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

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

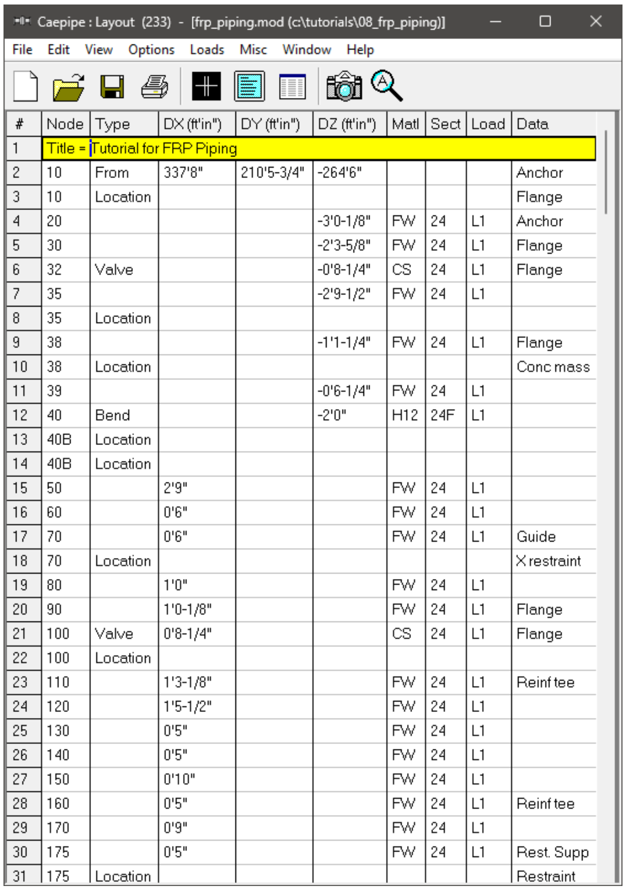
General

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.

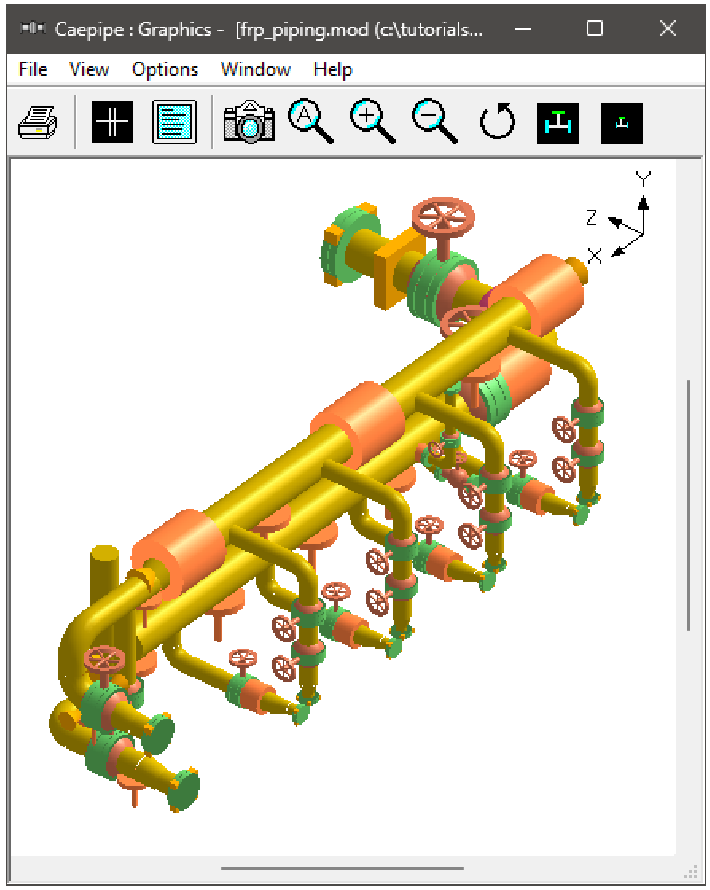
FRP piping can be modeled in CAEPIPE. CAEPIPE will then calculate deflections, element forces & moments, support loads and stresses.

