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Pressure Vessel Engineering Ltd. provides: ASME Vessel Code Calculations - Finite Element Analysis (FEA) - Solid Modeling / Drafting - Canadian Registration Number (CRN) Assistance

SolidWorks Simulation Validation Examples – SolidWorks Simulation 2010 x64 SP4.0

Summary

Simulation has a number of validation problems built into the software. These problems are designed to prove the validity of its operation. Each problem provides an analytical and Simulation generated solution for the problem.

Pressure Vessel Engineering validates each installation and update of the Simulation software individually. The Simulation validation problems are run in-house and results compared to the analytical solutions. All results are measured to be within 5% error or less of the Simulation results.

Solidworks Simulation Built in Validation Sets (Distributed with SolidWork Simulation 2010 SP4.0)

COSMOS Static Verification Problems

This document contains verification problems to demonstrate the accuracy of static analysis of the COSMOS software.

Simply Supported Rectangular Plate	Clamped Beam Subject to Prescribed Displacement
Deflection of a Cantilever Beam	Bending of a Solid Beam
Tip Displacements of a Circular Beam	Thermal Stress Analysis of a 3D Structure
Cylindrical Shell Roof	Rotating Solid Disk
Torsion of a Square Box Beam	Laterally Loaded Tapered Beam
Effect of Transverse Shear on Maximum Deflection	Bending of a Cantilever Beam
Reactions and Deflections of a Cantilever Beam	Pin with Rotational Spring
Bending of a T Section Beam	Deformation of a Uniformly Loaded Beam
Bending of a Circular Plate with a Center Hole	Shear Stress in Hollow Cylinder
Circular Plate Under a Concentrated Load	Deflection of a Cantilever Under Gravity
Test of a Pinched Cylinder with Diaphragm	Conical Shaped Vessel Under Centrifugal Load
Clamped Square Plate Under Uniform Loading	Tensile Stress in a Steel Bar
Thermal Stress Analysis of a 2D Structure	Hoop Stress in Thin Walled Pressure Vessel
Fixed Frame Subject to Horizontal Force	Space Truss with Vertical Load

NAFEMS Benchmarks

Additional verification files

COSMOS NAFEMS Verification Problems

This document contains selected NAFEMS benchmarks for linear static problems.

Cylindrical Shell Under Edge Moment	Cylindrical Shell Under Pressure
Elliptic Membrane Under Pressure	Z-section Cantilever Under Torsion Bending
Skew Plate Under Normal Pressure	Hemisphere Under Point Loads

All verification samples have been run by Pressure Vessel Engineering

Run on SolidWorks Simulation 2010 x64 SP4.0.

#1 Simply Supported Rectangular Plate

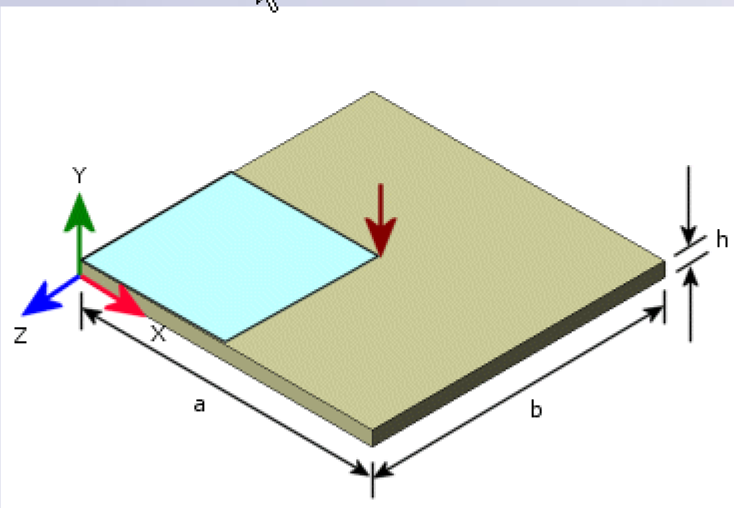
Description

Calculate the deflection at the center of a simply supported isotropic plate subjected to:

A. Concentrated load F = 400 lbs, and

B. Uniform pressure q = 1 psi.

Dimensions of the plate are as follows: h = 1 in, a = b = 40 in.



Results

The deflection at the center of the plate is calculated and compared to analytical solution.

Case	X (in)	Y (in)	Deflection at the center (UY), in	
			Theory	COSMOS
Study A	20	20	0.00270230	0.00270293
Study B	20	20	0.00378327	0.00378498

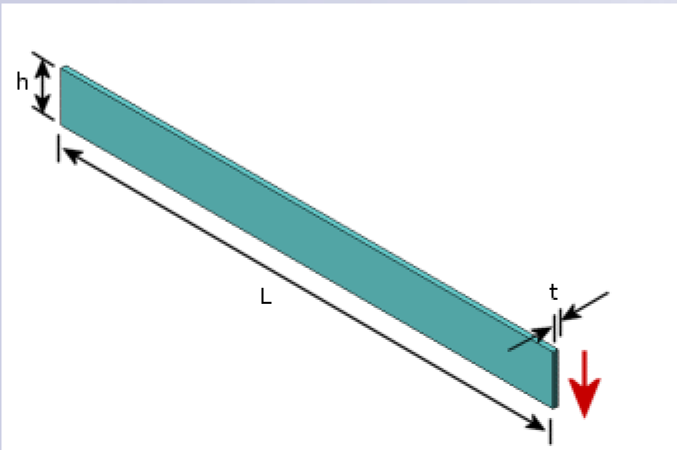
PVEng Results

Study A – 0.002703 inch Acceptable (0.03 % Error)
Study B – 0.003786 inch Acceptable (0.72 % Error)

#2 Deflection of a Cantilever Beam

Description

A cantilever beam is subjected to a concentrated load (F = 1 lb) at the free end. Determine the deflections at the free end and the average shear stress. Dimensions of the cantilever are: L = 10", h = 1", t = 0.1".



Results

	Theory	COSMOS
Deflection at free edge (UY), inch	0.001333	0.001344
Average Shear Stress (TauXY), psi	10.0	9.877

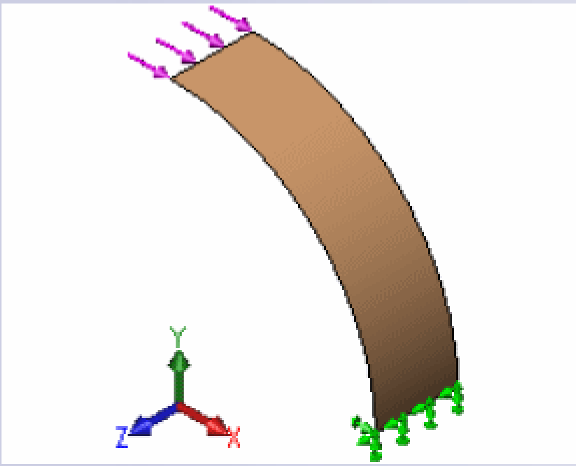
PVEng Results

Deflection – 0.001341 inch Acceptable (0.60 % Error)
Shear Stress - 9.9470 psi Acceptable (0.56 % Error)

#3 Tip Displacement of a Circular Beam

Description

A circular beam fixed at one end and free at the other end is subjected to a 200 lb force as shown in the figure. Determine the deflections in the X, Y direction. Radius of curvature of the beam = 10". The beam width and thickness are 4" and 1" respectively.



