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

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

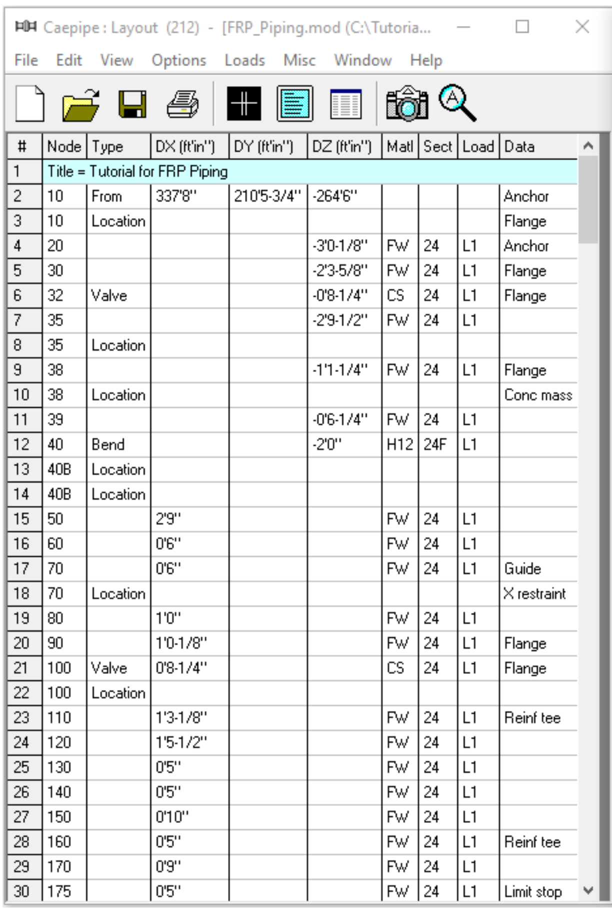
General

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.

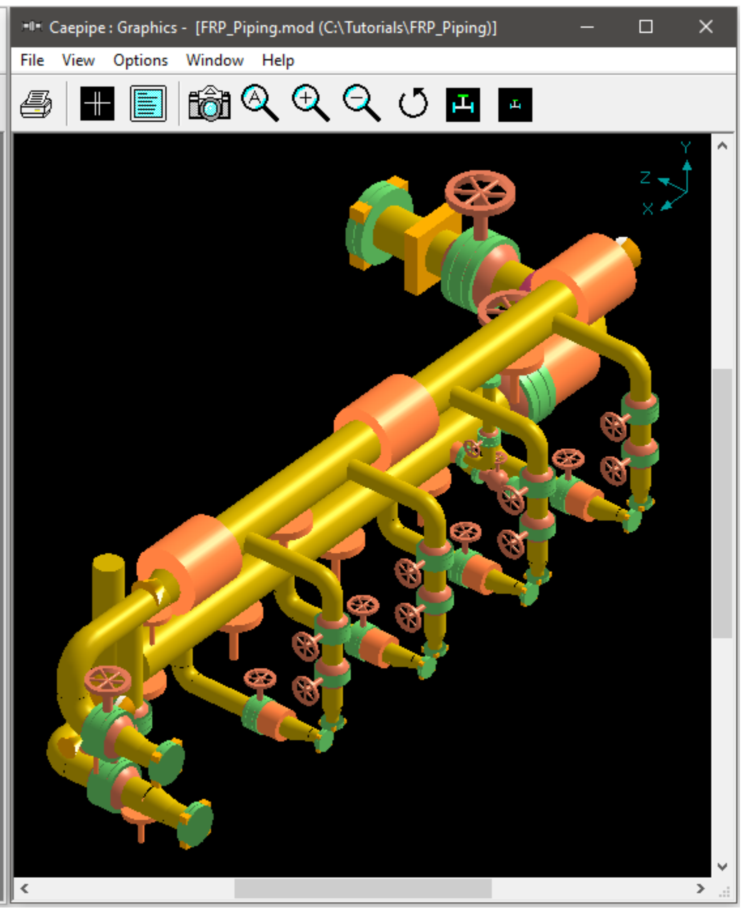
FRP piping can be modeled in CAEPIPE. CAEPIPE will then calculate deflections, element forces & moments, support loads and stresses.

