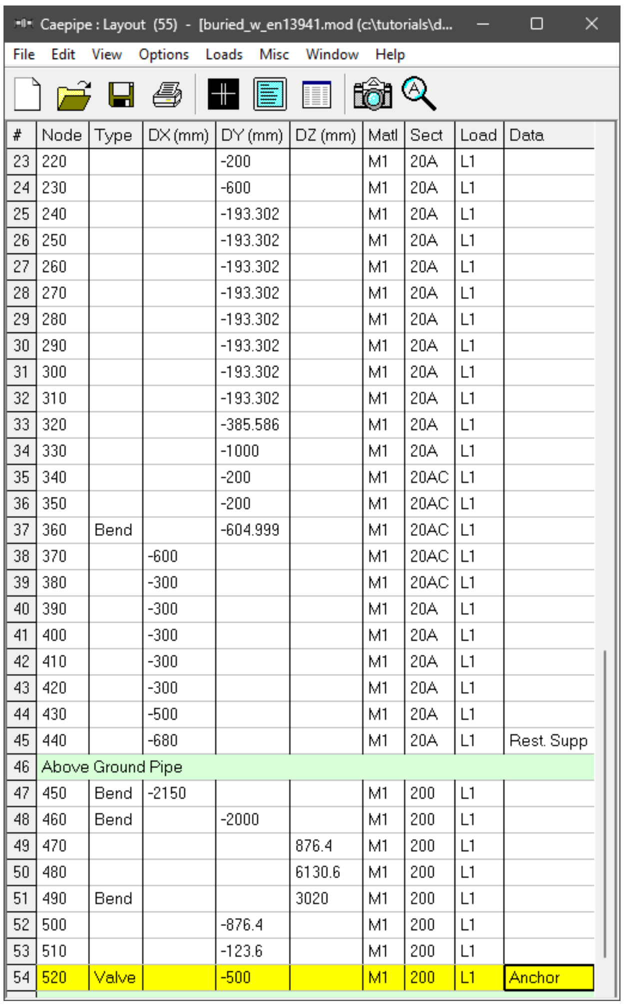
Tutorial for Analysis of buried, bonded heating pipes as per EN13941-1

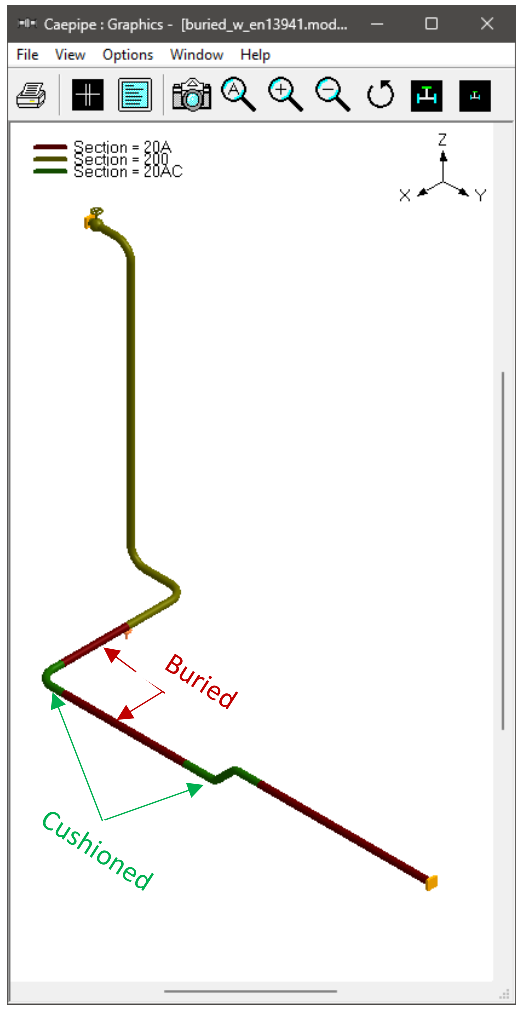
The European code EN13941-1 (2019) specifies requirements for design, calculation and installation of factory made thermal insulated bonded piping systems for directly buried hot water networks for continuous operation with treated hot water at various temperatures up to 120 deg. C and occasionally with peak temperatures up to 140 deg. C and maximum internal pressure of 2.5 MPa.

This tutorial provides guidelines and step-by-step procedure for performing buried piping analysis and EN13941-1 code compliance using CAEPIPE for Single bonded district heating pipes.

The piping model developed for this tutorial is shown below. This pipeline is partially below ground with expansion cushions at the buried bends.



