Tutorial for Fiber/Glass Reinforced Piping (FRP/GRP) Modeling and Analysis

as per ASME NM.2 using CAEPIPE

General

FRP/GRP are being extensively used in the process, water, and chemical industries due to their high service life (about 50 years) and high resistance to corrosion. This, in turn, reduces the total cost of GRP/FRP piping incurred during such long service life compared to metallic pipes. GRP/FRP pipes are increasingly used to transfer water, oil, Fuel, Glycol, wastewater, sewer, etc. Because of this, the demand for GRP/FRP piping is continuously increasing.

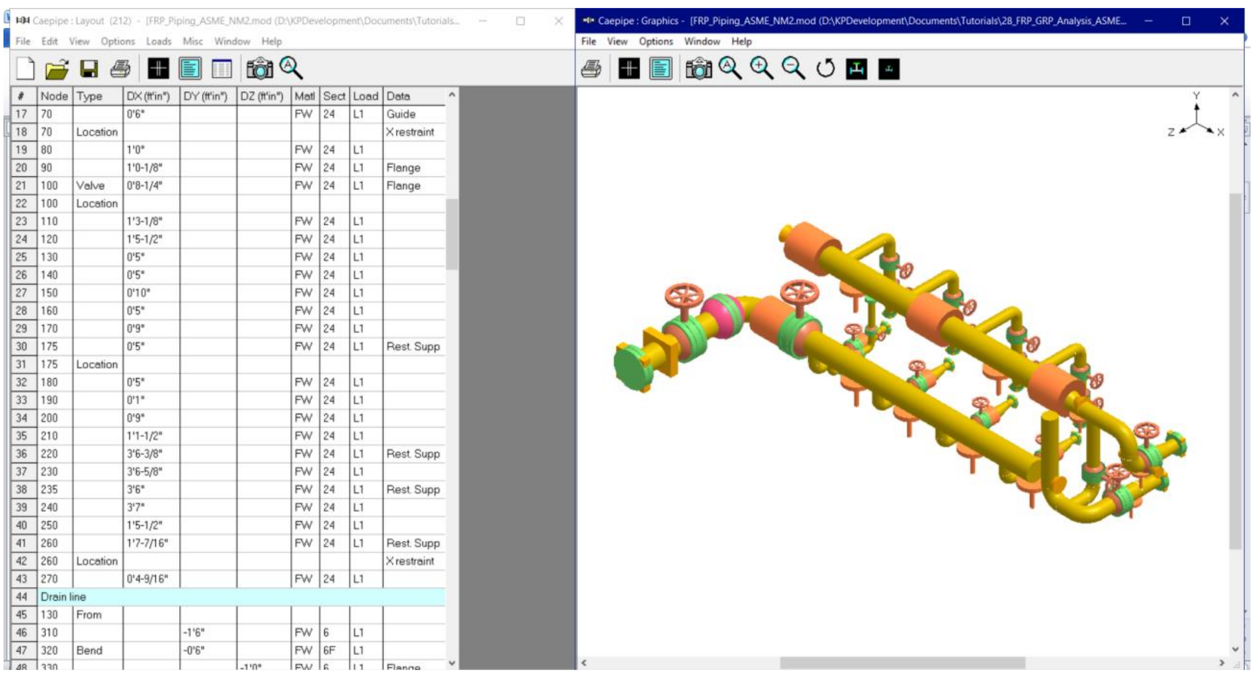
Pipe Flexibility specifications/Stress Analysis Design Basis requirements used in engineering industries consider FRP/GRP piping as stress critical. So, FRP/GRP systems, irrespective of their sizes and pressure, require analysis. Hence, demand for FRP/GRP pipe stress analysis is therefore ever-increasing.

This tutorial will help to learn the steps in performing piping stress analysis of above-ground FRP/GRP piping as per ASME NM.2 using CAEPIPE.

In case the FRP/GRP piping system for analysis includes only buried piping or both above-ground and buried piping, we recommend that such FRP/GRP system is analyzed as per ISO 14692-3. The tutorial titled “FRP/GRP Modeling and Analysis as per ISO 14692-3” provides the details of such piping analysis.

