Tutorial on Fiber/Glass Reinforced Piping (FRP/GRP) Modeling and Analysis as per ISO 14692-3 using CAEPIPE

General

FRP pipes, also known as GRP pipes, fiberglass reinforced plastic pipes, is a type of conveying pipes with lightweight, high strength and corrosion resistance performance. The excellent corrosion resistance property and outstanding mechanical, physical and chemical performance save engineering, installation and maintenance costs, so it is regarded as the "user friendly" pipe.

FRP pipes have been proved to be superior to steel pipes in many aspects. They are widely used in industrial, civil engineering, petroleum, power and other fields.

FRP/GRP products are proprietary and the choice of component sizes, fittings and material types can be limited depending on the supplier. Potential vendors should be identified early in design to determine possible limitations of component availability.

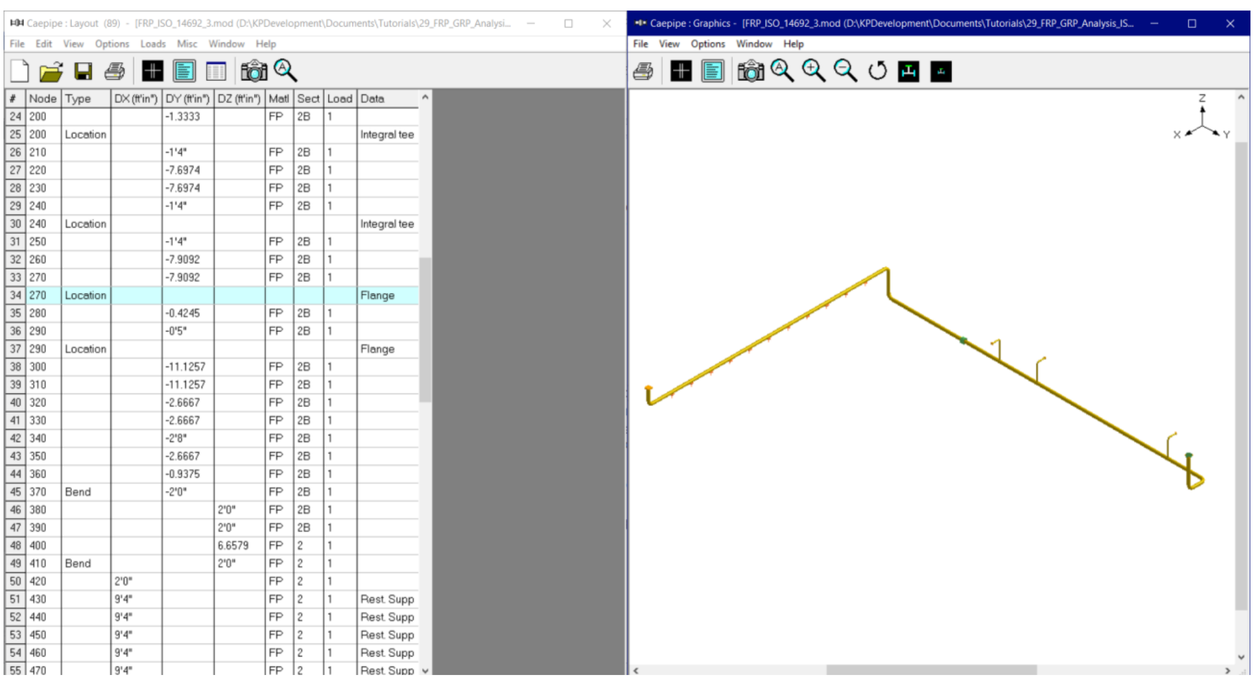
FRP piping systems can be supported using the same principles as those for metallic piping systems.

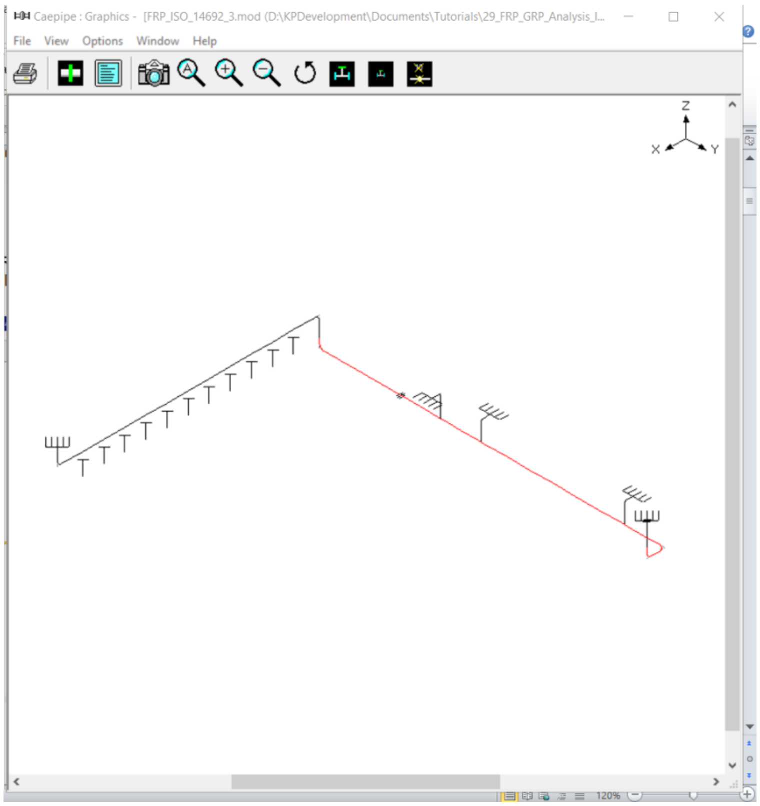
In addition to the above, Buried FRP analysis requires computation of vertical soil load on pipe sections, live load on pipe due to the traffic and considers the effect of static overburden soil pressure.