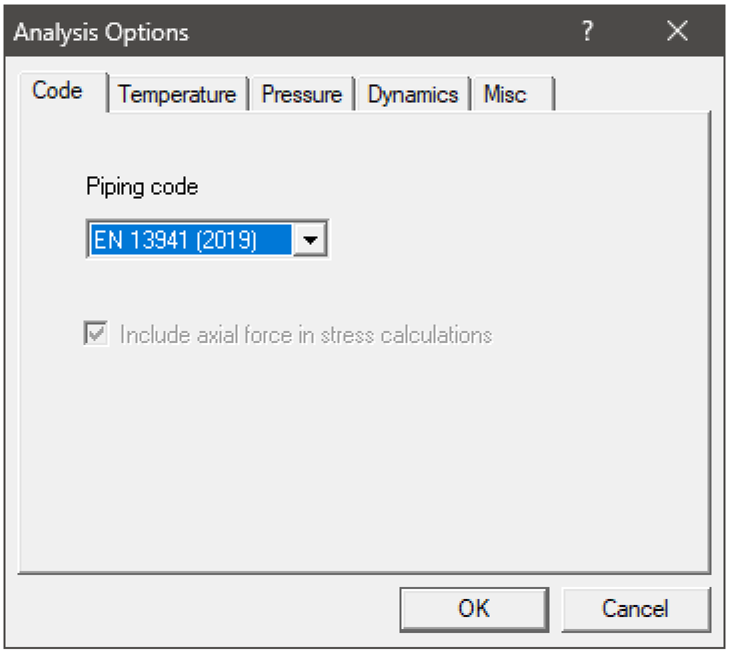
#	Node	Type	DX (mm)	DY (mm)	DZ (mm)	Matl	Sect	Load	Data
23	220			-200		M1	20A	L1	
24	230			-600		M1	20A	L1	
25	240			-193.302		M1	20A	L1	
26	250			-193.302		M1	20A	L1	
27	260			-193.302		M1	20A	L1	
28	270			-193.302		M1	20A	L1	
29	280			-193.302		M1	20A	L1	
30	290			-193.302		M1	20A	L1	
31	300			-193.302		M1	20A	L1	
32	310			-193.302		M1	20A	L1	
33	320			-385.586		M1	20A	L1	
34	330			-1000		M1	20A	L1	
35	340			-200		M1	20AC	L1	
36	350			-200		M1	20AC	L1	
37	360	Bend		-604.999		M1	20AC	L1	
38	370		-600			M1	20AC	L1	
39	380		-300			M1	20AC	L1	
40	390		-300			M1	20A	L1	
41	400		-300			M1	20A	L1	
42	410		-300			M1	20A	L1	
43	420		-300			M1	20A	L1	
44	430		-500			M1	20A	L1	
45	440		-680			M1	20A	L1	Rest. Supp
46	Above Ground Pipe								
47	450	Bend	-2150			M1	200	L1	
48	460	Bend		-2000		M1	200	L1	
49	470				876.4	M1	200	L1	
50	480				6130.6	M1	200	L1	
51	490	Bend			3020	M1	200	L1	
52	500			-876.4		M1	200	L1	
53	510			-123.6		M1	200	L1	
54	520	Valve		-500		M1	200	L1	Anchor



Step 1:

As the requirements for Analysis of buried, bonded heating pipes as per EN13941-1 are very different from those for other piping codes, it is important to set this code as piping code for analysis before the stress layout is developed. This will enable CAEPIPE to check and validate the data entered at different stages of the stress layout for buried, single bonded district heating pipes.

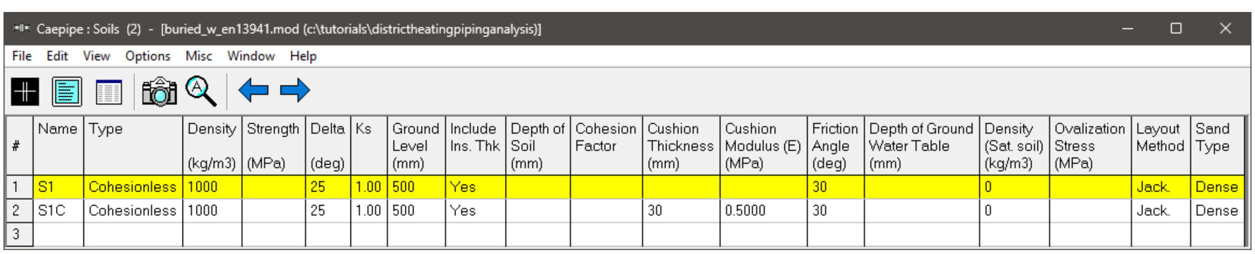
This analysis code can be selected through CAEPIPE Layout Window > Options > Analysis > Code > EN13941 (2019) as shown below.



Step 2:

Define the properties of soils along with expansion cushion. Soils with and without expansion cushion can be defined through CAEPIPE Layout Window > Misc > Soils.

The snapshot shown below provides properties of two (2) soils. Soil S1 without expansion cushion and soil S1C with expansion cushion.



Caepipe : Soils (2) - [buried_w_en13941.mod (c:\tutorials\districtheatingpipinganalysis)]

File Edit View Options Misc Window Help

#	Name	Type	Density (kg/m3)	Strength (MPa)	Delta (deg)	Ks	Ground Level (mm)	Include Ins. Thk	Depth of Soil (mm)	Cohesion Factor	Cushion Thickness (mm)	Cushion Modulus (E) (MPa)	Friction Angle (deg)	Depth of Ground Water Table (mm)	Density (Sat. soil) (kg/m3)	Ovalization Stress (MPa)	Layout Method	Sand Type
1	S1	Cohesionless	1000		25	1.00	500	Yes					30		0		Jack.	Dense
2	S1C	Cohesionless	1000		25	1.00	500	Yes			30	0.5000	30		0		Jack.	Dense
3																		

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.