Results

The UX and UY displacements at the free edge are calculated and compared to analytical values:

	Theory	COSMOS
X Deflection at free edge (UX), inch	0.00712	0.00713
Y Deflection at free edge (UY), inch	0.01	0.01

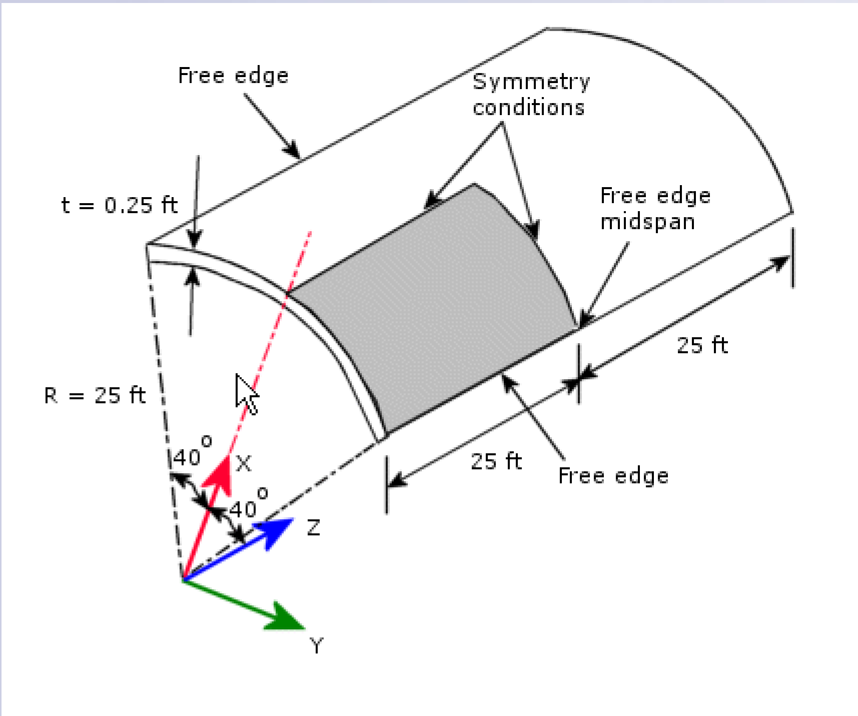
PVEng Results

Deflection X 0.007137–inch Acceptable (0.24 % Error)
Deflection Y 0.009915–inch Acceptable (0.08 % Error)

#4 Cylindrical Shell Roof

Description

Determine the vertical deflections across the midspan of a shell roof under its own weight. Dimensions and boundary conditions are shown in the figure below. The radius of curvature of the shell is R = 25 ft.



Results

The vertical displacement (UX) at midspan of the free edge is compared to analytical value:

	Theory	COSMOS
X Deflection at midspan of the free edge (UX), ft	-0.3024	-0.3009

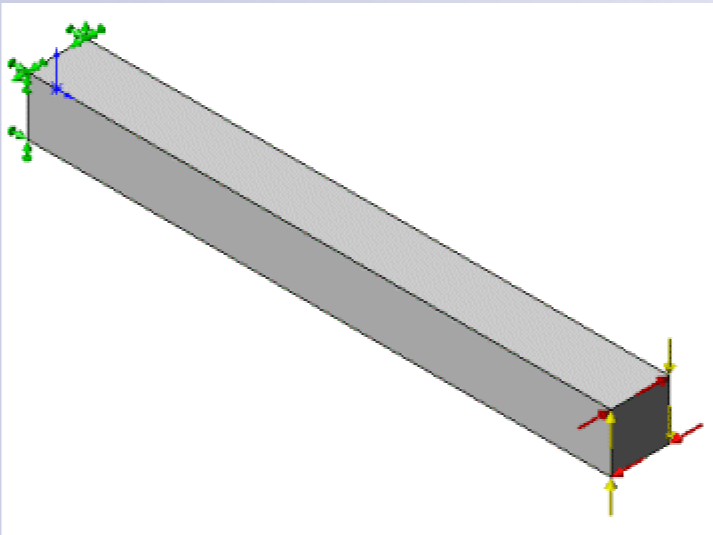
PVEng Results

Deflection X -3.610–inch (0.3008 ft) Acceptable (0.53 % Error)

#5 Torision of a Square Box Beam

Description

Find the shear stress and the angle of twist for the square box beam shown in the figure. The free end is subjected to a 300 lb-in torque. The beam has a length of 1500". The beam cross section is a square with a side length of 150".



Results

	Theory	COSMOS
Shear stress (τ xz), psi	0.0021365	0.0021866
Rotation (θ), radians	0.01541	0.01536

PVEng Results

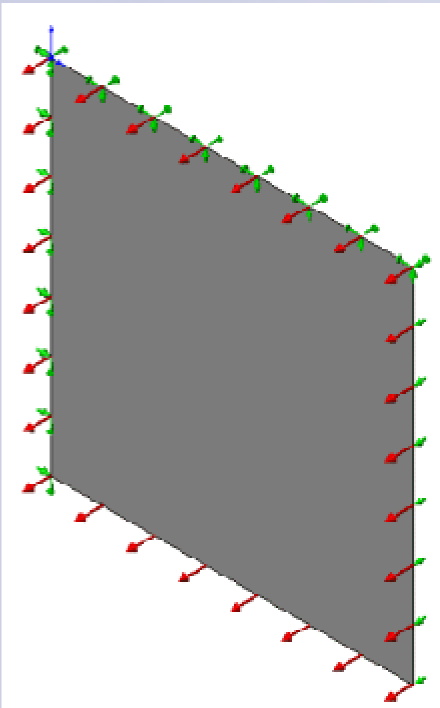
Shear Stress -0.002132 psi Acceptable (0.21 % Error)

Rotation – 0.01537 Acceptable (0.26 % Error)

#6 Effect of Transverse Shear on Maximum Deflection

Description

Find the effect of transverse shear on maximum deflection of an isotropic simply supported square plate of side (a) = 24" subjected to a constant pressure (q) = 30 psi. The plate thickness (H) varies according to the table shown below (in terms of the ratio H/a).



