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Effects of Geometric Imperfection on Collapse Pressure

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Abstract



Due to manufacturing tolerance and residual stresses in the stock material, it is not uncommon for a machined pipe to be out-of-round, eccentric and non-uniform in thickness. These geometric imperfections can considerably deteriorate the pipe's collapse pressure rating. Collapse pressure can be substantially overestimated if the geometric imperfections are not considered. As an example, the collapse pressure of a pipe with 15.458-in. OD and 14.842-in. ID under 400,000-lb tensile load can drop from 4,600 psi (317 bar) for a completely round pipe to 2,300 psi (158.6 bar) for an oval pipe with 0.005-in. ovality. Finite element analysis (FEA) can include the geometry imperfections in the model easily and is an ideal tool for calculating the collapse pressure.

In this presentation, the collapse pressure of the above-mentioned pipe with various tensile loads and different degrees of eccentricity, ovality, and material non-uniformity are investigated with MSC.Marc. Test results of a machined mandrel also are compared and guidelines for calculating collapse pressure with FEA are given.

Collapse Pressure

- External pressure that will cause the onset of pipe yielding. Heavily influenced by tension loads on the pipe. (SPE E&P Glossary)

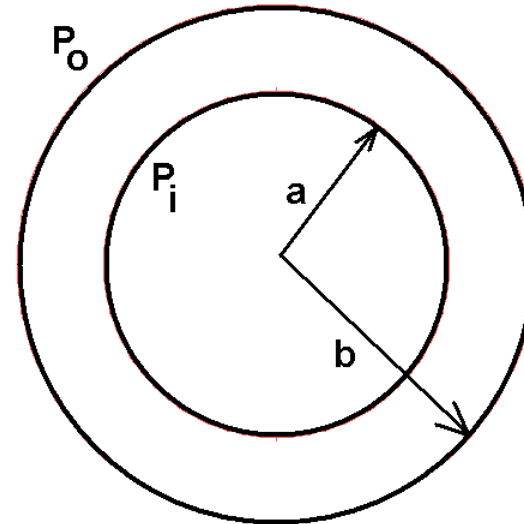


Stresses in a Pipe

- Perfectly Round, Long Pipe

$$\sigma_r = \frac{a^2 b^2 (P_o - P_i)}{b^2 - a^2} \frac{1}{r^2} + \frac{P_i a^2 - P_o b^2}{b^2 - a^2}$$

$$\sigma_\theta = -\frac{a^2 b^2 (P_o - P_i)}{b^2 - a^2} \frac{1}{r^2} + \frac{P_i a^2 - P_o b^2}{b^2 - a^2}$$



- Eccentric Pipe

Timoshenko and Goodier, "Theory of Elasticity"

Collapse Pressure – API 5C3

- Elastic Collapse

$$P_c = \frac{46.95 \times 10^6}{\left(\frac{D}{t}\right) \left(\left(\frac{D}{t}\right) - 1\right)^2}$$

- Plastic Collapse

$$P_c = \sigma_y \left(\frac{A}{\left(\frac{D}{t}\right)} - B \right) - C$$

- Transition Collapse

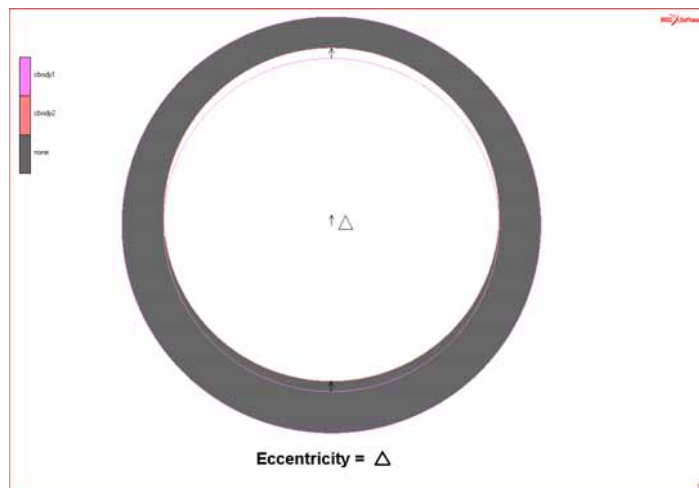
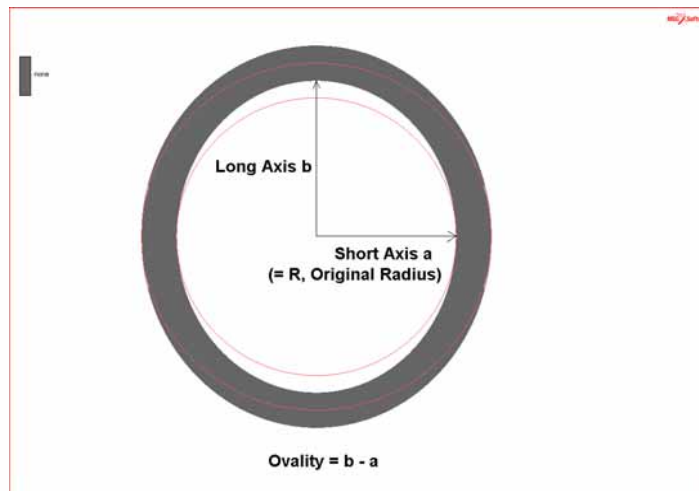
$$P_c = \sigma_y \left(\frac{F}{\left(\frac{D}{t}\right)} - G \right)$$