This tutorial provides steps in performing piping stress analysis of both buried and above-ground FRP/GRP piping as per ISO 14692-3 using CAEPIPE.

Tutorial

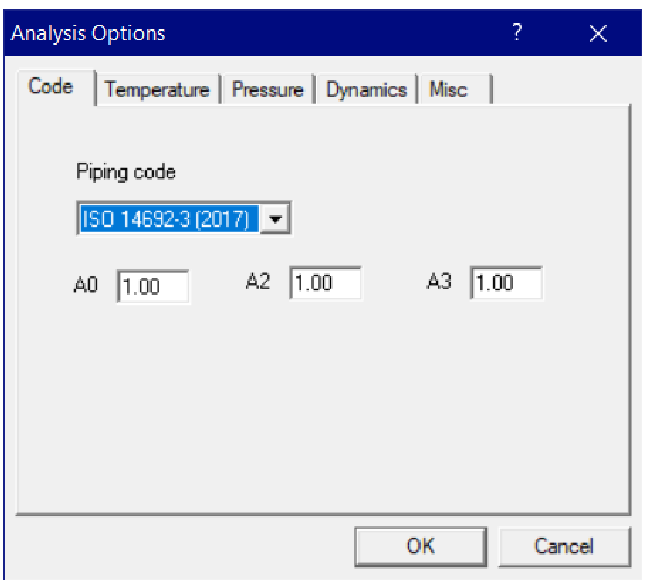
Snap shot shown below is a sample model for FRP/GRP Piping Analysis as per ISO 14692-3 where a portion of the layout is buried in soil (see the snapshot with RED highlight below) and the remaining portion of the layout is above the ground.





Step 1:

Select the piping code for analysis as “ISO 14692-3” through Layout Window > Options > Analysis > Code as shown below and press the button “OK”.

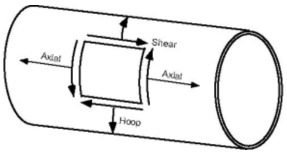


Step 2:

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.

FRP Material Moduli

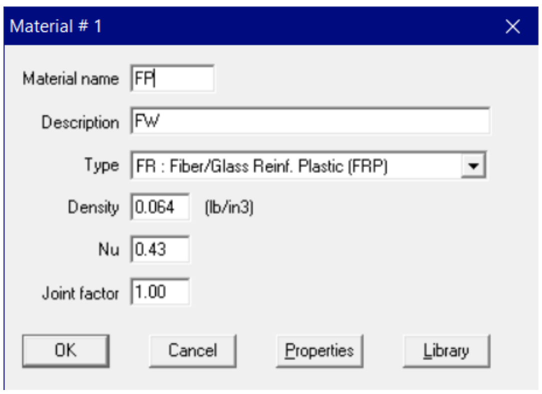
CAEPIPE requires three moduli for the FRP material:



- 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.

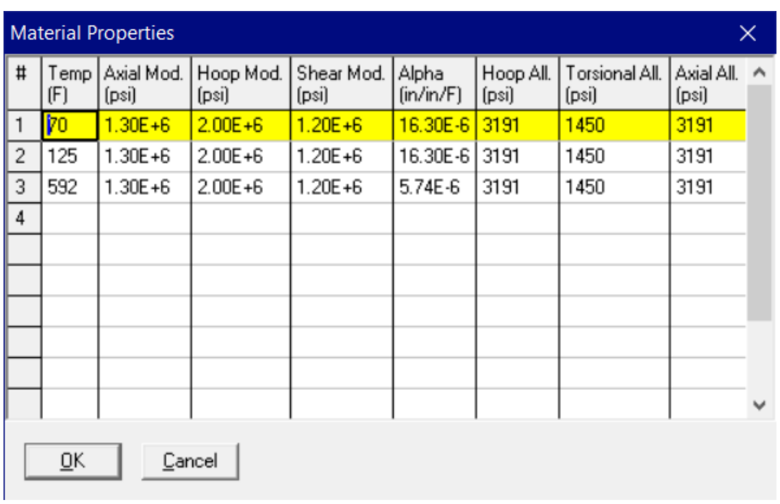
In the Material dialog shown, enter the FRP material properties as given below.



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 ISO 14692-3 and display them under "Sorted FRP Stresses" results.