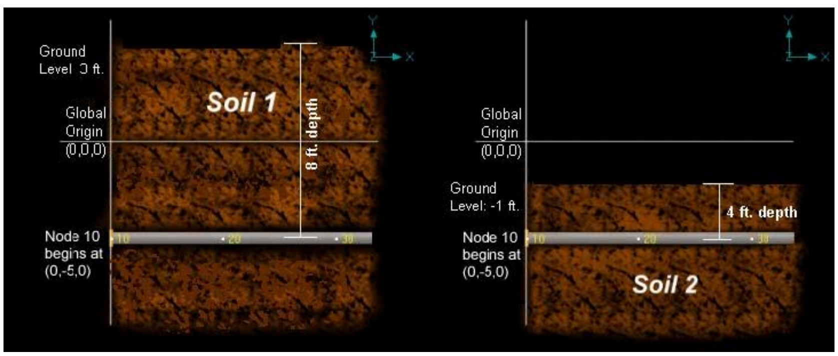
Soil density and **Ground level** are input for both cohesive and cohesionless soils. The **Ground level** is used to calculate depth of the buried section. For cohesive soil, **Strength** is the un-drained cohesive strength (Cs). For cohesionless soil, **Delta** is angle of friction between soil and pipe, and **Ks** is Coefficient of horizontal soil stress.

<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.

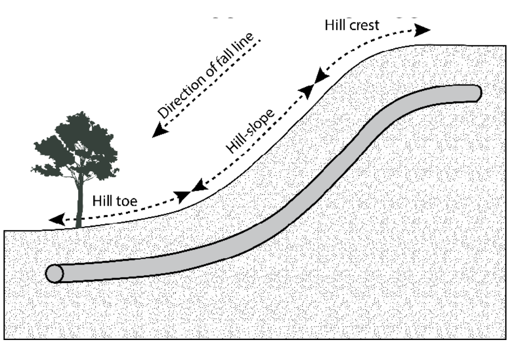
For example, in the figure below, the height of the soil surface for Soil 1 is 3 feet from the global origin. Pipe node 10 [model origin] is defined at (0,-5, 0). So, at Node 10, the pipe is buried 8' [= (3' – (-5')] deep into the soil. Define similarly for the other soil.

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



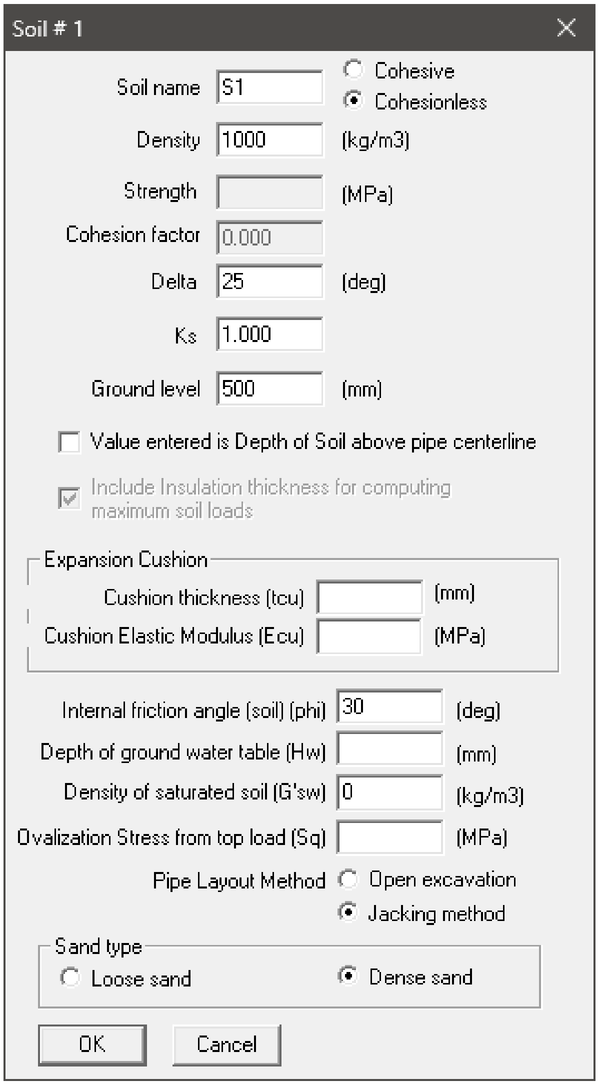
<u>Depth of Soil above Pipe's Centerline</u>