- Yield Collapse

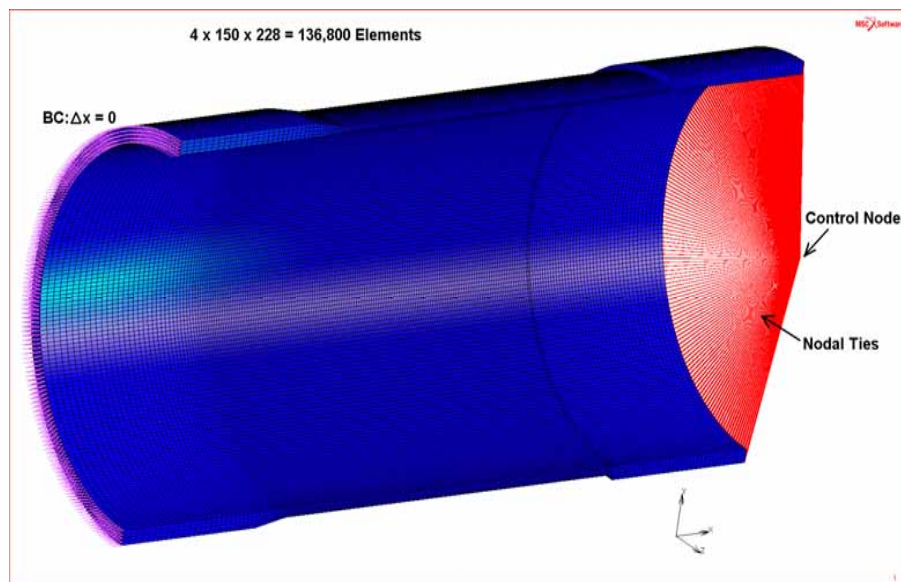
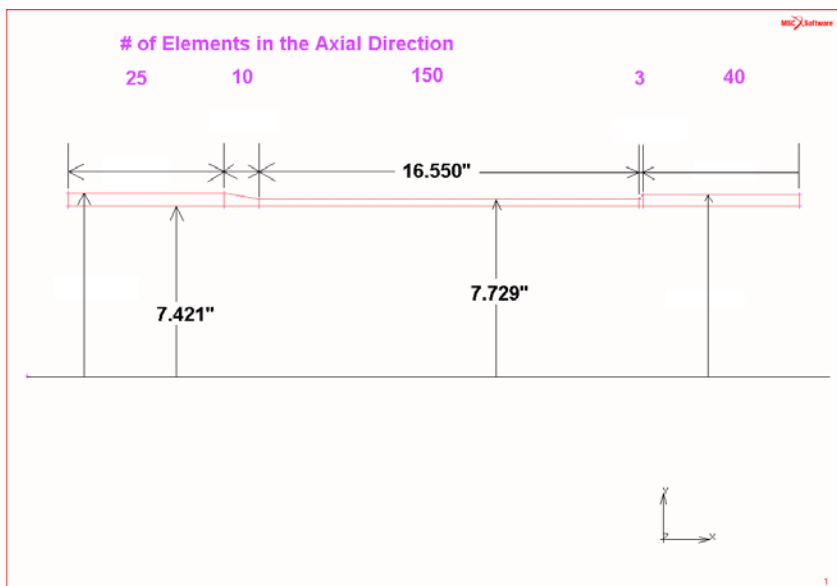
$$P_c = 2\sigma_y \left(\frac{\left(\frac{D}{t}\right) - 1}{\left(\frac{D}{t}\right)^2} \right)$$

