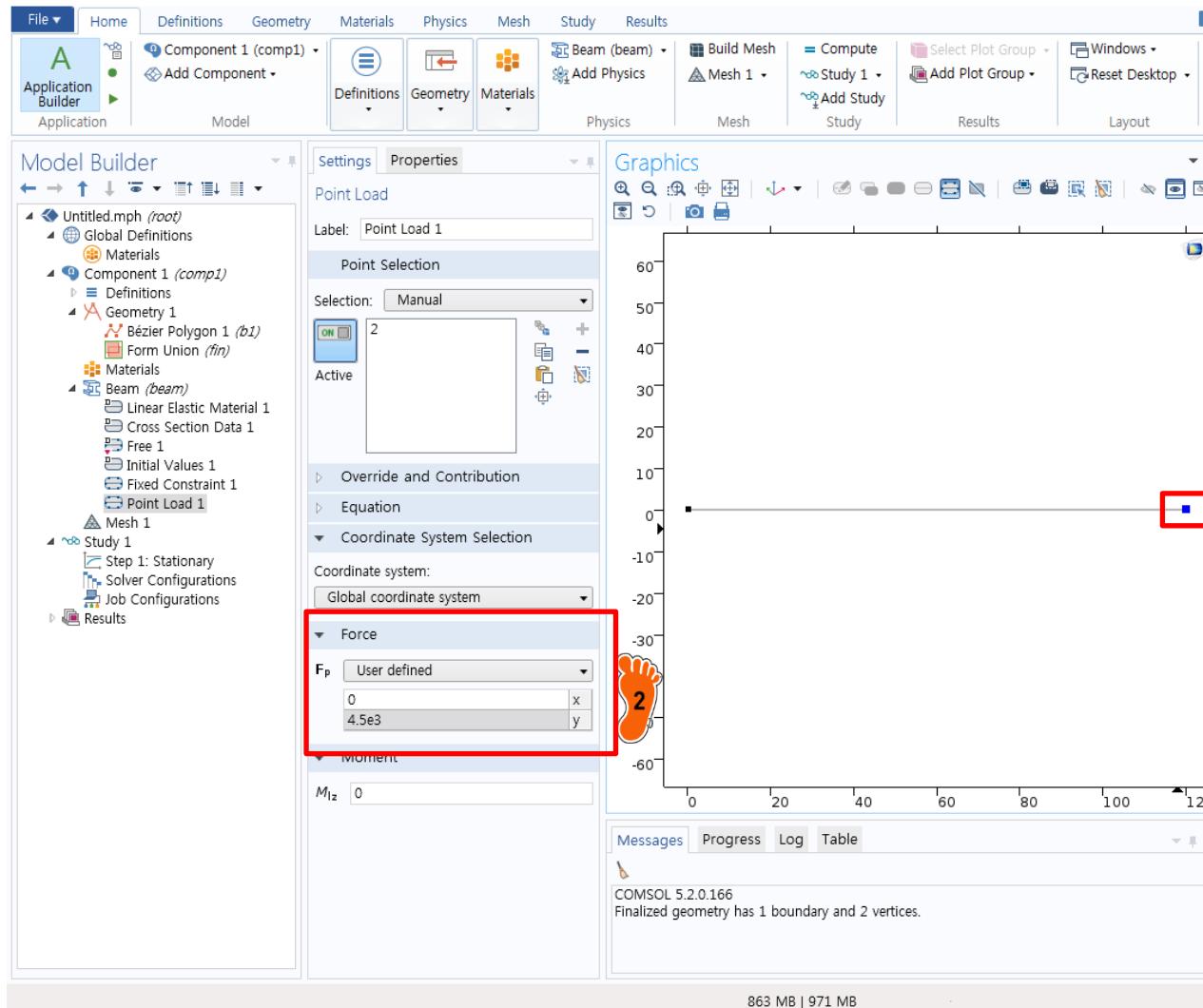
The screenshot shows the COMSOL Multiphysics interface with the following details:

- Model Builder:** Displays the project structure for "Untitled.mph (root)". Components include "Component 1 (comp1)" with "Geometry 1" containing "Bézier Polygon 1 (b1)" and "Form Union (fin)", and "Beam (beam)" with "Linear Elastic Material 1". Studies include "Study 1" with "Step 1: Stationary".
- Properties Window:** Set to "Fixed Constraint" under "Settings". The "Point Selection" section shows a selection labeled "1" with a red outline. The "Active" section shows a red footprint icon with the number "1". Other sections include "Override and Contribution", "Equation", and "Constraint Settings".
- Graphics Window:** Shows a 2D plot area with axes from -60 to 60. A red footprint icon with the number "1" is highlighted on the left boundary of a polygonal domain.
- Bottom Status Bar:** Shows "COMSOL 5.2.0.166 Finalized geometry has 1 boundary and 2 vertices." and memory usage "842 MB | 966 MB".

LOADING CONDITION



LOADING CONDITION

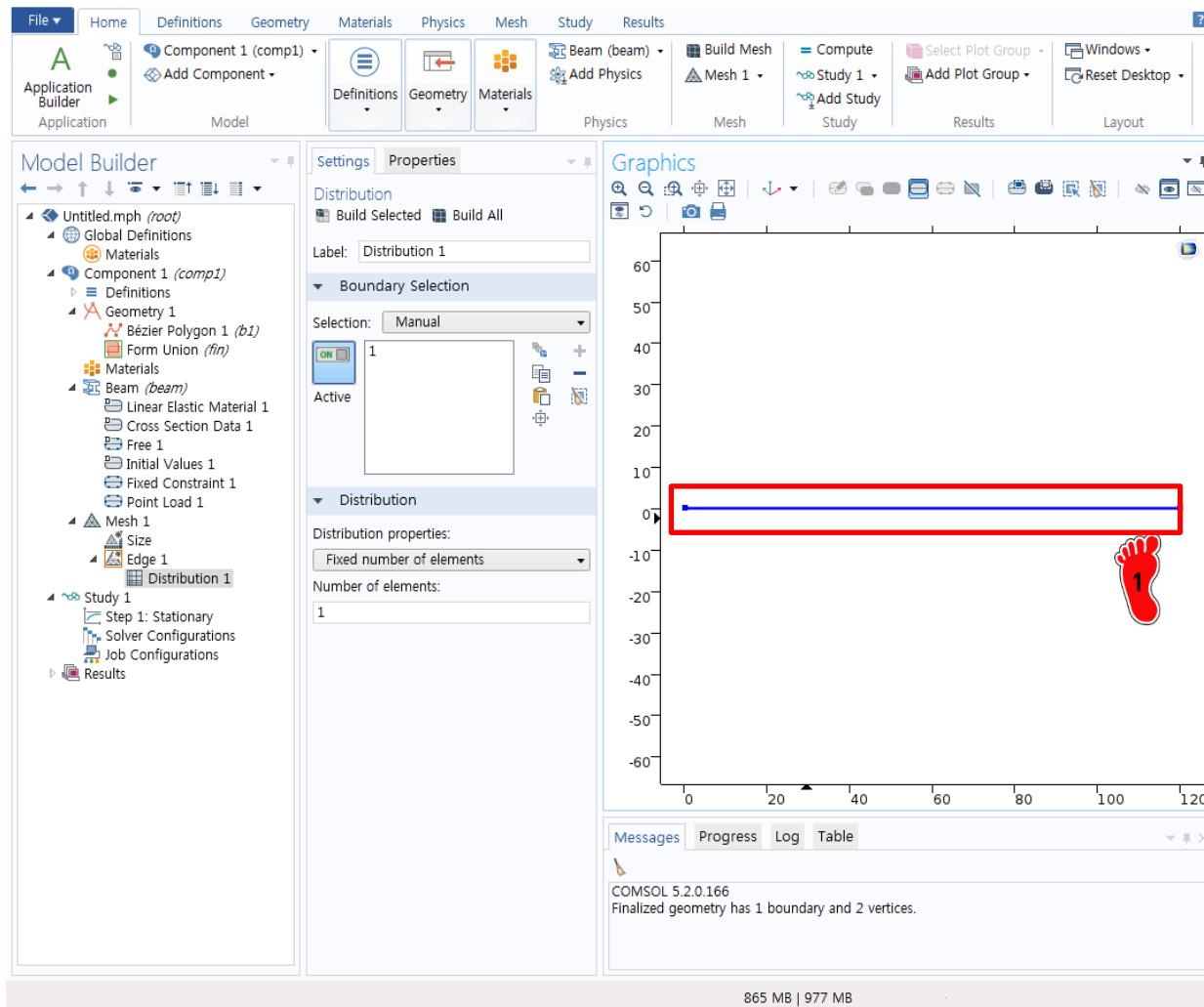


1 오른쪽 절점 선택

2 y 방향에 4.5e3 입력

lb-inch 단위
 $P_B = 4.5 \text{ kips} = 4.5\text{e}3 \text{ lb}$

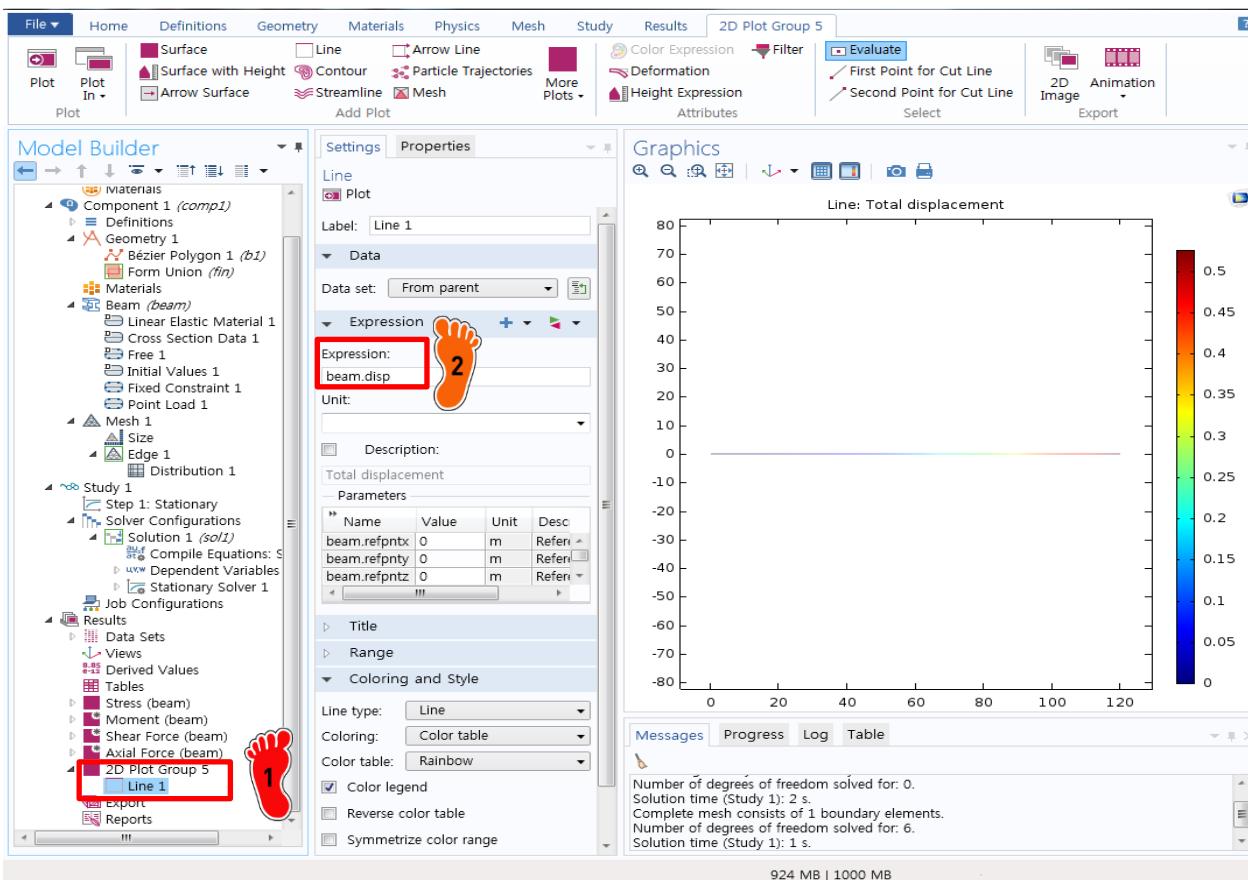
MESH



한 개의 요소가 되도록 메시
생성

그 후 compute로 유한요소
해석 수행

POST-PROCESSING



1 2D Plot Group 에서 Line
추가 후 beam.disp 를 확인

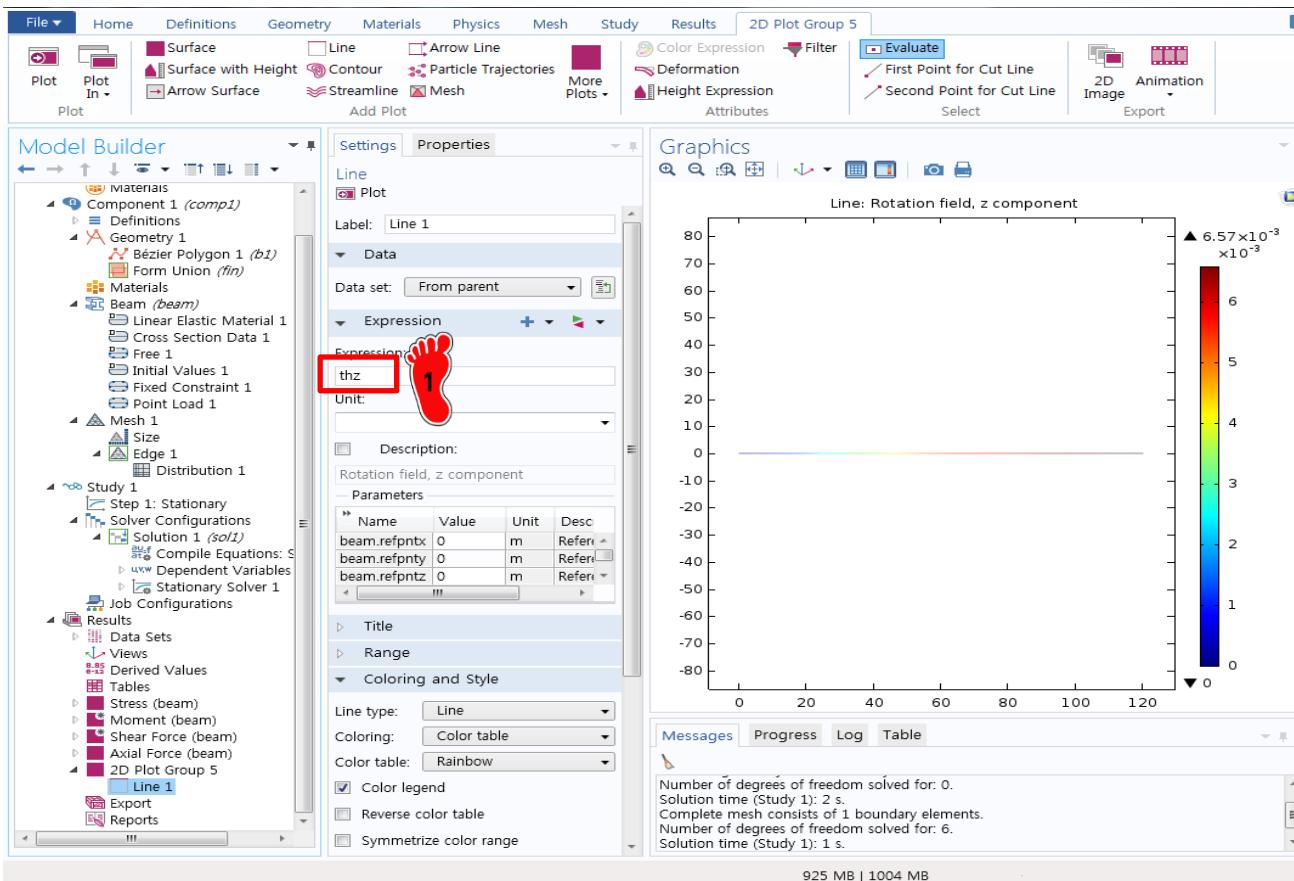
최대 변위는 0.5258

Analytical solution
0.526

Error: 0.038%

$$\begin{cases} \delta_B = \frac{1}{EI} \left[M_B \left(\frac{L^2}{2} \right) + P_B \left(\frac{L^3}{3} \right) \right] = 0.0730 + 0.526 = 0.599 \text{ in} \\ \theta_B = \frac{1}{EI} \left[M_B(L) + P_B \left(\frac{L^2}{2} \right) \right] = 0.00122 + 0.00657 = 0.00779 \text{ rad} \end{cases}$$

