Tutorial for Fiber Reinforced Piping (FRP) Modeling and Analysis using CAEPIPE

The following are the Steps for FRP Modeling and Analysis using CAEPIPE.

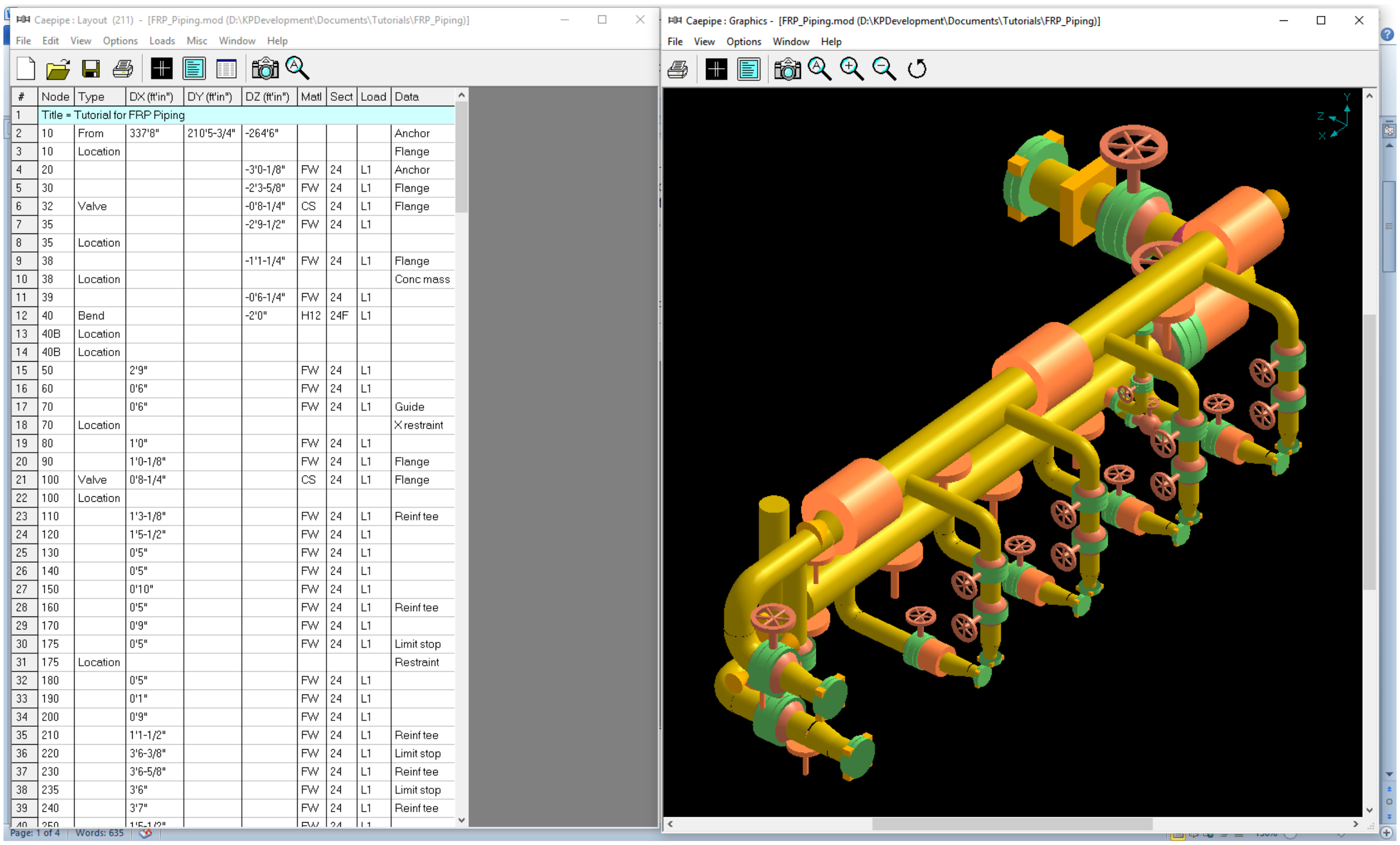
General

FRP piping has gained wide acceptance in many industries due to its lightweight nature, superior corrosion resistance, temperature capabilities and mechanical strength. Several manufacturers produce different types of FRP pipes and fittings and provide technical assistance to their customers on design matters through installation.