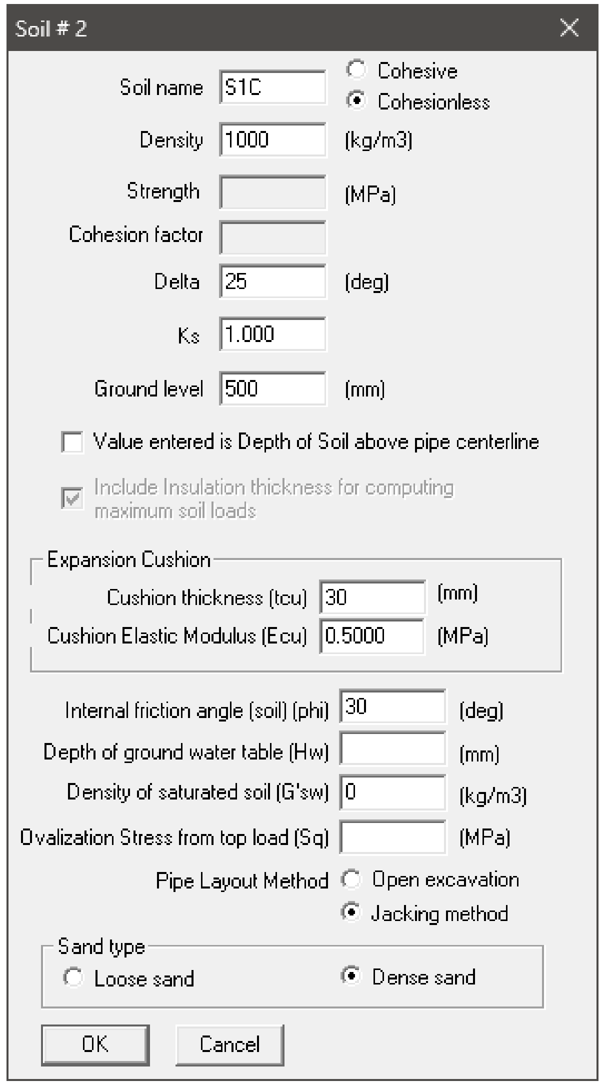
When the option "Value entered is Depth of Soil above pipe centerline" is turned ON in Soil input, then CAEPIPE will compute maximum soil loads for the sections buried using the Depth entered. This option will be helpful for modeling pipes that are running up or down a hill with same depth of soil filled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





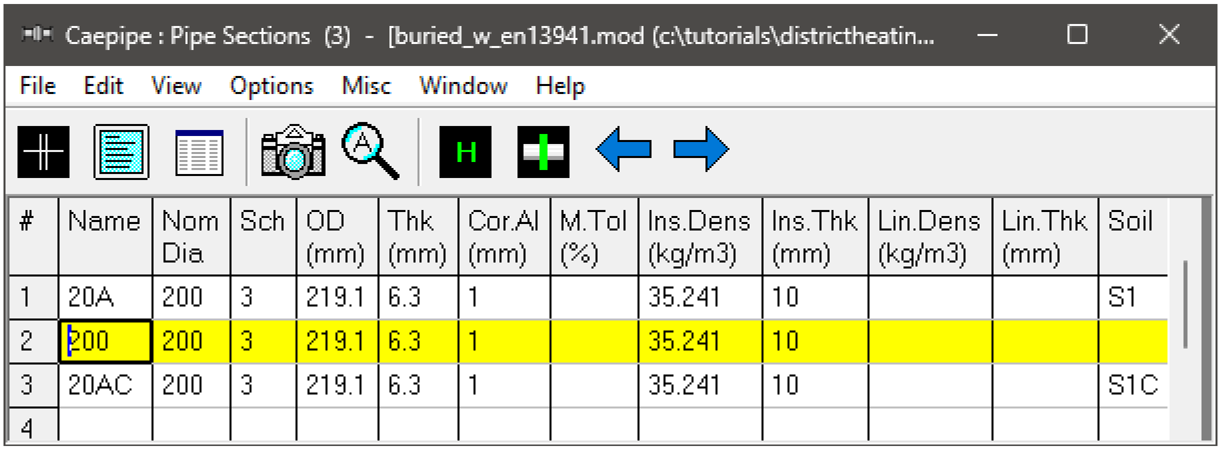
For further details on other input parameters, refer to CAEPIPE Technical Reference Manual. For details on calculation of soil restraints, refer to CAEPIPE Code Compliance Manual.

Step 3:

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.

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 pipe sections have to be defined, with one of them without soil and the other with soil.

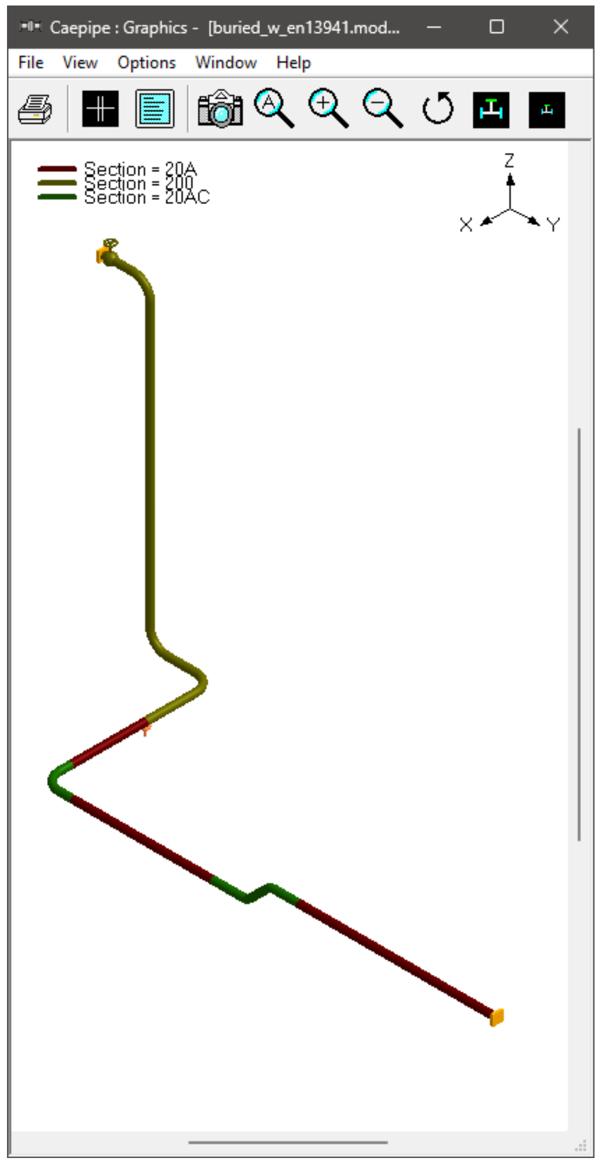
So, in the piping system used for this tutorial, two pipe sections named 20A and 20AC are defined for buried pipes without and with expansion cushion respectively. A pipe section named 200 is defined to represent above ground piping model. All three pipe sections have insulation as shown below.