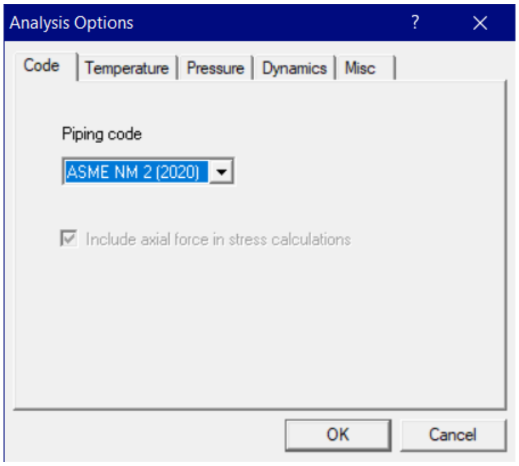
Tutorial

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



Step 1:

Select the piping code for analysis as “ASME NM.2” through Layout Window > Options > Analysis > Code as shown below and press the button “OK”.



Step 2:

Next define FRP materials required for piping system through Layout window > Misc > Materials by obtaining their properties from the manufacturer or through the piping standard.

ASME NM.3.3 provides tables and data sheets for allowable stresses, mechanical and physical properties (e.g., coefficient of thermal expansion and modulus of elasticity) for Fiberglass Unsaturated Polyester Resins Type I (SC-582), Type II (SC-582) and Type III (55-deg Filament Wound; ASME NM.2, Mandatory Appendix IV).

In this tutorial, Material properties for Fiberglass Unsaturated Polyester Resins Type I (SC-582) are referred from Table 1-2.1-1 of ASME NM.3.3 corresponding to the structural wall thickness of 0.2" and entered into CAEPIPE Material properties dialog.

Table 1-2.1-1 Data Sheet for Fiberglass Unsaturated Polyester Resin Type I (SC-582)

Description and Service Limits	
Reinforcement material:	Fiberglass (Type E or ECR glass)
Resin material:	Unsaturated polyester resin
Reinforcement pattern:	Random glass
Structural wall thickness range, in.:	0.1 to 0.7
Liner thickness, in.:	0.1

Modulus Data [Notes (1), (2), and (3)]

			Modulus of Elasticity for Total Wall Thickness, in. (Including 0.1-in. Liner), and Temperature, °F											
			Up to and Including 77°F				150°F				200°F			
Property	Symbol	ASTM Test Method	0.2	0.4	0.6	0.8 and Over	0.2	0.4	0.6	0.8 and Over	0.2	0.4	0.6	0.8 and Over
Axial tensile, psi	E_{AT}	D638, D1599, or D2105	1.12E+06	1.13E+06	1.13E+06	1.13E+06	9.92E+05	1.00E+06	1.01E+06	1.01E+06	8.69E+05	8.78E+05	8.82E+05	8.84E+05
Axial compressive, psi	E_{AC}	D695	1.12E+06	1.13E+06	1.13E+06	1.13E+06	9.92E+05	1.00E+06	1.01E+06	1.01E+06	8.69E+05	8.78E+05	8.82E+05	8.84E+05
Axial flexural, psi	E_{AF}	D790 or D2925	1.08E+06	1.10E+06	1.12E+06	1.12E+06	9.56E+05	9.80E+05	9.91E+05	9.97E+05	8.34E+05	8.58E+05	8.69E+05	8.74E+05
Hoop tensile, psi	E_{HT}	D638, D1599, or D2290	1.12E+06	1.13E+06	1.13E+06	1.13E+06	9.92E+05	1.00E+06	1.01E+06	1.01E+06	8.69E+05	8.78E+05	8.82E+05	8.84E+05
Hoop flexural, psi	E_{HF}	D790 or D2412	1.08E+06	1.10E+06	1.12E+06	1.12E+06	9.56E+05	9.80E+06	9.91E+05	9.97E+06	8.34E+05	8.58E+05	8.69E+05	8.74E+05
In-plane shear, psi	G	D4255	4.18E+05	4.21E+05	4.23E+05	4.23E+05	3.71E+05	3.74E+05	3.76E+05	3.77E+05	3.25E+05	3.29E+05	3.30E+05	3.31E+05