FRP piping can be modeled in CAEPIPE. CAEPIPE will then calculate deflections, element forces & moments, support loads and stresses.

Tutorial

Snap shot shown below is a sample model for FRP Modeling and Analysis

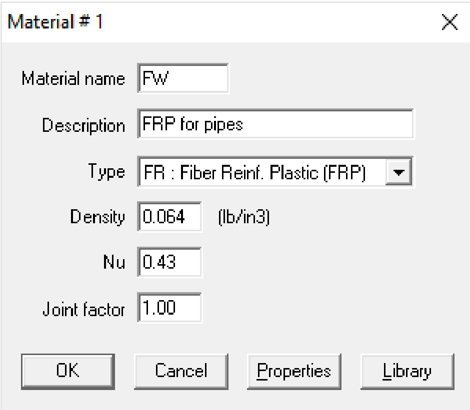


Step 1:

First define FRP materials required for piping system through Layout window > Misc > Materials. In the Material List window shown on the screen, double click on an empty row to input a new material or on a material description to edit the material properties.

Step 2:

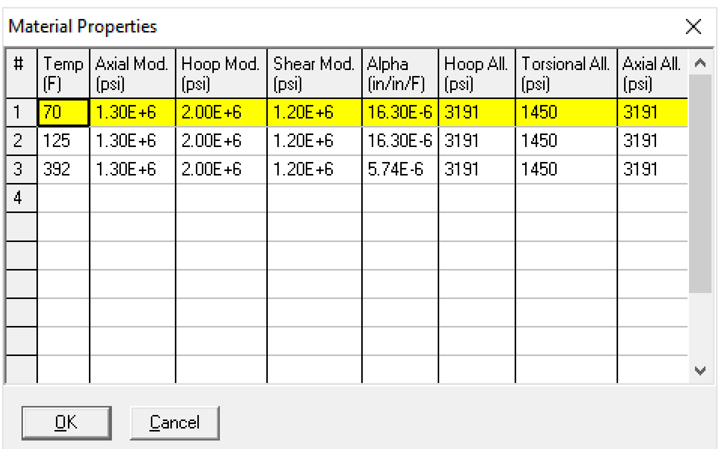
In the Material dialog shown, enter the FRP material properties as given below.



The material name can be up to five alpha-numeric characters. Enter description, density and Poisson's ratio. You need to select "FR: Fiber Reinf. Plastic (FRP)" from the Type drop-down combo box before you click on the Properties button.

Step 3:

Click on the Properties button, you are shown the table below where you can enter temperature-dependent properties. Additionally, you can also define the Hoop, Torsional and Axial allowable stresses so that CAEPIPE can use them to compare with calculated stresses under the FRP "Sorted Stresses" results.

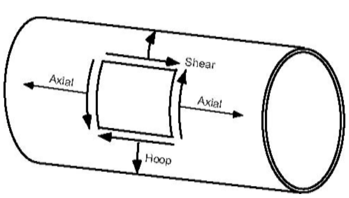

Material Properties

#	Temp (F)	Axial Mod. (psi)	Hoop Mod. (psi)	Shear Mod. (psi)	Alpha (in/in/F)	Hoop All. (psi)	Torsional All. (psi)	Axial All. (psi)
1	70	1.30E+6	2.00E+6	1.20E+6	16.30E-6	3191	1450	3191
2	125	1.30E+6	2.00E+6	1.20E+6	16.30E-6	3191	1450	3191
3	392	1.30E+6	2.00E+6	1.20E+6	5.74E-6	3191	1450	3191
4								

OK Cancel

FRP Material Moduli

CAEPIPE requires three moduli for the FRP material:



- Axial or Longitudinal (this is the most important one)
- Hoop (used in Bourdon effect calculations). If this modulus is not available, use axial modulus.

- Shear or Torsional. If this modulus is not available, use engineering judgment in specifying 1/2 of axial modulus or a similar value. Note that a high modulus will result in high stresses, and a low modulus will result in high deflections.