POST-PROCESSING



1 Expression 을 thz 로 변경

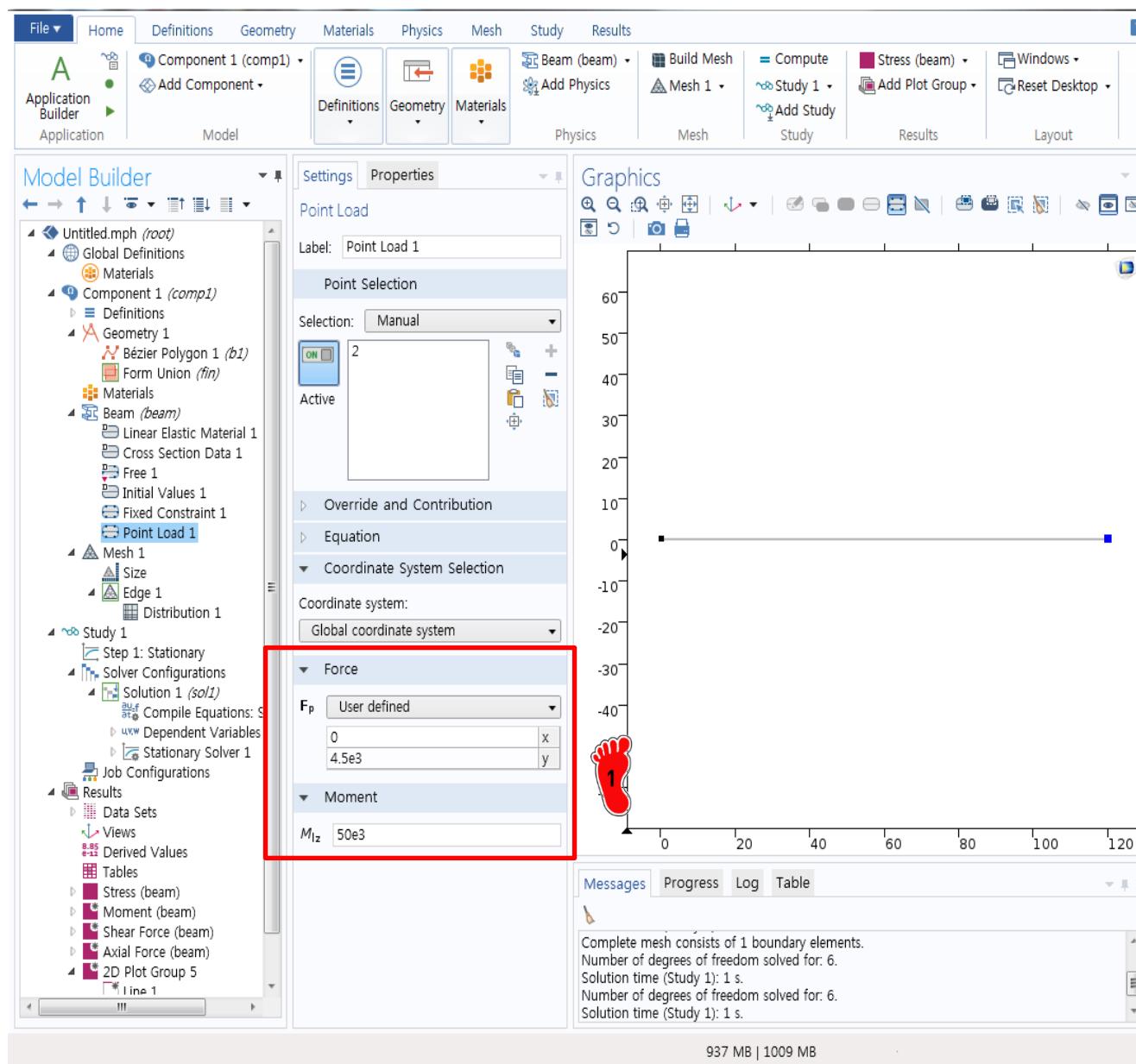
최대 각도는 $6.572\text{e-}3$

Analytical solution
 $6.57\text{e-}3$

Error: 0.03%

$$\begin{cases} \delta_B = \frac{1}{EI} \left[M_B \left(\frac{L^2}{2} \right) + P_B \left(\frac{L^3}{3} \right) \right] = 0.0730 + 0.526 = 0.599 \text{ in} \\ \theta_B = \frac{1}{EI} \left[M_B(L) + P_B \left(\frac{L^2}{2} \right) \right] = 0.00122 + \boxed{0.00657} = 0.00779 \text{ rad} \end{cases}$$

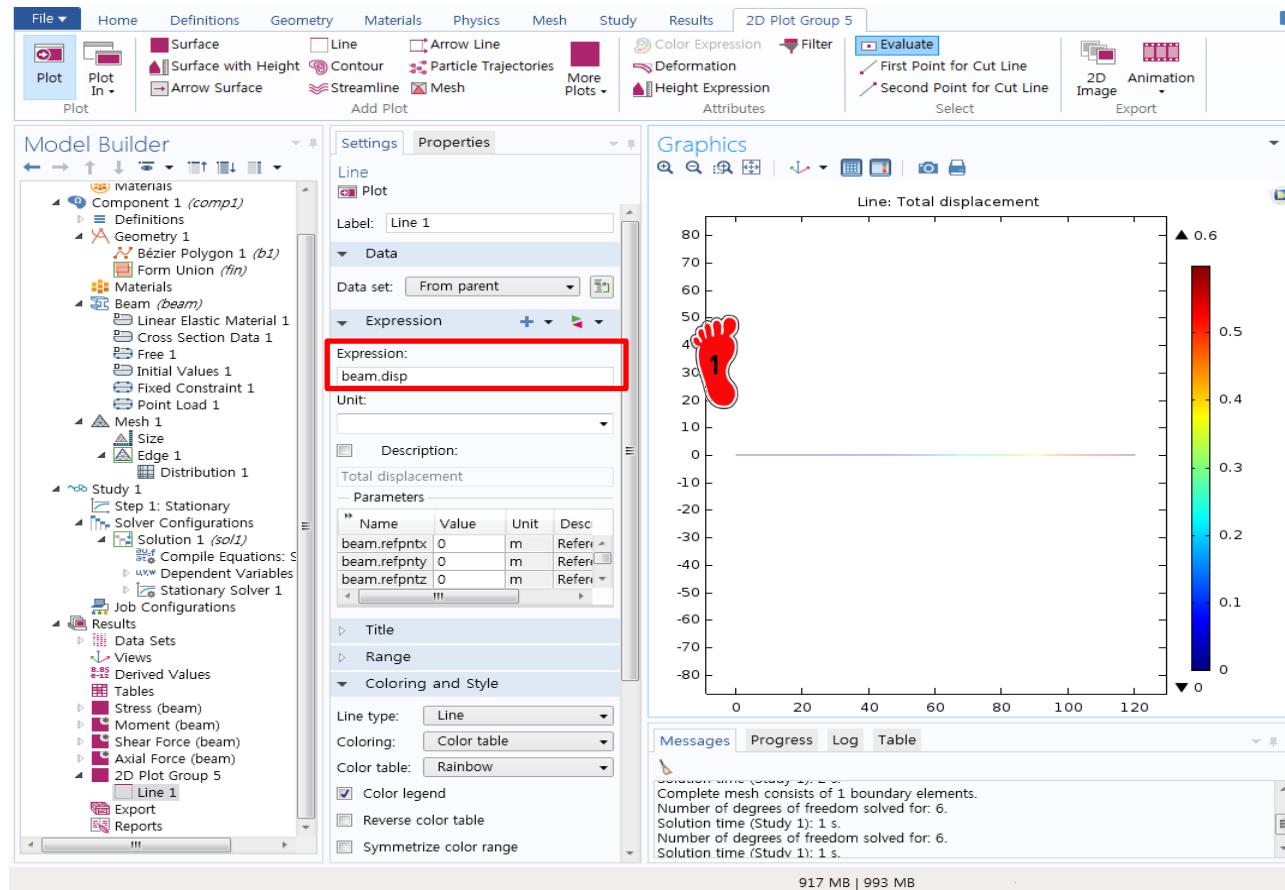
LOADING CONDITION



Point load 설정에서 모멘트 추가

50e3 입력

POST-PROCESSING



beam.disp 를 확인

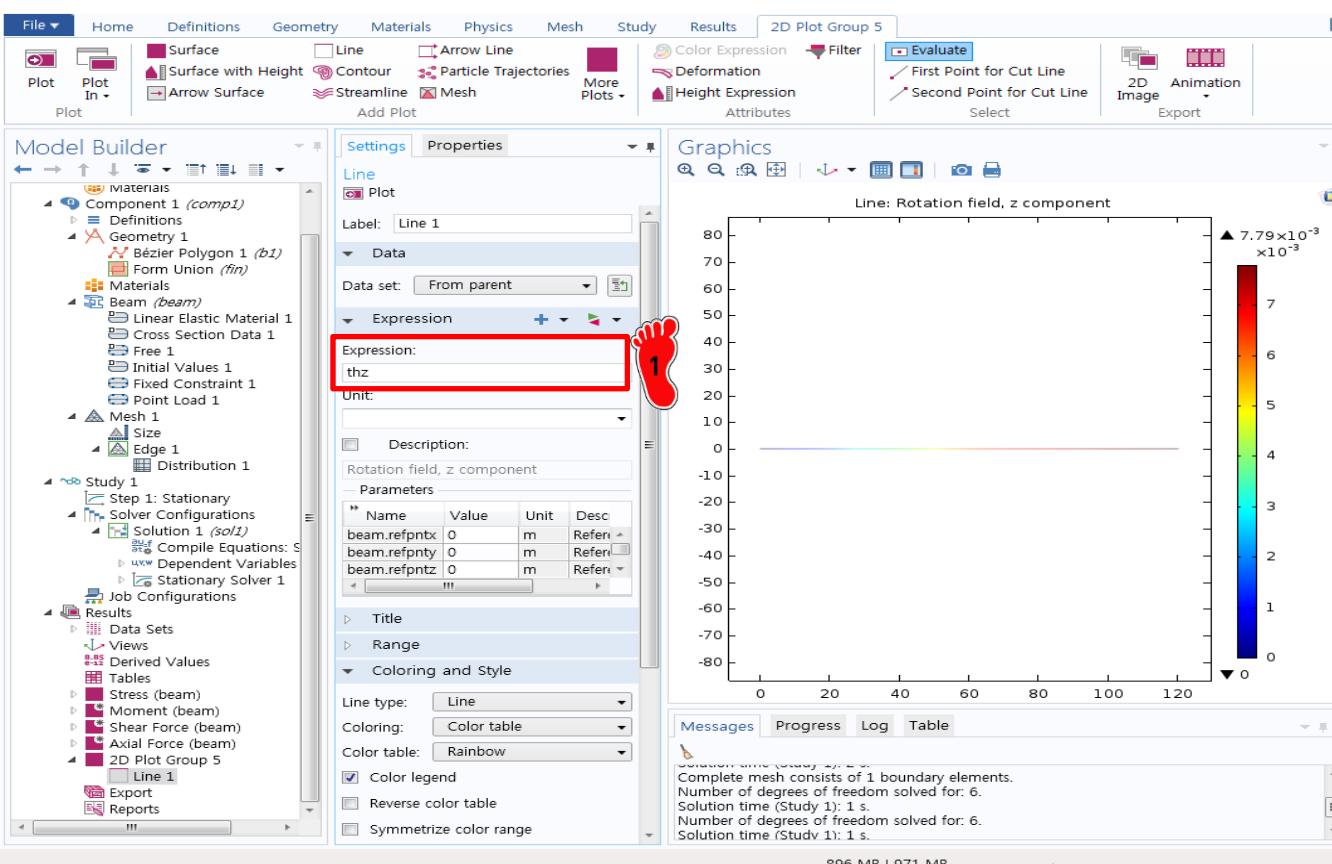
최대 변위는 0.598

Analytical solution
0.599

Error: 0.17%

$$\begin{cases} \delta_B = \frac{1}{EI} \left[M_B \left(\frac{L^2}{2} \right) + P_B \left(\frac{L^3}{3} \right) \right] = 0.0730 + 0.526 = 0.599 \text{ in} \\ \theta_B = \frac{1}{EI} \left[M_B(L) + P_B \left(\frac{L^2}{2} \right) \right] = 0.00122 + 0.00657 = 0.00779 \text{ rad} \end{cases}$$