Results

Thickness (inches)	Thickness ratio (H/a)	Maximum Deflection (in)*	β**	
			Reissner Theory	COSMOS
1.2	0.05	0.0089718	0.044936	0.046263
2.4	0.1	0.0012079	0.046659	0.049837
3.6	0.15	0.00039057	0.049533	0.054436

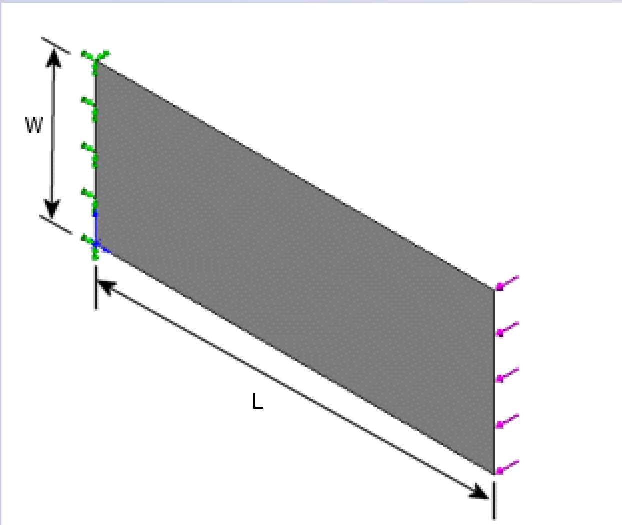
PVEng Results for Deflection

1.2 inches thick 0.0089718 Error Not Measured
2.4 inches thick 0.0012079 Error Not Measured
3.6 inches thick 0.00039057 Error Not Measured

#7 Reactions and Deflections of a Cantilevered Beam

Description

Calculate reactions and deflections of a cantilever beam subjected to an 8 lb force acting on the free end of the cantilever as shown in the figure below. The cantilever dimensions are: L = 10" and W = 4".



	Theory	COSMOS Shell Mesh	COSMOS Beam Mesh
Maximum deflection at tip, in	2.667e-4	2.572e-4	2.667e-4
Total reaction force, lb	8	8	8

PVEng Results for Deflection

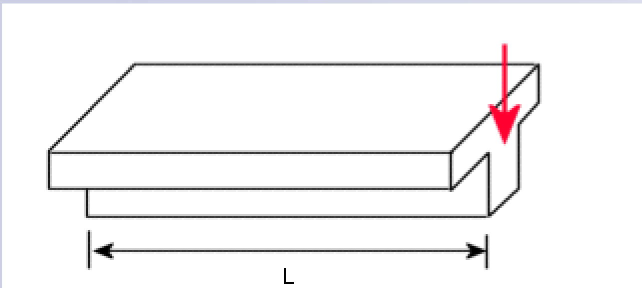
Beam Mesh: 2.667e-4 Acceptable (0.63% Error)
Beam Mesh Reaction: 8 Acceptable (0% Error)

Shell Mesh: 2.575e-4 Acceptable (3.67% Error)
Shell Mesh Reaction: 8 Acceptable (0% Error)

#8 Bending of a T Section Beam

Description

Calculate the deflections of a cantilever T beam of length L = 2000" subjected to a force of 100 lbs acting on its free end.



Results

The following analytical solutions are used to calculate displacements and rotations: δ (displacement) = $PL^3/3EI$, ϕ (rotation) = $PL^2/2EI$.

Where P is the value of the applied force, E is the cantilever's modulus of elasticity, and I is the moment of inertia of the beam cross section.

		Theory	COSMOS Solid Mesh	COSMOS Beam Mesh
Free end	Y-displacement (in)	-5.546e-6	-5.485e-6	-5.546e-6
	X-Rotation (rad)	4.159e-9	4.126e-9	4.159e-9

PVEng Results for Deflection and Rotation

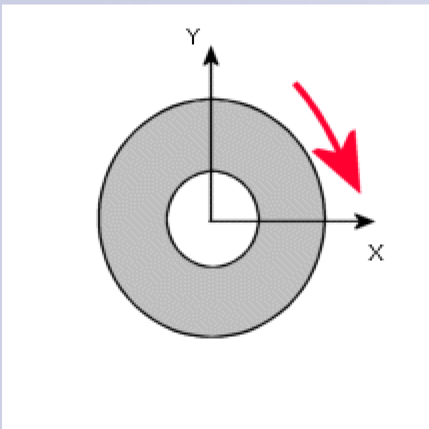
Beam Mesh Y-Displacement: -5.55e-6 Acceptable (0% Error)

Beam Mesh X-Rotation: 4.159e-9 Acceptable (0% Error)

#9 Bending of a Circular Plate with a Center Hole

Description

A circular plate with a center hole is fixed along the inner edge. The outer edge of the plate is subjected to bending by a moment M = 10 in-lb/in. Determine the maximum deflection and the maximum slope of the plate. The plate thickness is 0.25" and the outer and inner radii of the plate are 30" and 10" respectively. Due to symmetry of the problem, a 10^{o} wedge is modeled. The applied moment is equivalent to applying a moment of 52.359 lb-in per 10^{o} segment.



Results

	Theory	COSMOS
Maximum deflection (UZ), inch	0.04906	0.04786
Maximum rotation (RY), rad	0.0045089	0.004519

PVEng Results for Deflection and Rotation

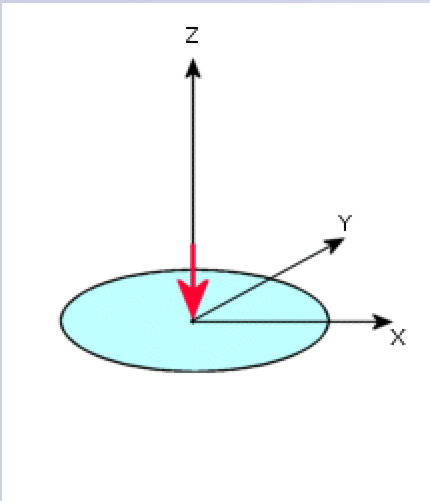
Deflection: 0.04784 Acceptable (2.49% Error)

Rotation: 0.00464 Acceptable (2.91% Error)

#10 Circular Plate Under a Concentrated Load

Description

A circular thick plate of radius 5" is subjected to a load of 4 lb at its center. The plate is clamped at its boundary. Determine the transverse displacement along the radius r.



