Tutorial on Hydrogen Pipeline Analysis as per ASME B31.12 Part PL using CAEPIPE

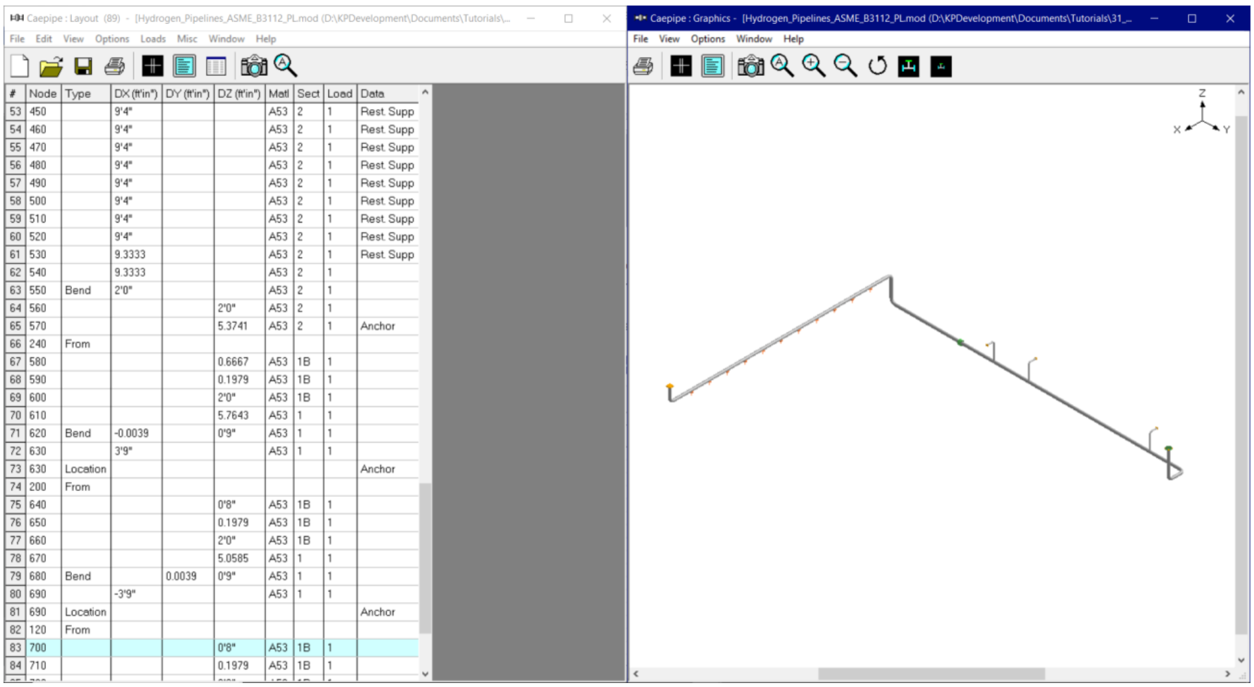
General

In the search for a sustainable and decarbonized future, hydrogen is emerging as a key energy carrier with tremendous potential. As the demand for hydrogen increases, the need for safe and efficient infrastructure becomes paramount. The American Society of Mechanical Engineers (ASME) recognized this need and developed the ASME B31.12 code to provide guidelines for the design, construction, and operation of hydrogen piping and pipeline systems. This comprehensive code ensures the integrity and safety of hydrogen infrastructure while promoting the growth of the hydrogen industry.

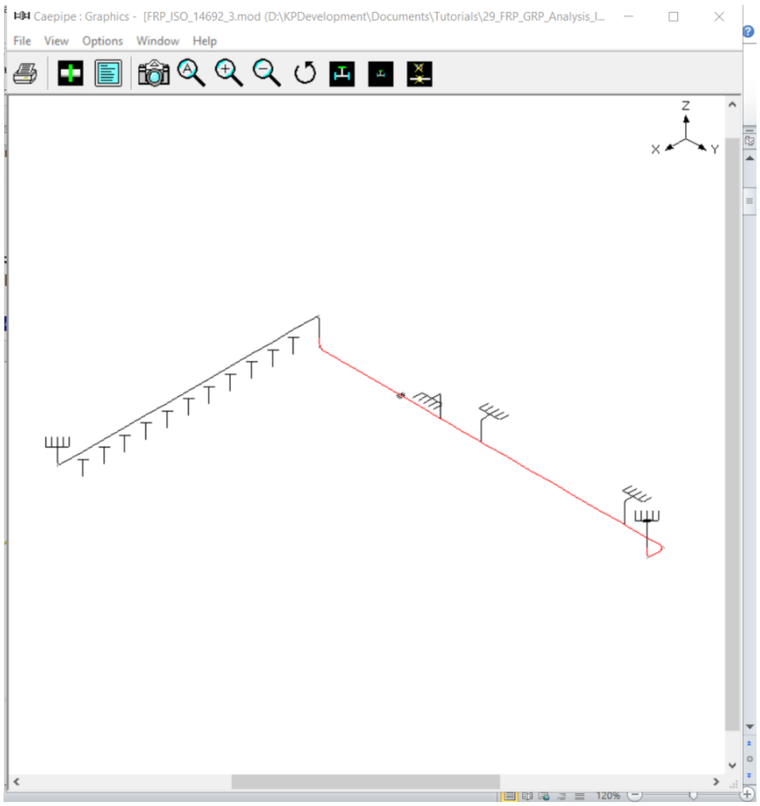
This tutorial provides steps in performing piping stress analysis of both buried and above-ground Hydrogen Pipelines as per ASME B31.12 Part PL using CAEPIPE.

Tutorial

Snap shot shown below is a sample model for Hydrogen Pipelines as per ASME B31.12 Part PL 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-ground.