POST-PROCESSING



1 Expression 을 thz 로 변경

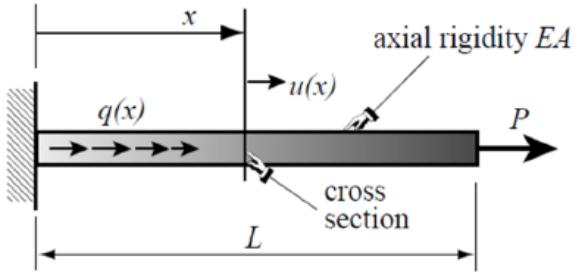
최대 각도는 $7.789e-3$ rad

Analytical solution
 $7.79e-3$ rad

Error: 0.013%

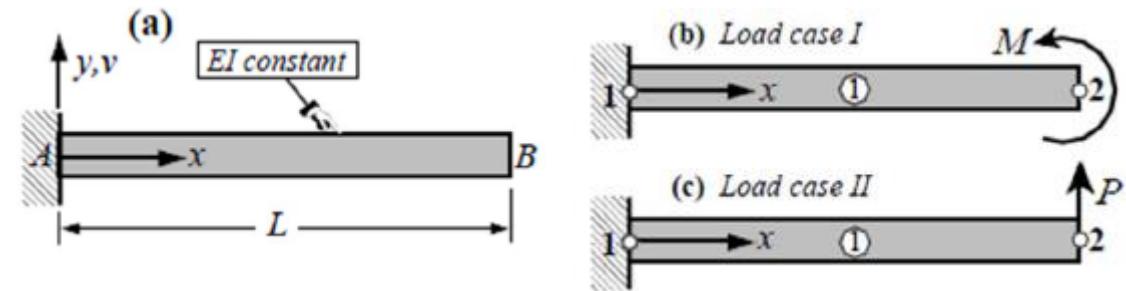
$$\left\{ \begin{array}{l} \delta_B = \frac{1}{EI} \left[M_B \left(\frac{L^2}{2} \right) + P_B \left(\frac{L^3}{3} \right) \right] = 0.0730 + 0.526 = 0.599 \text{ in} \\ \theta_B = \frac{1}{EI} \left[M_B (L) + P_B \left(\frac{L^2}{2} \right) \right] = 0.00122 + 0.00657 = 0.00779 \text{ rad} \end{array} \right.$$

SYSTEM EQUATION BY HAND



$$\frac{EA}{L} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} 0 \\ P \end{bmatrix}$$

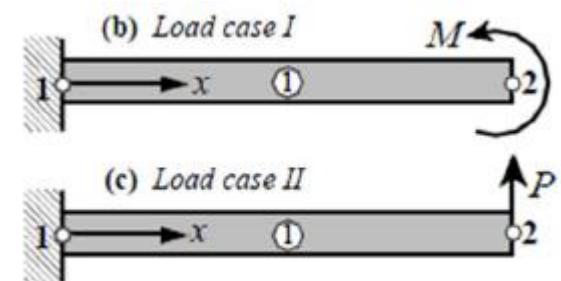
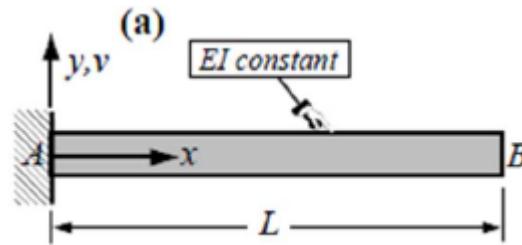
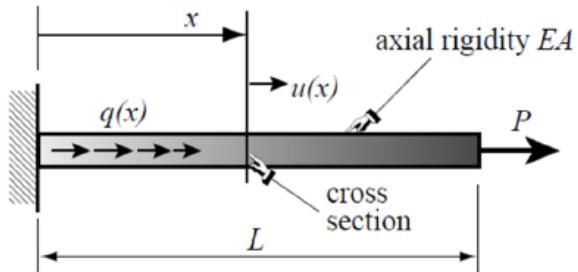
$$\rightarrow u_2 = \frac{PL}{EA}$$



$$\frac{EI}{L^3} \begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \begin{bmatrix} v_1 \\ \theta_1 \\ v_2 \\ M \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ M \end{bmatrix} \rightarrow \begin{bmatrix} v_2 \\ \theta_2 \end{bmatrix} = \begin{bmatrix} \frac{ML^2}{2EI} \\ \frac{ML}{EI} \end{bmatrix}$$

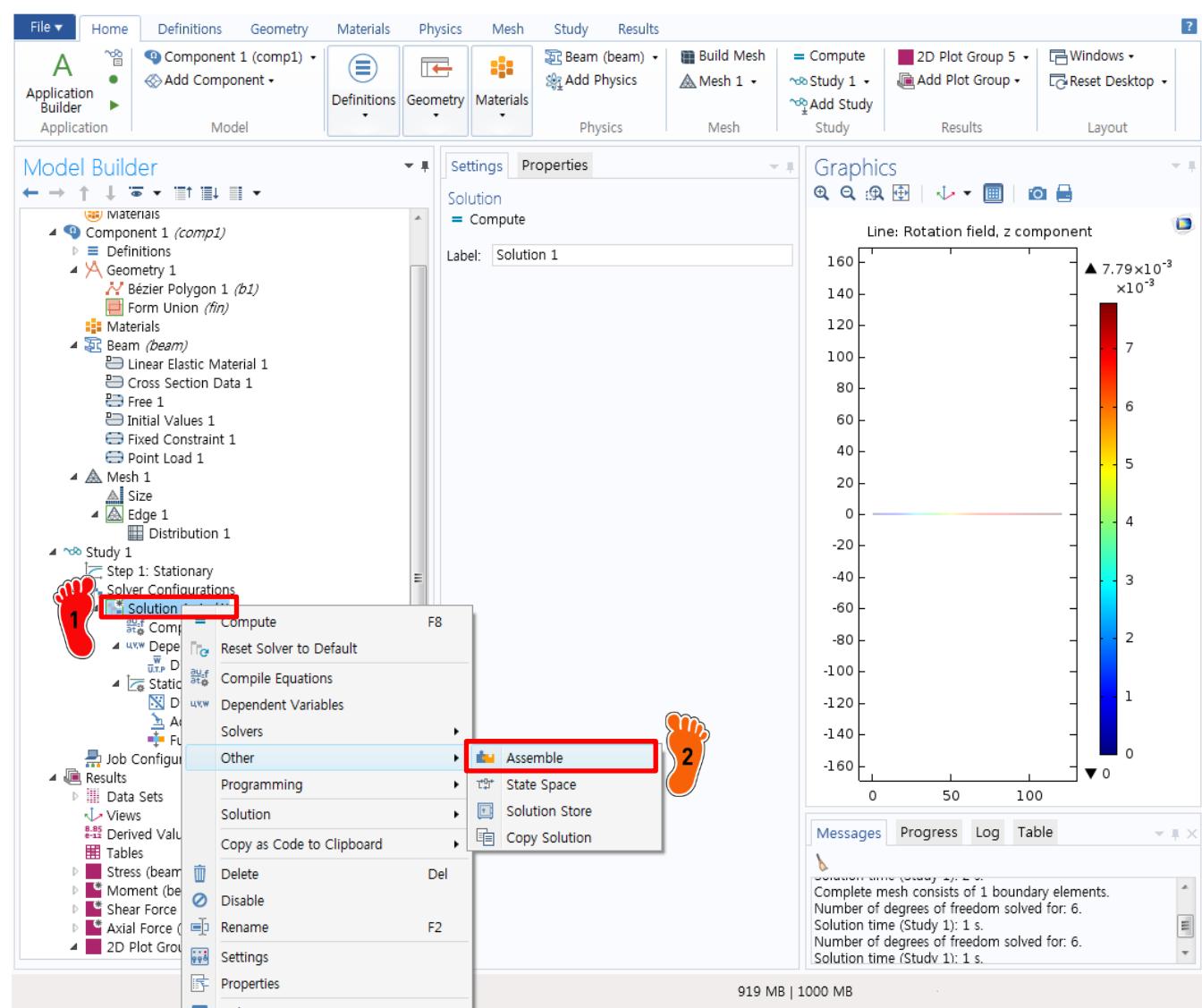
$$\frac{EI}{L^3} \begin{bmatrix} 12 & 6L & -12 & 6L \\ 6L & 4L^2 & -6L & 2L^2 \\ -12 & -6L & 12 & -6L \\ 6L & 2L^2 & -6L & 4L^2 \end{bmatrix} \begin{bmatrix} v_1 \\ \theta_1 \\ v_2 \\ P \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ P \\ 0 \end{bmatrix} \rightarrow \begin{bmatrix} v_2 \\ \theta_2 \end{bmatrix} = \begin{bmatrix} \frac{PL^3}{3EI} \\ \frac{PL^2}{2EI} \end{bmatrix}$$

SYSTEM EQUATION BY HAND



$$\begin{bmatrix} 1.64e^8 & 0 & -2.05e^6 & 8.22e^7 & 0 & 2.05e^6 \\ 0 & 2.14e^6 & 0 & 0 & -2.14e^6 & 0 \\ -2.05e^6 & 0 & 3.42e^4 & -2.05e^6 & 0 & -3.42e^4 \\ 8.22e^7 & 0 & -2.05e^6 & 1.64e^8 & 0 & 2.05e^6 \\ 0 & -2.14e^6 & 0 & 0 & 2.14e^6 & 0 \\ 2.05e^6 & 0 & -3.42e^4 & 2.05e^6 & 0 & 3.42e^4 \end{bmatrix} \begin{bmatrix} \theta_2 \\ u_2 \\ v_2 \\ \theta_1 \\ u_1 \\ v_1 \end{bmatrix} = \begin{bmatrix} M \\ P_x \\ P_y \\ 0 \\ 0 \\ 0 \end{bmatrix}$$