Results

Distance from the plate center, r (in)	Analytical	COSMOS
0.0	---	5.465E-06
1.0	3.53748E-06	3.566E-06
2.0	2.19719E-06	2.225E-06
3.0	1.14364E-06	1.152E-06
4.0	3.88628E-07	3.913E-07
5.0	0	0.00E+00

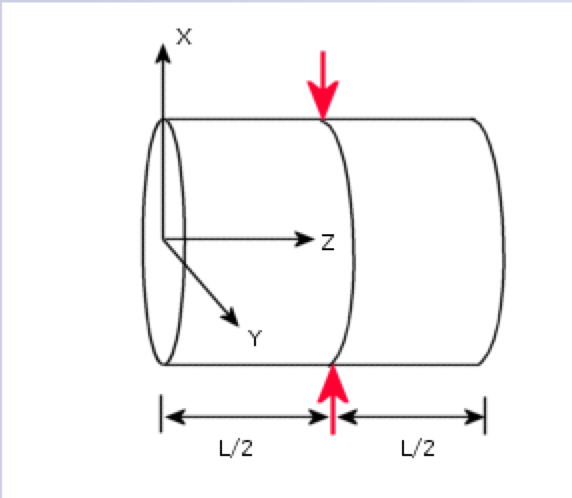
PVEng Result for Displacement

0.0: 5.465e-6 No Analytical
1.0: 3.565e-6 Acceptable (0.77% Error)
2.0: 2.224e-6 Acceptable (1.22% Error)
3.0: 1.151e-6 Acceptable (0.64% Error)
4.0 3.913e-7 Acceptable (0.69% Error)
5.0 0 (Zero) Acceptable (0% Error)

#11 Test of a Pinched Cylinder with Diaphragm

Description

A cylindrical shell of thickness 3" is covered at both ends with rigid diaphragms to allow displacement only along its axial direction. At the cylinder mid-span, a load of 1 lb is applied as shown in the figure below. Determine the radial deflection at the point where the load is applied. The radius and length of the cylinder are 300" and 600" respectively.



Results

	Theory	COSMOS
Radial deflection (UX), in	1.8248e-5	1.852e-5

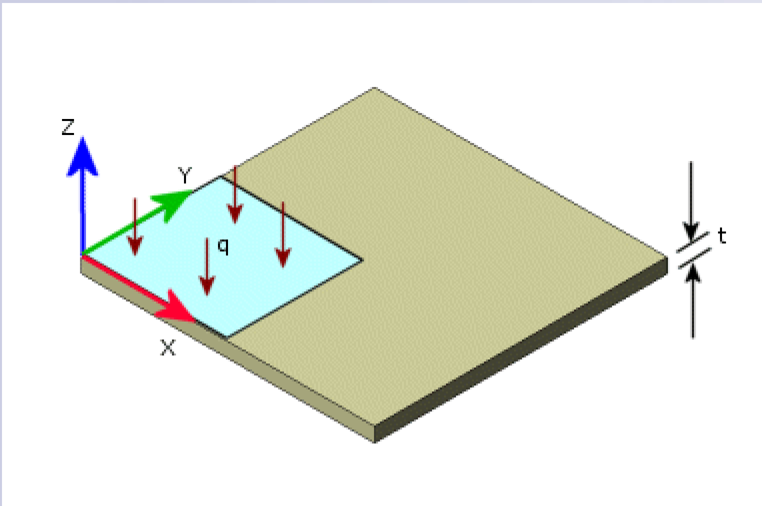
PVEng Results for Deflection

Deflection: 1.852e-5 Acceptable (1.49% Error)

#12 Clamped Square Plate Under Uniform Loading

Description

Determine the deflection at the center of a square plate of side 2" and thickness (t). The plate is clamped at its boundaries and subjected to uniform pressure (q). Various span-to-thickness ratios are investigated.



Results

Span/Thickness Ratio	Deflection (in)	
	Theory	COSMOS
10 (q = 1.0 psi)	-2.7518E-6	2.7923E-6
100 (q = 1.0 psi)	-2.7518E-3	2.7923E-3
1000 (q = 0.01 psi)	-2.7518E-2	2.7923E-2

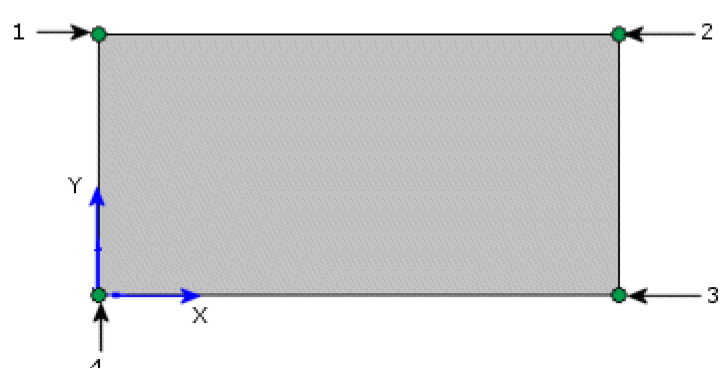
PVEng Results for Displacement

10(q = 1.0 psi): 2.7923e-6 Acceptable (1.47% Error)
100(q = 1.0 psi): 0.0027923 Acceptable (1.47% Error)
1000(q = 0.01 psi): 0.027923 Acceptable (1.47% Error)

#13 Thermal Stress Analysis of a 2D Structure

Description

A rectangular plate of dimensions 1"X2"X0.1" is subjected to a uniform temperature rise of 100^{o} F. The plate is restrained as shown in the figure. Determine the maximum Y displacement and the normal stress in the X direction.



Vetrices 1, 2, and 3 are restrained in the X-direction.
Vertex 4 is fixed.

Results

	Theory	COSMOS
Y - displacement (in)	0.0008125 ($6.5 * 10^{-6}$ x 100 x (1+0.25))	0.0008125
SX - stress (psi)	19500 ($3*10^{7}$ x $6.5 * 10^{-6}$ x 100)	19500

PVEng Results for Displacement and Stress

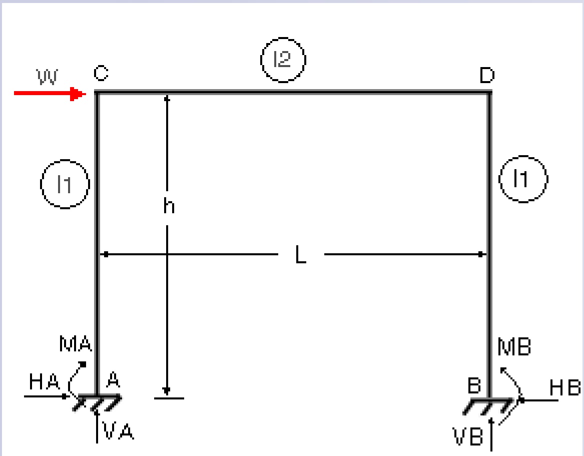
Y-Displacement: 0.0008125 Acceptable (0% Error)

SX – Stress: 19500 Acceptable (0% Error)

#14 Fixed Rectangular Frame Subject to Horizontal Force

Description

A fixed rectangular frame ABCD with dimensions: L = 360" and h = 180" is subjected to a horizontal force of 10 lb acting on joint C. Calculate the support reactions and moments.