Other Property Data [Notes (1), (2), and (3)]

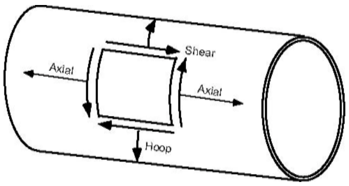
Property	Symbol	Test Method	Value for 0.2-in. Thickness
Poisson's ratio: hoop-axial tensile	ν_{HAT}	...	0.34
Poisson's ratio: axial-hoop tensile	ν_{AHT}	...	0.34
Coefficient of thermal expansion, in./in./°F: axial	α_A	D696	2.11E-05
Coefficient of thermal expansion, in./in./°F: hoop	α_H	...	2.11E-05
Density, lbm/in.^{3}	ρ	D792	0.051
Thermal conductivity, Btu-in./(hr-ft^2-°F)	k	C1045	1.2654

Allowable Stress Data [Note (4)]

Property	Symbol	ASTM Test Method	77°F	150°F	200°F
Axial tensile, psi	$S_{A(0:1)}$	D638 or D2105	1.13E+03	1.00E+03	8.78E+02
Axial flexural, psi	$S_{Af(0:1)}$	D790 or D2925	1.66E+03	1.47E+03	1.29E+03
Axial compressive, psi	$S_{A(0:-1)}$	D695	1.13E+03	1.00E+03	8.78E+02
Axial 2 × 1 biaxial tensile, psi	$S_{A(2:1)}$	D1599	1.13E+03	1.00E+03	8.78E+02
Hoop 2 × 1 biaxial tensile, psi	$S_{H(2:1)}$	D1599	1.13E+03	1.00E+03	8.78E+02
Hoop tensile, psi	$S_{H(1:0)}$	D638, D1599, or D2290	1.13E+03	1.00E+03	8.78E+02
In-plane shear, psi	τ	D4255	4.21E+02	3.74E+02	3.29E+02

FRP Material Moduli

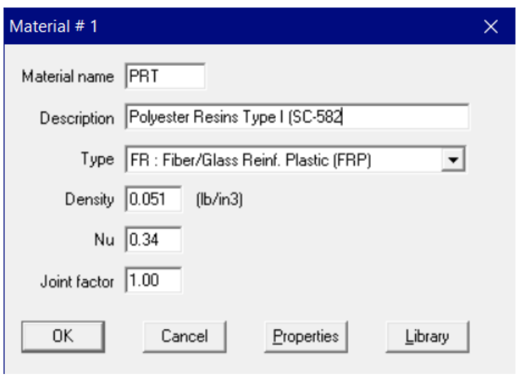
CAEPIPE requires three moduli for the FRP material:



- Axial or Longitudinal (this is the most important one)
- Hoop Modulus. 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.

In the Material List window shown on the screen, double click on an empty row to input a new material or double click on a material description to edit the material properties.

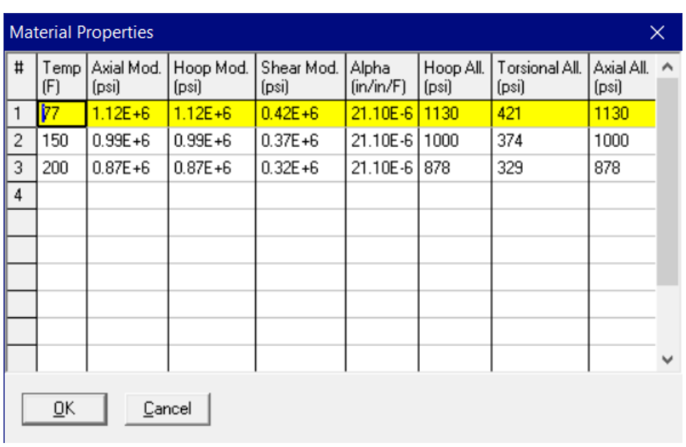
In the Material dialog shown, enter the FRP material properties as given below.