#	Name	Nom Dia	Sch	OD (mm)	Thk (mm)	Cor.Al (mm)	M.Tol (%)	Ins.Dens (kg/m3)	Ins.Thk (mm)	Lin.Dens (kg/m3)	Lin.Thk (mm)	Soil
1	20A	200	3	219.1	6.3	1		35.241	10			S1
2	200	200	3	219.1	6.3	1		35.241	10			
3	20AC	200	3	219.1	6.3	1		35.241	10			S1C
4												

Step 4:

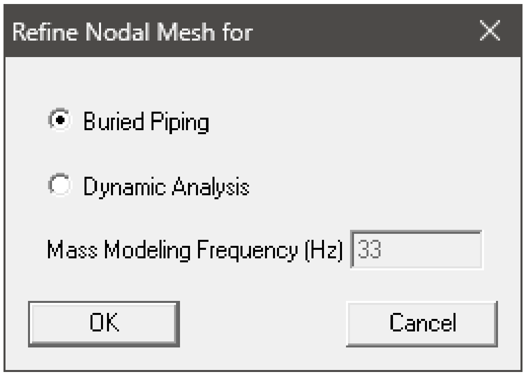
Review the stress layout by highlighting the buried sections of the model in graphics. If your model contains sections that are above ground and buried, then you can selectively see only the buried sections of piping in CAEPIPE graphics by highlighting the section that is tied to the soil. Use the Highlight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



Step 5:

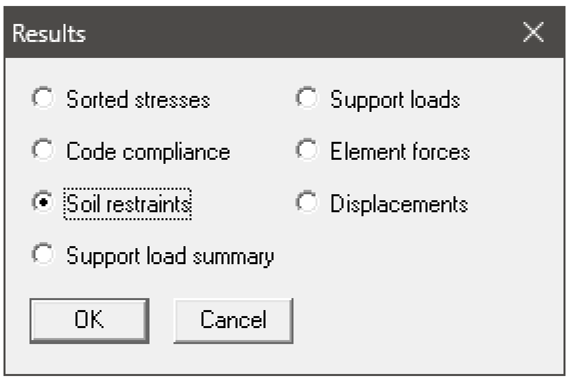
It is at the bends, elbows, and branch connections that the highest stresses are found in buried piping subjected to thermal expansion of the pipe. These stresses are due to the soil forces that bear against the transverse run. The stresses are proportional to the amount of soil deformation at the bend/elbow or branch connection. Hence, 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 the Technical Reference Manual for details on "Refine Nodal Mesh".



Step 6:

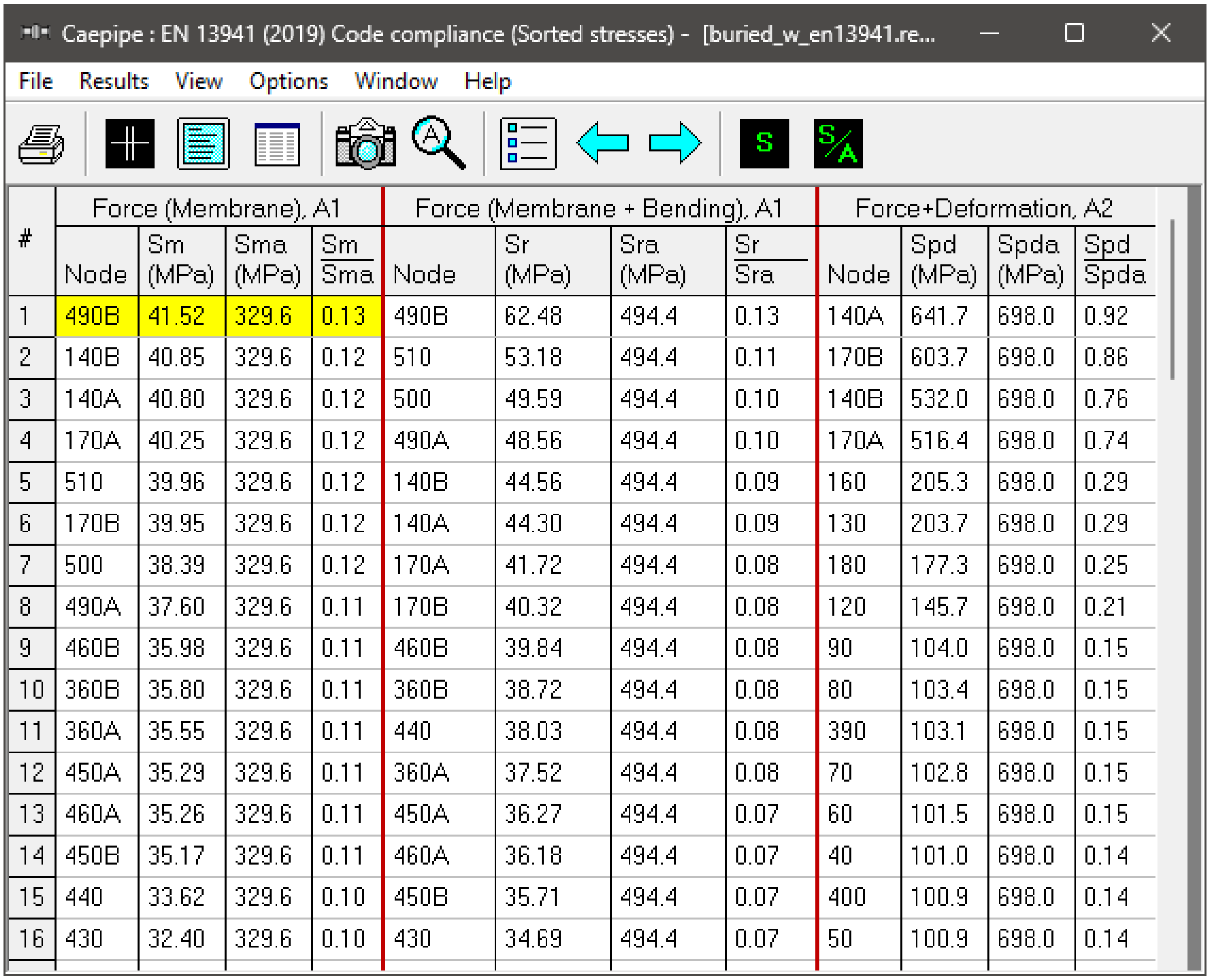
Save and analyze the model through File > Analyze. Upon analysis, under Results, CAEPIPE displays an option “Soil Restraints” in addition to other analysis results.