Results

	Theory	COSMOS
Vertical Reaction Force: VA = -VB (lb)	1.875	1.875
Horizontal Reaction Force: HA = - HB (lb)	5.0	5.0
Reaction Moment: MA = - MB (lb-in)	562.5	562.5

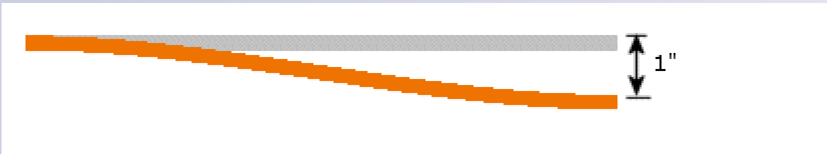
PVEng Results for Reaction Forces

Vertical Reaction Force: 1.875 Acceptable (0% Error)
Horizontal Reaction Force: 4.9999 Acceptable (0% Error)
Reaction Moment MA: 562.51 Acceptable (0% Error)

#15 Clamped Beam Subject to Prescribed Displacement

Description

Determine the maximum stress and support force of a clamped beam due to a 1 inch settlement at the right end. The length of the beam is 80" and the beam has a square cross section of dimensions 2"X2".



Results

	Theory	COSMOS Shell Mesh	COSMOS Beam Mesh
Maximum stress at support (psi)	28125	28407	28125
Support reaction force (lb)	937.50	916.22	937.50

PVEng Results Stress and Reactions

Shell Mesh Max Stress: 28343 Acceptable (0.78% Error)
Shell Mesh Reaction Force: 938.87 Acceptable (0.15% Error)

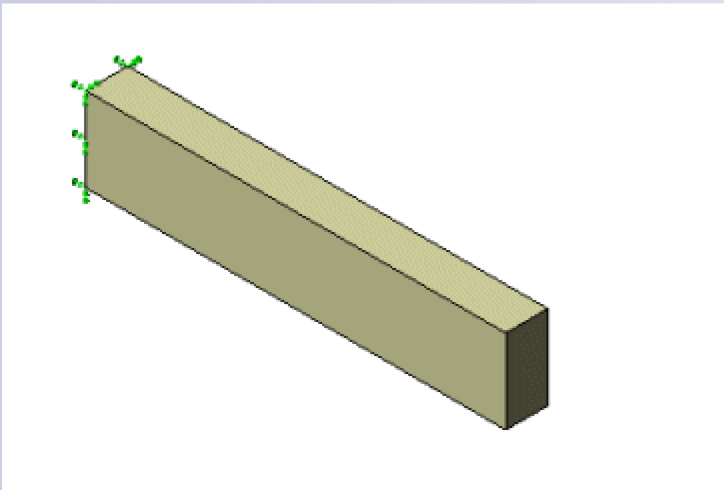
Beam Mesh Max Stress: 28090 Acceptable (0.12% Error)
Beam Mesh Reaction Force: 936.28 Acceptable (0.13% Error)

#16 Bending of a Solid Beam

Description

A 10" long cantilever beam has a rectangular cross section of 1" width and 2" height. Find the deflection of the free end under the effect of the following loads:

- an end moment of 2000 in-lb, and
- a shear force of 300 lbs.



Results

Y-displacement at the free end (UY), in	Theory	COSMOS Solid Mesh	COSMOS Beam Mesh
End moment (Moment Study)	-0.005	-0.005006	-0.005
Shear force (Force Study)	0.005	0.005093	0.005

PVEng Results for Moment and Shear Force

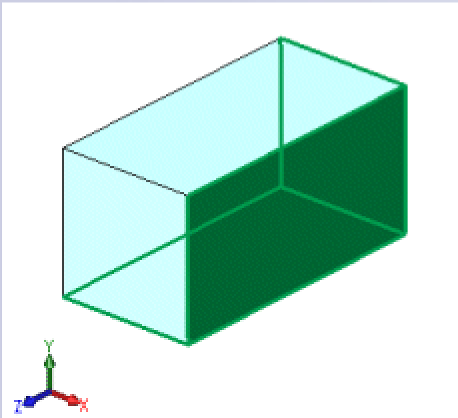
Solid Mesh Displacement End Moment: -0.005007 Acceptable (0.14% Error)
Solid Mesh Displacement Shear Force: -0.005092 Acceptable (1.84% Error)

Beam Mesh Displacement End Moment: -0.005 Acceptable (0% Error)
Beam Mesh Displacement Shear Force: -0.005 Acceptable (0% Error)

#17 Thermal Stress Analysis of a 3D Structure

Description

Determine the maximum displacements of a solid rectangular block of dimensions 1"X1"X2" due to a uniform temperature rise of 100 ^{o}F. Three orthogonal faces of the block are restrained in their normal directions.



Results

Z-translation (UZ), in	Theory	COSMOS
At Mid plane	6.5e-4 (1*100*6.5e-6)	6.5e-4
At Free End	1.3e-3 (2*100*6.5e-6)	1.3e-3

PVEng Results for Translation

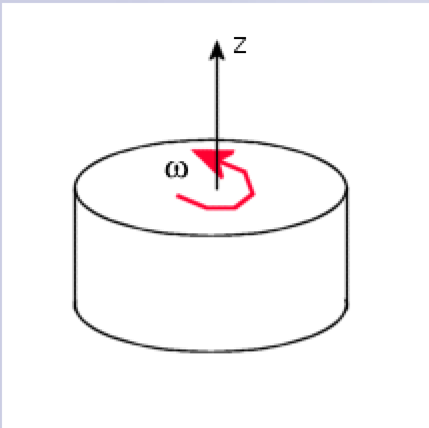
At Mid Plane: 6.5e-4 Acceptable (0% Error)

At Free End: 1.3e-3 Acceptable (0% Error)

#18 Rotating Solid Disk

Description

A solid disk of radius 9" and thickness 1" rotates about its center with angular velocity ω = 25 rad/sec. Determine the stress distribution in the disk.



Results

		Theory	COSMOS
Location (r = 0.5")	Radial stress (**SX**), psi	416.37	404.3
	Tangential stress (**SY**), psi	416.91	415.8
Location (r = 8.5")	Radial stress (**SX**), psi	45.12	44.74
	Tangential stress (**SY**), psi	203.16	202.8

PVEng Results for Stress

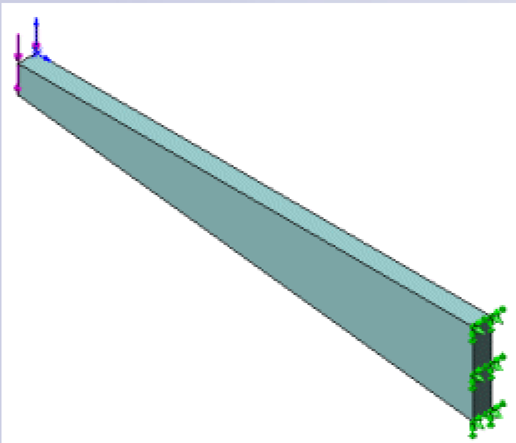
Location R 0.5" –Radial Stress: 402.1 Acceptable (3.42% Error)
Location R 0.5" –Tangential Stress: 414.4 Acceptable (0.60% Error)

Location R 8.5" –Radial Stress: 44.80 Acceptable (0.71% Error)
Location R 8.5" –Tangential Stress: 202.8 Acceptable (0.18% Error)

#19 Laterally Loaded Tapered Beam

Description

A cantilever beam of width 2" and length 50" has a depth which tapers uniformly from 3" at the tip to 9" at the wall. The cantilever beam is loaded by a 4000 lb force at the tip. Find the maximum bending stress at the mid-span of the cantilever.