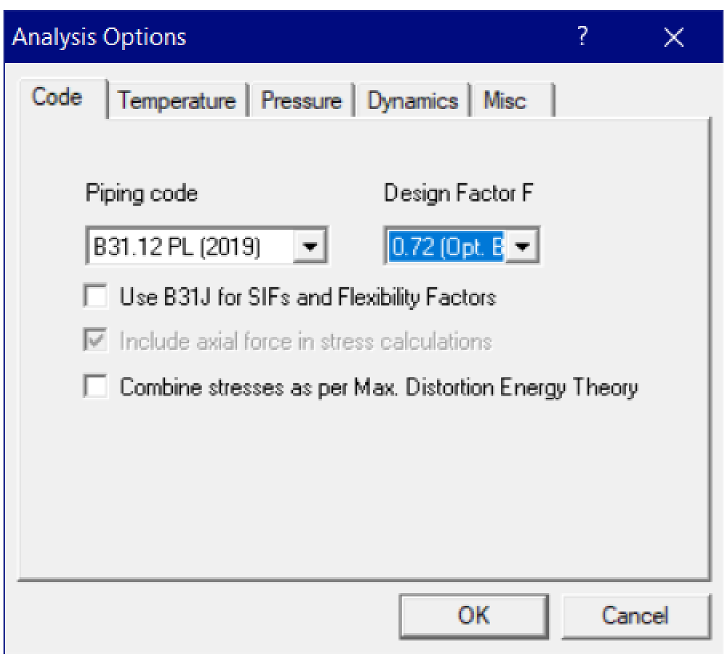


#	Node	Type	DX (ft'in")	DY (ft'in")	DZ (ft'in")	Matl	Sect	Load	Data
53	450		9'4"			A53	2	1	Rest. Supp
54	460		9'4"			A53	2	1	Rest. Supp
55	470		9'4"			A53	2	1	Rest. Supp
56	480		9'4"			A53	2	1	Rest. Supp
57	490		9'4"			A53	2	1	Rest. Supp
58	500		9'4"			A53	2	1	Rest. Supp
59	510		9'4"			A53	2	1	Rest. Supp
60	520		9'4"			A53	2	1	Rest. Supp
61	530		9.3333			A53	2	1	Rest. Supp
62	540		9.3333			A53	2	1	
63	550	Bend	2'0"			A53	2	1	
64	560				2'0"	A53	2	1	
65	570				5.3741	A53	2	1	Anchor
66	240	From							
67	580				0.6667	A53	1B	1	
68	590				0.1979	A53	1B	1	
69	600				2'0"	A53	1B	1	
70	610				5.7643	A53	1	1	
71	620	Bend	-0.0039		0'9"	A53	1	1	
72	630		3'9"			A53	1	1	
73	630	Location							Anchor
74	200	From							
75	640				0'8"	A53	1B	1	
76	650				0.1979	A53	1B	1	
77	660				2'0"	A53	1B	1	
78	670				5.0585	A53	1	1	
79	680	Bend		0.0039	0'9"	A53	1	1	
80	690		-3'9"			A53	1	1	
81	690	Location							Anchor
82	120	From							
83	700				0'8"	A53	1B	1	
84	710				0.1979	A53	1B	1	



Step 1:

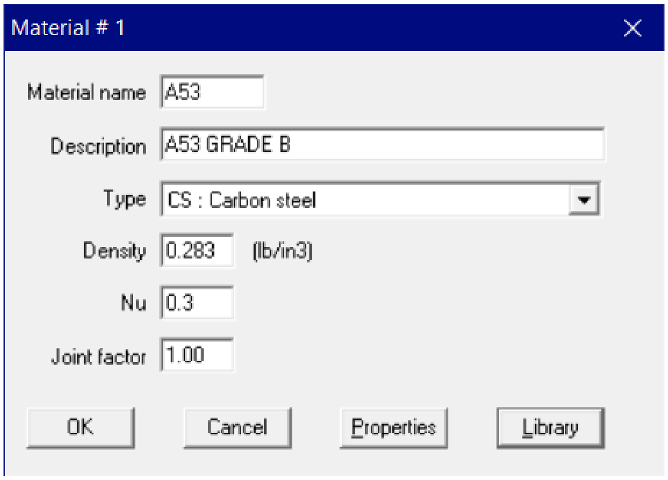
Select the piping code for analysis as “B31.12 PL” and the “Design Factor F” through Layout Window > Options > Analysis > Code as shown below and press the button “OK”. See para. PL-3.7.1 (b) for details on Design Factor F in ASME B31.12 Part PL.



Step 2:

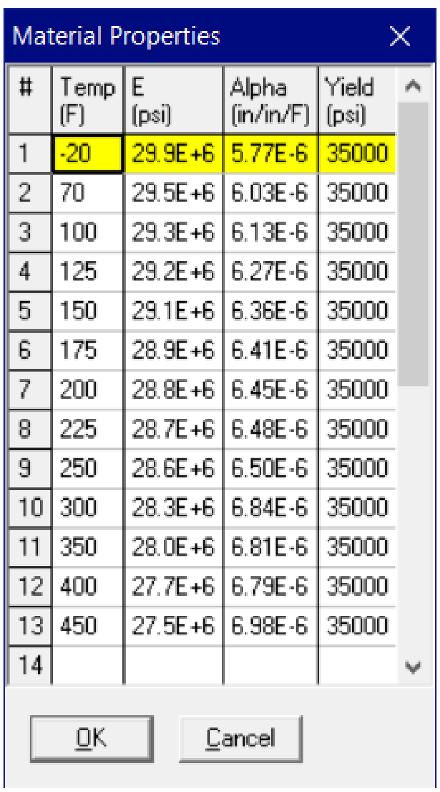
Next define materials required for piping system through Layout window > Misc > Materials by obtaining their properties from the manufacturer or through the piping standard.

In the Material List window shown on the screen, double click on an empty row to input a new material. Enter the material properties as shown below and press the button “Ok”.



Step 3:

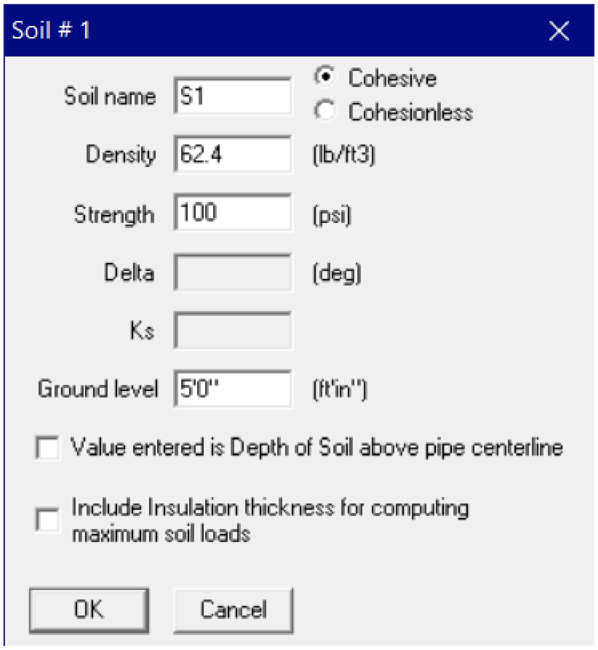
Click on the Properties button and input the temperature related properties as shown below.