Geometric Imperfections

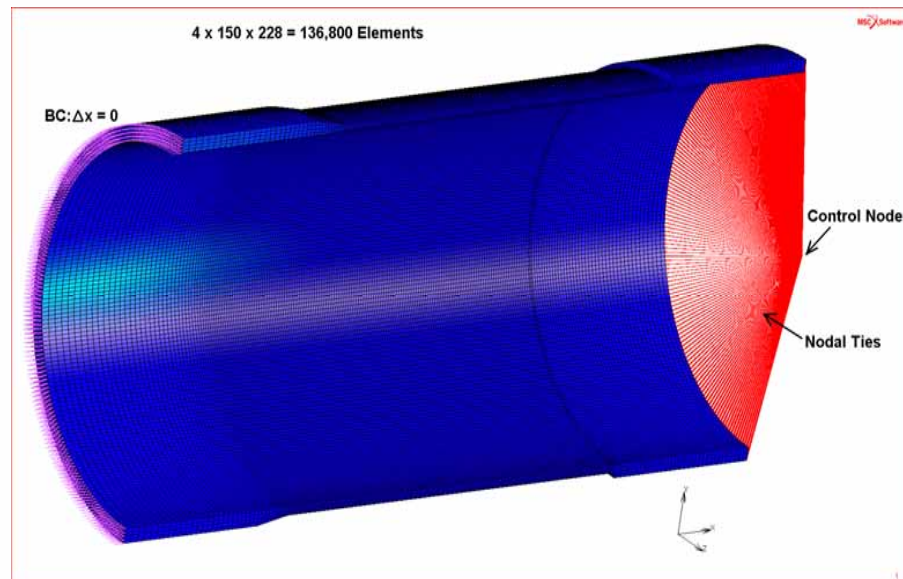
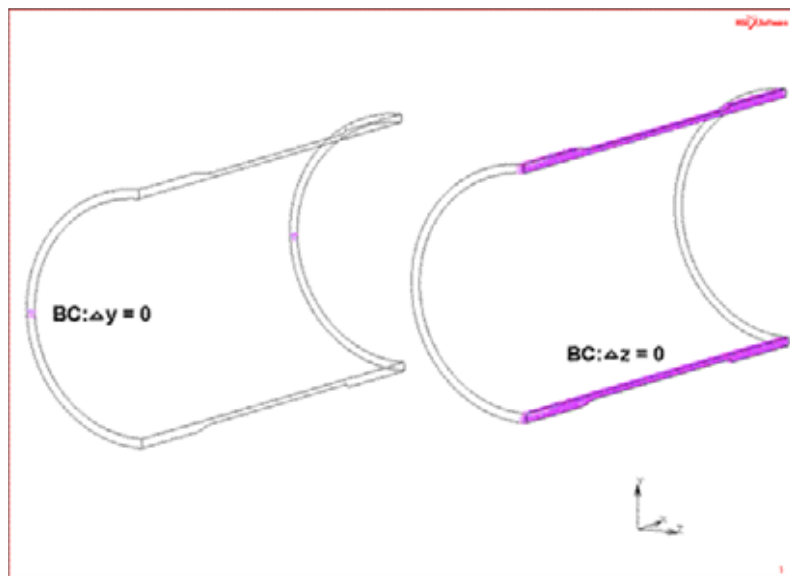
- Ovality
- Eccentricity
- Non-Uniform Thickness
- Combination of the Above