Results

Bending stress at midspan (SX), psi	Solid mesh	Shell mesh using mid-surfaces
Theory	8333	8333
COSMOS	8371	8327

PVEng Results for Bending Stress

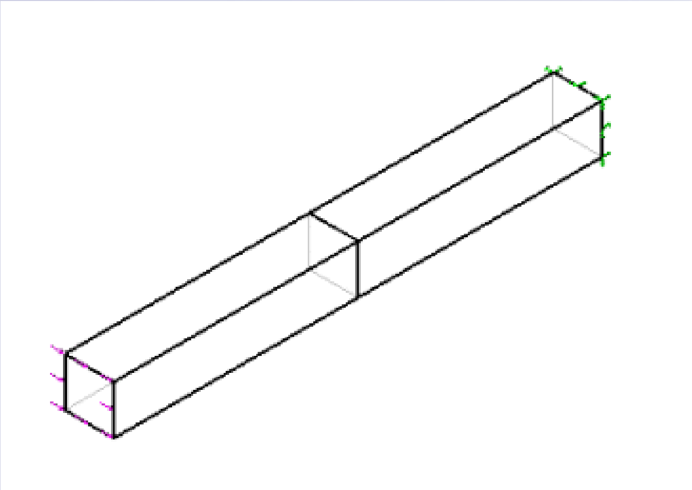
Solid Mesh: 8374 Acceptable (0.49% Error)

Shell Mesh: 8319 Acceptable (0.17% Error)

#20 Bending of a Cantilever Beam

Description

Calculate the maximum deflection and maximum rotation (θ) of a cantilever beam loaded by a shear force of magnitude 1 lb acting on the free end of the cantilever. The length of the cantilever is 10" and the dimensions of its cross section are 1"X1". The cantilever beam is modeled as two identical cantilevers connected at their common interface with a **Bonded** contact condition.



Results

	Theory	COSMOS Solid Mesh	COSMOS Beam Mesh
Displacement at the free end (UX), in	-0.004	-0.004	-0.004
Rotation at the free end, rad	-0.0006	-0.0006	-0.0006

PVEng Results for Displacement and Rotation

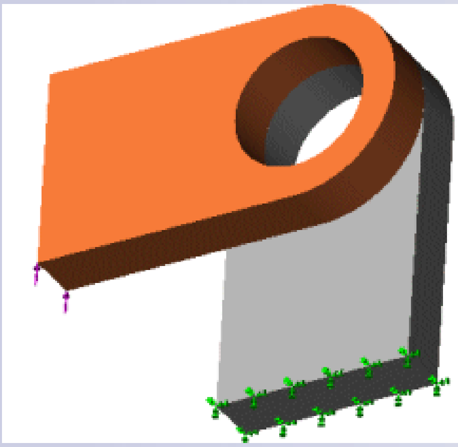
Solid Mesh Displacement: -0.004024 Acceptable (0.60% Error)
Solid Mesh Rotation: Not Measured

Beam Mesh Displacement: -0.004 Acceptable (0% Error)
Beam Mesh Rotation: -0.0006 Acceptable (0% Error)

#21 Pin with Rotational Spring

Description

The joint shown in the figure provides a 1000 lb.in/radian resistance to relative rotation. The rotation of the moving part is verified against the theoretical value.



Results

- View the UY displacement with reference to the axis of the cylindrical faces. The UY value shown in the table corresponds to the average value of UY on the cylindrical face of the moving arm.
- UY (theoretical) = (Moment/K)* Radius = (5*2/1000)*0.5= 0.005 in

	COSMOS	Theory
UY Tangential Displacement (in)	5.0027e-3	5.0000e-3

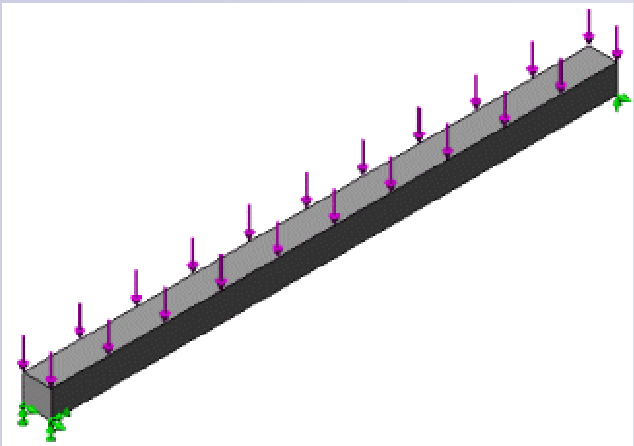
PVEng Results for Displacement

Tangential Displacement: 0.0050027 Acceptable (0% Error)

#22 Deformation of a Uniformly Loaded Beam

Description

Determine the maximum displacement in Y-direction of a uniformly loaded beam with a fixed support at one end and a simple support at the other end. The length of the beam is 20" and the beam section is a square of side 1".



Results

	Theory	COSMOS Solid Mesh	COSMOS Beam Mesh
Maximum Displacement in the Y-direction (UY), inch	1.733e-3	1.755e-3	1.728e-3

PVEng Results for Displacement

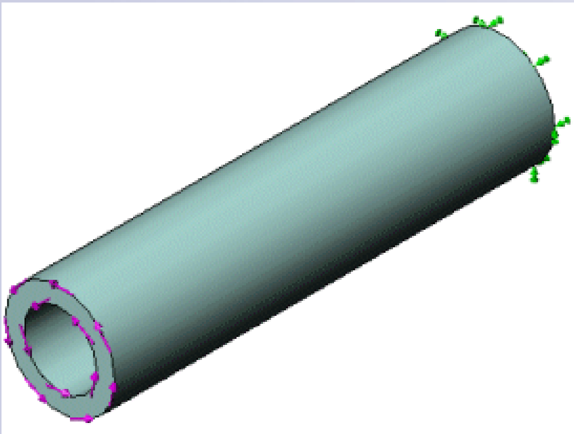
Solid Mesh Max Displacement in the Y-Direction: 1.755e-3 Acceptable (1.27% Error)

Beam Mesh Max Displacement in the Y-Direction: 1.758e-3 Acceptable (1.44% Error)

#23 Shear Stress in Hollow Cylinder

Description

Determine the shear stress in a hollow concentric cylinder fixed at one end and subjected to a torque of 10 lb-in at the other end. The inner and outer radii of the cylinder are 1" and 1.5" respectively and the length of the cylinder is 12".