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 for code compliance checks as per ASME NM.2 and display them in 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	77	1.12E+6	1.12E+6	0.42E+6	21.10E-6	1130	421	1130
2	150	0.99E+6	0.99E+6	0.37E+6	21.10E-6	1000	374	1000
3	200	0.87E+6	0.87E+6	0.32E+6	21.10E-6	878	329	878
4								

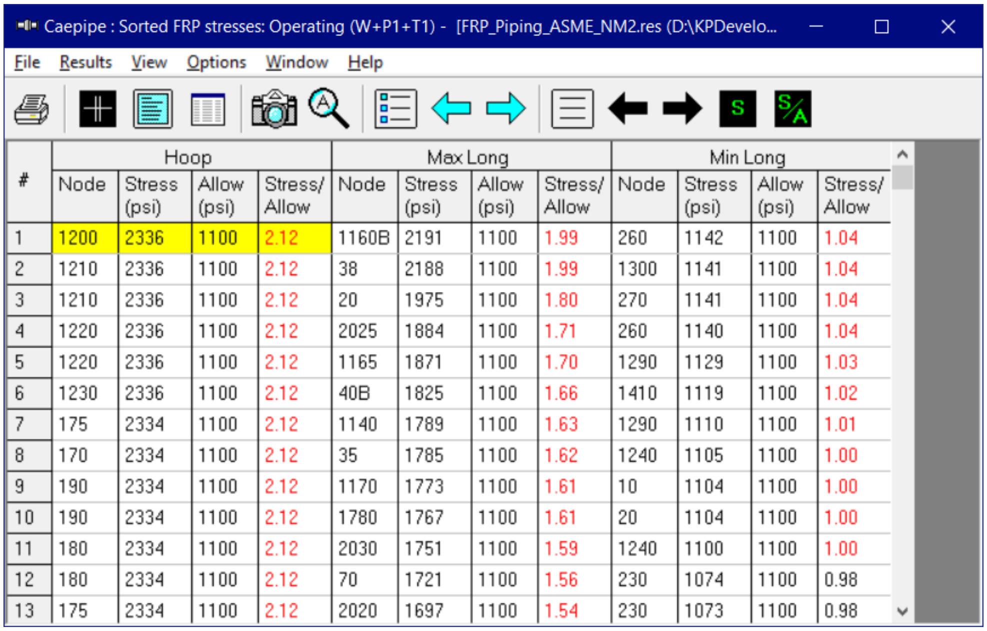
OK Cancel

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.

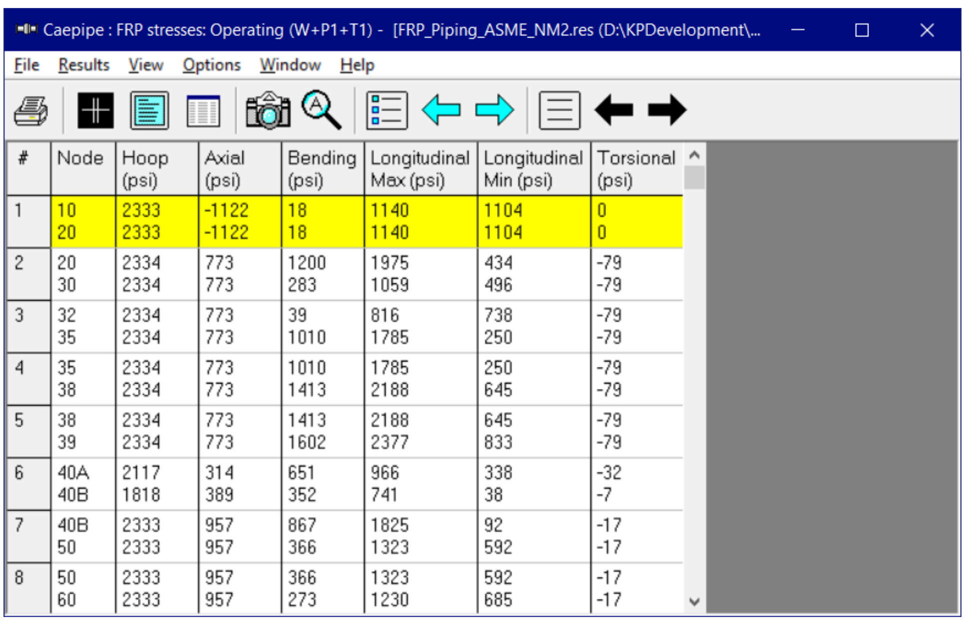
Step 5:

Upon successful analysis, CAEPIPE shows the code compliance as per ASME NM.2 under Sorted FRP stresses as shown below.



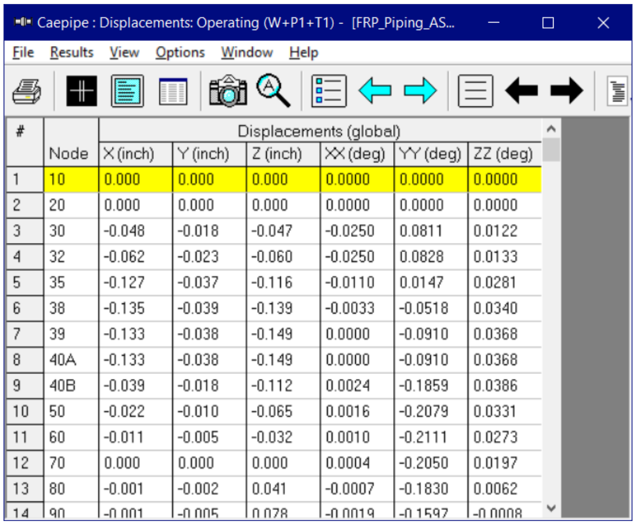
#	Hoop				Max Long				Min Long			
	Node	Stress (psi)	Allow (psi)	Stress/ Allow	Node	Stress (psi)	Allow (psi)	Stress/ Allow	Node	Stress (psi)	Allow (psi)	Stress/ Allow
1	1200	2336	1100	2.12	1160B	2191	1100	1.99	260	1142	1100	1.04
2	1210	2336	1100	2.12	38	2188	1100	1.99	1300	1141	1100	1.04
3	1210	2336	1100	2.12	20	1975	1100	1.80	270	1141	1100	1.04
4	1220	2336	1100	2.12	2025	1884	1100	1.71	260	1140	1100	1.04
5	1220	2336	1100	2.12	1165	1871	1100	1.70	1290	1129	1100	1.03
6	1230	2336	1100	2.12	40B	1825	1100	1.66	1410	1119	1100	1.02
7	175	2334	1100	2.12	1140	1789	1100	1.63	1290	1110	1100	1.01
8	170	2334	1100	2.12	35	1785	1100	1.62	1240	1105	1100	1.00
9	190	2334	1100	2.12	1170	1773	1100	1.61	10	1104	1100	1.00
10	190	2334	1100	2.12	1780	1767	1100	1.61	20	1104	1100	1.00
11	180	2334	1100	2.12	2030	1751	1100	1.59	1240	1100	1100	1.00
12	180	2334	1100	2.12	70	1721	1100	1.56	230	1074	1100	0.98
13	175	2334	1100	2.12	2020	1697	1100	1.54	230	1073	1100	0.98

FRP stresses results of CAEPIPE display the stresses computed as per ASME NM.2 on an element-by-element basis as shown below.