#	From	To	Name	Type	Axial		Transverse		Vertical Down		Vertical Up	
					Stiffness (N/mm)	Max Load (N)	Stiffness (N/mm)	Max Load (N)	Stiffness (N/mm)	Max Load (N)	Stiffness (N/mm)	Max Load (N)
1	10	20	S1	Cohesionless	9022.3	27067	23466	238506	304700	5351742	1389.4	24403
2	20	30	S1	Cohesionless	9022.3	27067	23466	238506	304700	5351742	1389.4	24403
3	30	40	S1	Cohesionless	3608.9	10827	9386.6	95402	121880	2140697	555.8	9761.2
4	40	50	S1	Cohesionless	902.2	2706.7	2346.6	23851	30470	535175	138.9	2440.3
5	50	60	S1	Cohesionless	902.2	2706.7	2346.6	23851	30470	535175	138.9	2440.3
6	60	70	S1	Cohesionless	1804.5	5413.4	4693.3	47701	60940	1070348	277.9	4880.6
7	70	80	S1	Cohesionless	1804.5	5413.4	4693.3	47701	60940	1070348	277.9	4880.6
8	80	90	S1	Cohesionless	4511.2	13533	11733	119253	152350	2675871	694.7	12202
9	90	100	S1	Cohesionless	4511.2	13533	11733	119253	152350	2675871	694.7	12202
10	100	110	S1	Cohesionless	6315.6	18947	16426	166954	213290	3746219	972.6	17082
11	110	120	S1	Cohesionless	14090	42271	36648	372476	475851	8357837	2169.8	38110
12	120	130	S1C	Cohesionless	3953.6	11861	3059.2	104513	56422	2345133	257.3	10693
13	130	140A	S1C	Cohesionless	3285.6	9856.7	2542.3	86854	46889	1948890	213.8	8886.6
14	140B	150	S1C	Cohesionless	2867.2	8601.6	2218.5	75792	29406	1222236	132.0	5484.6
15	150	160	S1C	Cohesionless	4128.5	12385	3194.3	109128	43246	1797480	190.0	7899.1
16	160	170A	S1C	Cohesionless	136.0	407.9	105.2	3594.3	1442.4	59951	6.3	260.2