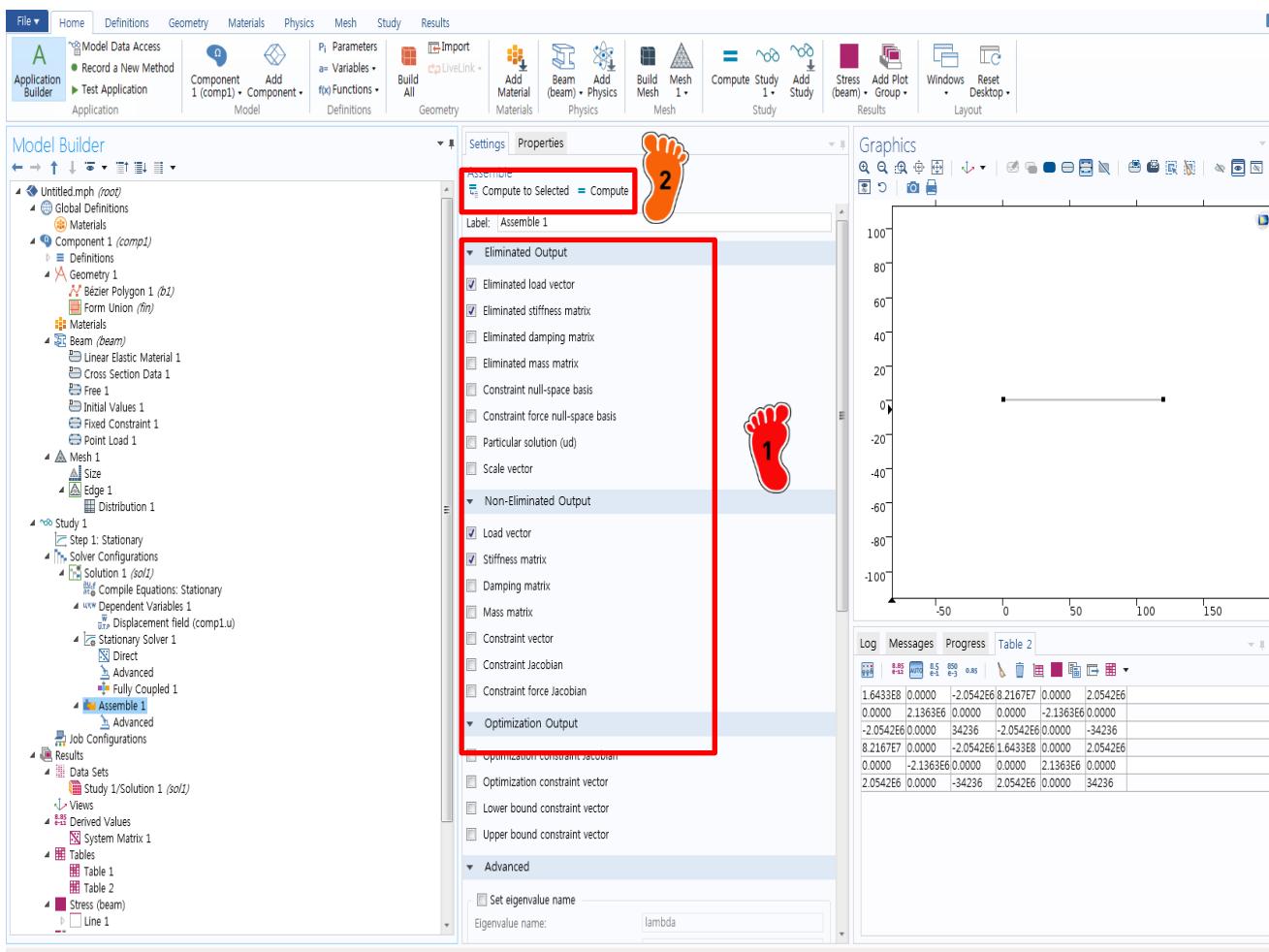
ASSEMBLE OPTION



Solution 마우스 우클릭

2 Assemble 클릭

ASSEMBLE OPTION



1 Eliminated load vector
1 Eliminated stiffness matrix

Load vector
Stiffness matrix

체크박스에 체크

2 Compute to Selected 클릭

COMPARISON

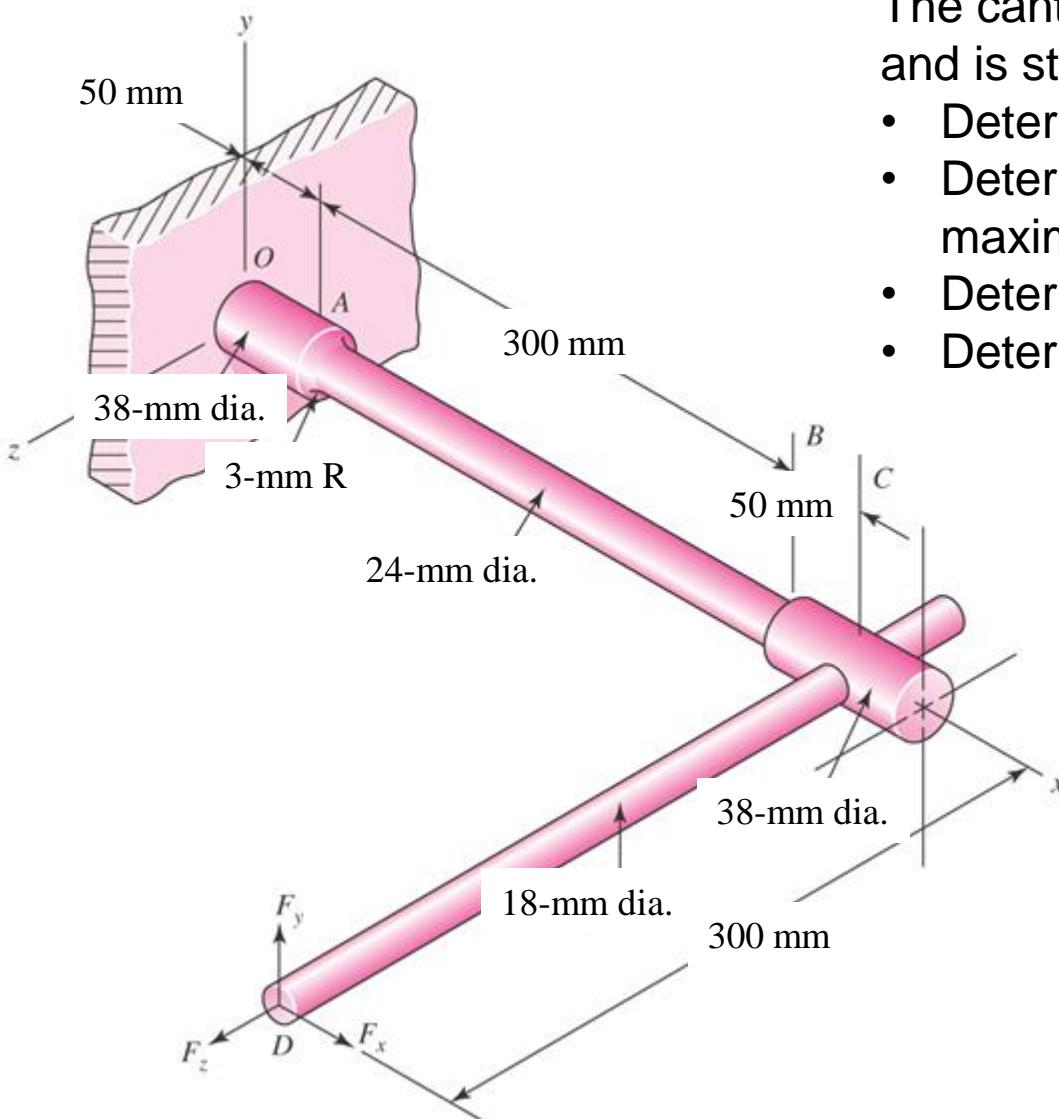
$$\mathbf{K}_{by\ hand} = \begin{bmatrix} 1.64e^8 & 0 & -2.05e^6 & 8.22e^7 & 0 & 2.05e^6 \\ 0 & 2.14e^6 & 0 & 0 & -2.14e^6 & 0 \\ -2.05e^6 & 0 & 3.42e^4 & -2.05e^6 & 0 & -3.42e^4 \\ 8.22e^7 & 0 & -2.05e^6 & 1.64e^8 & 0 & 2.05e^6 \\ 0 & -2.14e^6 & 0 & 0 & 2.14e^6 & 0 \\ 2.05e^6 & 0 & -3.42e^4 & 2.05e^6 & 0 & 3.42e^4 \end{bmatrix}$$

1.6433E8	0.0000	-2.0542E6	8.2167E7	0.0000	2.0542E6
0.0000	2.1363E6	0.0000	0.0000	-2.1363E6	0.0000
-2.0542E6	0.0000	34236	-2.0542E6	0.0000	-34236
8.2167E7	0.0000	-2.0542E6	1.6433E8	0.0000	2.0542E6
0.0000	-2.1363E6	0.0000	0.0000	2.1363E6	0.0000
2.0542E6	0.0000	-34236	2.0542E6	0.0000	34236

Stiffness matrix by COMSOL

- Beam model: 2D
 - ✓ Textbook of “Solid Mechanics”
- Beam model: 3D
- Assignment

CANTILEVERED HANDLE



The cantilevered bar is made from mild steel and is statically loaded. At cross section A,

- Determine the location of the critical stress.
- Determine the principal stresses and the maximum shear stress.
- Determine the angle of twist in bar OC.
- Determine the vertical deflection at the tip.

$$E = 207 \text{ GPa}, G = 79.3 \text{ GPa}$$

$$F_{y@D} = 1000 \text{ N}$$

$$\sigma_1 = 298.8 \text{ MPa}$$

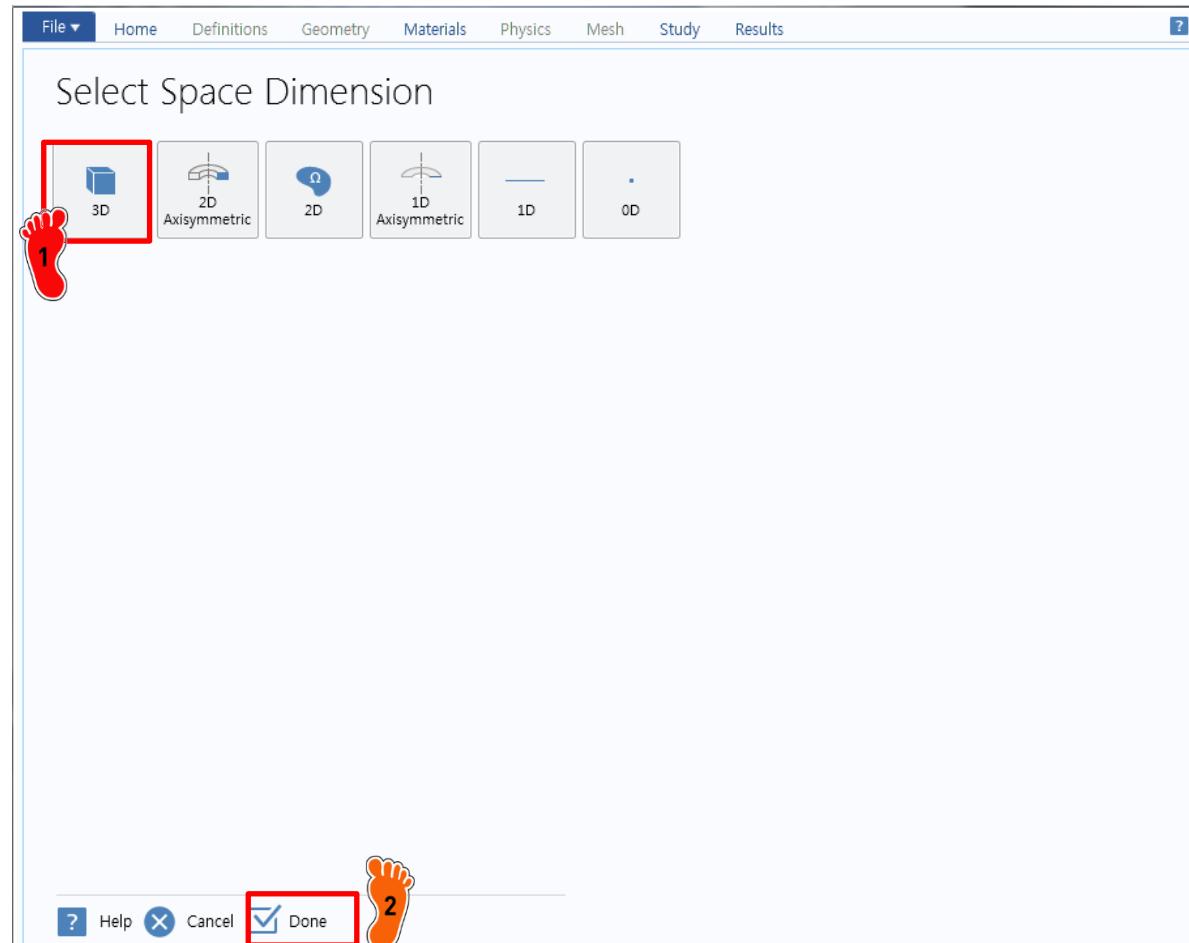
$$\sigma_2 = -40.9 \text{ MPa}$$

$$\tau_{\max} = 169.8 \text{ MPa}$$

$$\theta_C = 0.0367 \text{ rad}$$

$$y_D = 24.005 \text{ mm}$$

DIMENSION SELECTION



- 1 3D 선택
- 2 Done 클릭

PHYSICS SELECTION

Search

- Recently Used
- AC/DC
- Acoustics
- Chemical Species Transport
- Electrochemistry
- Fluid Flow
- Heat Transfer
- Optics
- Plasma
- Radio Frequency
- Semiconductor
- Structural Mechanics
 - Solid Mechanics (solid)
 - Plate (plate)
 - Beam (beam)** 
 - Truss (truss)
 - Multibody Dynamics (mbd)
- Thermal Stress
- Thermoelasticity (te)
- Joule Heating and Thermal Expansion
- Piezoelectric Devices
- Electromechanics (emi)
- Porelasticity (poro)
- Fatigue (ftg)
- Beam Cross Section (bcs)

Add

Added physics interfaces:

Remove

 Space Dimension  Study 

? Help  Cancel  Done

652 MB | 863 MB

-  1 Structural Mechanics 의 Beam 추가
-  2 Study 클릭

STUDY TYPE SELECTION

File ▾ Home Definitions Geometry Materials Physics Mesh Study Results

Select Study

Preset Studies

- Eigenfrequency
- Frequency Domain
- Frequency-Domain Modal
- Modal Reduction Model
- Stationary** 
- Time Dependent
- Time-Dependent Modal

Custom Studies

Empty Study

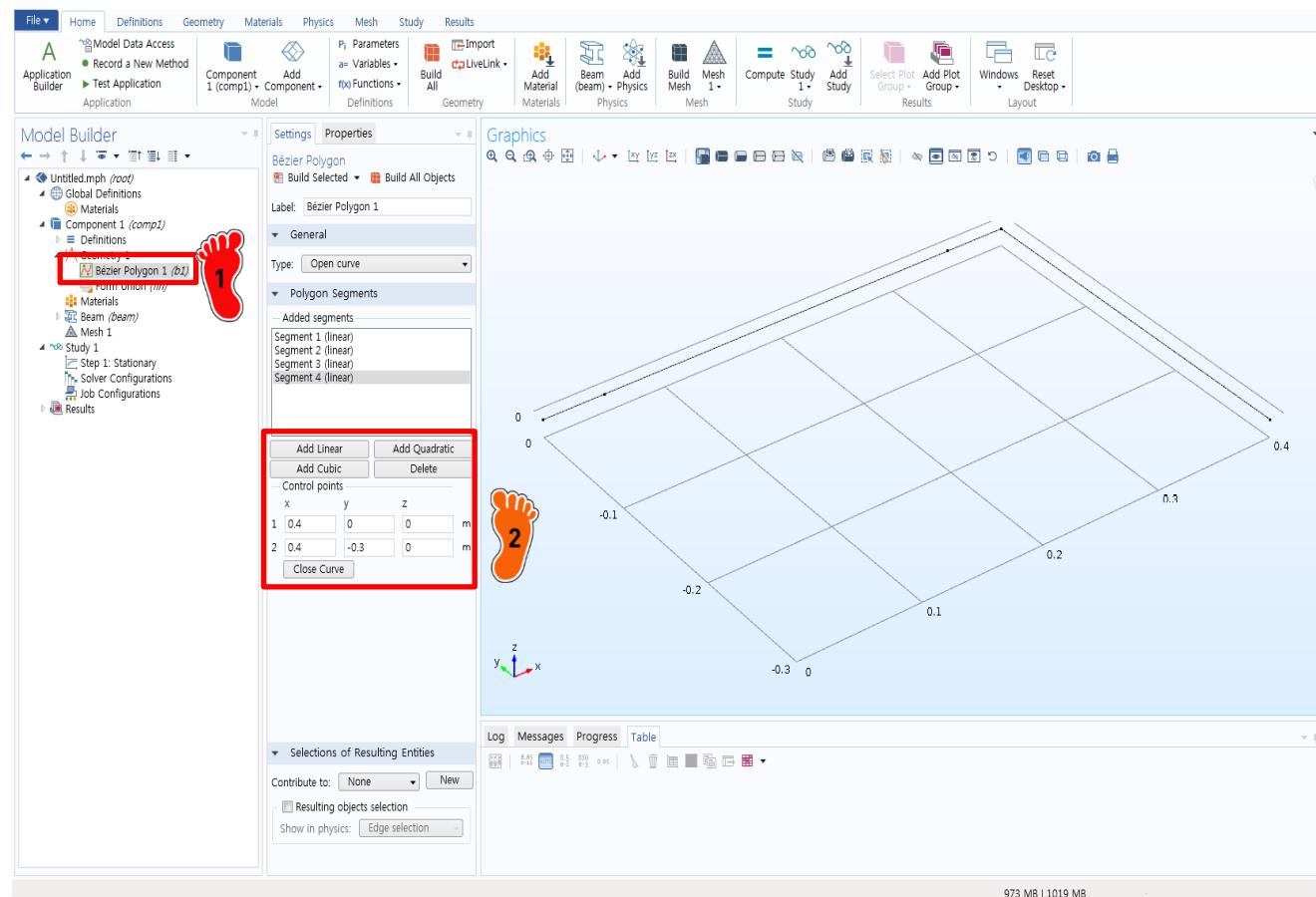
Added study: Stationary

Added physics interfaces: Beam (beam)