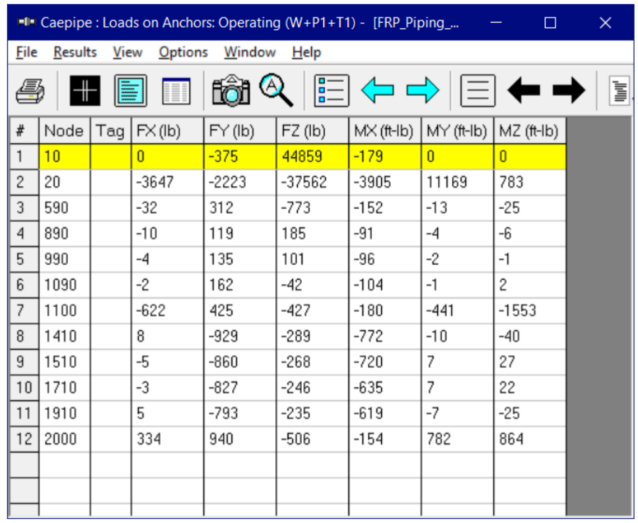


#	Node	Hoop (psi)	Axial (psi)	Bending (psi)	Longitudinal Max (psi)	Longitudinal Min (psi)	Torsional (psi)
1	10 20	2333 2333	-1122 -1122	18 18	1140 1140	1104 1104	0 0
2	20 30	2334 2334	773 773	1200 283	1975 1059	434 496	-79 -79
3	32 35	2334 2334	773 773	39 1010	816 1785	738 250	-79 -79
4	35 38	2334 2334	773 773	1010 1413	1785 2188	250 645	-79 -79
5	38 39	2334 2334	773 773	1413 1602	2188 2377	645 833	-79 -79
6	40A 40B	2117 1818	314 389	651 352	966 741	338 38	-32 -7
7	40B 50	2333 2333	957 957	867 366	1825 1323	92 592	-17 -17
8	50 60	2333 2333	957 957	366 273	1323 1230	592 685	-17 -17

CAEPIPE will show the deflections and support loads for each load case under Deflections and Support loads results as shown below.

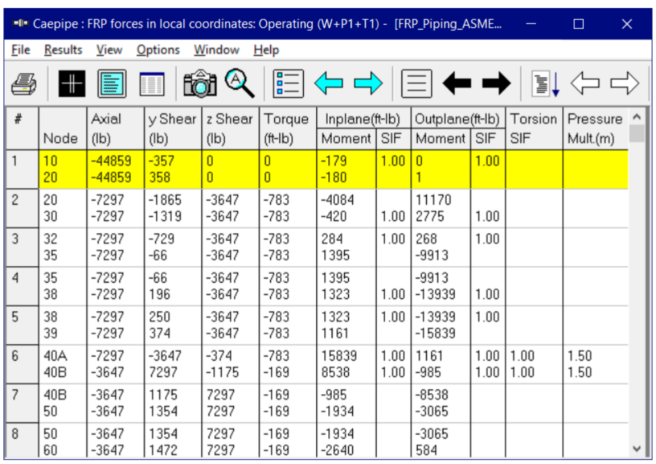


#	Node	Displacements (global)					
		X (inch)	Y (inch)	Z (inch)	XX (deg)	YY (deg)	ZZ (deg)
1	10	0.000	0.000	0.000	0.0000	0.0000	0.0000
2	20	0.000	0.000	0.000	0.0000	0.0000	0.0000
3	30	-0.048	-0.018	-0.047	-0.0250	0.0811	0.0122
4	32	-0.062	-0.023	-0.060	-0.0250	0.0828	0.0133
5	35	-0.127	-0.037	-0.116	-0.0110	0.0147	0.0281
6	38	-0.135	-0.039	-0.139	-0.0033	-0.0518	0.0340
7	39	-0.133	-0.038	-0.149	0.0000	-0.0910	0.0368
8	40A	-0.133	-0.038	-0.149	0.0000	-0.0910	0.0368
9	40B	-0.039	-0.018	-0.112	0.0024	-0.1859	0.0386
10	50	-0.022	-0.010	-0.065	0.0016	-0.2079	0.0331
11	60	-0.011	-0.005	-0.032	0.0010	-0.2111	0.0273
12	70	0.000	0.000	0.000	0.0004	-0.2050	0.0197
13	80	-0.001	-0.002	0.041	-0.0007	-0.1830	0.0062
14	90	-0.001	-0.005	0.078	-0.0019	-0.1597	-0.0008