Tutorial

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



#	Node	Type	DX (ft'in")	DY (ft'in")	DZ (ft'in")	Matl	Sect	Load	Data
1	Title = Tutorial for FRP Piping								
2	10	From	337'8"	210'5-3/4"	-264'6"				Anchor
3	10	Location							Flange
4	20				-3'0-1/8"	FW	24	L1	Anchor
5	30				-2'3-5/8"	FW	24	L1	Flange
6	32	Valve			-0'8-1/4"	CS	24	L1	Flange
7	35				-2'9-1/2"	FW	24	L1	
8	35	Location							
9	38				-1'1-1/4"	FW	24	L1	Flange
10	38	Location							Conc mass
11	39				-0'6-1/4"	FW	24	L1	
12	40	Bend			-2'0"	H12	24F	L1	
13	40B	Location							
14	40B	Location							
15	50		2'9"			FW	24	L1	
16	60		0'6"			FW	24	L1	
17	70		0'6"			FW	24	L1	Guide
18	70	Location							X restraint
19	80		1'0"			FW	24	L1	
20	90		1'0-1/8"			FW	24	L1	Flange
21	100	Valve	0'8-1/4"			CS	24	L1	Flange
22	100	Location							
23	110		1'3-1/8"			FW	24	L1	Reinf tee
24	120		1'5-1/2"			FW	24	L1	
25	130		0'5"			FW	24	L1	
26	140		0'5"			FW	24	L1	
27	150		0'10"			FW	24	L1	
28	160		0'5"			FW	24	L1	Reinf tee
29	170		0'9"			FW	24	L1	
30	175		0'5"			FW	24	L1	Limit stop

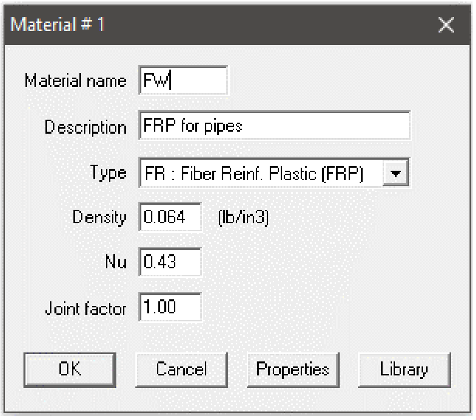


Step 1:

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:

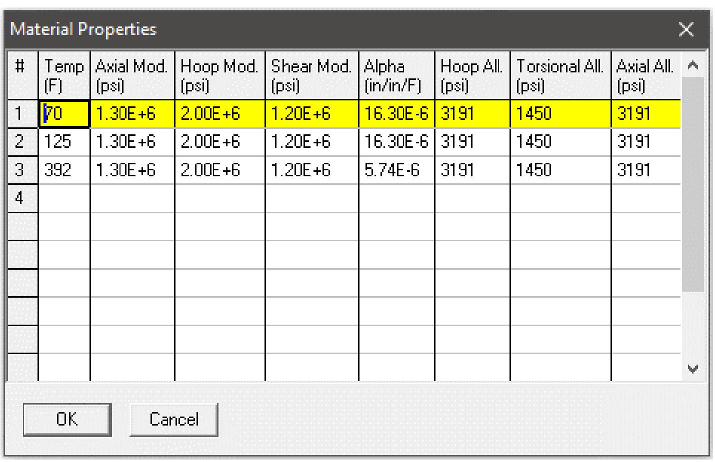
In the Material dialog shown, enter the FRP material properties as given below.



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.