Geometry and Mesh



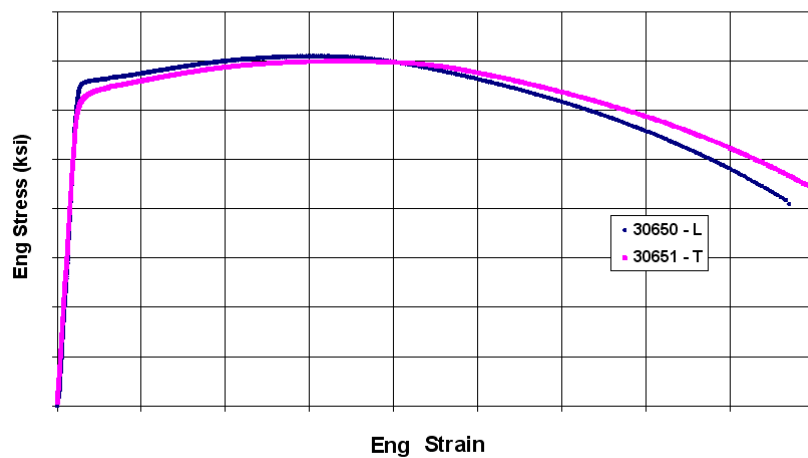
Boundary Conditions



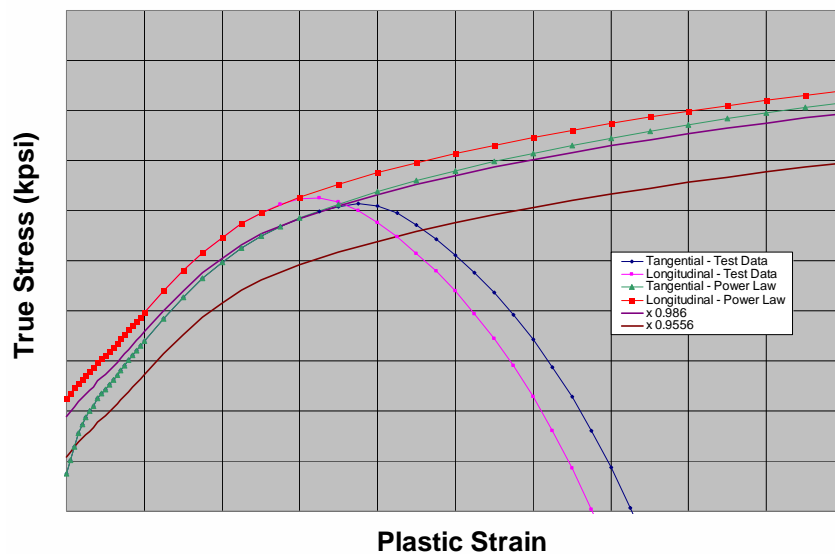
Material Properties

- Orthotropic Material with Hill's Yield Criteria

Eng Stress/Strain Curves



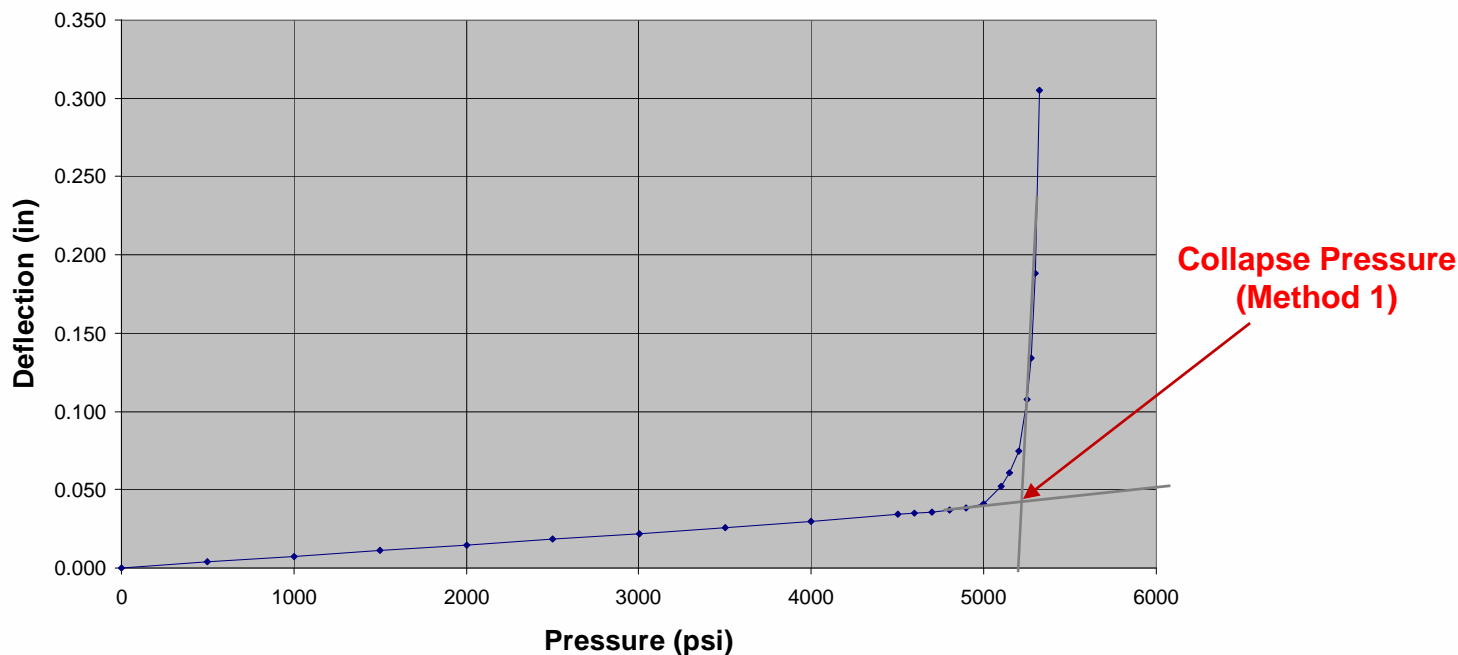
True Stress - Plastic Strain Curve



Determination of Collapse Pressure

- Method 1: Intersection of two tangent curves
- Method 2: Maximum Inward Deflection = 0.050"
- Method 3: Highest plastic strain reaches 0.002