#	Temp (F)	E (psi)	Alpha (in/in/F)	Yield (psi)
1	-20	29.9E+6	5.77E-6	35000
2	70	29.5E+6	6.03E-6	35000
3	100	29.3E+6	6.13E-6	35000
4	125	29.2E+6	6.27E-6	35000
5	150	29.1E+6	6.36E-6	35000
6	175	28.9E+6	6.41E-6	35000
7	200	28.8E+6	6.45E-6	35000
8	225	28.7E+6	6.48E-6	35000
9	250	28.6E+6	6.50E-6	35000
10	300	28.3E+6	6.84E-6	35000
11	350	28.0E+6	6.81E-6	35000
12	400	27.7E+6	6.79E-6	35000
13	450	27.5E+6	6.98E-6	35000
14				

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.

Density is the density of the soil.

<u>Strength</u>

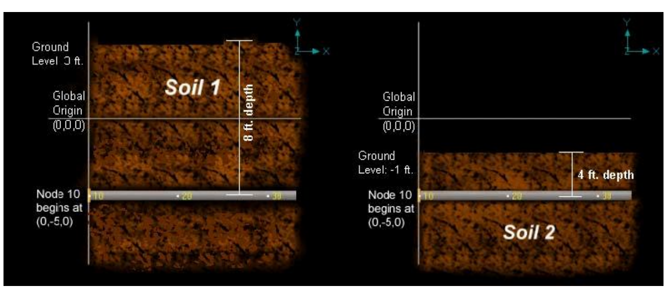
Soil strength. This field needs to be input only for Cohesive soil. For cohesive soil, Strength is the un-drained cohesive strength (Cs).

<u>Ground Level</u>

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.

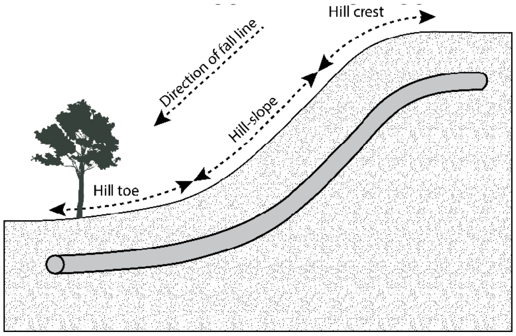
In the figure below, the height of the soil surface for Soil 1 is 3 feet from the global origin. Pipe node 10 [model origin] is defined at (0,-5, 0). So, at Node 10, the pipe is buried 8' [= (3' – (-5')] deep into the soil. Define similarly for the other soil.

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



<u>Depth of Soil above Pipe's Centerline</u>

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 the same depth of soil filled above pipe's centerline as shown in the figure given below.

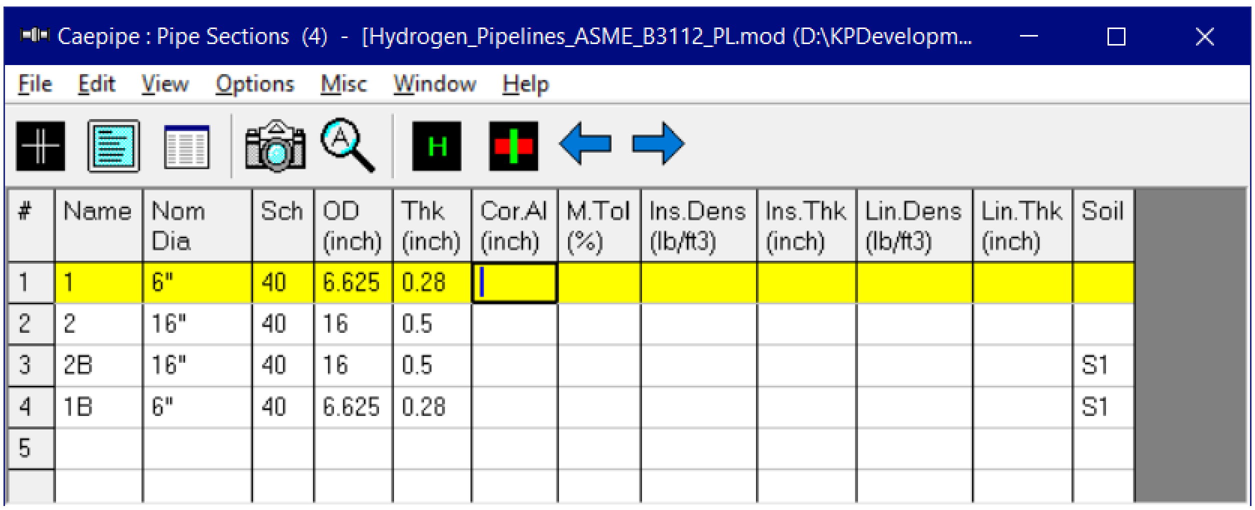


Warning:

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.