Physics  Help  Cancel  Done 



GEOMETRY CREATION



1 Bezier Polygon 생성

2 Segment1
(0,0,0)~(0.05,0,0)

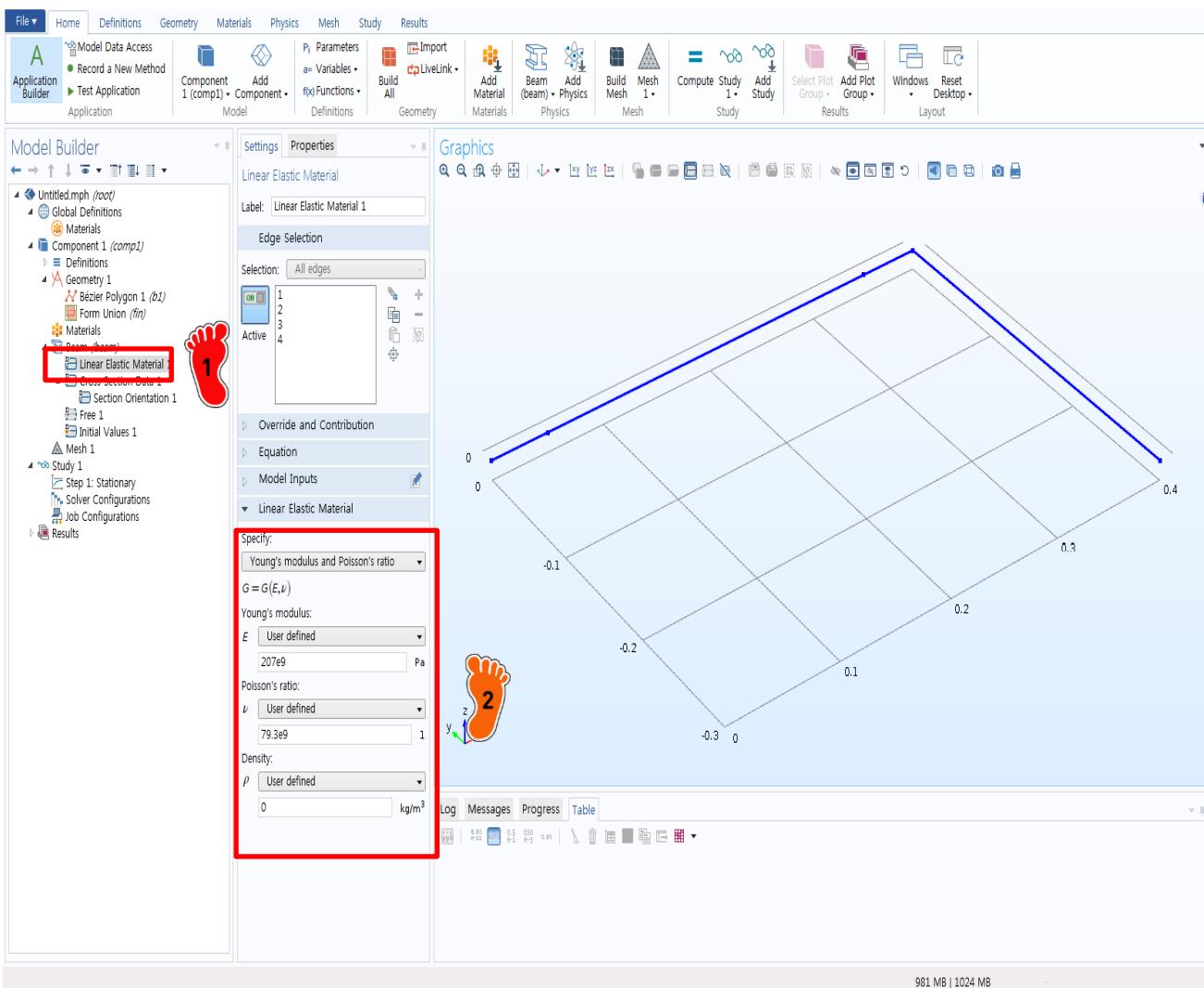
Segment2
(0.05,0,0)~(0.35,0,0)

Segment3
(0.35,0,0)~(0.4,0,0)

Segment4
(0.4,0,0)~(0.4,-0.3,0)