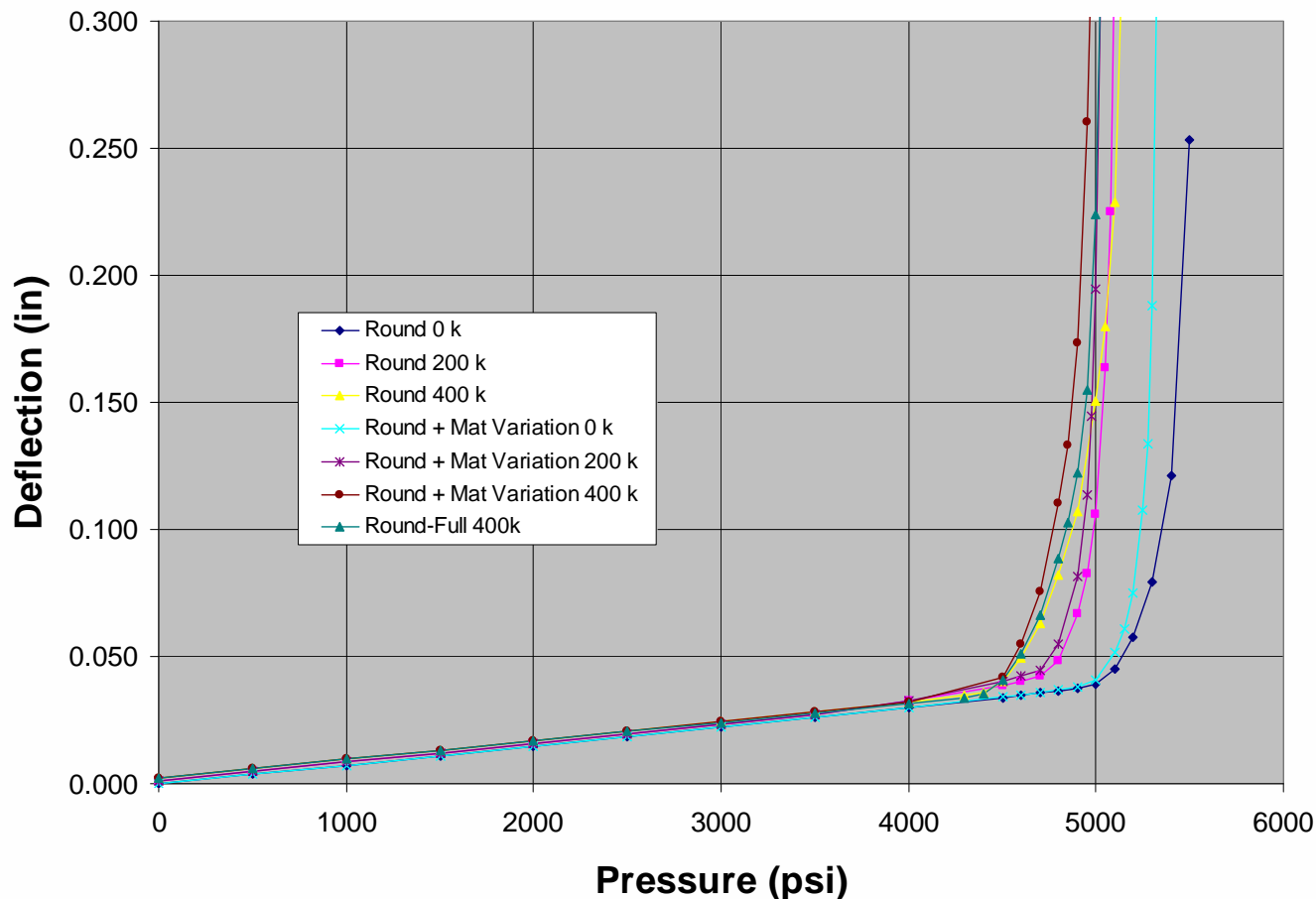
Pressure vs Max Inward Deflection



Collapse Pressure of Round Mandrel

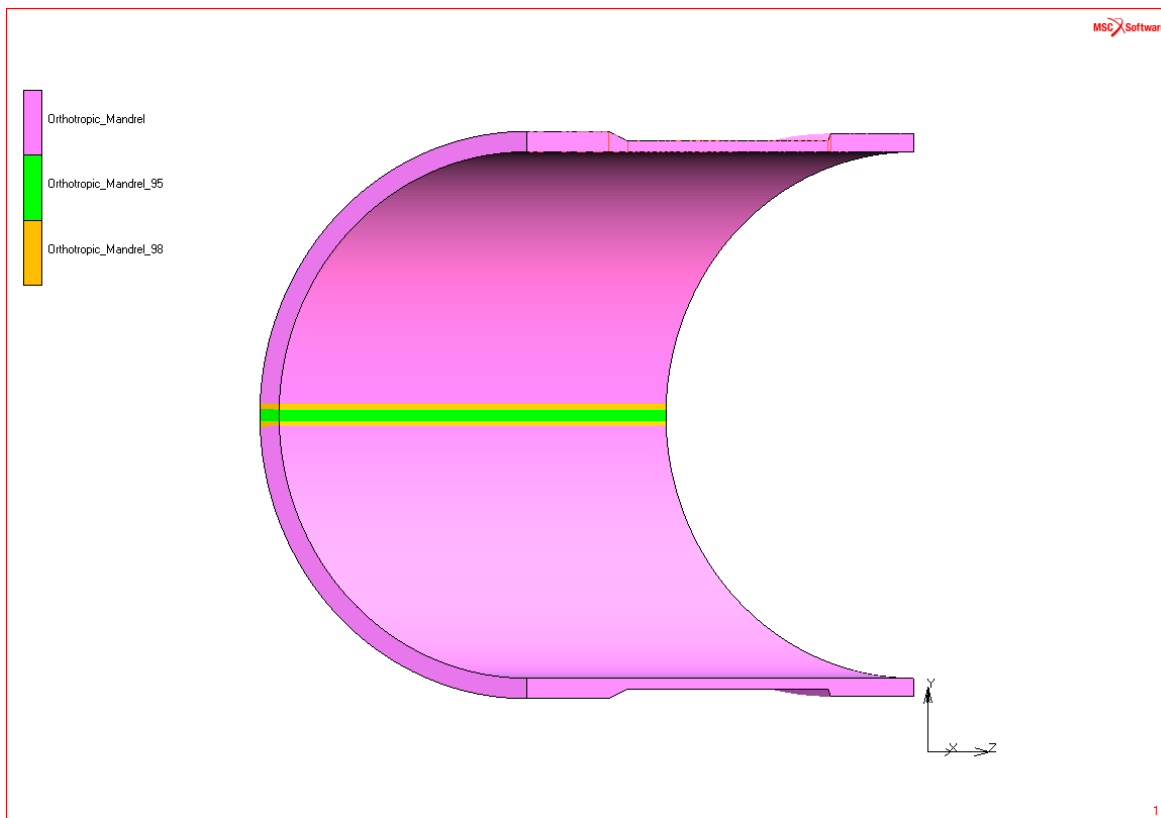


Pressure vs Max Inward Deflection - Round Mandrel



Collapse Pressure – Effects of Nonuniform Material Properties

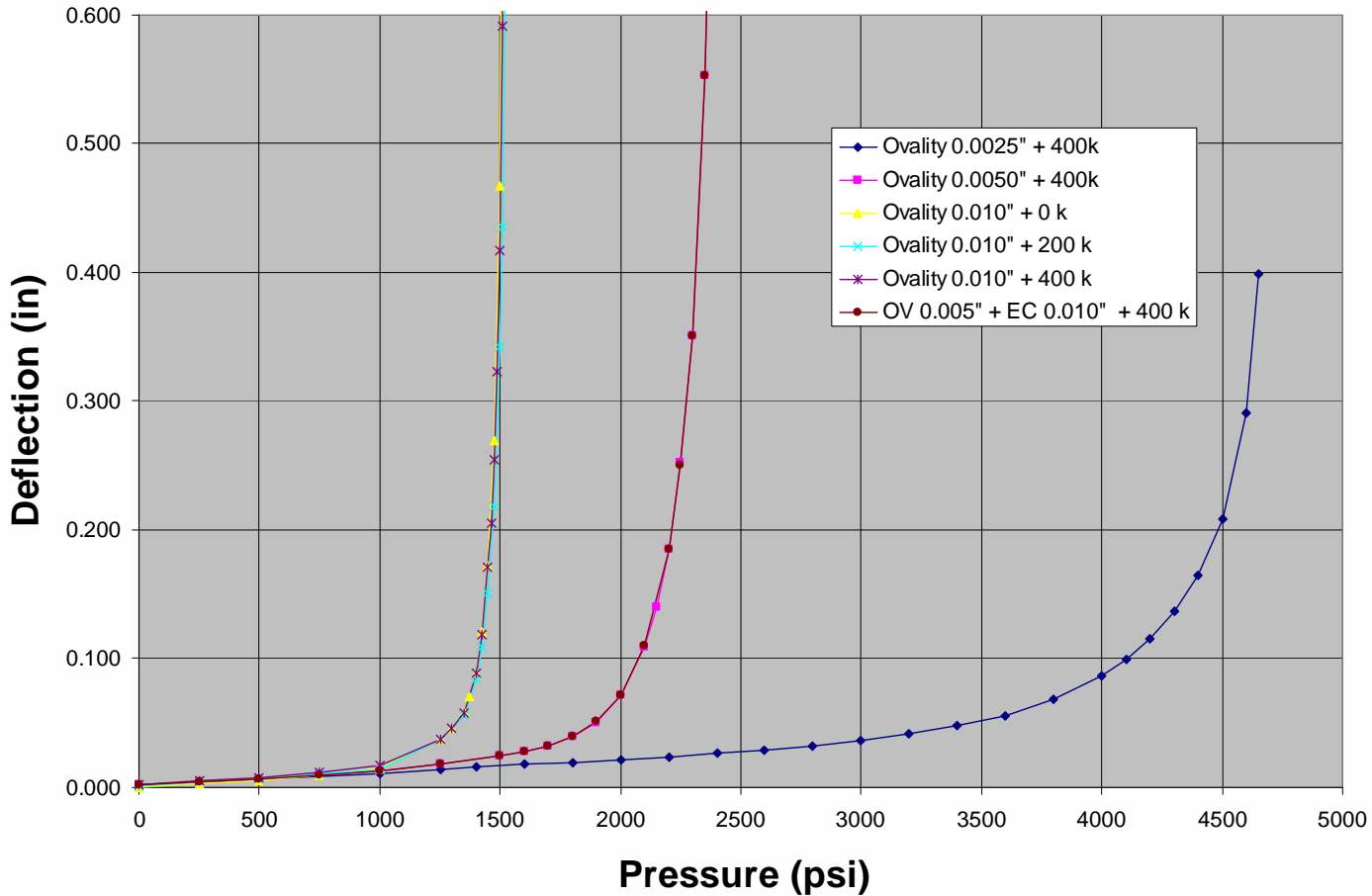
- Nonuniform Material Properties



Collapse Pressure – Effects of Ovality