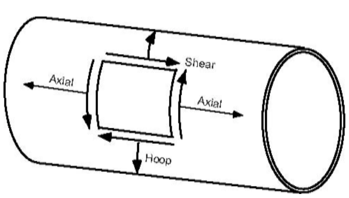

Material Properties

#	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.

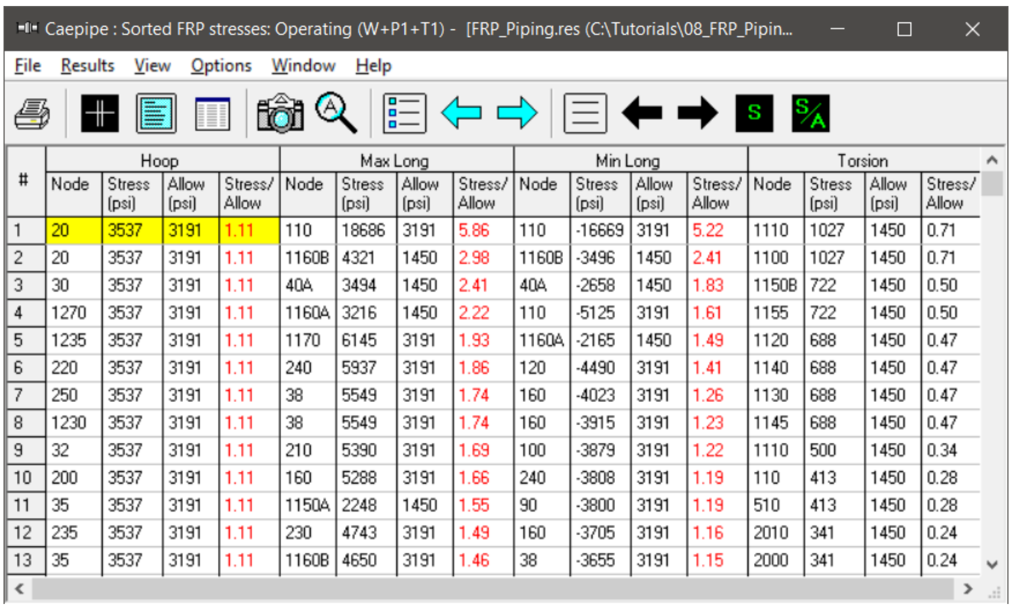
For FRP bends, a Flexibility factor of 1.0 is used unless you override it by specifying a Flexibility factor inside the bend dialog. Also for FRP bends, CAEPIPE uses a default SIF of 2.3. You can override this too by specifying User-SIFs at the bend end nodes (A and B nodes).

Step 4:

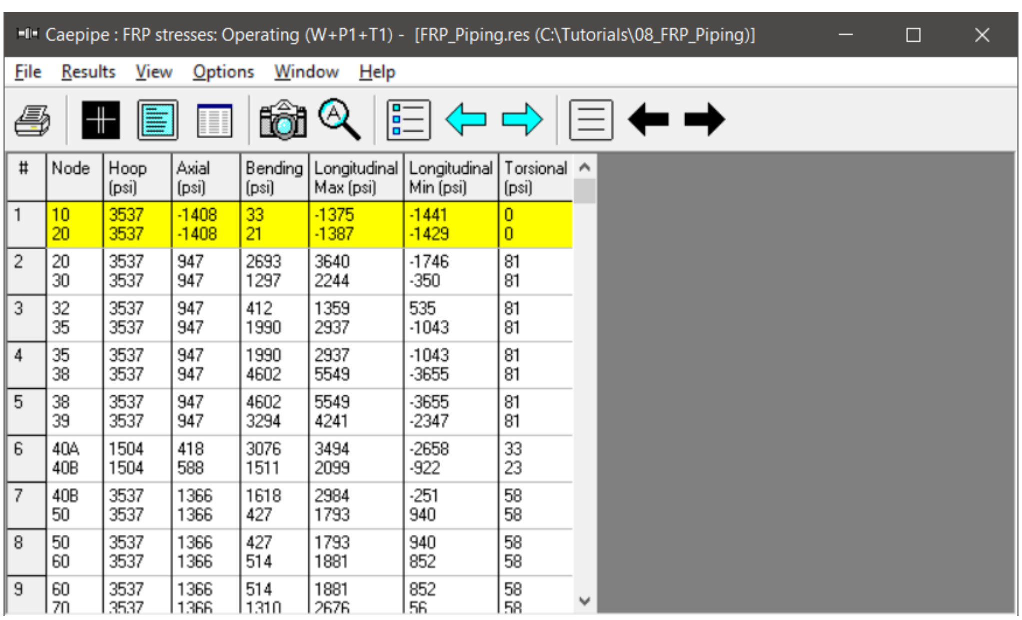
After defining the FRP material properties, Section Properties and Loads required for the stress analysis, complete the stress layout. Save the model and Analyze through Layout window > File > Analyze.