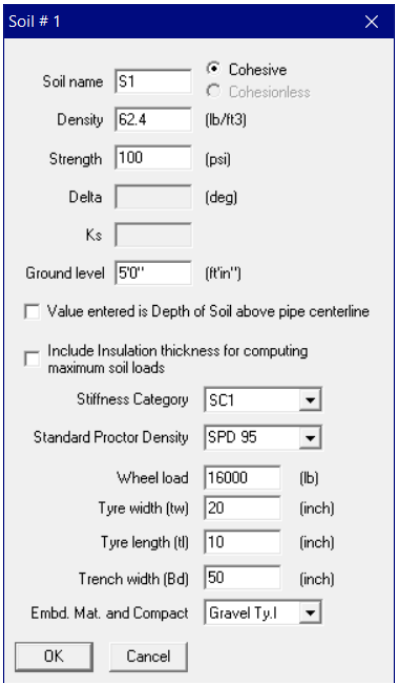

Material Properties

#	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	592	1.30E+6	2.00E+6	1.20E+6	5.74E-6	3191	1450	3191
4								

OK Cancel

Step 4:

Define soils properties using the command Layout window > Misc > Soils.



Two types of soils can be defined - Cohesive and Cohesionless.

Cohesive soil is hard to break up when dry, and exhibits significant **cohesion** when submerged. **Cohesive soils** include clayey silt, sandy clay, silty clay, clay and organic clay.

Cohesionless soil is any free-running type of **soil**, such as sand or gravel, whose strength depends on friction between particles. Cohesionless soil is not applicable for ISO 14692-3. Hence, the option is grayed out in the input screen.

Density is the density of the soil.

Strength

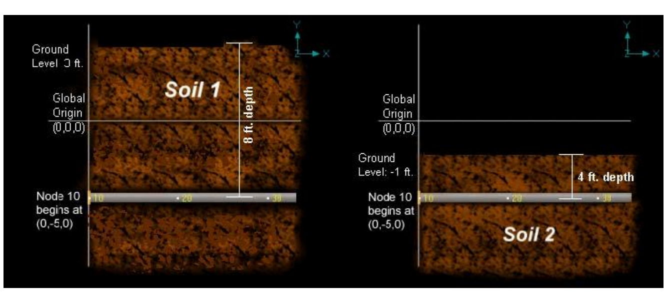
For cohesive soil, Strength is the same as Constrained modulus “Msn” defined in Table 5-6 of AWWA Manual M45 (second edition).

Ground Level

Ground level for a soil is the height of the soil surface from the global origin (height could be positive or negative). It is NOT a measure of the depth of the pipe’s centerline.

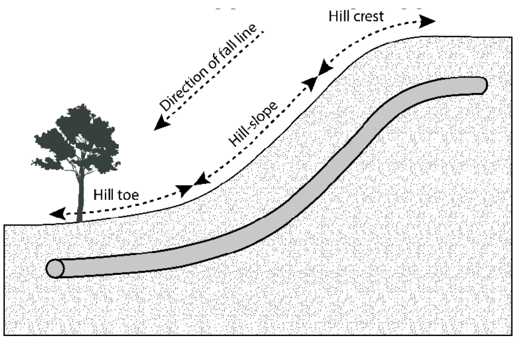
In the figure below, the height of the soil surface for Soil 1 is 3 feet from the global origin. Pipe node 10 [model origin] is defined at (0,-5, 0). So, at Node 10, the pipe is buried 8’ [= (3’ – (-5’)] deep into the soil. Define similarly for the other soil.

The pipe centerline is calculated by CAEPIPE from the given data.



Depth of Soil above Pipe's Centerline

When the option "Value entered is Depth of Soil above pipe centerline" is turned ON in Soil input, then CAEPIPE will compute maximum soil loads for the sections buried using the Depth entered. This option will be helpful for modeling pipes that are running up or down a hill with same depth of soil filled above pipe's centerline as shown in the figure given below.



Warning:

Assign Soil only to those elements that are really buried in soil when the option "Value entered is Depth of Soil above pipe centerline" is turned ON.

Stiffness Category

Stiffness Category is required to compute the value of "M_{sb}" the constrained soil modulus of the pipe zone embedment listed in Table 5-4 of AWWA Manual M45 (second edition). See the snapshot shown below.

Table 5-4 M_{sb} based on soil type and compaction condition

Inch-Pound Units					
		Stiffness Categories 1 and 2 (SC1, SC2)			
Vertical Stress Level (see note 5), *psi*	Depth for γ_s = 120 pcf, *ft*	SPD100, *psi*	SPD95, *psi*	SPD90, *psi*	SPD85, *psi*
1	1.2	2,350	2,000	1,275	470
5	6	3,450	2,600	1,500	520
10	12	4,200	3,000	1,625	570
20	24	5,500	3,450	1,800	650
40	48	7,500	4,250	2,100	825
60	72	9,300	5,000	2,500	1,000
			Stiffness Category 3 (SC3)		
1	1.2		1,415	670	360
5	6		1,670	740	390
10	12		1,770	750	400
20	24		1,880	790	430
40	48		2,090	900	510
60	72		2,300	1,025	600
			Stiffness Category 4 (SC4)		
1	1.2		530	255	130
5	6		625	320	175
10	12		690	355	200
20	24		740	395	230
40	48		815	460	285
60	72		895	525	345

Standard Proctor Density

Standard Proctor Density is required to obtain the value of "Msb" (the constrained soil modulus of the pipe zone embedment) listed in Table 5-4 of AWWA Manual M45 (second edition).

Wheel Load

Value entered in "Wheel Load" field will be used to compute the Live Load (WL) on pipe. Refer to Sub-section 5.7.3.6 of AWWA Manual M45 (second edition). For example, the Truck Load field can be input as 16,000 lb for AASHTO-20 or 20,000 lb for AASHTO-25.