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	Rest. Supp
31	175	Location							Restraint

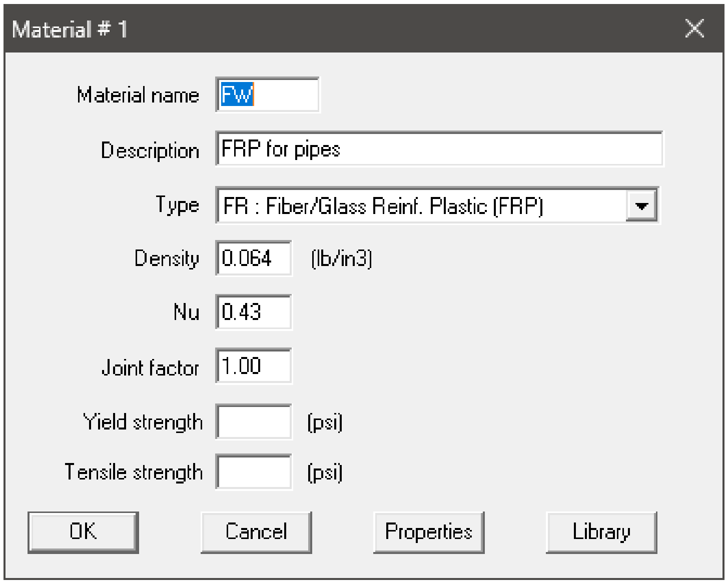


Step 1:

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:

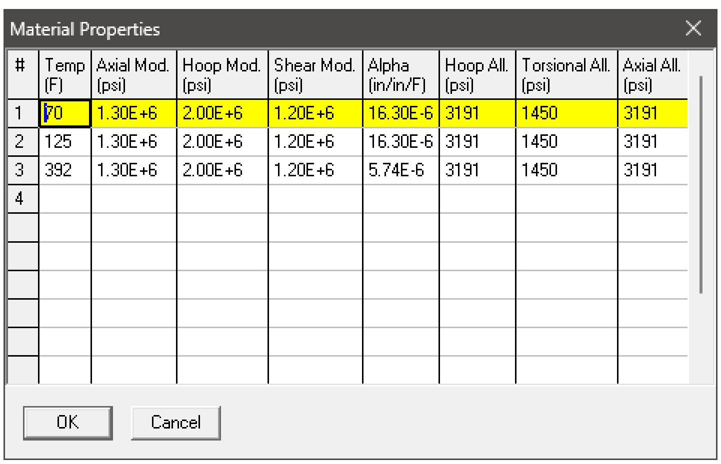
In the Material dialog shown, enter the FRP material properties as given below.



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.



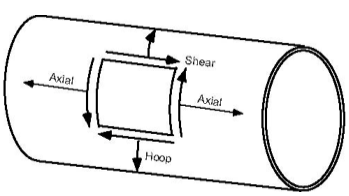
Material Properties

#	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.

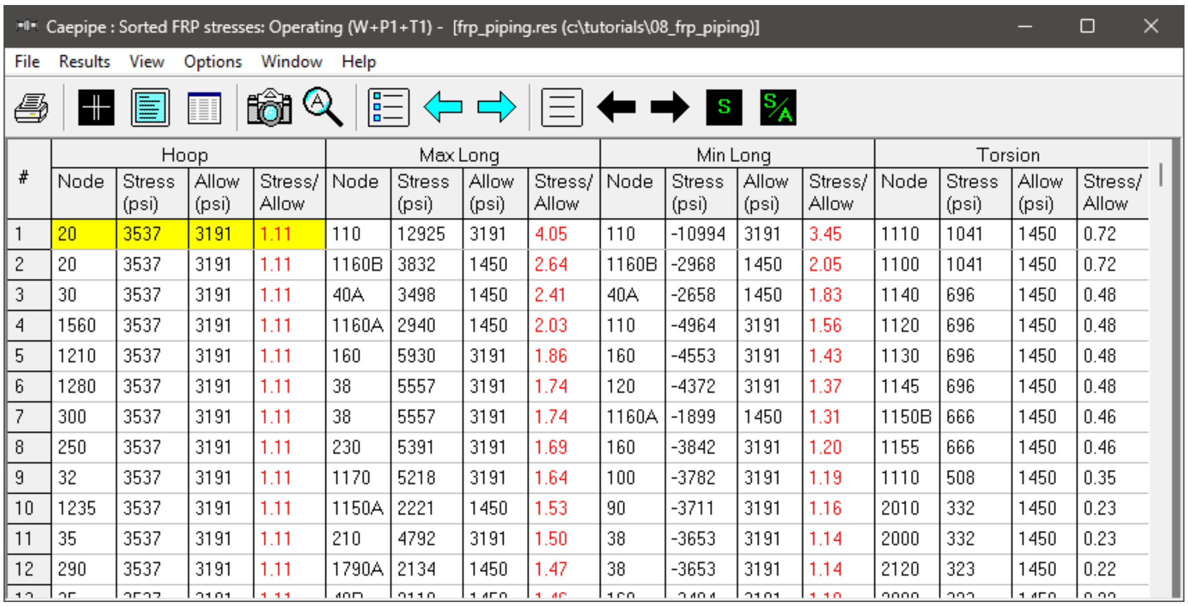
For FRP bends, a Flexibility factor of 1.0 is used unless you override it by specifying a Flexibility factor inside the bend dialog. Also, for FRP bends, CAEPIPE uses a default SIF of 2.3. You can override this too by specifying User-SIFs at the bend end nodes (A and B nodes).