Step 5:

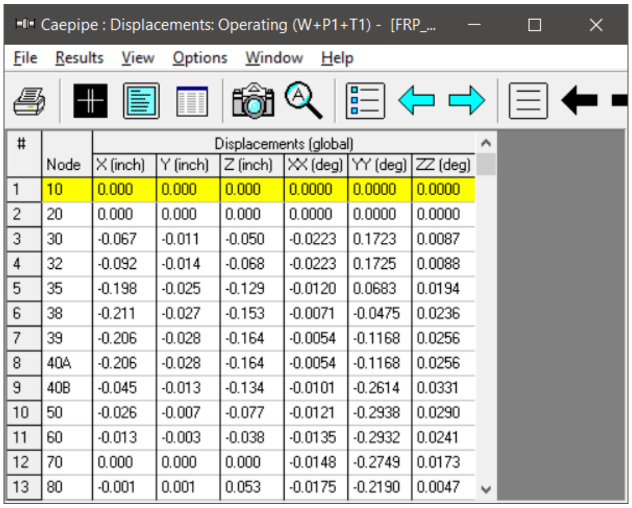
Upon successful analysis, CAEPIPE will show the calculated stresses, deflections, support loads, element forces and support load summary. Each item can be seen under the respective title in Results. FRP element stresses can be seen, sorted or unsorted.



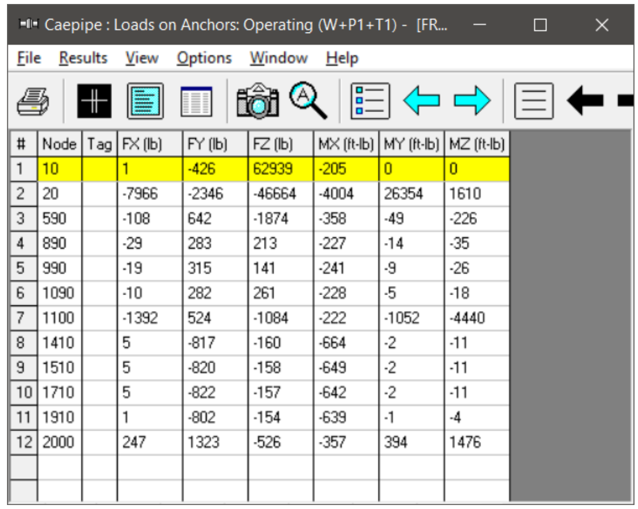
#	Hoop				Max Long				Min Long				Torsion			
	Node	Stress (psi)	Allow (psi)	Stress/ Allow	Node	Stress (psi)	Allow (psi)	Stress/ Allow	Node	Stress (psi)	Allow (psi)	Stress/ Allow	Node	Stress (psi)	Allow (psi)	Stress/ Allow
1	20	3537	3191	1.11	110	18686	3191	5.86	110	-16669	3191	5.22	1110	1027	1450	0.71
2	20	3537	3191	1.11	1160B	4321	1450	2.98	1160B	-3496	1450	2.41	1100	1027	1450	0.71
3	30	3537	3191	1.11	40A	3494	1450	2.41	40A	-2658	1450	1.83	1150B	722	1450	0.50
4	1270	3537	3191	1.11	1160A	3216	1450	2.22	110	-5125	3191	1.61	1155	722	1450	0.50
5	1235	3537	3191	1.11	1170	6145	3191	1.93	1160A	-2165	1450	1.49	1120	688	1450	0.47
6	220	3537	3191	1.11	240	5937	3191	1.86	120	-4490	3191	1.41	1140	688	1450	0.47
7	250	3537	3191	1.11	38	5549	3191	1.74	160	-4023	3191	1.26	1130	688	1450	0.47
8	1230	3537	3191	1.11	38	5549	3191	1.74	160	-3915	3191	1.23	1145	688	1450	0.47
9	32	3537	3191	1.11	210	5390	3191	1.69	100	-3879	3191	1.22	1110	500	1450	0.34
10	200	3537	3191	1.11	160	5288	3191	1.66	240	-3808	3191	1.19	110	413	1450	0.28
11	35	3537	3191	1.11	1150A	2248	1450	1.55	90	-3800	3191	1.19	510	413	1450	0.28
12	235	3537	3191	1.11	230	4743	3191	1.49	160	-3705	3191	1.16	2010	341	1450	0.24
13	35	3537	3191	1.11	1160B	4650	3191	1.46	38	-3655	3191	1.15	2000	341	1450	0.24