Tyre Width & Tyre Length

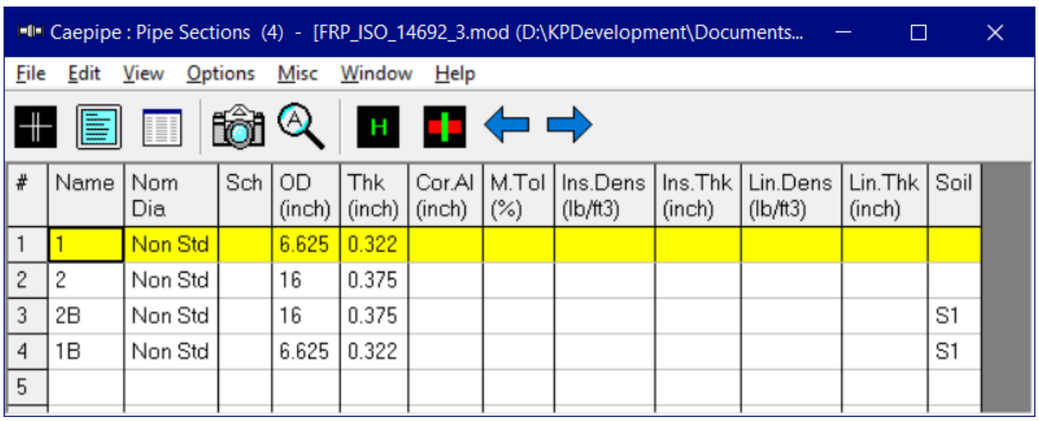
Tyre Width and Length input are used for computing the Live Load (WL) on pipe. By default, these values are set as 20" and 10" respectively. Refer to Sub-section 5.7.3.6 of AWWA Manual M45 (second edition) and Section "ISO 14692-3" in CAEPIPE Code Compliance Manual for further details.

Trench Width

Trench Width input is used to obtain the value of Sc from Table 5-5 which in turn is used for computing the maximum allowable vertical pipe deflection of pipe. Refer to Sub-section 5.7.3 and Table 5-5 of AWWA Manual M45 (second edition) and Section "ISO 14692-3" in CAEPIPE Code Compliance Manual for further details.

Step 5:

Tie the soils defined above with pipe sections through Layout window > Misc > Sections or Ctrl+Shft+S (to list Sections). Double click on the required section property. You will see the field Soil in the bottom right corner. Pick the soil name from the drop-down combo box.



#	Name	Nom Dia	Sch	OD (inch)	Thk (inch)	Cor.Al (inch)	M.Tol (%)	Ins.Dens (lb/ft3)	Ins.Thk (inch)	Lin.Dens (lb/ft3)	Lin.Thk (inch)	Soil
1	1	Non Std		6.625	0.322							
2	2	Non Std		16	0.375							
3	2B	Non Std		16	0.375							S1
4	1B	Non Std		6.625	0.322							S1
5												

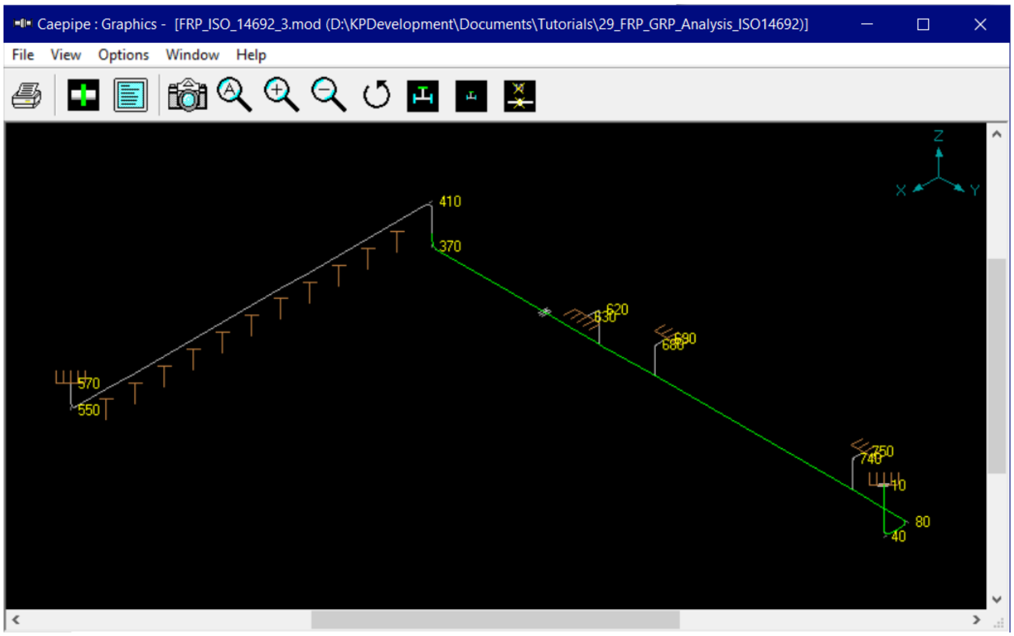
If a part of a piping system uses a certain pipe section with some portion of it buried and the balance not buried, then two separate sections have to be defined, with one of them without soil and the other with soil as shown above for Sections 2 and 2B.

Step 6:

Assign the appropriate section for each buried element on the Layout window with the correct soil around it.