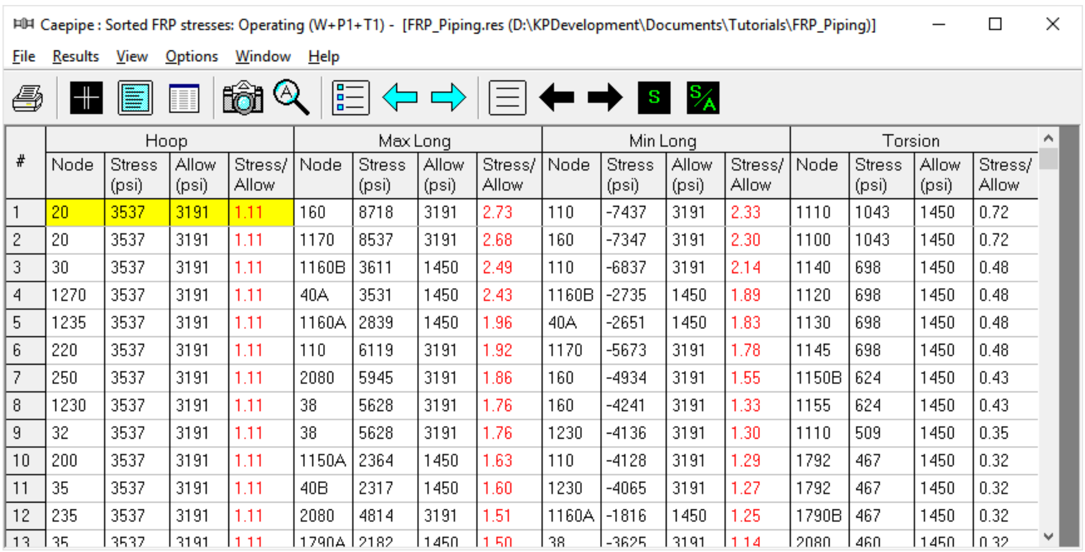
For FRP bends, a Flexibility factor of 1.0 is used unless you override it by specifying a Flexibility factor inside the bend dialog. Also for FRP bends, CAEPIPE uses a default SIF of 2.3. You can override this too by specifying User-SIFs at the bend end nodes (A and B nodes).

Step 4:

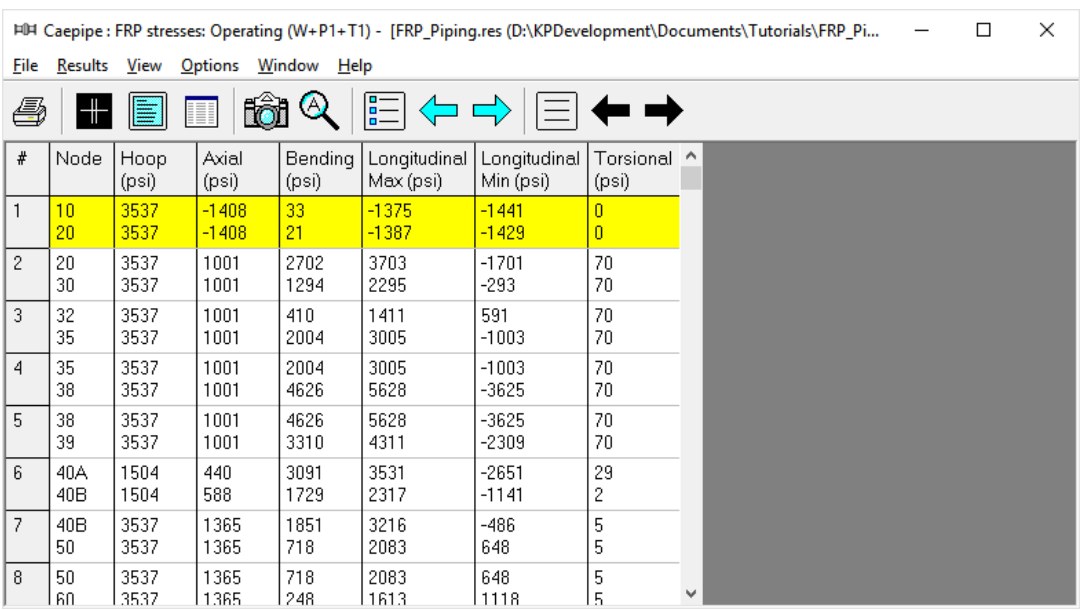
After defining the FRP material properties, Section Properties and Loads required for the stress analysis, complete the stress layout. Save the model and Analyze through Layout window > File > Analyze.