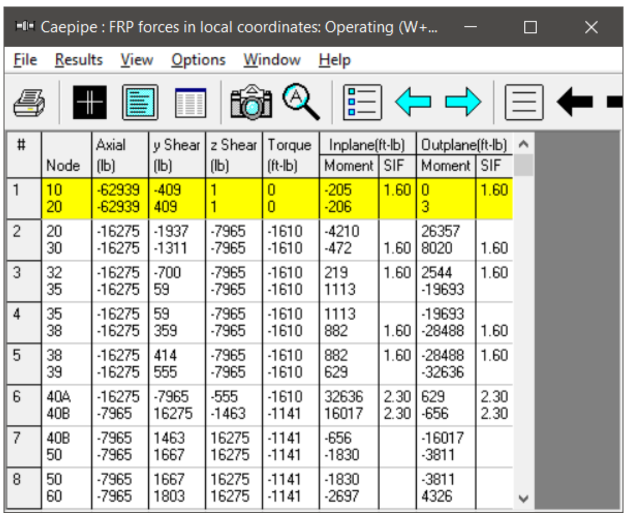
#	Node	Hoop (psi)	Axial (psi)	Bending (psi)	Longitudinal Max (psi)	Longitudinal Min (psi)	Torsional (psi)
1	10 20	3537 3537	-1408 -1408	33 21	-1375 -1387	-1441 -1429	0 0
2	20 30	3537 3537	947 947	2693 1297	3640 2244	-1746 -350	81 81
3	32 35	3537 3537	947 947	412 1990	1359 2937	535 -1043	81 81
4	35 38	3537 3537	947 947	1990 4602	2937 5549	-1043 -3655	81 81
5	38 39	3537 3537	947 947	4602 3294	5549 4241	-3655 -2347	81 81
6	40A 40B	1504 1504	418 588	3076 1511	3494 2099	-2658 -922	33 23
7	40B 50	3537 3537	1366 1366	1618 427	2984 1793	-251 940	58 58
8	50 60	3537 3537	1366 1366	427 514	1793 1881	940 852	58 58
9	60 70	3537 3537	1366 1366	514 1310	1881 2676	852 56	58 58