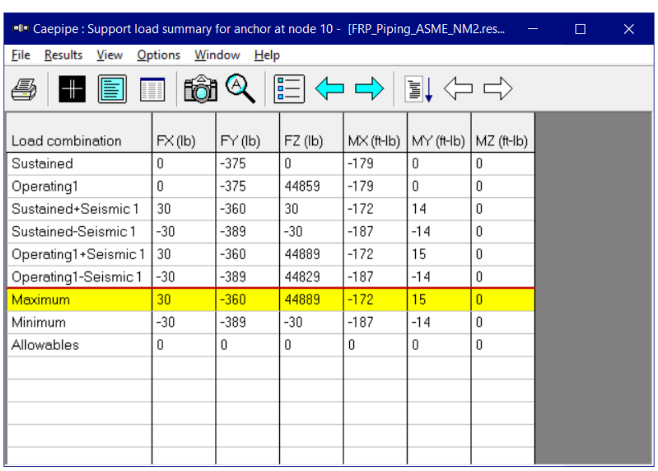
#	Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	10		0	-375	44859	-179	0	0
2	20		-3647	-2223	-37562	-3905	11169	783
3	590		-32	312	-773	-152	-13	-25
4	890		-10	119	185	-91	-4	-6
5	990		-4	135	101	-96	-2	-1
6	1090		-2	162	-42	-104	-1	2
7	1100		-622	425	-427	-180	-441	-1553
8	1410		8	-929	-289	-772	-10	-40
9	1510		-5	-860	-268	-720	7	27
10	1710		-3	-827	-246	-635	7	22
11	1910		5	-793	-235	-619	-7	-25
12	2000		334	940	-506	-154	782	864

Element forces results for each load case (such as Sustained, Operating, etc.) show the Element forces and moments in local coordinate system along with Stress Intensification Factors (SIFs) and Pressure Multiplier (m) computed as per ASME NM.2 for each element as shown below.



#	Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (ft-lb)	Inplane(ft-lb) Moment	Inplane SIF	Outplane(ft-lb) Moment	Outplane SIF	Torsion SIF	Pressure Mult.(m)
1	10 20	-44859 -44859	-357 358	0 0	0 0	-179 -180	1.00	0 1	1.00		
2	20 30	-7297 -7297	-1865 -1319	-3647 -3647	-783 -783	-4084 -420	 1.00	11170 2775	 1.00		
3	32 35	-7297 -7297	-729 -66	-3647 -3647	-783 -783	284 1395	1.00	268 -9913	1.00		
4	35 38	-7297 -7297	-66 196	-3647 -3647	-783 -783	1395 1323	 1.00	-9913 -13939	 1.00		
5	38 39	-7297 -7297	250 374	-3647 -3647	-783 -783	1323 1161	1.00	-13939 -15839	1.00		
6	40A 40B	-7297 -3647	-3647 7297	-374 -1175	-783 -169	15839 8538	1.00 1.00	1161 -985	1.00 1.00	1.00 1.00	1.50 1.50
7	40B 50	-3647 -3647	1175 1354	7297 7297	-169 -169	-985 -1934		-8538 -3065			
8	50 60	-3647 -3647	1354 1472	7297 7297	-169 -169	-1934 -2640		-3065 584			

For the design of supports, Support Load Summary of CAEPIPE will show the loads on each support for all load cases selected for analysis as given below.



Load combination	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
Sustained	0	-375	0	-179	0	0
Operating1	0	-375	44859	-179	0	0
Sustained+Seismic 1	30	-360	30	-172	14	0
Sustained-Seismic 1	-30	-389	-30	-187	-14	0
Operating1+Seismic 1	30	-360	44889	-172	15	0
Operating1-Seismic 1	-30	-389	44829	-187	-14	0
Maximum	30	-360	44889	-172	15	0
Minimum	-30	-389	-30	-187	-14	0
Allowables	0	0	0	0	0	0

Stiffness matrix formulated internally in CAEPIPE is 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)

Note:

Refer to Section titled "ASME NM.2" in CAEPIPE Code Compliance Manual of CAEPIPE for details on how CAEPIPE computes the Flexibility Factors, Stress Intensification Factors and Code Stresses as per ASME NM.2.