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	6"	40	6.625	0.28							
2	2	16"	40	16	0.5							
3	2B	16"	40	16	0.5							S1
4	1B	6"	40	6.625	0.28							S1
5												

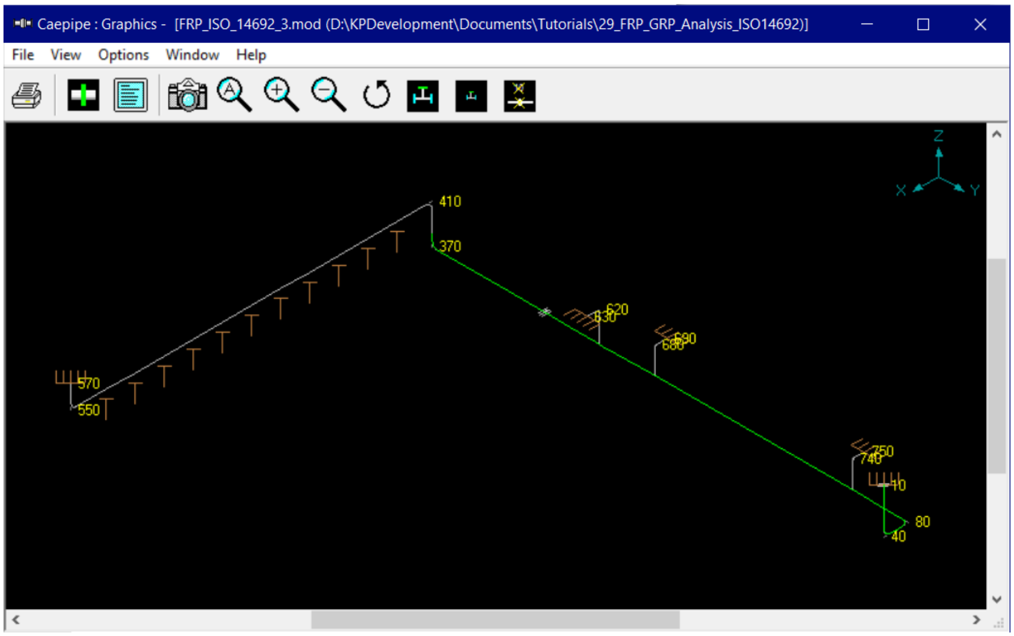
If a part of a piping system uses a certain pipe section with some portion of it buried and the balance not buried, then two separate sections have to be defined, with one of them without soil and the other with soil as shown above for Sections 2 and 2B.

Step 6:

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

Step 7:

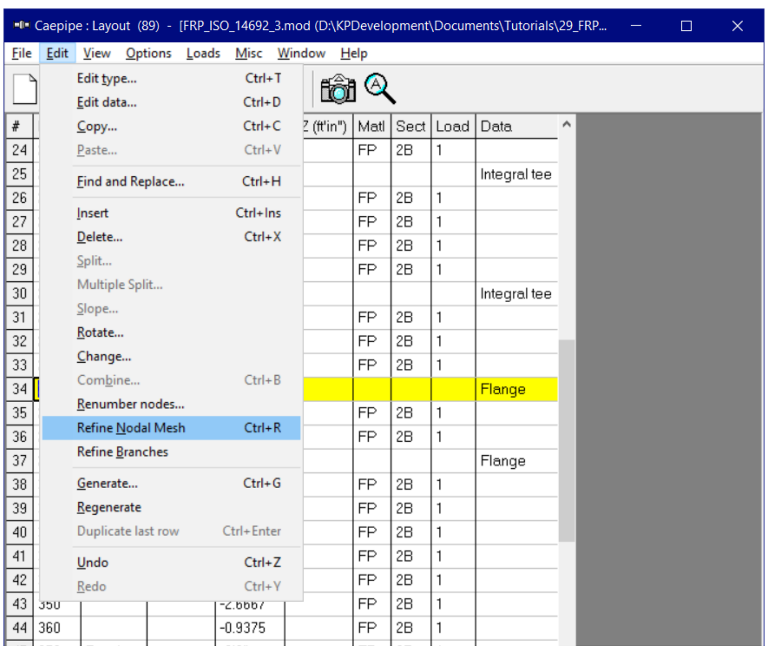
Review the stress layout by highlighting the buried sections of the model in graphics. If your model contains sections that are above-ground and buried, then you can selectively see only the buried sections of piping in CAEPIPE graphics by highlighting the section that is tied to the soil. Use the Highlight 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.

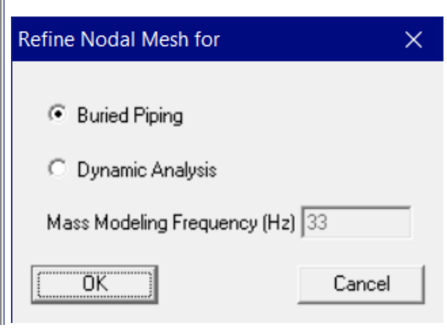


Step 8:

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”.



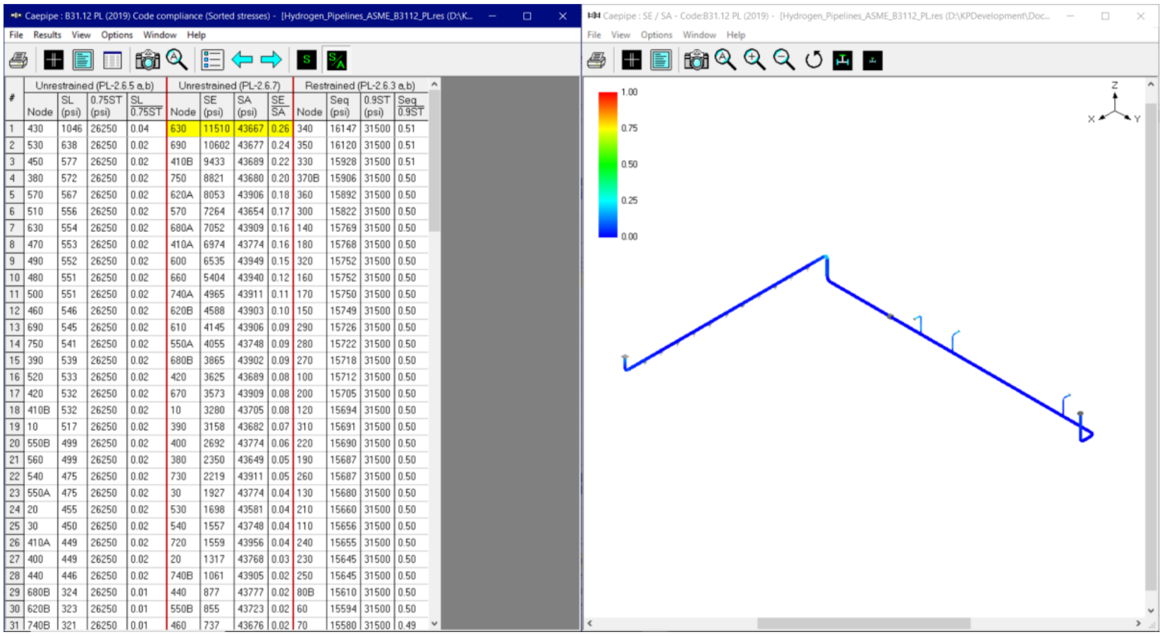


Step 9:

After completing the stress layout, save the model and analyze through Layout window > File > Analyze. See the file “Hydrogen_Pipeline_ASME_B3112_PL.mod” available with this tutorial for further details.