Results

	Theory	COSMOS
Maximum Shear Stress (TYZ), psi	2.351	2.362

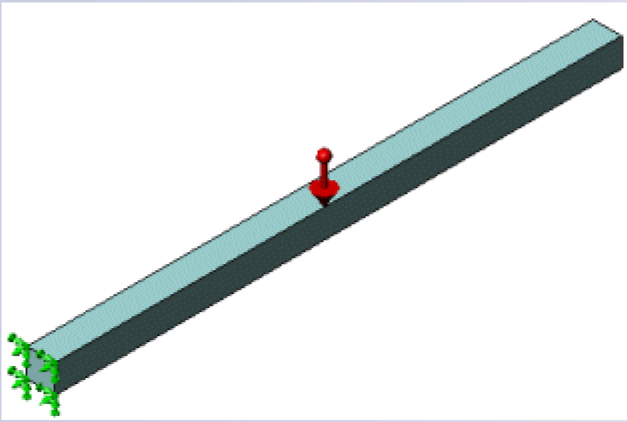
PVEng Results for Shear Stress

Max Shear Stress: 2.361 Acceptable (0.42% Error)

#24 Deflection of a Cantilever Under Gravity

Description

Determine the maximum displacement in Y-direction of a cantilever, fixed at one end, under its own weight. The length of the cantilever is 20" and its section is a square of side 1".



Results

	Theory	COSMOS
Maximum Displacement in the Y-direction (UY), inch	2.2256e-3	2.2223e-3

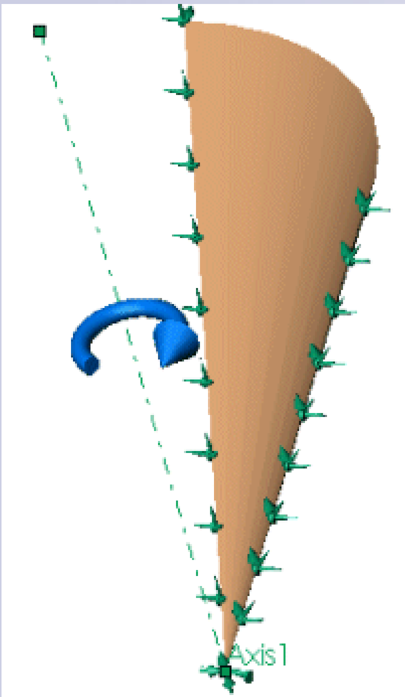
PVEng Results for Displacement

Maximum Displacement: 2.22233e-3 Acceptable (0.15% Error)

#25 Conical Shaped Vessel Under Centrifugal Load

Description

Determine the hoop stress in a thin walled conical shaped vessel subjected to centrifugal load due to angular velocity of 5 rad/sec.



Results:

	Theory	COSMOS
Hoop Stress (SY with reference to Axis1), psi	6.979e-4	6.876e-4

PVEng Results for Stress

Hoop Stress: 6.935e-4 Acceptable (0.63% Error)

#26 Tensile Stress in a Steel Bar

Description

Determine the Maximum tensile stress in a steel bar (shaped like a truncated cone with radii 1.5" and 0.5" and a height of 24") rigidly held at both ends and subjected to a temperature drop of ΔT = 50 F.

Results

	Theory	COSMOS
Maximum Tensile Stress (SY), psi	2.9265e4	3.0534e4

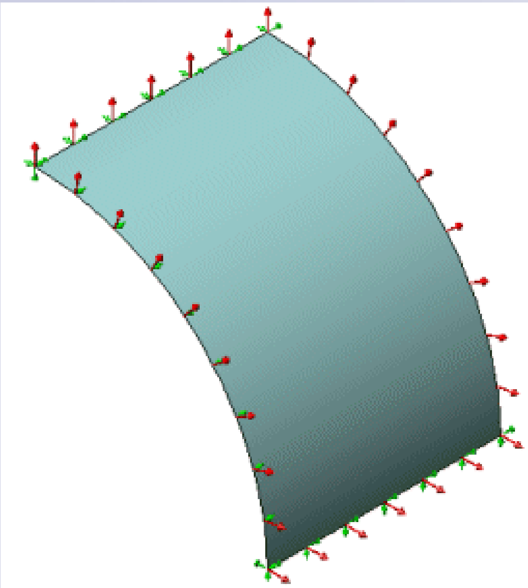
PVEng Results for Stress

Max Tensile Stress: 3.053e+4 Acceptable (4.32% Error)

#27 Hoop Stress in Thin-Walled Pressure Vessel

Description

Determine the hoop stress in a thin-walled pressure vessel under uniform radial pressure of magnitude 100 psi. The radius and thickness of the pressure vessel are 1" and 0.01" respectively.



Results

	Theory	COSMOS
Membrane Stress (SY with reference to Axis1), psi	10000	10000

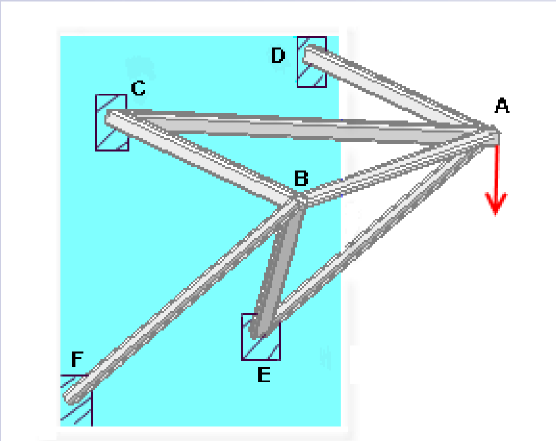
PVEng Results for Stress

Membrane Stress: 10004 Acceptable (0.4% Error)

#28 Space Truss with Vertical Load

Description

A 3D truss consists of two panels ABCD and ABEF, which are attached to a vertical wall at points C, D, E, and F. The panel ABCD is in a horizontal plane. Calculate the axial force of bar AC due to a vertical load of 1,000 lb acting on joint A.



Results

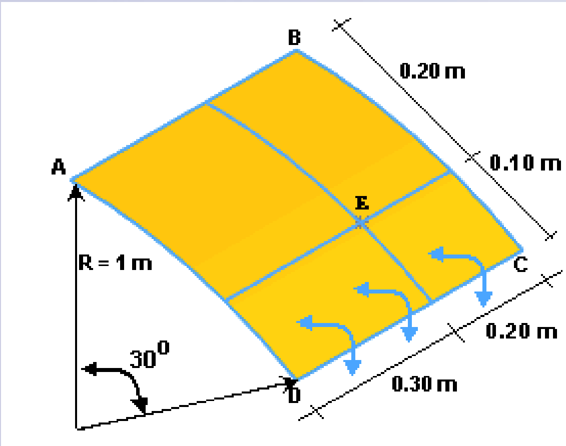
	Theory	COSMOS
Axial force of member AC (lb)	56.0	55.92

PVEng Results for Force

Axial Force of Member AC: 55.921 Acceptable (0.14% Error)

#29 Cylindrical Shell Under Edge Moment

Calculate the tangential stress at point E of the cylindrical shell under uniform edge moment on side DC of 1.0 KNm / m.