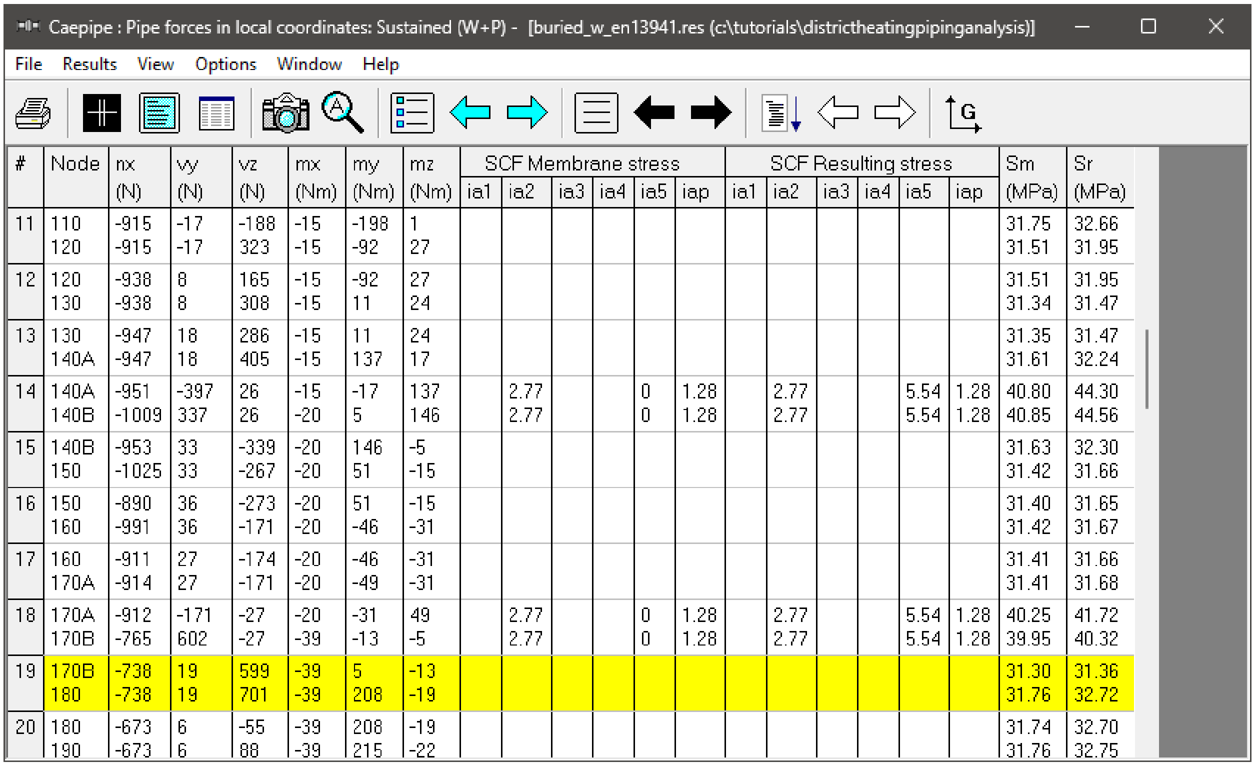
Step 7:

The stresses computed by CAEPIPE as per EN13941-1 (2019) are sorted in the descending order of stress ratios. This can be seen through CAEPIPE Results window > Results > Results… > Sorted stresses.



#	Force (Membrane), A1 Node	Sm (MPa)	Sma (MPa)	Sm/Sma	Force (Membrane + Bending), A1 Node	Sr (MPa)	Sra (MPa)	Sr/Sra	Force+Deformation, A2 Node	Spd (MPa)	Spda (MPa)	Spd/Spda
1	490B	41.52	329.6	0.13	490B	62.48	494.4	0.13	140A	641.7	698.0	0.92
2	140B	40.85	329.6	0.12	510	53.18	494.4	0.11	170B	603.7	698.0	0.86
3	140A	40.80	329.6	0.12	500	49.59	494.4	0.10	140B	532.0	698.0	0.76
4	170A	40.25	329.6	0.12	490A	48.56	494.4	0.10	170A	516.4	698.0	0.74
5	510	39.96	329.6	0.12	140B	44.56	494.4	0.09	160	205.3	698.0	0.29
6	170B	39.95	329.6	0.12	140A	44.30	494.4	0.09	130	203.7	698.0	0.29
7	500	38.39	329.6	0.12	170A	41.72	494.4	0.08	180	177.3	698.0	0.25
8	490A	37.60	329.6	0.11	170B	40.32	494.4	0.08	120	145.7	698.0	0.21
9	460B	35.98	329.6	0.11	460B	39.84	494.4	0.08	90	104.0	698.0	0.15
10	360B	35.80	329.6	0.11	360B	38.72	494.4	0.08	80	103.4	698.0	0.15
11	360A	35.55	329.6	0.11	440	38.03	494.4	0.08	390	103.1	698.0	0.15
12	450A	35.29	329.6	0.11	360A	37.52	494.4	0.08	70	102.8	698.0	0.15
13	460A	35.26	329.6	0.11	450A	36.27	494.4	0.07	60	101.5	698.0	0.15
14	450B	35.17	329.6	0.11	460A	36.18	494.4	0.07	40	101.0	698.0	0.14
15	440	33.62	329.6	0.10	450B	35.71	494.4	0.07	400	100.9	698.0	0.14
16	430	32.40	329.6	0.10	430	34.69	494.4	0.07	50	100.9	698.0	0.14

Under the Results > Element forces, the element forces in local coordinates as well as Stress Concentration Factors and Stresses computed as per EN13941-1 (2019) for each element (pipe/bend) are shown for each selected load case.

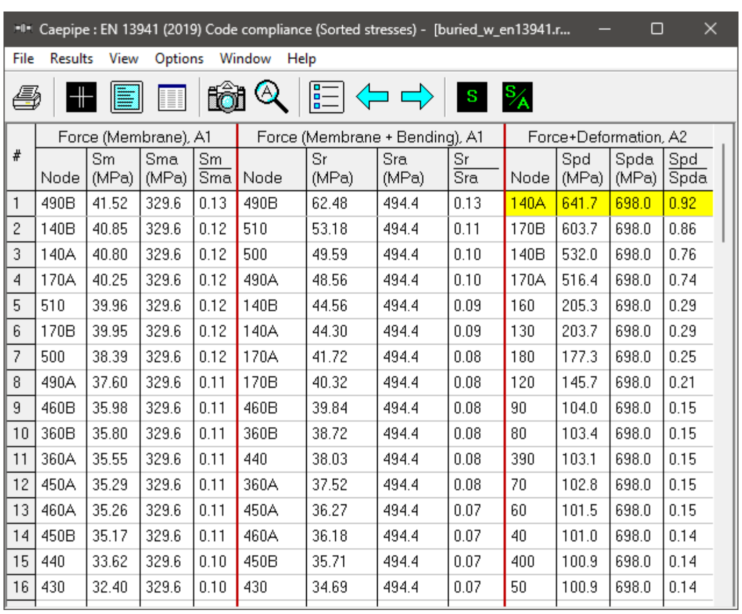


Caepipe : Pipe forces in local coordinates: Sustained (W+P) - [buried_w_en13941.res (c:\tutorials\districtheatingpipinganalysis)]