Step 5:

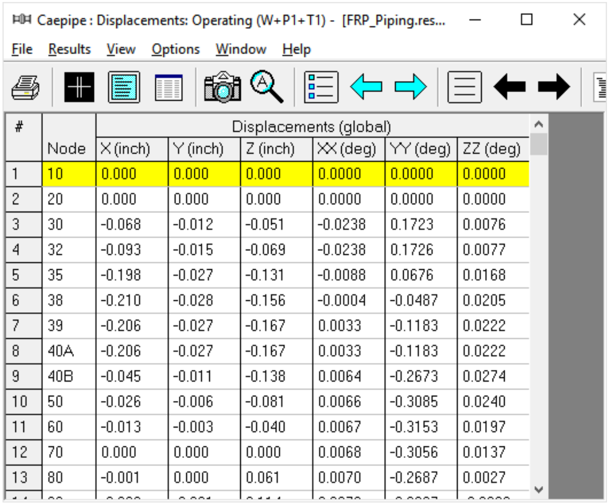
Upon successful analysis, CAEPIPE will show the calculated stresses, deflections, support loads, element forces and support load summary. Each item can be seen under the respective title in Results. FRP element stresses can be seen, sorted or unsorted.



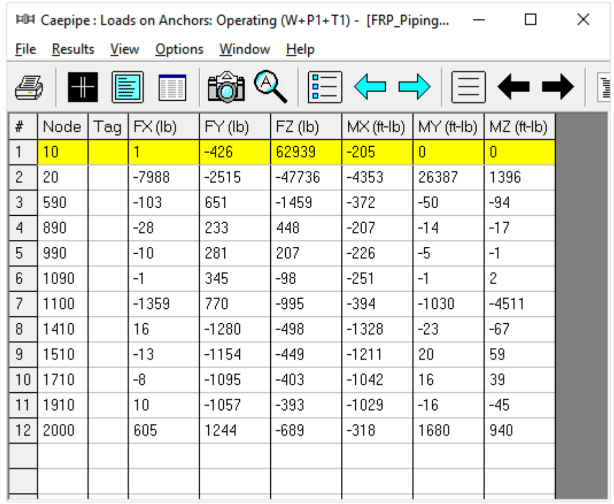
#	Hoop				Max Long				Min Long				Torsion			
	Node	Stress (psi)	Allow (psi)	Stress/ Allow	Node	Stress (psi)	Allow (psi)	Stress/ Allow	Node	Stress (psi)	Allow (psi)	Stress/ Allow	Node	Stress (psi)	Allow (psi)	Stress/ Allow
1	20	3537	3191	1.11	160	8718	3191	2.73	110	-7437	3191	2.33	1110	1043	1450	0.72
2	20	3537	3191	1.11	1170	8537	3191	2.68	160	-7347	3191	2.30	1100	1043	1450	0.72
3	30	3537	3191	1.11	1160B	3611	1450	2.49	110	-6837	3191	2.14	1140	698	1450	0.48
4	1270	3537	3191	1.11	40A	3531	1450	2.43	1160B	-2735	1450	1.89	1120	698	1450	0.48
5	1235	3537	3191	1.11	1160A	2839	1450	1.96	40A	-2651	1450	1.83	1130	698	1450	0.48
6	220	3537	3191	1.11	110	6119	3191	1.92	1170	-5673	3191	1.78	1145	698	1450	0.48
7	250	3537	3191	1.11	2080	5945	3191	1.86	160	-4934	3191	1.55	1150B	624	1450	0.43
8	1230	3537	3191	1.11	38	5628	3191	1.76	160	-4241	3191	1.33	1155	624	1450	0.43
9	32	3537	3191	1.11	38	5628	3191	1.76	1230	-4136	3191	1.30	1110	509	1450	0.35
10	200	3537	3191	1.11	1150A	2364	1450	1.63	110	-4128	3191	1.29	1792	467	1450	0.32
11	35	3537	3191	1.11	40B	2317	1450	1.60	1230	-4065	3191	1.27	1792	467	1450	0.32
12	235	3537	3191	1.11	2080	4814	3191	1.51	1160A	-1816	1450	1.25	1790B	467	1450	0.32
13	35	3537	3191	1.11	1790A	2182	1450	1.50	38	-3625	3191	1.14	2080	460	1450	0.32