Step 7:

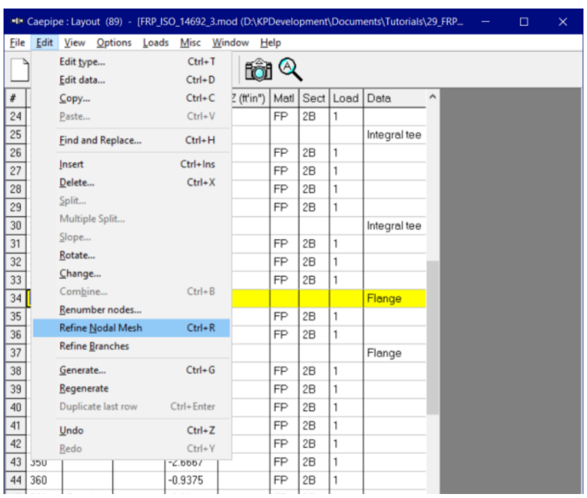
Review the stress layout by highlighting the buried sections of the model in graphics. If your model contains sections that are above-ground and buried, then you can selectively see only the buried sections of piping in CAEPIPE graphics by highlighting the section that is tied to the soil. Use the Highlight feature under the Section List window and place highlight on the buried piping section (see Highlight under List window>View menu, or press Ctrl+H). The Graphics window should highlight only that portion of the model that is using that specific section/soil. See the portion shown in green in the figure below.

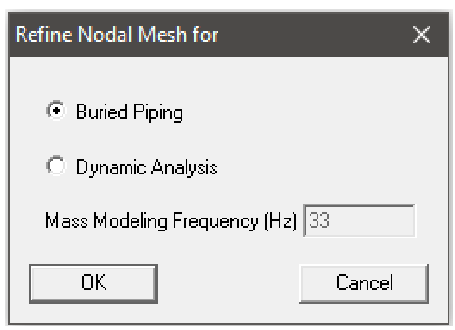


Step 8:

It is at the bends, elbows, and branch connections that the highest stresses are found in buried piping subjected to thermal expansion of the pipe. Hence, buried piping elements at the junction of bends, elbows and branch connections are to be refined in the stress layout.

This can be performed through Layout window > Edit > Refine Nodal Mesh > Buried Piping. Please see the section titled “Buried Piping” in CAEPIPE User’s Manual for details on “Nodal mesh generation”.



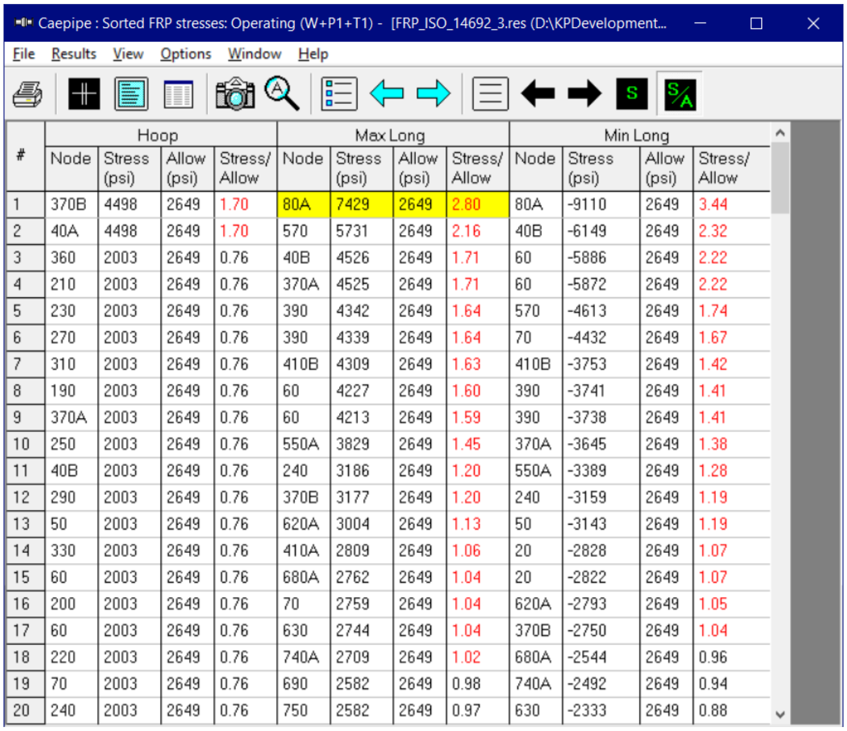


Step 9:

After completing the stress layout, save the model and analyze through Layout window > File > Analyze. See the file “FRP_ISO_14692_3.mod” available with this tutorials for further details.

Step 10:

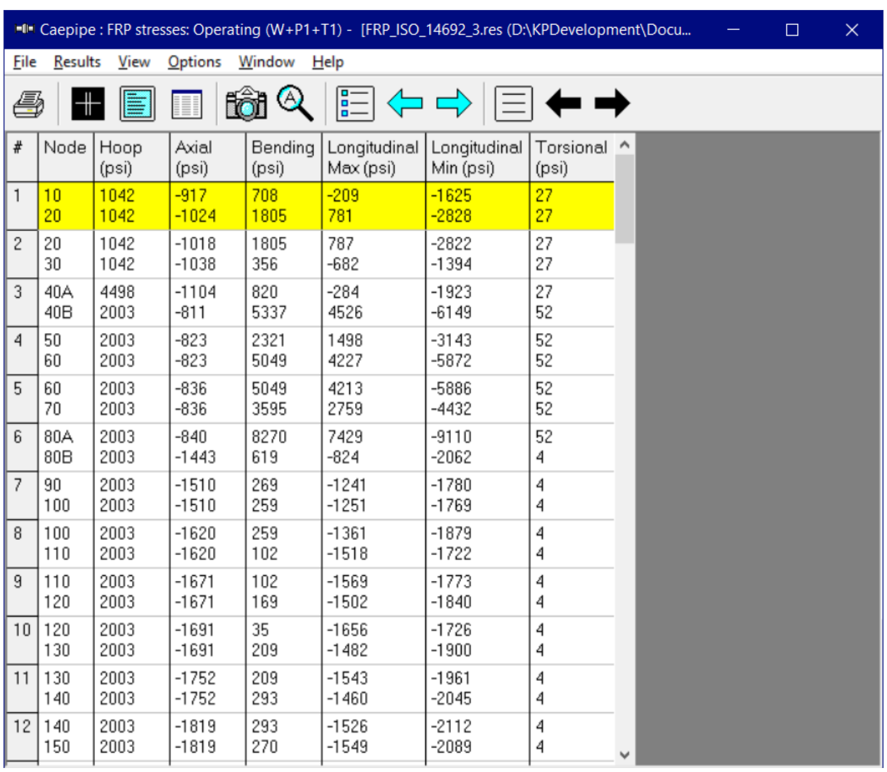
Upon successful analysis, CAEPIPE shows the code compliance as per ISO 14692-3 under Sorted FRP stresses as shown below.


Caepipe : Sorted FRP stresses: Operating (W+P1+T1) - [FRP_ISO_14692_3.res (D:\KPDevelopment...

File Results View Options Window Help

#	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	370B	4498	2649	1.70	80A	7429	2649	2.80	80A	-9110	2649	3.44
2	40A	4498	2649	1.70	570	5731	2649	2.16	40B	-6149	2649	2.32
3	360	2003	2649	0.76	40B	4526	2649	1.71	60	-5886	2649	2.22
4	210	2003	2649	0.76	370A	4525	2649	1.71	60	-5872	2649	2.22
5	230	2003	2649	0.76	390	4342	2649	1.64	570	-4613	2649	1.74
6	270	2003	2649	0.76	390	4339	2649	1.64	70	-4432	2649	1.67
7	310	2003	2649	0.76	410B	4309	2649	1.63	410B	-3753	2649	1.42
8	190	2003	2649	0.76	60	4227	2649	1.60	390	-3741	2649	1.41
9	370A	2003	2649	0.76	60	4213	2649	1.59	390	-3738	2649	1.41
10	250	2003	2649	0.76	550A	3829	2649	1.45	370A	-3645	2649	1.38
11	40B	2003	2649	0.76	240	3186	2649	1.20	550A	-3389	2649	1.28
12	290	2003	2649	0.76	370B	3177	2649	1.20	240	-3159	2649	1.19
13	50	2003	2649	0.76	620A	3004	2649	1.13	50	-3143	2649	1.19
14	330	2003	2649	0.76	410A	2809	2649	1.06	20	-2828	2649	1.07
15	60	2003	2649	0.76	680A	2762	2649	1.04	20	-2822	2649	1.07
16	200	2003	2649	0.76	70	2759	2649	1.04	620A	-2793	2649	1.05
17	60	2003	2649	0.76	630	2744	2649	1.04	370B	-2750	2649	1.04
18	220	2003	2649	0.76	740A	2709	2649	1.02	680A	-2544	2649	0.96
19	70	2003	2649	0.76	690	2582	2649	0.98	740A	-2492	2649	0.94
20	240	2003	2649	0.76	750	2582	2649	0.97	630	-2333	2649	0.88

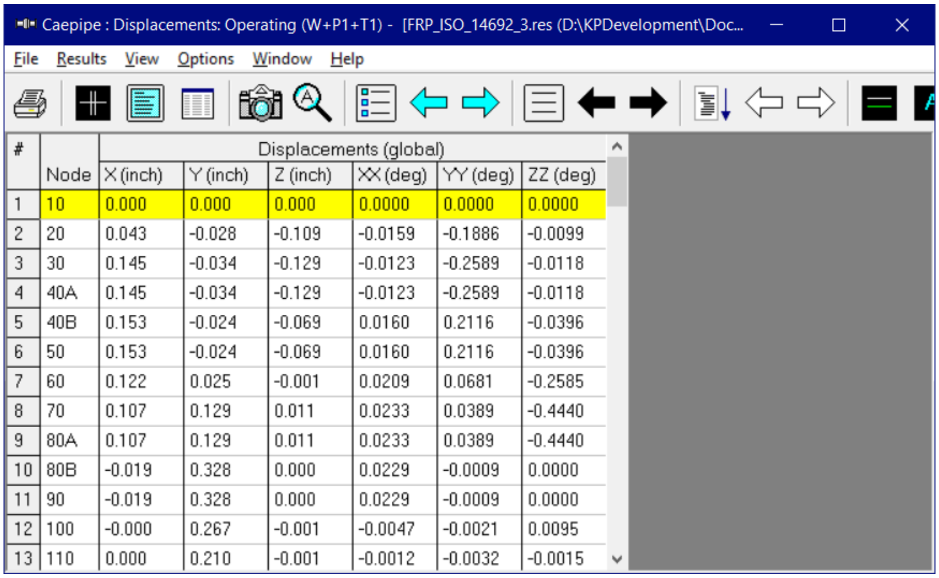
FRP stresses results of CAEPIPE display the stresses computed as per ISO 14692-3 on an element-by-element basis as shown below.