Step 4:

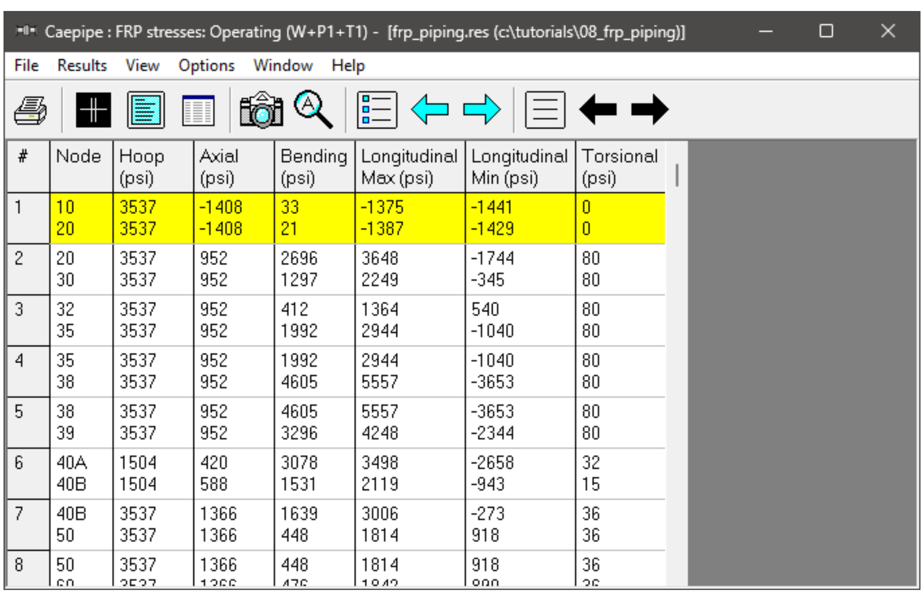
After defining the FRP material properties, Section Properties and Loads required for the stress analysis, complete the stress layout. Save the model and Analyze through Layout window > File > Analyze.

Step 5:

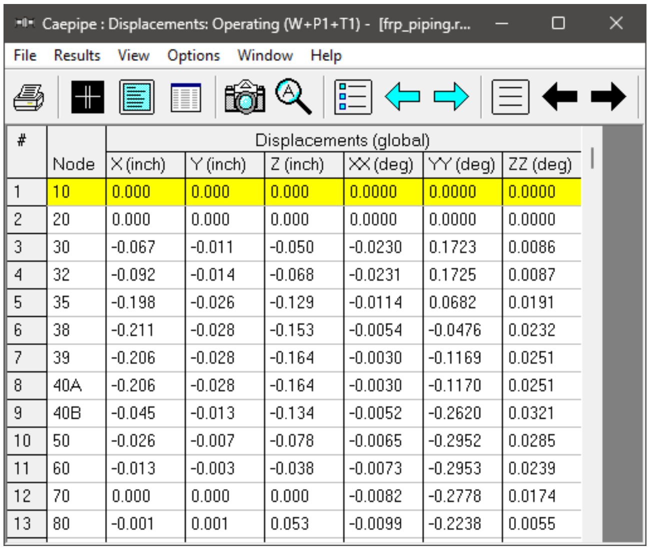
Upon successful analysis, CAEPIPE will show the calculated stresses, deflections, support loads, element forces and support load summary. Each item can be seen under the respective title in Results. FRP element stresses can be seen, sorted or unsorted.