기하형상 생성

MATERIAL PROPERTY



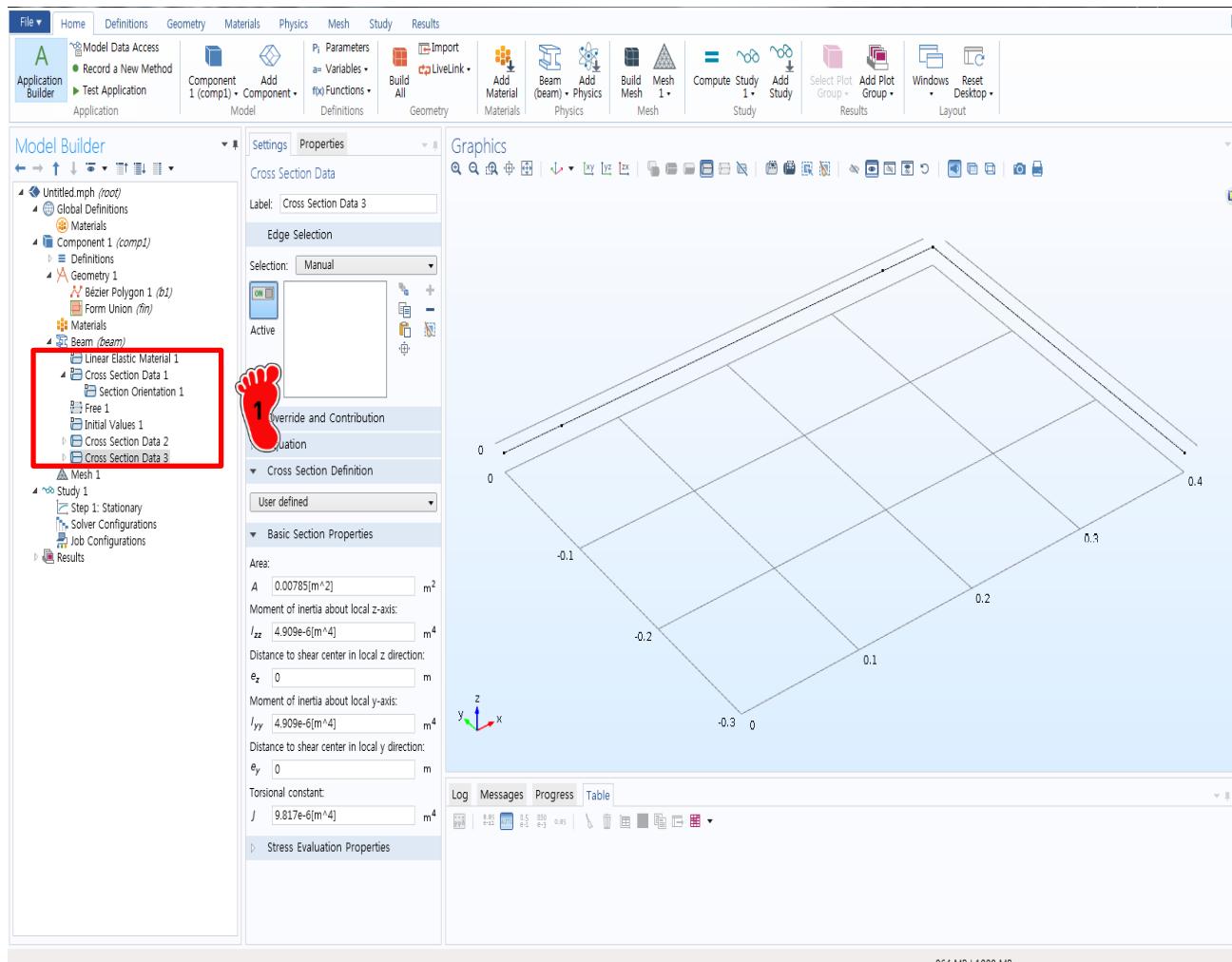
1 Linear Elastic Material 클릭

2 Specify 를
Young's modulus and
shear modulus 로 변경 후

E: 207e9
G: 79.3e9
rho : 0

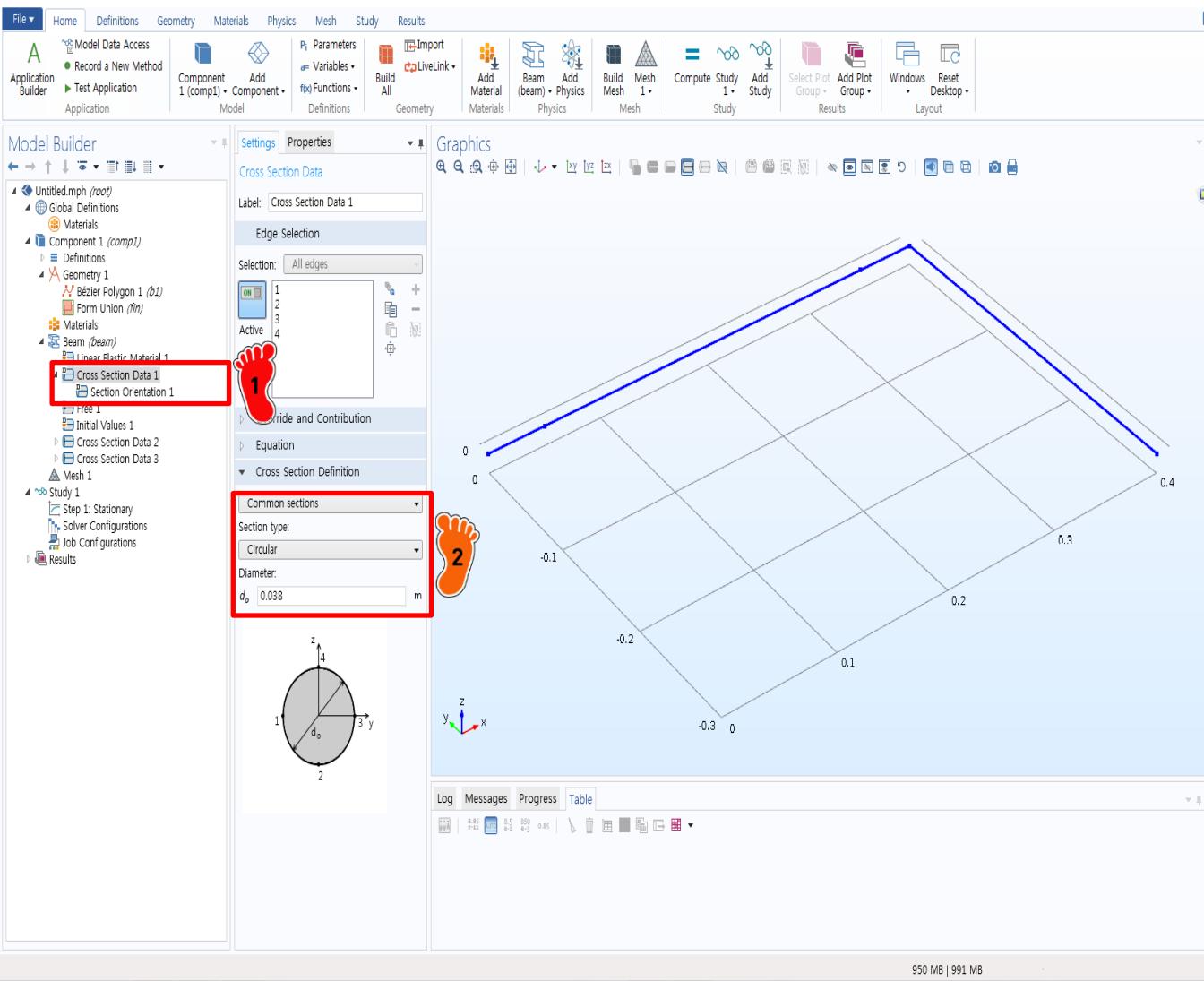
입력

CROSS SECTION



1 Cross Section Data 를 Duplicate 로 2 개 더 복사

CROSS SECTION



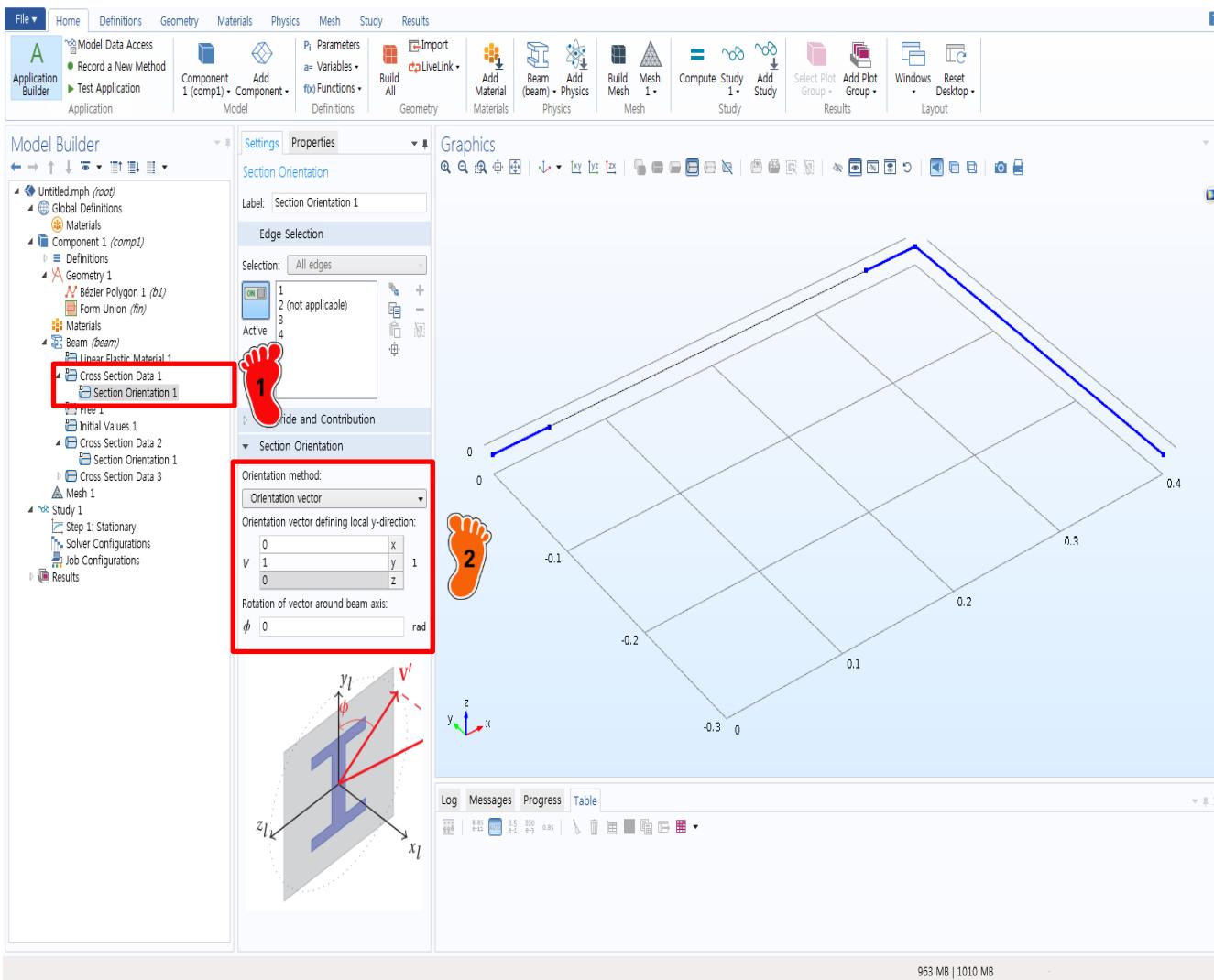
1 Cross Section Data 1 클릭

2 Common sections 변경

Circular 변경

지름 0.038 입력

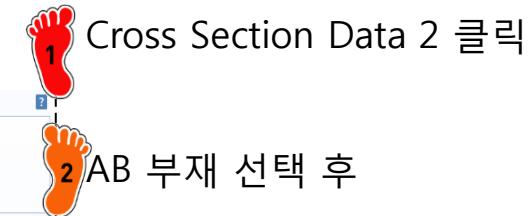
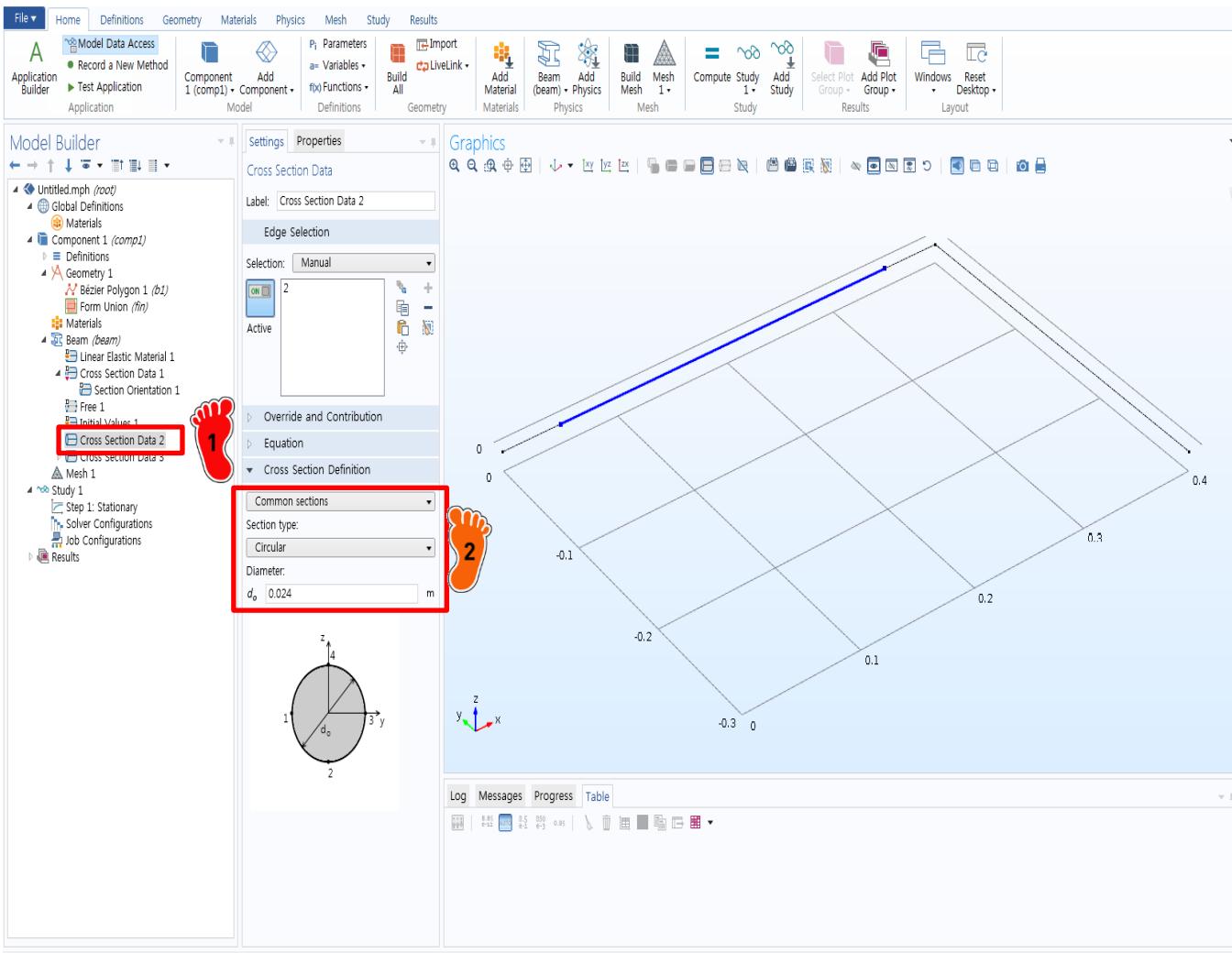
CROSS SECTION