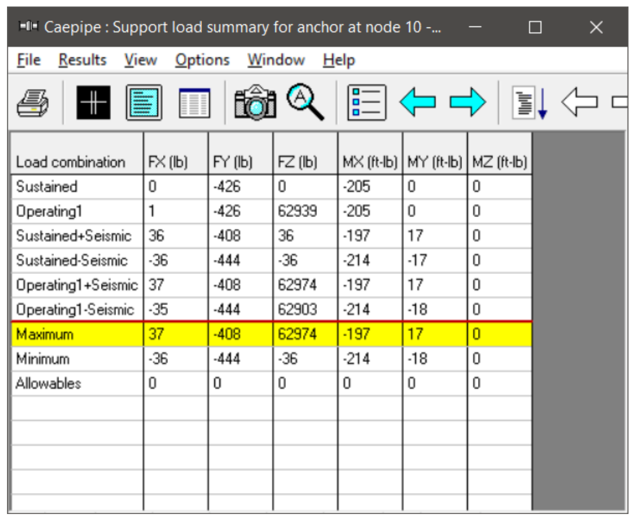
#	Node	Displacements (global)					
		X (inch)	Y (inch)	Z (inch)	XX (deg)	YY (deg)	ZZ (deg)
1	10	0.000	0.000	0.000	0.0000	0.0000	0.0000
2	20	0.000	0.000	0.000	0.0000	0.0000	0.0000
3	30	-0.067	-0.011	-0.050	-0.0223	0.1723	0.0087
4	32	-0.092	-0.014	-0.068	-0.0223	0.1725	0.0088
5	35	-0.198	-0.025	-0.129	-0.0120	0.0683	0.0194
6	38	-0.211	-0.027	-0.153	-0.0071	-0.0475	0.0236
7	39	-0.206	-0.028	-0.164	-0.0054	-0.1168	0.0256
8	40A	-0.206	-0.028	-0.164	-0.0054	-0.1168	0.0256
9	40B	-0.045	-0.013	-0.134	-0.0101	-0.2614	0.0331
10	50	-0.026	-0.007	-0.077	-0.0121	-0.2938	0.0290
11	60	-0.013	-0.003	-0.038	-0.0135	-0.2932	0.0241
12	70	0.000	0.000	0.000	-0.0148	-0.2749	0.0173
13	80	-0.001	0.001	0.053	-0.0175	-0.2190	0.0047



#	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		-7966	-2346	-46664	-4004	26354	1610
3	590		-108	642	-1874	-358	-49	-226
4	890		-29	283	213	-227	-14	-35
5	990		-19	315	141	-241	-9	-26
6	1090		-10	282	261	-228	-5	-18
7	1100		-1392	524	-1084	-222	-1052	-4440
8	1410		5	-817	-160	-664	-2	-11
9	1510		5	-820	-158	-649	-2	-11
10	1710		5	-822	-157	-642	-2	-11
11	1910		1	-802	-154	-639	-1	-4
12	2000		247	1323	-526	-357	394	1476



#	Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (ft-lb)	Inplane(ft-lb) Moment	SIF	Outplane(ft-lb) Moment	SIF
1	10 20	-62939 -62939	-409 409	1 1	0 0	-205 -206	1.60	0 3	1.60
2	20 30	-16275 -16275	-1937 -1311	-7965 -7965	-1610 -1610	-4210 -472	1.60	26357 8020	1.60
3	32 35	-16275 -16275	-700 59	-7965 -7965	-1610 -1610	219 1113	1.60	2544 -19693	1.60
4	35 38	-16275 -16275	59 359	-7965 -7965	-1610 -1610	1113 882	1.60	-19693 -28488	1.60
5	38 39	-16275 -16275	414 555	-7965 -7965	-1610 -1610	882 629	1.60	-28488 -32636	1.60
6	40A 40B	-16275 -7965	-7965 16275	-555 -1463	-1610 -1141	32636 16017	2.30 2.30	629 -656	2.30 2.30
7	40B 50	-7965 -7965	1463 1667	16275 16275	-1141 -1141	-656 -1830		-16017 -3811	
8	50 60	-7965 -7965	1667 1803	16275 16275	-1141 -1141	-1830 -2697		-3811 4326	



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