Step 10:

Upon successful analysis, CAEPIPE shows the code compliance as per ASME B31.12 Part PL under Sorted stresses as shown below.



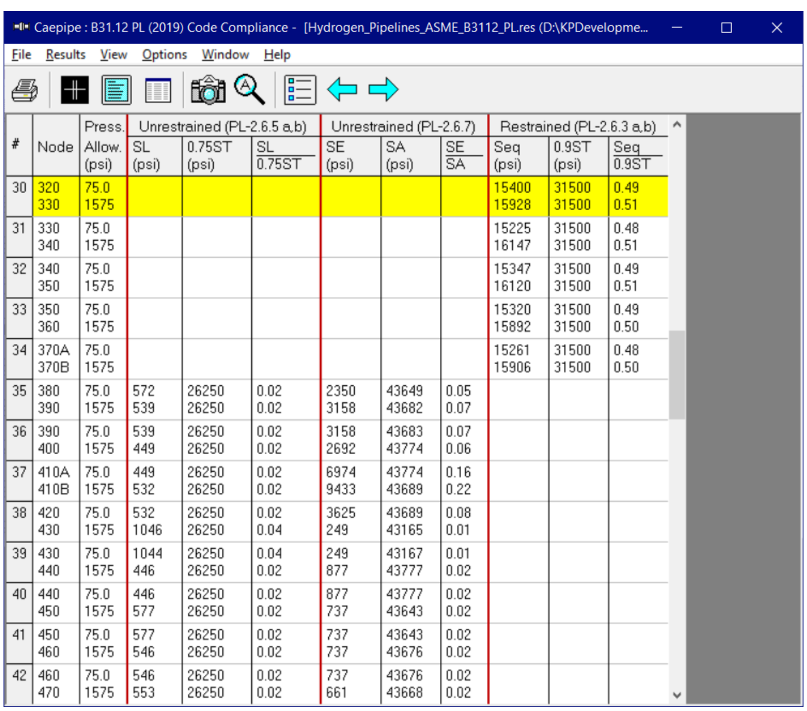
#	Unrestrained (PL-2.6.5 a,b) Node	SL (psi)	0.75ST (psi)	SL / 0.75ST	Unrestrained (PL-2.6.7) Node	SE (psi)	SA (psi)	SE / SA	Restrained (PL-2.6.3 a,b) Node	Seq (psi)	0.9ST (psi)	Seq / 0.9ST
1	430	1046	26250	0.04	630	11510	43667	0.26	340	16147	31500	0.51
2	530	638	26250	0.02	690	10602	43677	0.24	350	16120	31500	0.51
3	450	577	26250	0.02	410B	9433	43689	0.22	330	15928	31500	0.51
4	380	572	26250	0.02	750	8821	43680	0.20	370B	15906	31500	0.50
5	570	567	26250	0.02	620A	8053	43906	0.18	360	15892	31500	0.50
6	510	556	26250	0.02	570	7264	43654	0.17	300	15822	31500	0.50
7	630	554	26250	0.02	680A	7052	43909	0.16	140	15769	31500	0.50
8	470	553	26250	0.02	410A	6974	43774	0.16	180	15768	31500	0.50
9	490	552	26250	0.02	600	6535	43949	0.15	320	15752	31500	0.50
10	480	551	26250	0.02	660	5404	43940	0.12	160	15752	31500	0.50
11	500	551	26250	0.02	740A	4965	43911	0.11	170	15750	31500	0.50
12	460	546	26250	0.02	620B	4588	43903	0.10	150	15749	31500	0.50
13	690	545	26250	0.02	610	4145	43906	0.09	290	15726	31500	0.50
14	750	541	26250	0.02	550A	4055	43748	0.09	280	15722	31500	0.50
15	390	539	26250	0.02	680B	3865	43902	0.09	270	15718	31500	0.50
16	520	533	26250	0.02	420	3625	43689	0.08	100	15712	31500	0.50
17	420	532	26250	0.02	670	3573	43909	0.08	200	15705	31500	0.50
18	410B	532	26250	0.02	10	3280	43705	0.08	120	15694	31500	0.50
19	10	517	26250	0.02	390	3158	43682	0.07	310	15691	31500	0.50
20	550B	499	26250	0.02	400	2692	43774	0.06	220	15690	31500	0.50
21	560	499	26250	0.02	380	2350	43649	0.05	190	15687	31500	0.50
22	540	475	26250	0.02	730	2219	43911	0.05	260	15687	31500	0.50
23	550A	475	26250	0.02	30	1927	43774	0.04	130	15680	31500	0.50
24	20	455	26250	0.02	530	1698	43581	0.04	210	15660	31500	0.50
25	30	450	26250	0.02	540	1557	43748	0.04	110	15656	31500	0.50
26	410A	449	26250	0.02	720	1559	43956	0.04	240	15655	31500	0.50
27	400	449	26250	0.02	20	1317	43768	0.03	230	15645	31500	0.50
28	440	446	26250	0.02	740B	1061	43905	0.02	250	15645	31500	0.50
29	680B	324	26250	0.01	440	877	43777	0.02	80B	15610	31500	0.50
30	620B	323	26250	0.01	550B	855	43723	0.02	60	15594	31500	0.50
31	740B	321	26250	0.01	460	737	43676	0.02	70	15580	31500	0.49

Step 11:

Code Compliance results of CAEPIPE display the stresses on an element-by-element basis. For the tutorial problem, a snapshot of Code Compliance results is shown below, in which the first element from node 320 to node 330 is highlighted. You will observe that the 2nd Column titled "Press. Allow" output the following for each element.