Caepipe : FRP stresses: Operating (W+P1+T1) - [FRP_ISO_14692_3.res (D:\KPDevelopment\Docu...

File Results View Options Window Help

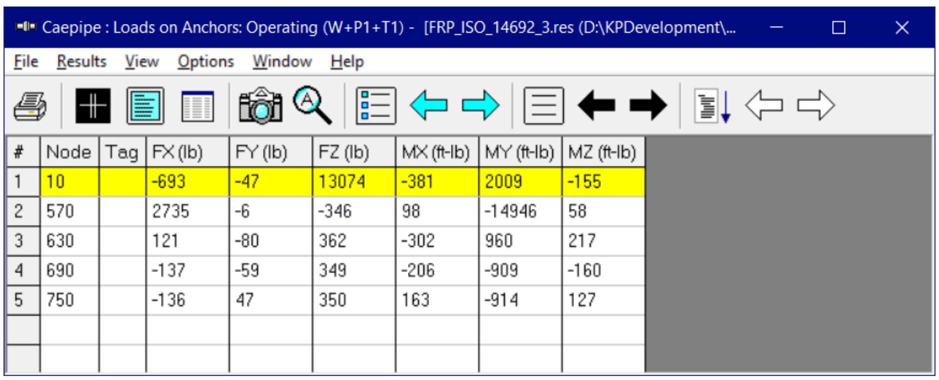
#	Node	Hoop (psi)	Axial (psi)	Bending (psi)	Longitudinal Max (psi)	Longitudinal Min (psi)	Torsional (psi)
1	10 20	1042 1042	-917 -1024	708 1805	-209 781	-1625 -2828	27 27
2	20 30	1042 1042	-1018 -1038	1805 356	787 -682	-2822 -1394	27 27
3	40A 40B	4498 2003	-1104 -811	820 5337	-284 4526	-1923 -6149	27 52
4	50 60	2003 2003	-823 -823	2321 5049	1498 4227	-3143 -5872	52 52
5	60 70	2003 2003	-836 -836	5049 3595	4213 2759	-5886 -4432	52 52
6	80A 80B	2003 2003	-840 -1443	8270 619	7429 -824	-9110 -2062	52 4
7	90 100	2003 2003	-1510 -1510	269 259	-1241 -1251	-1780 -1769	4 4
8	100 110	2003 2003	-1620 -1620	259 102	-1361 -1518	-1879 -1722	4 4
9	110 120	2003 2003	-1671 -1671	102 169	-1569 -1502	-1773 -1840	4 4
10	120 130	2003 2003	-1691 -1691	35 209	-1656 -1482	-1726 -1900	4 4
11	130 140	2003 2003	-1752 -1752	209 293	-1543 -1460	-1961 -2045	4 4
12	140 150	2003 2003	-1819 -1819	293 270	-1526 -1549	-2112 -2089	4 4

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


Caepipe : Displacements: Operating (W+P1+T1) - [FRP_ISO_14692_3.res (D:\KPDevelopment\Doc...

File Results View Options Window Help

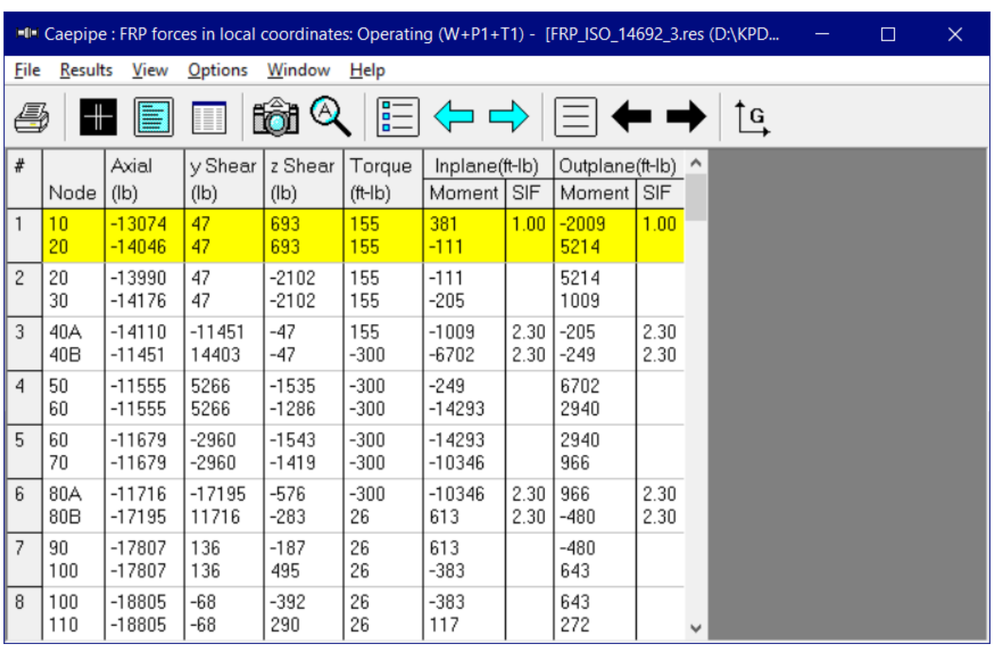
#		Displacements (global)					
	Node	X (inch)	Y (inch)	Z (inch)	XX (deg)	YY (deg)	ZZ (deg)
1	10	0.000	0.000	0.000	0.0000	0.0000	0.0000
2	20	0.043	-0.028	-0.109	-0.0159	-0.1886	-0.0099
3	30	0.145	-0.034	-0.129	-0.0123	-0.2589	-0.0118
4	40A	0.145	-0.034	-0.129	-0.0123	-0.2589	-0.0118
5	40B	0.153	-0.024	-0.069	0.0160	0.2116	-0.0396
6	50	0.153	-0.024	-0.069	0.0160	0.2116	-0.0396
7	60	0.122	0.025	-0.001	0.0209	0.0681	-0.2585
8	70	0.107	0.129	0.011	0.0233	0.0389	-0.4440
9	80A	0.107	0.129	0.011	0.0233	0.0389	-0.4440
10	80B	-0.019	0.328	0.000	0.0229	-0.0009	0.0000
11	90	-0.019	0.328	0.000	0.0229	-0.0009	0.0000
12	100	-0.000	0.267	-0.001	-0.0047	-0.0021	0.0095
13	110	0.000	0.210	-0.001	-0.0012	-0.0032	-0.0015