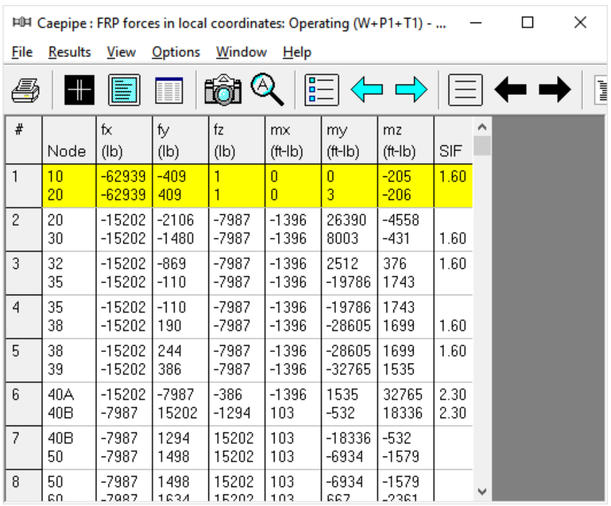
#	Node	Hoop (psi)	Axial (psi)	Bending (psi)	Longitudinal Max (psi)	Longitudinal Min (psi)	Torsional (psi)
1	10 20	3537 3537	-1408 -1408	33 21	-1375 -1387	-1441 -1429	0 0
2	20 30	3537 3537	1001 1001	2702 1294	3703 2295	-1701 -293	70 70
3	32 35	3537 3537	1001 1001	410 2004	1411 3005	591 -1003	70 70
4	35 38	3537 3537	1001 1001	2004 4626	3005 5628	-1003 -3625	70 70
5	38 39	3537 3537	1001 1001	4626 3310	5628 4311	-3625 -2309	70 70
6	40A 40B	1504 1504	440 588	3091 1729	3531 2317	-2651 -1141	29 2
7	40B 50	3537 3537	1365 1365	1851 718	3216 2083	-486 648	5 5
8	50 60	3537 3537	1365 1365	718 248	2083 1613	648 1118	5 5


Caepipe : Displacements: Operating (W+P1+T1) - [FRP_Piping.res...

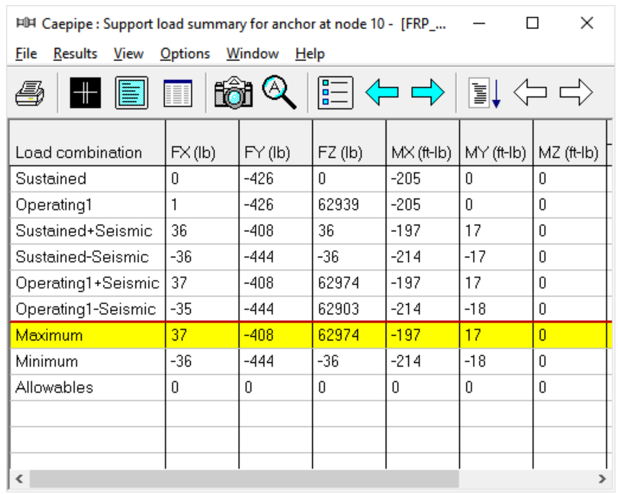
#	Node	Displacements (global)					
		X (inch)	Y (inch)	Z (inch)	XX (deg)	YY (deg)	ZZ (deg)
1	10	0.000	0.000	0.000	0.0000	0.0000	0.0000
2	20	0.000	0.000	0.000	0.0000	0.0000	0.0000
3	30	-0.068	-0.012	-0.051	-0.0238	0.1723	0.0076
4	32	-0.093	-0.015	-0.069	-0.0238	0.1726	0.0077
5	35	-0.198	-0.027	-0.131	-0.0088	0.0676	0.0168
6	38	-0.210	-0.028	-0.156	-0.0004	-0.0487	0.0205
7	39	-0.206	-0.027	-0.167	0.0033	-0.1183	0.0222
8	40A	-0.206	-0.027	-0.167	0.0033	-0.1183	0.0222
9	40B	-0.045	-0.011	-0.138	0.0064	-0.2673	0.0274
10	50	-0.026	-0.006	-0.081	0.0066	-0.3085	0.0240
11	60	-0.013	-0.003	-0.040	0.0067	-0.3153	0.0197
12	70	0.000	0.000	0.000	0.0068	-0.3056	0.0137
13	80	-0.001	0.000	0.061	0.0070	-0.2687	0.0027


Caepipe : Loads on Anchors: Operating (W+P1+T1) - [FRP_Piping...