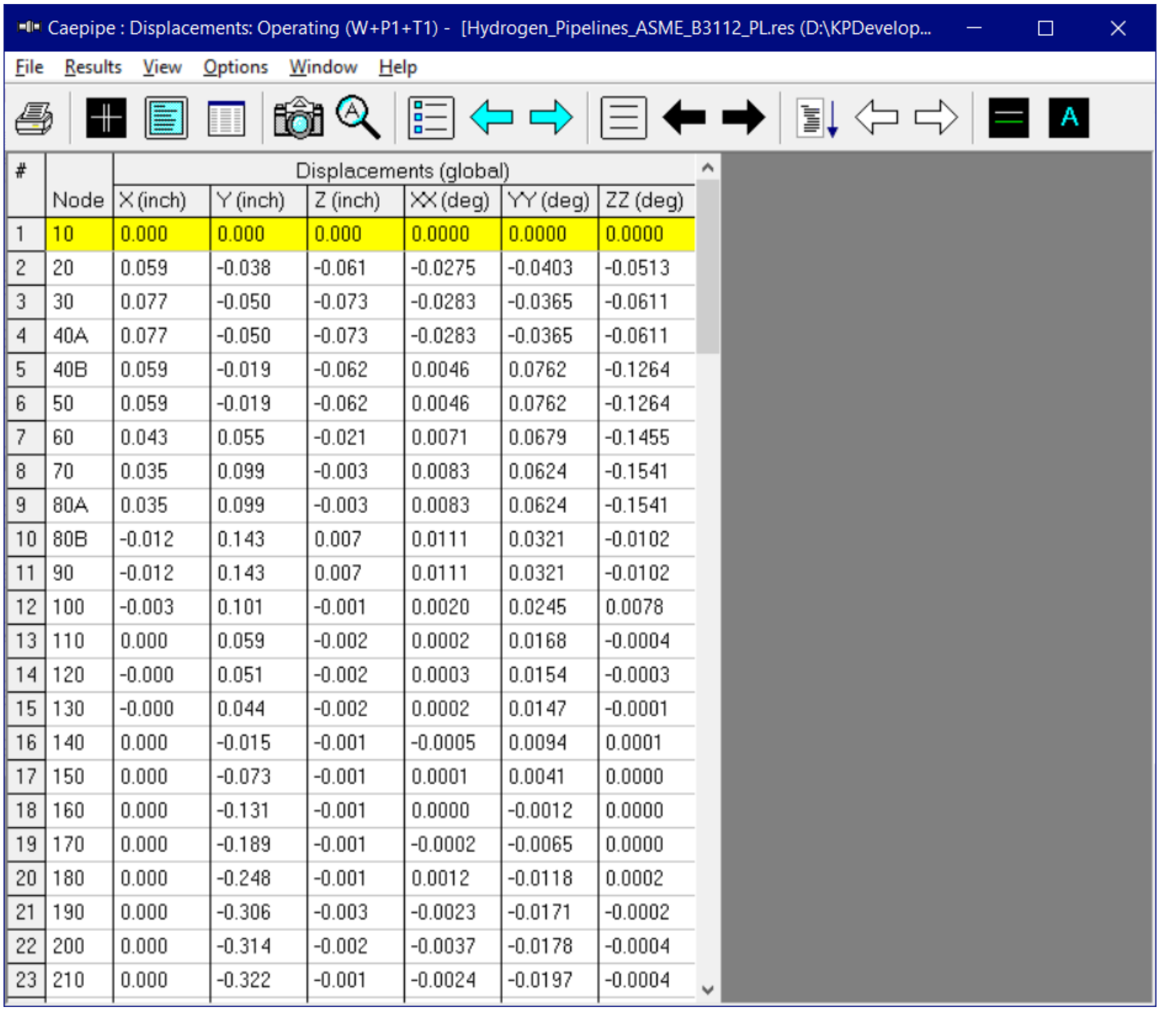
1. First row outputs the "Design Pressure" input for that element.

2. Second row outputs the "Calculated Allowable Pressure" for that element as per the equation provided in ASME B31.12 PL. Please note, when the "Design Pressure" input for an element exceeds the "Allowable Pressure" computed for that element, then CAEPIPE will change the display color of Design Pressure to RED.