Caepipe : Loads on Anchors: Operating (W+P1+T1) - [FRP_ISO_14692_3.res (D:\KPDevelopment\...

File Results View Options Window Help

#	Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	10		-693	-47	13074	-381	2009	-155
2	570		2735	-6	-346	98	-14946	58
3	630		121	-80	362	-302	960	217
4	690		-137	-59	349	-206	-909	-160
5	750		-136	47	350	163	-914	127

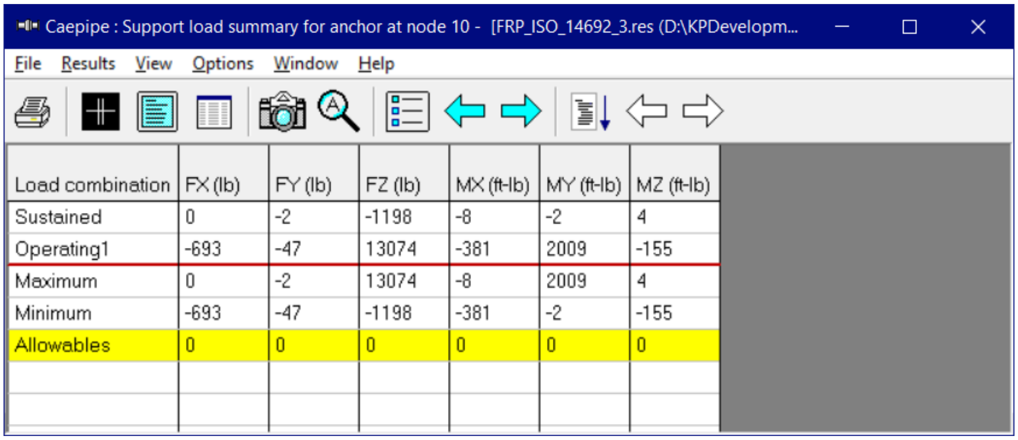
Element forces results for each load case (such as Sustained, Operating, etc.) show the Element forces and moments in local coordinate system along with Stress Intensification Factors (SIFs) computed as per analysis code ISO 14692-3 for each element as given below.


Caepipe : FRP forces in local coordinates: Operating (W+P1+T1) - [FRP_ISO_14692_3.res (D:\KPD...

File Results View Options Window Help

#		Axial	y Shear	z Shear	Torque	Inplane(ft-lb)		Outplane(ft-lb)	
	Node	(lb)	(lb)	(lb)	(ft-lb)	Moment	SIF	Moment	SIF
1	10 20	-13074 -14046	47 47	693 693	155 155	381 -111	1.00	-2009 5214	1.00
2	20 30	-13990 -14176	47 47	-2102 -2102	155 155	-111 -205		5214 1009	
3	40A 40B	-14110 -11451	-11451 14403	-47 -47	155 -300	-1009 -6702	2.30 2.30	-205 -249	2.30 2.30
4	50 60	-11555 -11555	5266 5266	-1535 -1286	-300 -300	-249 -14293		6702 2940	
5	60 70	-11679 -11679	-2960 -2960	-1543 -1419	-300 -300	-14293 -10346		2940 966	
6	80A 80B	-11716 -17195	-17195 11716	-576 -283	-300 26	-10346 613	2.30 2.30	966 -480	2.30 2.30
7	90 100	-17807 -17807	136 136	-187 495	26 26	613 -383		-480 643	
8	100 110	-18805 -18805	-68 -68	-392 290	26 26	-383 117		643 272	

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	-2	-1198	-8	-2	4
Operating1	-693	-47	13074	-381	2009	-155
Maximum	0	-2	13074	-8	2009	4
Minimum	-693	-47	-1198	-381	-2	-155
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 "ISO 14692-3" in CAEPIPE Code Compliance Manual of CAEPIPE for details on how CAEPIPE computes the Flexibility Factors, Stress Intensification Factors and Code Stresses as per ISO 14692-3.