#	Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	10		1	-426	62939	-205	0	0
2	20		-7988	-2515	-47736	-4353	26387	1396
3	590		-103	651	-1459	-372	-50	-94
4	890		-28	233	448	-207	-14	-17
5	990		-10	281	207	-226	-5	-1
6	1090		-1	345	-98	-251	-1	2
7	1100		-1359	770	-995	-394	-1030	-4511
8	1410		16	-1280	-498	-1328	-23	-67
9	1510		-13	-1154	-449	-1211	20	59
10	1710		-8	-1095	-403	-1042	16	39
11	1910		10	-1057	-393	-1029	-16	-45
12	2000		605	1244	-689	-318	1680	940


Caepipe : FRP forces in local coordinates: Operating (W+P1+T1) - ...

#	Node	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)	SIF
1	10 20	-62939 -62939	-409 409	1 1	0 0	0 3	-205 -206	1.60
2	20 30	-15202 -15202	-2106 -1480	-7987 -7987	-1396 -1396	26390 8003	-4558 -431	 1.60
3	32 35	-15202 -15202	-869 -110	-7987 -7987	-1396 -1396	2512 -19786	376 1743	1.60
4	35 38	-15202 -15202	-110 190	-7987 -7987	-1396 -1396	-19786 -28605	1743 1699	 1.60
5	38 39	-15202 -15202	244 386	-7987 -7987	-1396 -1396	-28605 -32765	1699 1535	1.60
6	40A 40B	-15202 -7987	-7987 15202	-386 -1294	-1396 103	1535 -532	32765 18336	2.30 2.30
7	40B 50	-7987 -7987	1294 1498	15202 15202	103 103	-18336 -6934	-532 -1579	
8	50	-7987	1498	15202	103	-6934	-1579	


Caepipe : Support load summary for anchor at node 10 - [FRP_...

Load combination	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
Sustained	0	-426	0	-205	0	0
Operating1	1	-426	62939	-205	0	0
Sustained+Seismic	36	-408	36	-197	17	0
Sustained-Seismic	-36	-444	-36	-214	-17	0
Operating1+Seismic	37	-408	62974	-197	17	0
Operating1-Seismic	-35	-444	62903	-214	-18	0
Maximum	37	-408	62974	-197	17	0
Minimum	-36	-444	-36	-214	-18	0
Allowables	0	0	0	0	0	0

Stiffness matrix formulated internally in CAEPIPE and the formulas used for computing different stresses are given below for quick reference.

Stiffness matrix

The stiffness matrix for a pipe is calculated using the following terms:

Axial term = L / EA

Shear term = shape factor x L / GA

Bending term = L / EI

Torsion term = L / 2GI

where L = length, A = area, **I** = moment of inertia, E = elastic modulus, G = shear modulus

For an isotropic material, G = E / 2(1 + ν), where ν = Poisson's ratio,

For a FRP material, E = axial modulus and G is independently specified (i.e., it is not calculated using E and ν).

The hoop modulus and FRP Poisson's ratio are only used in Bourdon effect calculation where,

Poisson's ratio used = FRP Poisson's ratio input x (axial modulus / hoop modulus)

FRP Stresses

Hoop stress: $S_H = \frac{PD}{2t_m}$

Axial stress: $S_A = \frac{PD}{4t_m} + \frac{F}{A}$

Bending stress: $S_B = \frac{\sqrt{(i_i M_i)^2 + (i_o M_o)^2}}{Z}$

Torsional stress: $S_T = \frac{M_t}{2Z}$

Longitudinal maximum = Axial + Bending = $S_A + S_B$

Longitudinal Minimum = Axial – Bending = $S_A - S_B$

where

P = pressure
D = outside diameter
t_m = minimum thickness
= nominal thickness x (1 – mill tolerance/100) – corrosion allowance
i_i = in-plane stress intensification factor
i_o = out-of-plane stress intensification factor
M_i = in-plane bending moment
M_o = out-of-plane bending moment
M_t = torque
Z = section modulus
F = axial force
A = cross-section area