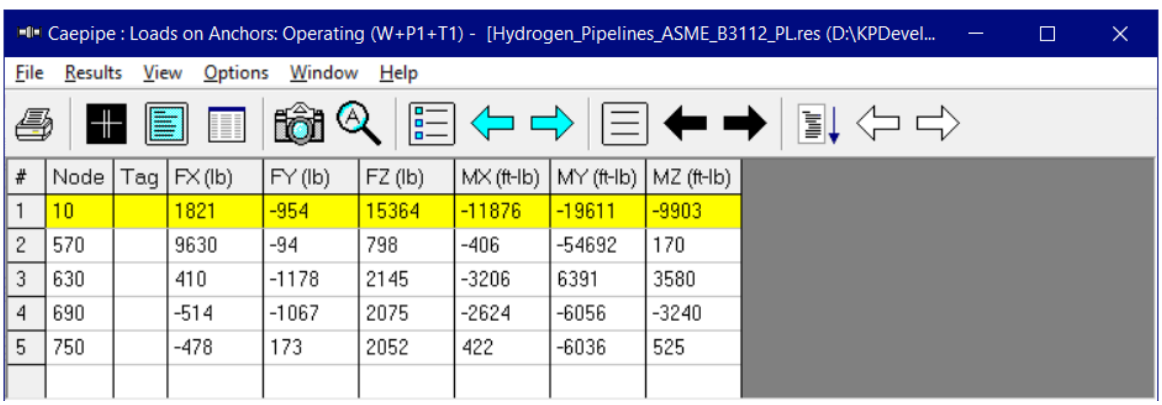


#	Node	Press. Allow. (psi)	Unrestrained (PL-2.6.5 a,b) SL (psi)	0.75ST (psi)	SL / 0.75ST	Unrestrained (PL-2.6.7) SE (psi)	SA (psi)	SE / SA	Restrained (PL-2.6.3 a,b) Seq (psi)	0.9ST (psi)	Seq / 0.9ST
30	320 330	75.0 1575							15400 15928	31500 31500	0.49 0.51
31	330 340	75.0 1575							15225 16147	31500 31500	0.48 0.51
32	340 350	75.0 1575							15347 16120	31500 31500	0.49 0.51
33	350 360	75.0 1575							15320 15892	31500 31500	0.49 0.50
34	370A 370B	75.0 1575							15261 15906	31500 31500	0.48 0.50
35	380 390	75.0 1575	572 539	26250 26250	0.02 0.02	2350 3158	43649 43682	0.05 0.07			
36	390 400	75.0 1575	539 449	26250 26250	0.02 0.02	3158 2692	43683 43774	0.07 0.06			
37	410A 410B	75.0 1575	449 532	26250 26250	0.02 0.02	6974 9433	43774 43689	0.16 0.22			
38	420 430	75.0 1575	532 1046	26250 26250	0.02 0.04	3625 249	43689 43165	0.08 0.01			
39	430 440	75.0 1575	1044 446	26250 26250	0.04 0.02	249 877	43167 43777	0.01 0.02			
40	440 450	75.0 1575	446 577	26250 26250	0.02 0.02	877 737	43777 43643	0.02 0.02			
41	450 460	75.0 1575	577 546	26250 26250	0.02 0.02	737 737	43643 43676	0.02 0.02			
42	460 470	75.0 1575	546 553	26250 26250	0.02 0.02	737 661	43676 43668	0.02 0.02			

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

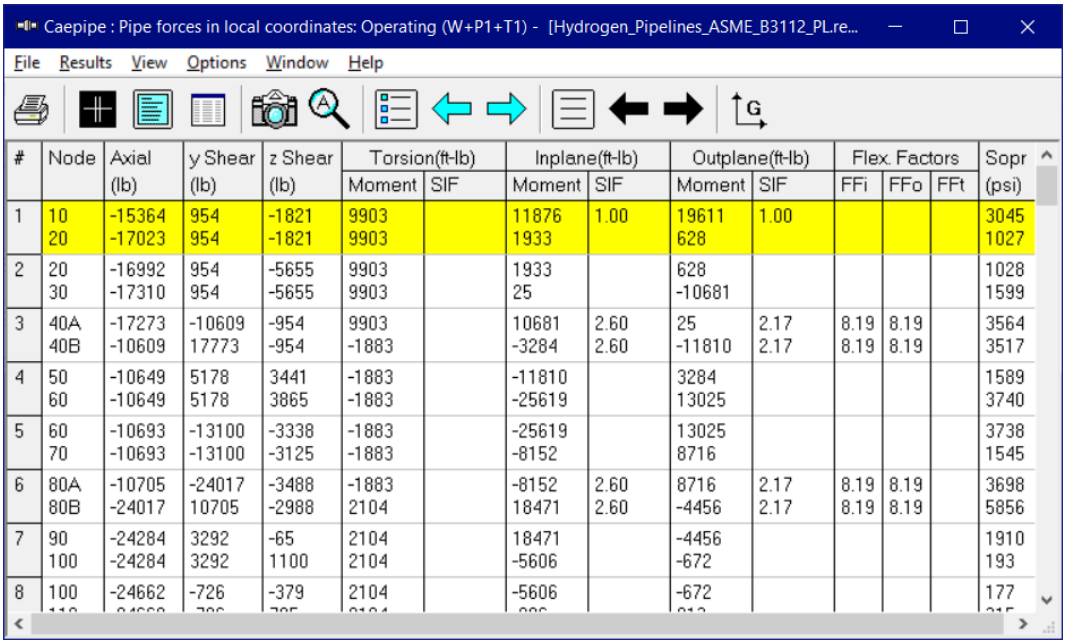


#	Node	Displacements (global)					
		X (inch)	Y (inch)	Z (inch)	XX (deg)	YY (deg)	ZZ (deg)
1	10	0.000	0.000	0.000	0.0000	0.0000	0.0000
2	20	0.059	-0.038	-0.061	-0.0275	-0.0403	-0.0513
3	30	0.077	-0.050	-0.073	-0.0283	-0.0365	-0.0611
4	40A	0.077	-0.050	-0.073	-0.0283	-0.0365	-0.0611
5	40B	0.059	-0.019	-0.062	0.0046	0.0762	-0.1264
6	50	0.059	-0.019	-0.062	0.0046	0.0762	-0.1264
7	60	0.043	0.055	-0.021	0.0071	0.0679	-0.1455
8	70	0.035	0.099	-0.003	0.0083	0.0624	-0.1541
9	80A	0.035	0.099	-0.003	0.0083	0.0624	-0.1541
10	80B	-0.012	0.143	0.007	0.0111	0.0321	-0.0102
11	90	-0.012	0.143	0.007	0.0111	0.0321	-0.0102
12	100	-0.003	0.101	-0.001	0.0020	0.0245	0.0078
13	110	0.000	0.059	-0.002	0.0002	0.0168	-0.0004
14	120	-0.000	0.051	-0.002	0.0003	0.0154	-0.0003
15	130	-0.000	0.044	-0.002	0.0002	0.0147	-0.0001
16	140	0.000	-0.015	-0.001	-0.0005	0.0094	0.0001
17	150	0.000	-0.073	-0.001	0.0001	0.0041	0.0000
18	160	0.000	-0.131	-0.001	0.0000	-0.0012	0.0000
19	170	0.000	-0.189	-0.001	-0.0002	-0.0065	0.0000
20	180	0.000	-0.248	-0.001	0.0012	-0.0118	0.0002
21	190	0.000	-0.306	-0.003	-0.0023	-0.0171	-0.0002
22	200	0.000	-0.314	-0.002	-0.0037	-0.0178	-0.0004
23	210	0.000	-0.322	-0.001	-0.0024	-0.0197	-0.0004