File Results View Options Window Help

#	Node	nx (N)	vy (N)	vz (N)	mx (Nm)	my (Nm)	mz (Nm)	SCF Membrane stress ia1	ia2	ia3	ia4	ia5	iap	SCF Resulting stress ia1	ia2	ia3	ia4	ia5	iap	Sm (MPa)	Sr (MPa)
11	110	-915	-17	-188	-15	-198	1													31.75	32.66
	120	-915	-17	323	-15	-92	27													31.51	31.95
12	120	-938	8	165	-15	-92	27													31.51	31.95
	130	-938	8	308	-15	11	24													31.34	31.47
13	130	-947	18	286	-15	11	24													31.35	31.47
	140A	-947	18	405	-15	137	17													31.61	32.24
14	140A	-951	-397	26	-15	-17	137		2.77			0	1.28		2.77			5.54	1.28	40.80	44.30
	140B	-1009	337	26	-20	5	146		2.77			0	1.28		2.77			5.54	1.28	40.85	44.56
15	140B	-953	33	-339	-20	146	-5													31.63	32.30
	150	-1025	33	-267	-20	51	-15													31.42	31.66
16	150	-890	36	-273	-20	51	-15													31.40	31.65
	160	-991	36	-171	-20	-46	-31													31.42	31.67
17	160	-911	27	-174	-20	-46	-31													31.41	31.66
	170A	-914	27	-171	-20	-49	-31													31.41	31.68
18	170A	-912	-171	-27	-20	-31	49		2.77			0	1.28		2.77			5.54	1.28	40.25	41.72
	170B	-765	602	-27	-39	-13	-5		2.77			0	1.28		2.77			5.54	1.28	39.95	40.32
19	170B	-738	19	599	-39	5	-13													31.30	31.36
	180	-738	19	701	-39	208	-19													31.76	32.72
20	180	-673	6	-55	-39	208	-19													31.74	32.70
	190	-673	6	88	-39	215	-22													31.76	32.75

Color coded stresses may be rendered in the graphics window by pressing the Show Stress Ratio (S/A) button (or choose View > Show Stress Ratio). The stress ratios under the highlighted columns (the bar highlights the relevant column simultaneously) are displayed in the graphics window. Use the left and right arrow keys to change the highlighted columns or click in a particular column.



Caepipe : EN 13941 (2019) Code compliance (Sorted stresses) - [buried_w_en13941.r...

File Results View Options Window Help

#	Force (Membrane), A1 Node	Sm (MPa)	Sma (MPa)	Sm/Sma	Force (Membrane + Bending), A1 Node	Sr (MPa)	Sra (MPa)	Sr/Sra	Force+Deformation, A2 Node	Spd (MPa)	Spda (MPa)	Spd/Spda
1	490B	41.52	329.6	0.13	490B	62.48	494.4	0.13	140A	641.7	698.0	0.92
2	140B	40.85	329.6	0.12	510	53.18	494.4	0.11	170B	603.7	698.0	0.86
3	140A	40.80	329.6	0.12	500	49.59	494.4	0.10	140B	532.0	698.0	0.76
4	170A	40.25	329.6	0.12	490A	48.56	494.4	0.10	170A	516.4	698.0	0.74
5	510	39.96	329.6	0.12	140B	44.56	494.4	0.09	160	205.3	698.0	0.29
6	170B	39.95	329.6	0.12	140A	44.30	494.4	0.09	130	203.7	698.0	0.29
7	500	38.39	329.6	0.12	170A	41.72	494.4	0.08	180	177.3	698.0	0.25
8	490A	37.60	329.6	0.11	170B	40.32	494.4	0.08	120	145.7	698.0	0.21
9	460B	35.98	329.6	0.11	460B	39.84	494.4	0.08	90	104.0	698.0	0.15
10	360B	35.80	329.6	0.11	360B	38.72	494.4	0.08	80	103.4	698.0	0.15
11	360A	35.55	329.6	0.11	440	38.03	494.4	0.08	390	103.1	698.0	0.15
12	450A	35.29	329.6	0.11	360A	37.52	494.4	0.08	70	102.8	698.0	0.15
13	460A	35.26	329.6	0.11	450A	36.27	494.4	0.07	60	101.5	698.0	0.15
14	450B	35.17	329.6	0.11	460A	36.18	494.4	0.07	40	101.0	698.0	0.14
15	440	33.62	329.6	0.10	450B	35.71	494.4	0.07	400	100.9	698.0	0.14
16	430	32.40	329.6	0.10	430	34.69	494.4	0.07	50	100.9	698.0	0.14