Results

	NAFEMS	COSMOS
Tangential SY stress (Reference Axis 1) at point E (MPa)	60.0	60.05

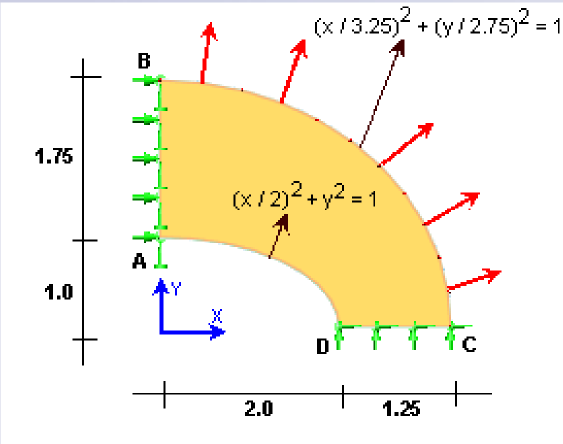
PVEng Results for Stress

Tangential Stress: 60.05 Acceptable (0.08% Error)

#30 Elliptic Membrane under Pressure

Description

Calculate the normal SY stresses at point D of an elliptic membrane under a uniform outward pressure of magnitude 10 MPa.



Results

	NAFEMS	COSMOS
Normal SY stress at point D (MPa)	92.70	92.98

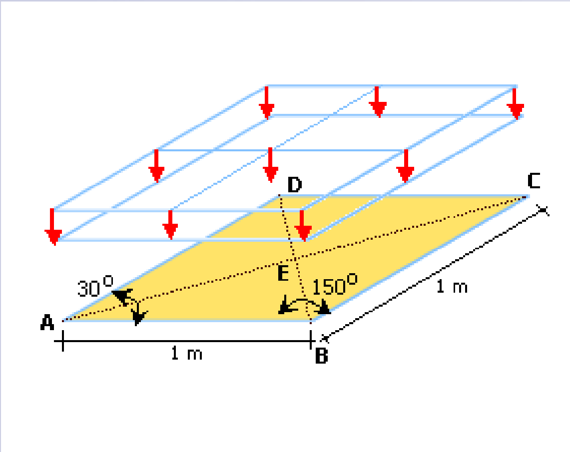
PVEng Results for Stress

Normal Stress at D: 91.56 Acceptable (1.23% Error)

#31 Skew Plate under Normal Pressure

Description

Calculate the maximum principal stress at the center E of a skew plate under a normal pressure of 0.7 KPa.



Results

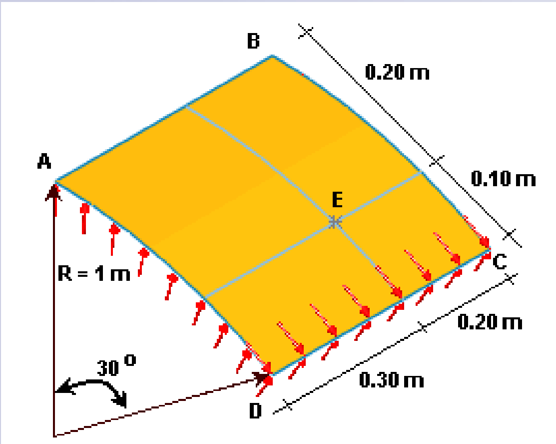
	NAFEMS	COSMOS
Maximum Principal Stress at point E (MPa)	0.802	0.806

PVEng Results for Stress

Max Principal Stress: 0.8065 Acceptable (0.56% Error)

#32 Cylindrical Shell Under Pressure Load

Calculate the tangential stress at point E of the cylindrical shell under uniform normal pressure of 0.6 MPa and tangential normal pressure of 60 MPa on edge DC.



Results

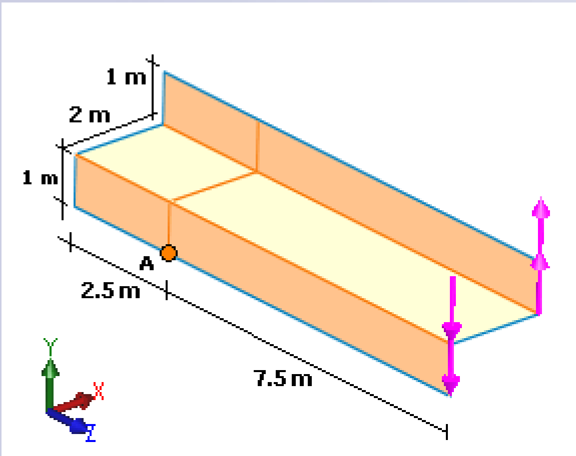
	NAFEMS	COSMOS
Tangential SY stress (Reference Axis 1) at point E (MPa)	60.0	59.85

PVEng Results for Stress

Tangential Stress at E: 59.976 Acceptable (0.04% Error)

#33 Z-section Cantilever under Torsion Bending

Calculate the normal SZ stress at point A of the cantilever under torque of 1.2 MNm. applied at the end.



Results

	NAFEMS	COSMOS
Normal SZ stress at point A (MPa)	-108.8	-109.7

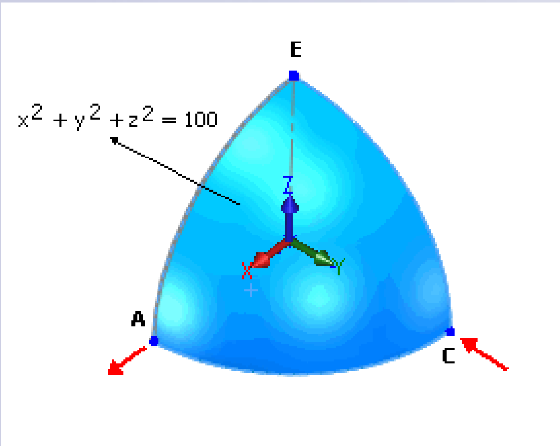
PVEng Results for Stress

Normal Stress at A: -103.6 Acceptable (4.78% Error)

#34 Hemisphere Under Point Loads

Calculate the X displacement at point A of the hemisphere due to concentrated radial loads of magnitude 2 KN applied outwards at point A and inwards at point C.

The sphere has a radius of 10 m.



Results

	NAFEMS	COSMOS
UX displacement at point A (m)	0.185	0.1847

PVEng Results for Displacement

Displacement at A: 0.185 Acceptable (0% Error)