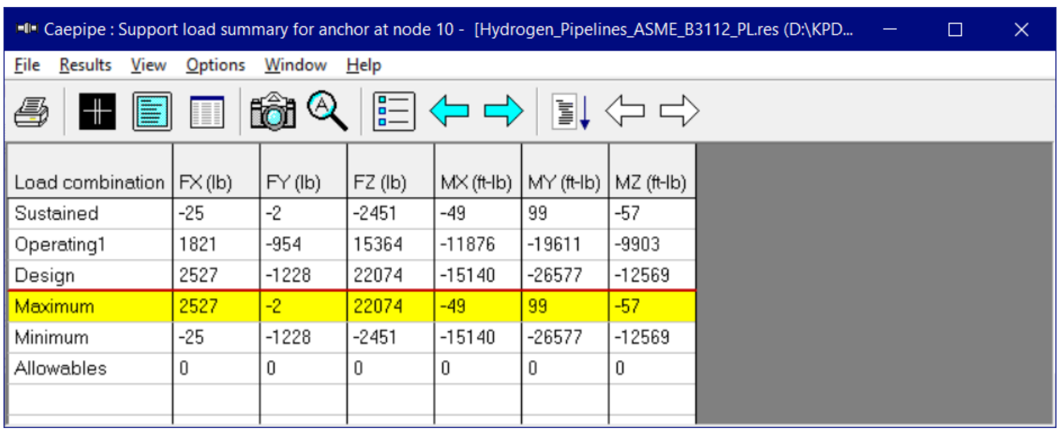
#	Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	10		1821	-954	15364	-11876	-19611	-9903
2	570		9630	-94	798	-406	-54692	170
3	630		410	-1178	2145	-3206	6391	3580
4	690		-514	-1067	2075	-2624	-6056	-3240
5	750		-478	173	2052	422	-6036	525

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 ASME B31.12 Part PL for each element as given below.



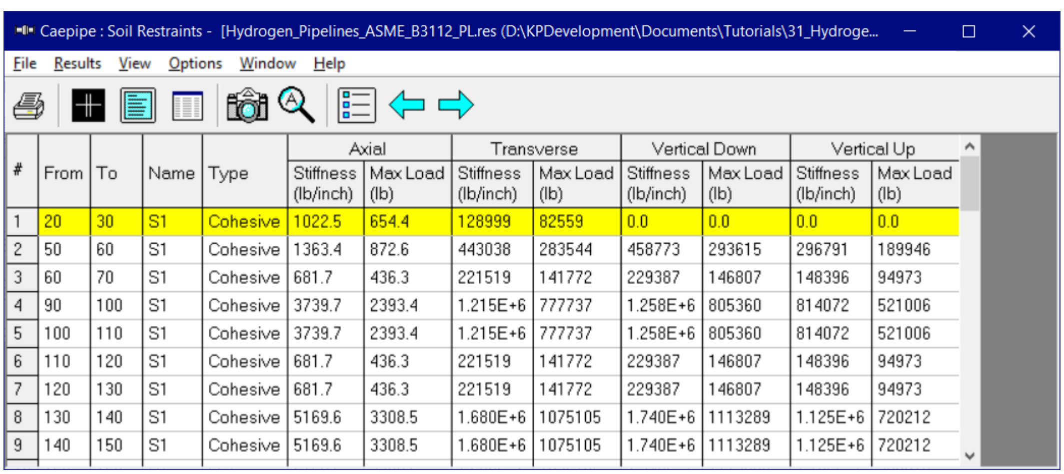
#	Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torsion(ft-lb) Moment	Torsion SIF	Inplane(ft-lb) Moment	Inplane SIF	Outplane(ft-lb) Moment	Outplane SIF	Flex. Factors FFi	FFo	FFt	Sopr (psi)
1	10 20	-15364 -17023	954 954	-1821 -1821	9903 9903		11876 1933	1.00	19611 628	1.00				3045 1027
2	20 30	-16992 -17310	954 954	-5655 -5655	9903 9903		1933 25		628 -10681					1028 1599
3	40A 40B	-17273 -10609	-10609 17773	-954 -954	9903 -1883		10681 -3284	2.60 2.60	25 -11810	2.17 2.17	8.19 8.19	8.19 8.19		3564 3517
4	50 60	-10649 -10649	5178 5178	3441 3865	-1883 -1883		-11810 -25619		3284 13025					1589 3740
5	60 70	-10693 -10693	-13100 -13100	-3338 -3125	-1883 -1883		-25619 -8152		13025 8716					3738 1545
6	80A 80B	-10705 -24017	-24017 10705	-3488 -2988	-1883 2104		-8152 18471	2.60 2.60	8716 -4456	2.17 2.17	8.19 8.19	8.19 8.19		3698 5856
7	90 100	-24284 -24284	3292 3292	-65 1100	2104 2104		18471 -5606		-4456 -672					1910 193
8	100	-24662	-726	-379	2104		-5606		-672					177

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	-25	-2	-2451	-49	99	-57
Operating1	1821	-954	15364	-11876	-19611	-9903
Design	2527	-1228	22074	-15140	-26577	-12569
Maximum	2527	-2	22074	-49	99	-57
Minimum	-25	-1228	-2451	-15140	-26577	-12569
Allowables	0	0	0	0	0	0

CAEPIPE displays an option “Soil Restraints” in addition to other analysis results as shown below.



#	From	To	Name	Type	Axial Stiffness (lb/inch)	Axial Max Load (lb)	Transverse Stiffness (lb/inch)	Transverse Max Load (lb)	Vertical Down Stiffness (lb/inch)	Vertical Down Max Load (lb)	Vertical Up Stiffness (lb/inch)	Vertical Up Max Load (lb)
1	20	30	S1	Cohesive	1022.5	654.4	128999	82559	0.0	0.0	0.0	0.0
2	50	60	S1	Cohesive	1363.4	872.6	443038	283544	458773	293615	296791	189946
3	60	70	S1	Cohesive	681.7	436.3	221519	141772	229387	146807	148396	94973
4	90	100	S1	Cohesive	3739.7	2393.4	1.215E+6	777737	1.258E+6	805360	814072	521006
5	100	110	S1	Cohesive	3739.7	2393.4	1.215E+6	777737	1.258E+6	805360	814072	521006
6	110	120	S1	Cohesive	681.7	436.3	221519	141772	229387	146807	148396	94973
7	120	130	S1	Cohesive	681.7	436.3	221519	141772	229387	146807	148396	94973
8	130	140	S1	Cohesive	5169.6	3308.5	1.680E+6	1075105	1.740E+6	1113289	1.125E+6	720212
9	140	150	S1	Cohesive	5169.6	3308.5	1.680E+6	1075105	1.740E+6	1113289	1.125E+6	720212