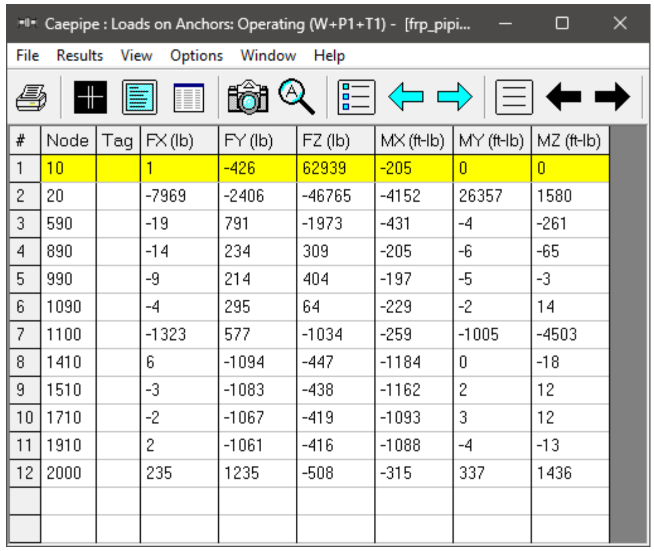
#	Hoop				Max Long				Min Long				Torsion			
	Node	Stress (psi)	Allow (psi)	Stress/ Allow	Node	Stress (psi)	Allow (psi)	Stress/ Allow	Node	Stress (psi)	Allow (psi)	Stress/ Allow	Node	Stress (psi)	Allow (psi)	Stress/ Allow
1	20	3537	3191	1.11	110	12925	3191	4.05	110	-10994	3191	3.45	1110	1041	1450	0.72
2	20	3537	3191	1.11	1160B	3832	1450	2.64	1160B	-2968	1450	2.05	1100	1041	1450	0.72
3	30	3537	3191	1.11	40A	3498	1450	2.41	40A	-2658	1450	1.83	1140	696	1450	0.48
4	1560	3537	3191	1.11	1160A	2940	1450	2.03	110	-4964	3191	1.56	1120	696	1450	0.48
5	1210	3537	3191	1.11	160	5930	3191	1.86	160	-4553	3191	1.43	1130	696	1450	0.48
6	1280	3537	3191	1.11	38	5557	3191	1.74	120	-4372	3191	1.37	1145	696	1450	0.48
7	300	3537	3191	1.11	38	5557	3191	1.74	1160A	-1899	1450	1.31	1150B	666	1450	0.46
8	250	3537	3191	1.11	230	5391	3191	1.69	160	-3842	3191	1.20	1155	666	1450	0.46
9	32	3537	3191	1.11	1170	5218	3191	1.64	100	-3782	3191	1.19	1110	508	1450	0.35
10	1235	3537	3191	1.11	1150A	2221	1450	1.53	90	-3711	3191	1.16	2010	332	1450	0.23
11	35	3537	3191	1.11	210	4792	3191	1.50	38	-3653	3191	1.14	2000	332	1450	0.23
12	290	3537	3191	1.11	1790A	2134	1450	1.47	38	-3653	3191	1.14	2120	323	1450	0.22



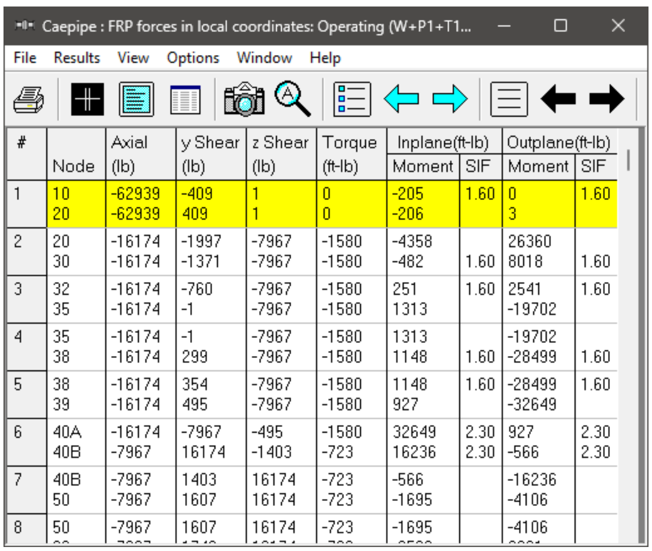
#	Node	Hoop (psi)	Axial (psi)	Bending (psi)	Longitudinal Max (psi)	Longitudinal Min (psi)	Torsional (psi)
1	10 20	3537 3537	-1408 -1408	33 21	-1375 -1387	-1441 -1429	0 0
2	20 30	3537 3537	952 952	2696 1297	3648 2249	-1744 -345	80 80
3	32 35	3537 3537	952 952	412 1992	1364 2944	540 -1040	80 80
4	35 38	3537 3537	952 952	1992 4605	2944 5557	-1040 -3653	80 80
5	38 39	3537 3537	952 952	4605 3296	5557 4248	-3653 -2344	80 80
6	40A 40B	1504 1504	420 588	3078 1531	3498 2119	-2658 -943	32 15
7	40B 50	3537 3537	1366 1366	1639 448	3006 1814	-273 918	36 36
8	50	3537	1366	448	1814	918	36