1 Cross Section Data 1 하위
메뉴인 Section Orientation
1 클릭

2 Orientation vector 변경 후
(0,1,0) 입력

CROSS SECTION



Cross Section Data 2 클릭

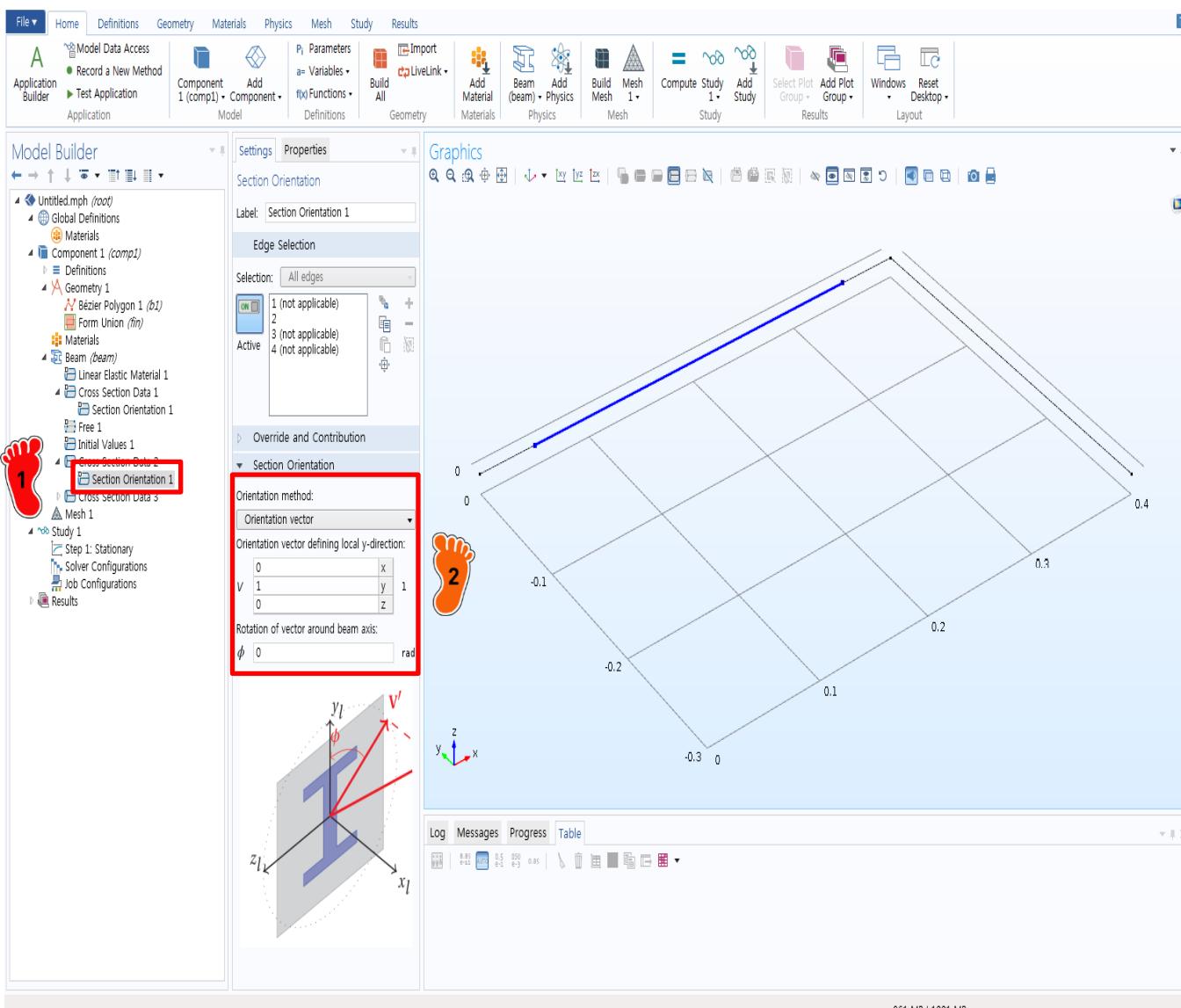
AB 부재 선택 후

Common sections 변경

Circular 변경

지름 0.024 입력

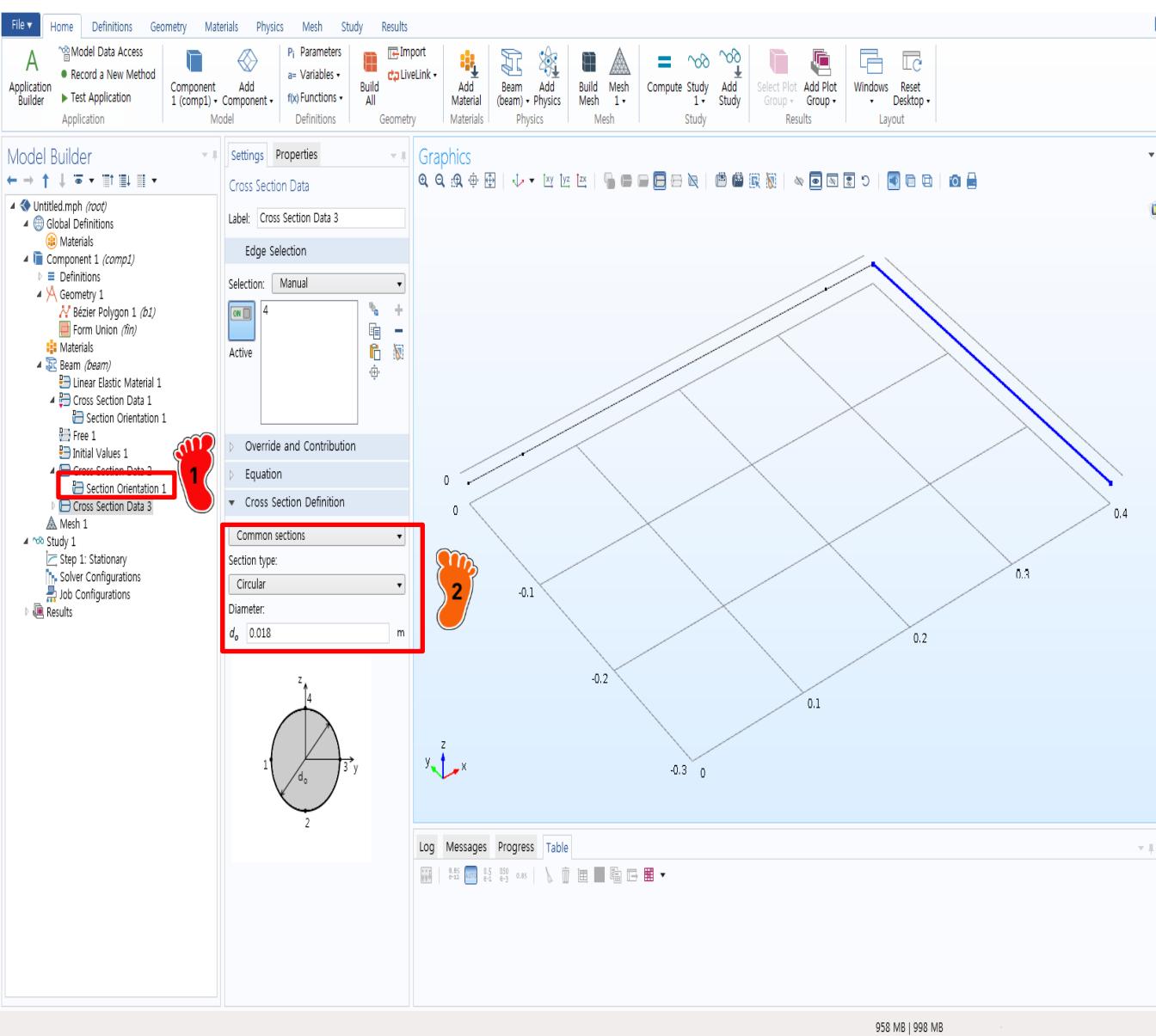
CROSS SECTION



1 Cross Section Data 2 하위
메뉴인 Section Orientation
1 클릭

2 Orientation vector 변경 후
(0,1,0) 입력

CROSS SECTION



1 Cross Section Data 2 클릭



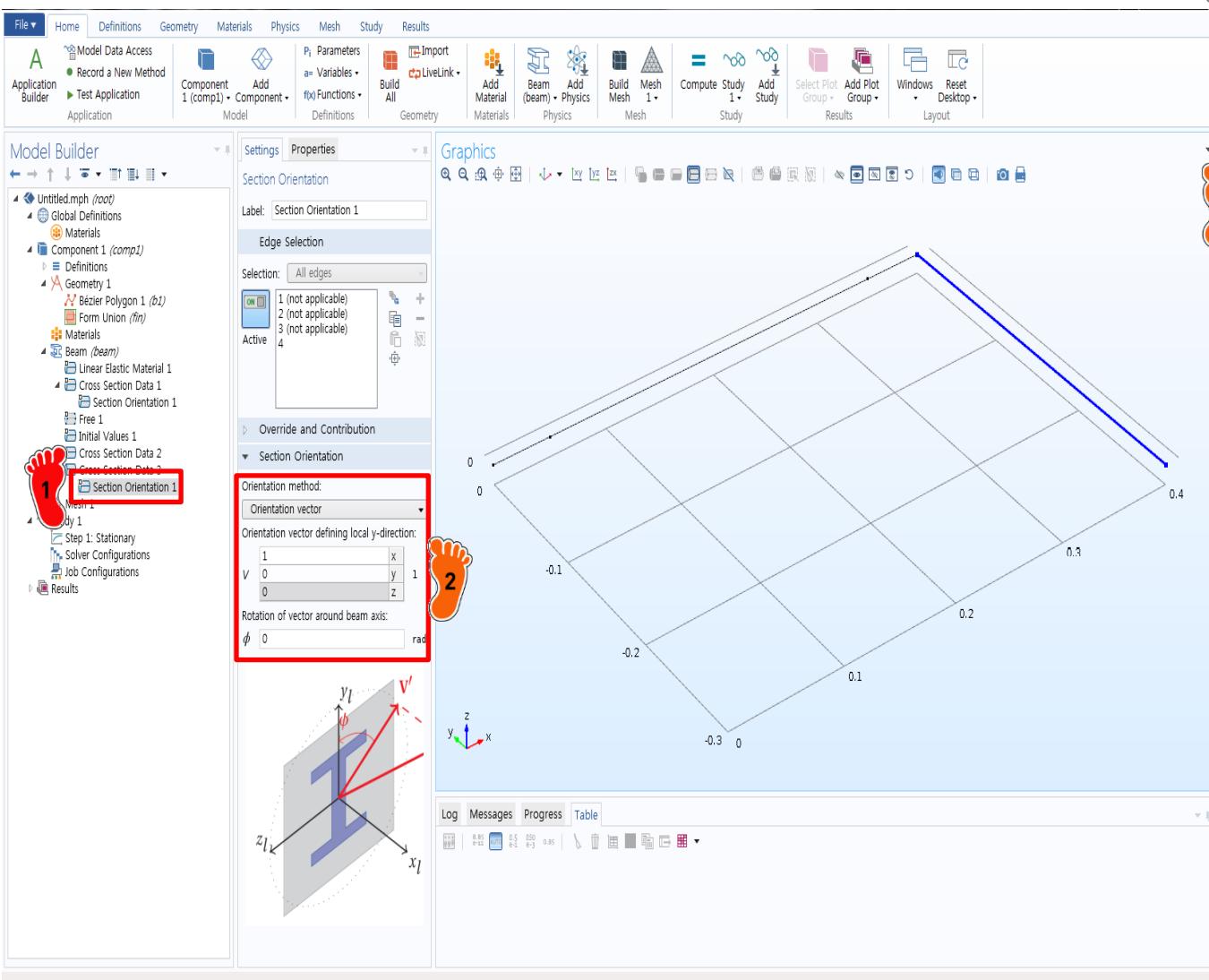
2 CD 부재 선택 후

Common sections 변경

Circular 변경

지름 0.018 입력

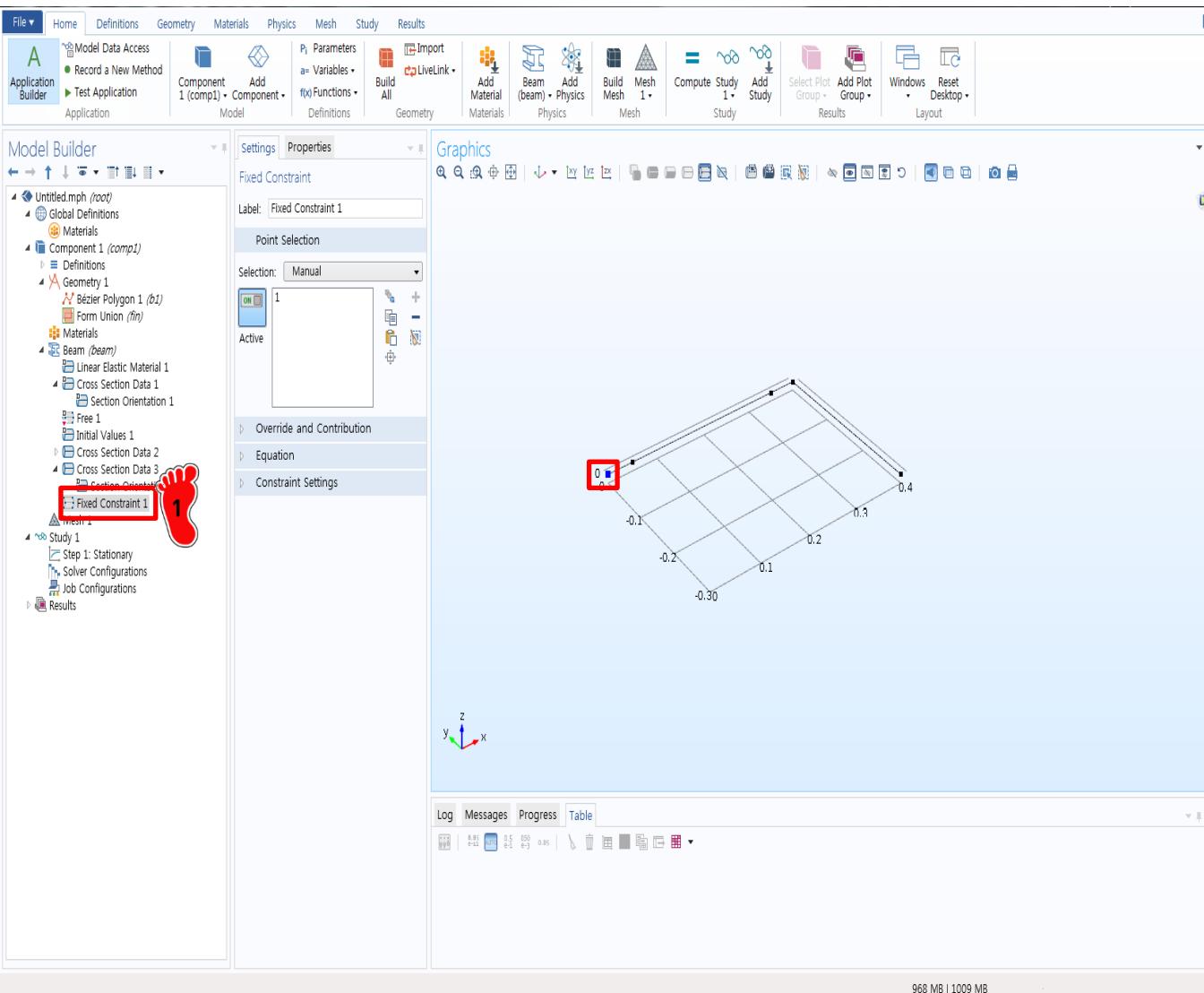
CROSS SECTION



1 Cross Section Data 3 하위
메뉴인 Section Orientation
1 클릭

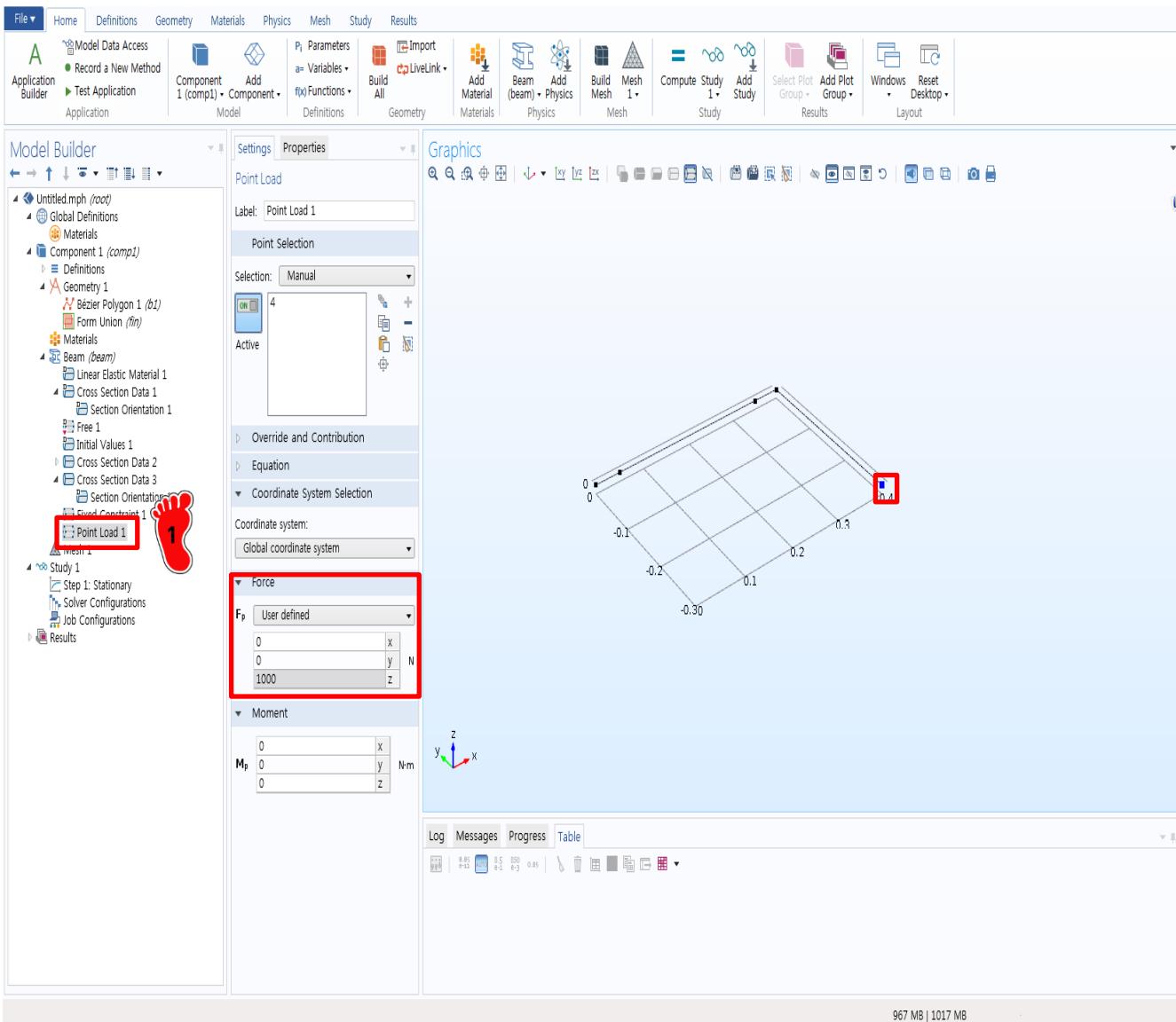
2 Orientation vector 변경 후
(1,0,0) 입력

BOUNDARY CONDITION



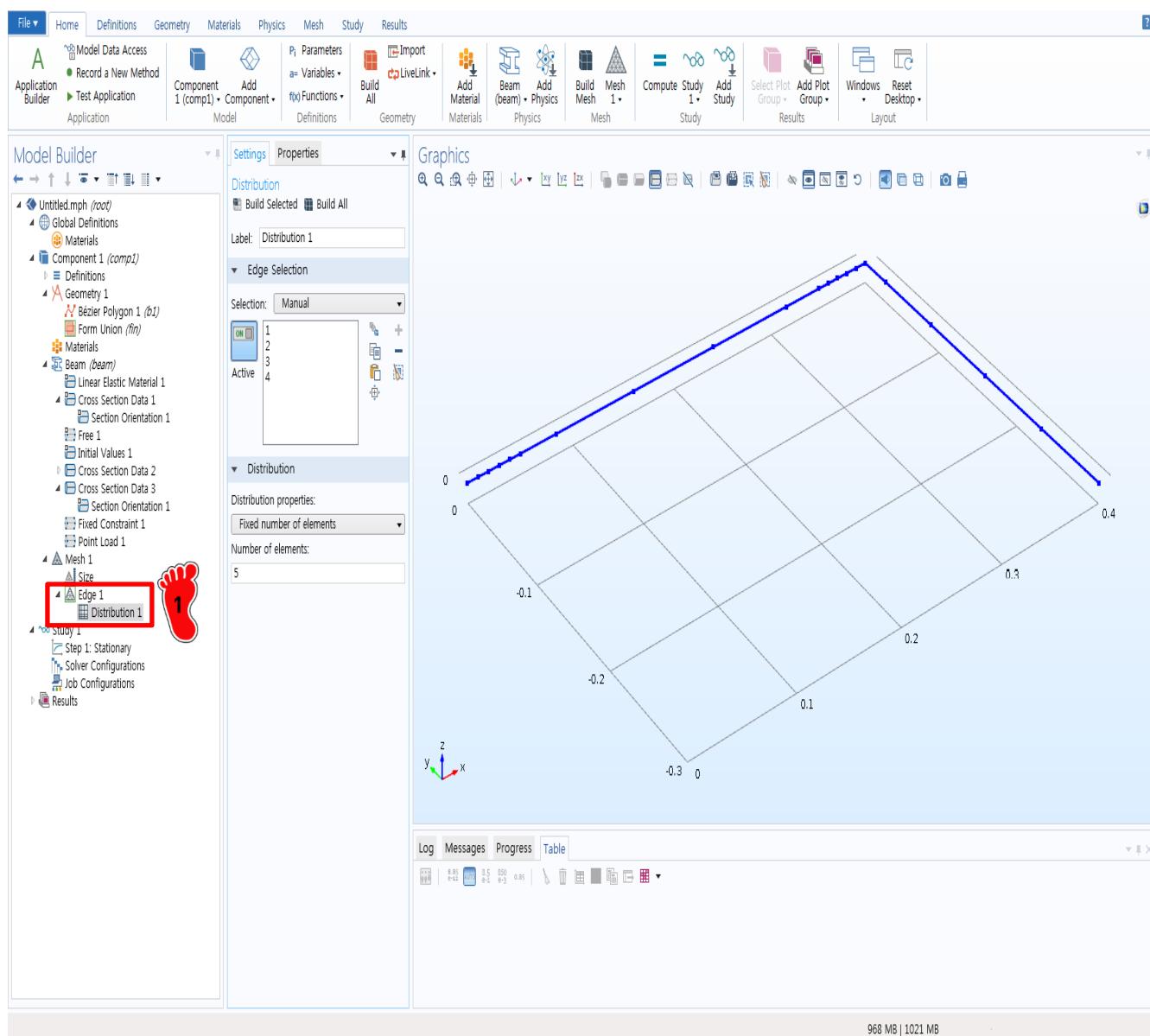
1 Fixed Constraint 를 그림에
표기된 절점에 입력

LOADING CONDITION



Point Load 조건을 그림에
표기된 절점에 z 방향으로
1000 N 입력

MESH



Distribution 5 를 갖는 메시
생성

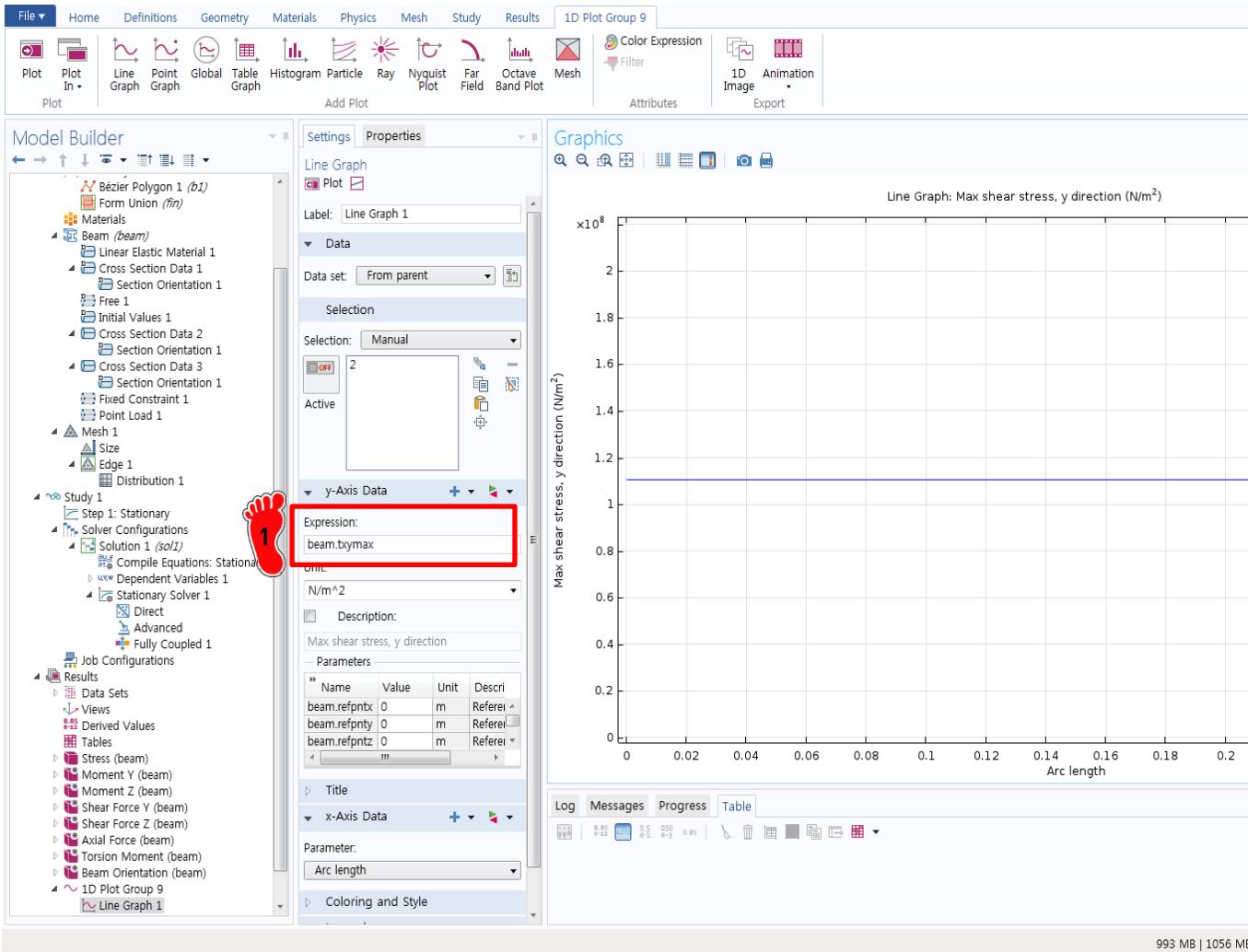
확인 후 유한요소 해석 실행

POST-PROCESSING

The screenshot shows the COMSOL Multiphysics interface with the following details:

- Toolbar:** File, Model, Definitions, Geometry, Materials, Physics, Mesh, Study, Results, 1D Plot Group 9.
- Plot Buttons:** Plot, Plot In, Line Graph, Point Graph, Global Table Graph, Histogram, Particle, Ray, Nyquist Plot, Far Field.
- Model Builder:**
 - Free 1, Initial Values 1, Cross Section Data 2, Section Orientation 1, Cross Section Data 3, Section Orientation 1, Fixed Constraint 1, Point Load 1.
 - Mesh 1, Size, Edge 1, Distribution 1.
 - Study 1, Step 1: Stationary, Solver Configurations, Solution 1, Compile Equations: Stationary, Dependent Variables, Stationary Solver 1.
 - Job Configurations.
- 1D Plot Group 9 Settings:**
 - Selection:** Manual, Active edge 2 selected.
 - y-Axis Data:** Expression: beam.smax.
 - Unit:** N/m².
 - Parameters:** beam.refpntx: 0, beam.refpnty: 0, beam.refpntz: 0.
- Graphics Window:** Shows a 3D plot of a beam structure with a blue line representing the stress distribution. The axes are labeled x, y, z.
- Plot Window:** A 2D line graph titled "Line Graph: Bending stress at second evaluation point (N/m²)". The x-axis is "Arc length" from 0 to 0.3, and the y-axis is "Bending stress at second evaluation point (N/m²)" from 0.4 to 2.4. The curve starts at approximately (0, 2.4) and decreases linearly to about (0.3, 0.4).
- Footprints:** Red and orange footprints are overlaid on the interface to guide the user through the process:
 - 1D Plot Group 9에서 Line 추가
 - 2번 부재 선택 후 beam.smax 입력
 - Plot 클릭
 - A 지점에서 $\sigma_x = 258 \text{ MPa}$

POST-PROCESSING



beam.txymax 입력 후 결과 확인

A 지점에서 $\tau_{xy} = 110.5$ MPa

따라서 principal stress 를 계산하면

$$\sigma_1 = 298.9 \text{ MPa}$$

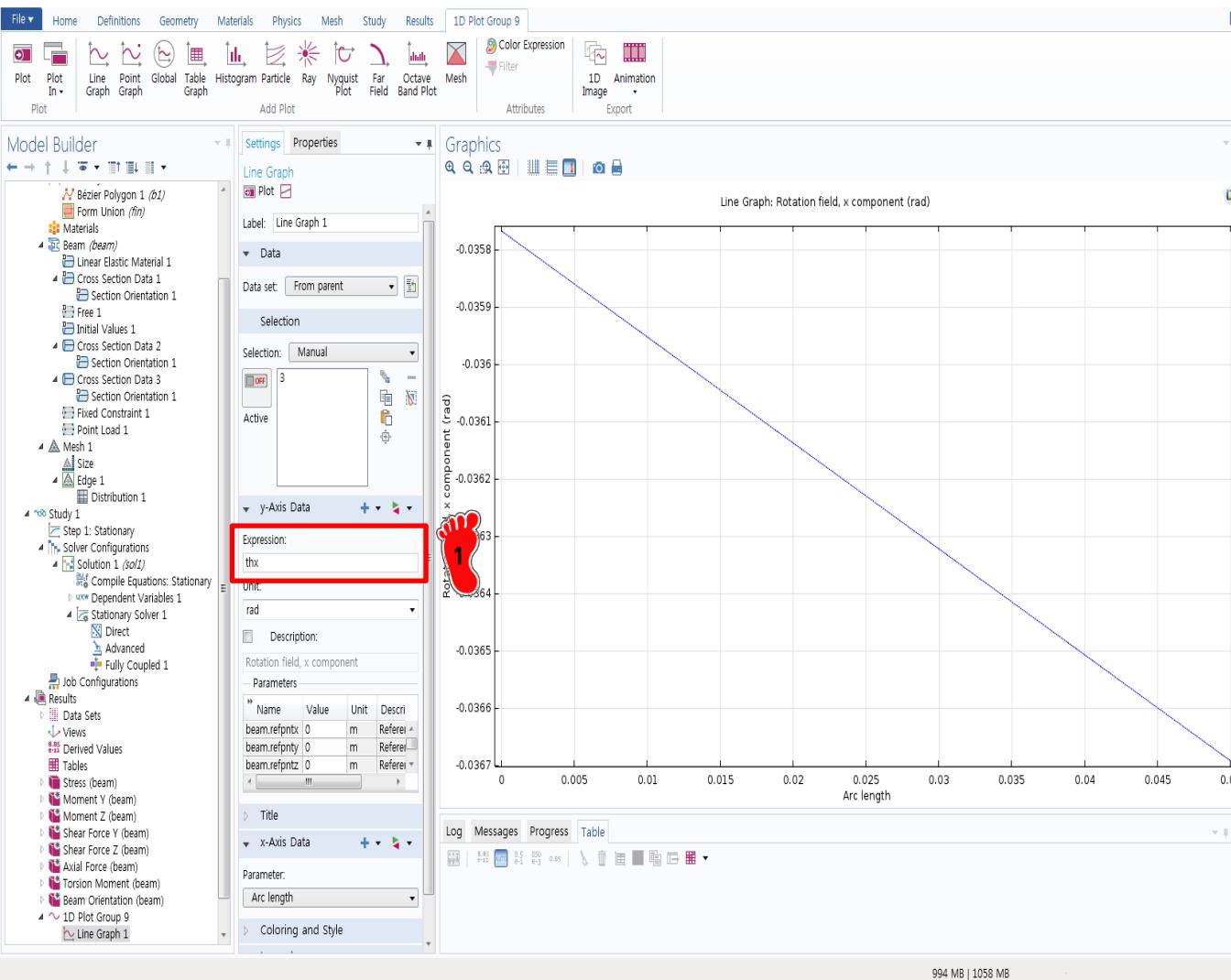
$$\sigma_2 = -40.9 \text{ MPa}$$

$$\tau_{\max} = 169.9 \text{ MPa}$$

$$\sigma_{1,2} = \frac{\sigma_x + \sigma_y}{2} \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$\tau_{\max} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

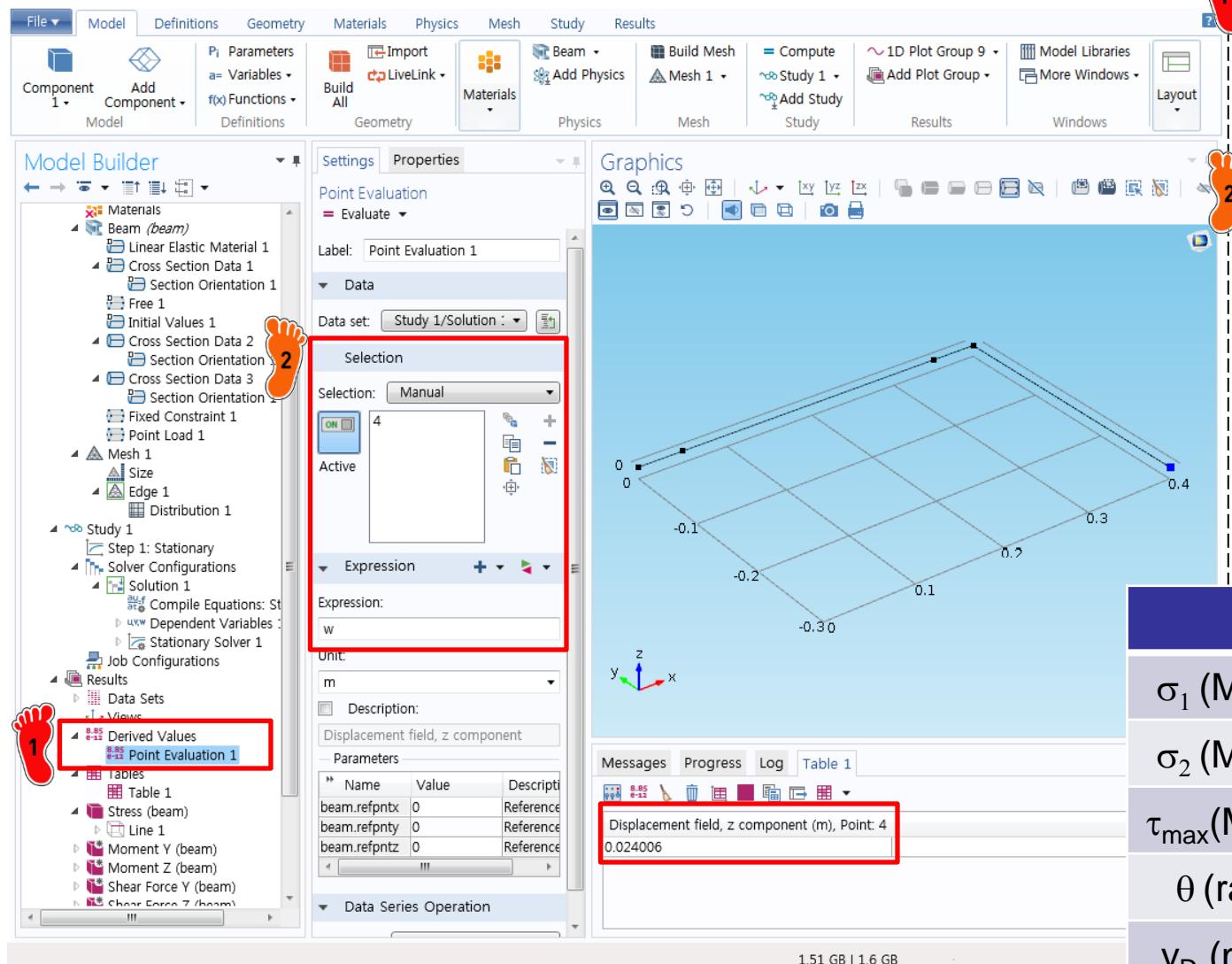
POST-PROCESSING



3번 부재의 회전 각도는 thx Expression 으로 확인

0.0367 rad 회전

POST-PROCESSING



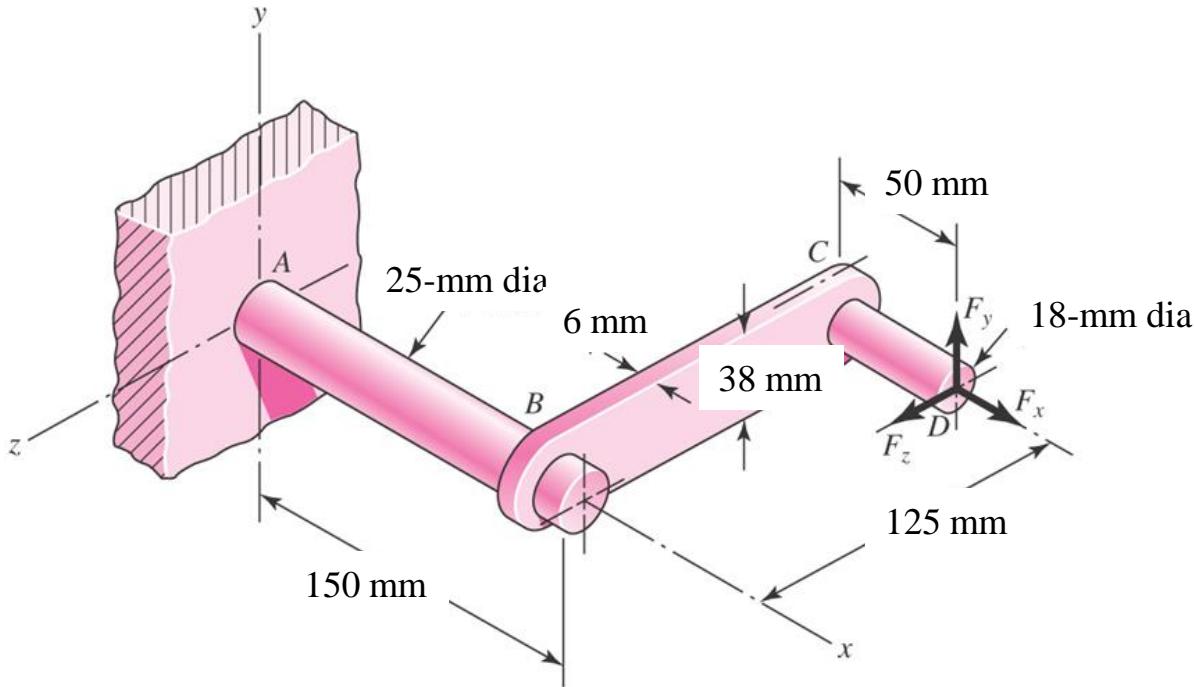
1 Derived Values에서 Point Evaluation 생성

2 4번 Point 선택 후 w 입력

z 방향 변위는 24.006 mm

	Anal.	FEM
σ_1 (MPa)	298.8	298.9
σ_2 (MPa)	-40.9	-40.9
τ_{max} (MPa)	169.8	169.9
θ (rad)	0.0367	0.0367
y_D (mm)	24.005	24.006

ASSIGNMENT



Loads

- $F_y = 800 \text{ N}$
- $F_x = F_z = 0 \text{ N}$

[Obtain both analytical and numerical solutions]

The cantilevered handle is made from mild steel that has been welded at the joints.

- Determine the location of the critical stress.
- Determine the principal stresses and the maximum shear stress.
- Determine the vertical deflection at the tip. (Use superposition for the analytical solution.)

[solutions]

$$\sigma_1 = 113.7 \text{ MPa}, \sigma_2 = -9.4 \text{ MPa}, \tau_{\max} = 61.6 \text{ MPa}, y_D = -2.55 \text{ mm}$$