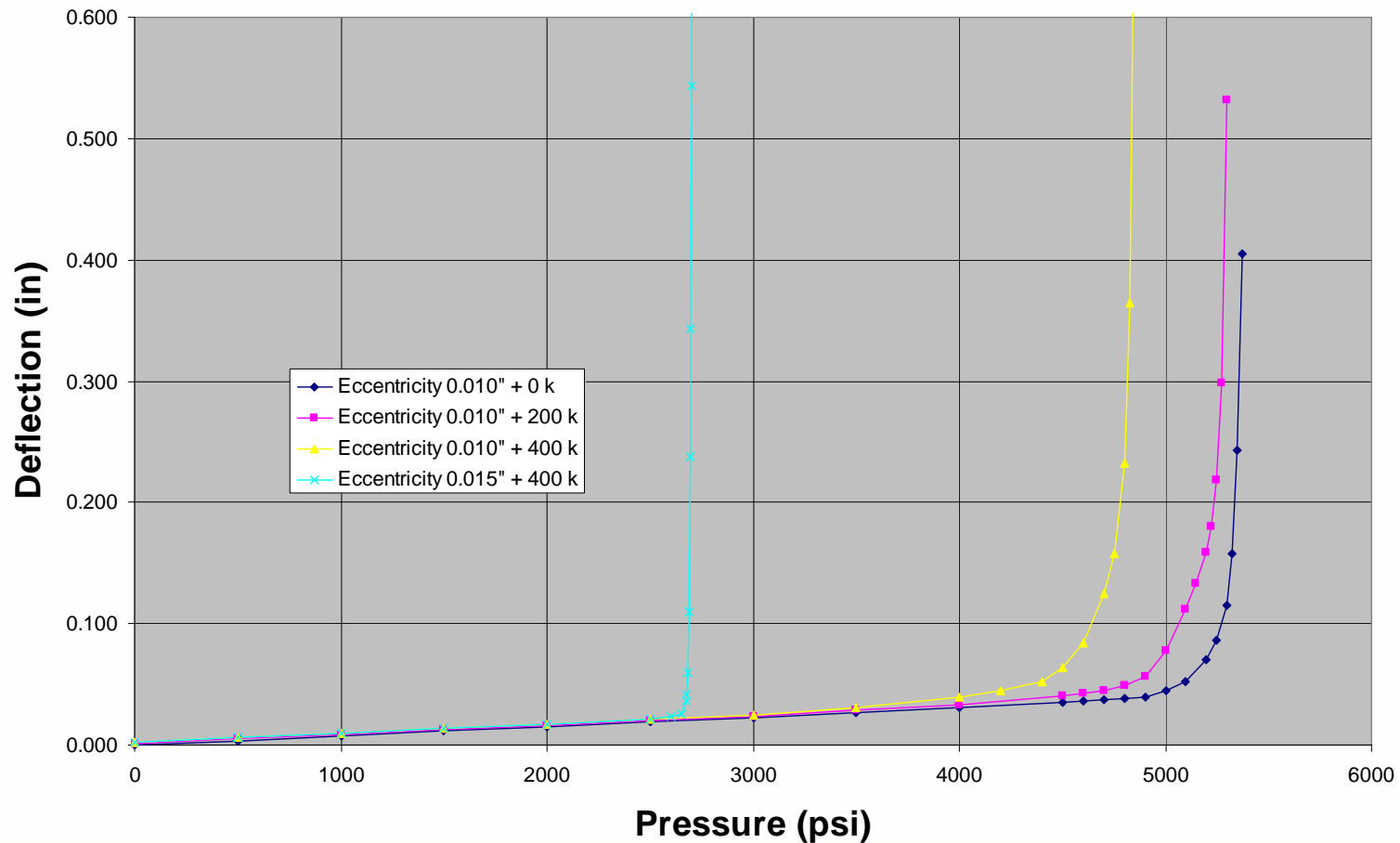
Pressure vs Max Inward Deflection - Ovality



Collapse Pressure – Effects of Eccentricity



Pressure vs Max Inward Deflection - Eccentricity



Collapse Pressure



	Collapse Pressure (psi)		
	Method 1	Method 2	Method 3
Round + 0K	5350	5150	5200
Round + 200K	5050	4800	4900
Round + 400K	5100	4600	4600
Round + 400K Full Model	5000	4600	4600
M95 + 0K	5250	5100	5100
M95 + 200K	4950	4750	4800
M95 + 400K	4850	4550	4550
OV 0.0025" + 400K	4500	3450	4400
OV 0.0050" + 400K	2250	1900	2300
OV 0.0100" + 0K	1450	1300	1500
OV 0.0100" + 200K	1450	1300	1500
OV 0.0100" + 400K	1450	1300	1500
EC 0.010" + 0K	5250	5100	5100
EC 0.010" + 200K	5200	4800	4900
EC 0.010" + 400K	4800	4350	4500
EC 0.015" + 400K	2700	2700	2700
EC 0.015" + 400K Full Model	2500	2500	2500
OV 0.0050" + EC 0.010" + 400K	2250	1900	2300



Conclusions

- Eccentricity and ovality considerably reduces the collapse pressure rating of a round pipe.
- The imperfection of a manufactured mandrel needs to be measured accurately in order to determine the collapse pressure by FEA.



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