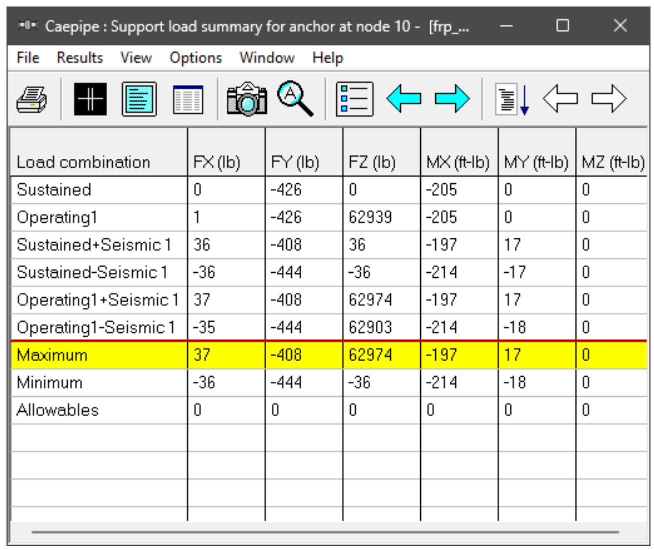
#	Node	X (inch)	Y (inch)	Z (inch)	XX (deg)	YY (deg)	ZZ (deg)
		Displacements (global)					
1	10	0.000	0.000	0.000	0.0000	0.0000	0.0000
2	20	0.000	0.000	0.000	0.0000	0.0000	0.0000
3	30	-0.067	-0.011	-0.050	-0.0230	0.1723	0.0086
4	32	-0.092	-0.014	-0.068	-0.0231	0.1725	0.0087
5	35	-0.198	-0.026	-0.129	-0.0114	0.0682	0.0191
6	38	-0.211	-0.028	-0.153	-0.0054	-0.0476	0.0232
7	39	-0.206	-0.028	-0.164	-0.0030	-0.1169	0.0251
8	40A	-0.206	-0.028	-0.164	-0.0030	-0.1170	0.0251
9	40B	-0.045	-0.013	-0.134	-0.0052	-0.2620	0.0321
10	50	-0.026	-0.007	-0.078	-0.0065	-0.2952	0.0285
11	60	-0.013	-0.003	-0.038	-0.0073	-0.2953	0.0239
12	70	0.000	0.000	0.000	-0.0082	-0.2778	0.0174
13	80	-0.001	0.001	0.053	-0.0099	-0.2238	0.0055



#	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		-7969	-2406	-46765	-4152	26357	1580
3	590		-19	791	-1973	-431	-4	-261
4	890		-14	234	309	-205	-6	-65
5	990		-9	214	404	-197	-5	-3
6	1090		-4	295	64	-229	-2	14
7	1100		-1323	577	-1034	-259	-1005	-4503
8	1410		6	-1094	-447	-1184	0	-18
9	1510		-3	-1083	-438	-1162	2	12
10	1710		-2	-1067	-419	-1093	3	12
11	1910		2	-1061	-416	-1088	-4	-13
12	2000		235	1235	-508	-315	337	1436



#	Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (ft-lb)	Inplane(ft-lb) Moment	Inplane SIF	Outplane(ft-lb) Moment	Outplane SIF
1	10 20	-62939 -62939	-409 409	1 1	0 0	-205 -206	1.60	0 3	1.60
2	20 30	-16174 -16174	-1997 -1371	-7967 -7967	-1580 -1580	-4358 -482	 1.60	26360 8018	 1.60
3	32 35	-16174 -16174	-760 -1	-7967 -7967	-1580 -1580	251 1313	1.60	2541 -19702	1.60
4	35 38	-16174 -16174	-1 299	-7967 -7967	-1580 -1580	1313 1148	 1.60	-19702 -28499	 1.60
5	38 39	-16174 -16174	354 495	-7967 -7967	-1580 -1580	1148 927	1.60	-28499 -32649	1.60
6	40A 40B	-16174 -7967	-7967 16174	-495 -1403	-1580 -723	32649 16236	2.30 2.30	927 -566	2.30 2.30
7	40B 50	-7967 -7967	1403 1607	16174 16174	-723 -723	-566 -1695		-16236 -4106	
8	50	-7967	1607	16174	-723	-1695		-4106	



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+Seismic1	36	-408	36	-197	17	0
Sustained-Seismic1	-36	-444	-36	-214	-17	0
Operating1+Seismic1	37	-408	62974	-197	17	0
Operating1-Seismic1	-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