Tutorial for Buried Piping Modeling and Analysis using CAEPIPE

The following are the Steps to perform Buried Piping Modeling and Analysis using CAEPIPE.

General

In CAEPIPE, Soil in Buried piping analysis is modeled using bilinear restraints with an initial stiffness and an ultimate load. After the ultimate load is reached, the displacement continues without any further increase in load, i.e., the yield stiffness is zero. The initial stiffness is calculated by dividing the ultimate load by the yield displacement which is initially assumed to be D/25 where D is outside diameter of the pipe.

Soil modeling is based on Winkler's soil model of infinite number of closely spaced elastic springs. Soil stiffness is calculated for all three directions at each node. Pressure value in the load is suitably modified to consider the effect of static overburden soil pressure. Model is analyzed for operating (W+P1+T1) condition and the displacements in the three global directions are noted. A check is made for whether skin friction is mobilized and the soil has attained the yield state. If true, then the spring is released in that direction indicating that soil no longer offers resistance in that direction. This modified model is again analyzed and checked for yield stage. The iterative process is continued till the percentage difference between displacements at each node for two successive iterations is less than 1%. The final stiffness in each direction is the true resistance offered by the soil to the pipe in that direction.

From the above, you may note that elastic springs representing the soil stiffnesses in the Global X, Y and Z directions are to be added at as many nodes in the buried portion of the Stress model as required to simulate Winkler's soil model. So, it is important that even long buried straight pipes are discretized so that such elastic springs are added at all intermediate nodes generated along those long straight pipes. In addition, 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 elbow or branch connection. Hence, before performing the analysis, discretize the stress layout as given below.

1. Piping elements at the junction of bends, elbows, and branch connections can be refined through Layout window > Edit > Refine Nodal Mesh > Buried Piping, and
2. Long pipe sections can be discretized manually through Layout Window > Edit > Multiple Split.

When the refinement length for adding intermediate nodes on long buried straight pipes is not known, then the influence length used to refine pipes near bends, elbows and branch connections can be used to split long straight pipes. Details on computing Influence length is given below.

Modulus of Subgrade Reaction (k)

This factor k defines the resistance of the soil or backfill to pipe movement due to the bearing pressure at the pipe/soil interface. Several methods for calculating modulus of subgrade reaction (k) have been developed in recent years. As per Trautmann, C.H., and O'Rourke, T.D., "Lateral Force-Displacement Response of Buried Pipes," Journal of Geotechnical Engineering, ASCE, Vol. 111, No. 9 Sep 1985, pp. 1077-1092, the modulus of subgrade reaction, k, can be calculated as per Eq. (2) in Appendix VII of ASME B31.1-2014 code.

$$k = C_k N_h w D$$

where,

C_k = a dimensionless factor for estimating horizontal stiffness of compacted backfill. C_k may be estimated at 20 for loose soil, 30 for medium soil, and 80 for dense or compacted soil. In the current version of CAEPIPE, the value of C_k is internally set as 80 for both cohesive and cohesionless soil.

D = pipe outside diameter, in

w = soil density, lb/in3

N_h = a dimensionless horizontal force factor from Fig. 8 of above stated technical paper. For a typical value where the soil internal friction angle is 30 deg. the curve from Fig. 8 may be approximated by a straight line defined by

$N_h = (0.285H)/D) + 4.3$

H = the depth of pipe below grade at the pipe centerline, in

Influence Length (L_k)

The influence length is defined as the portion of a transverse pipe run which is deflected or "influenced" by pipe thermal expansion along the axis of the longitudinal run.

From Hetenyi's theory, (Beams on Elastic Foundation, The University of Michigan Press, Ann Arbor, Michigan 1967) (also, see Section VII-3.3.2 of Appendix VII of ASME B31.1-2014 code)

$$L_k = \frac{3\pi}{4\beta}$$

where,

Pipe / Soil System Characteristics = $\beta = \left[\frac{k}{4EI}\right]^{1/4}$

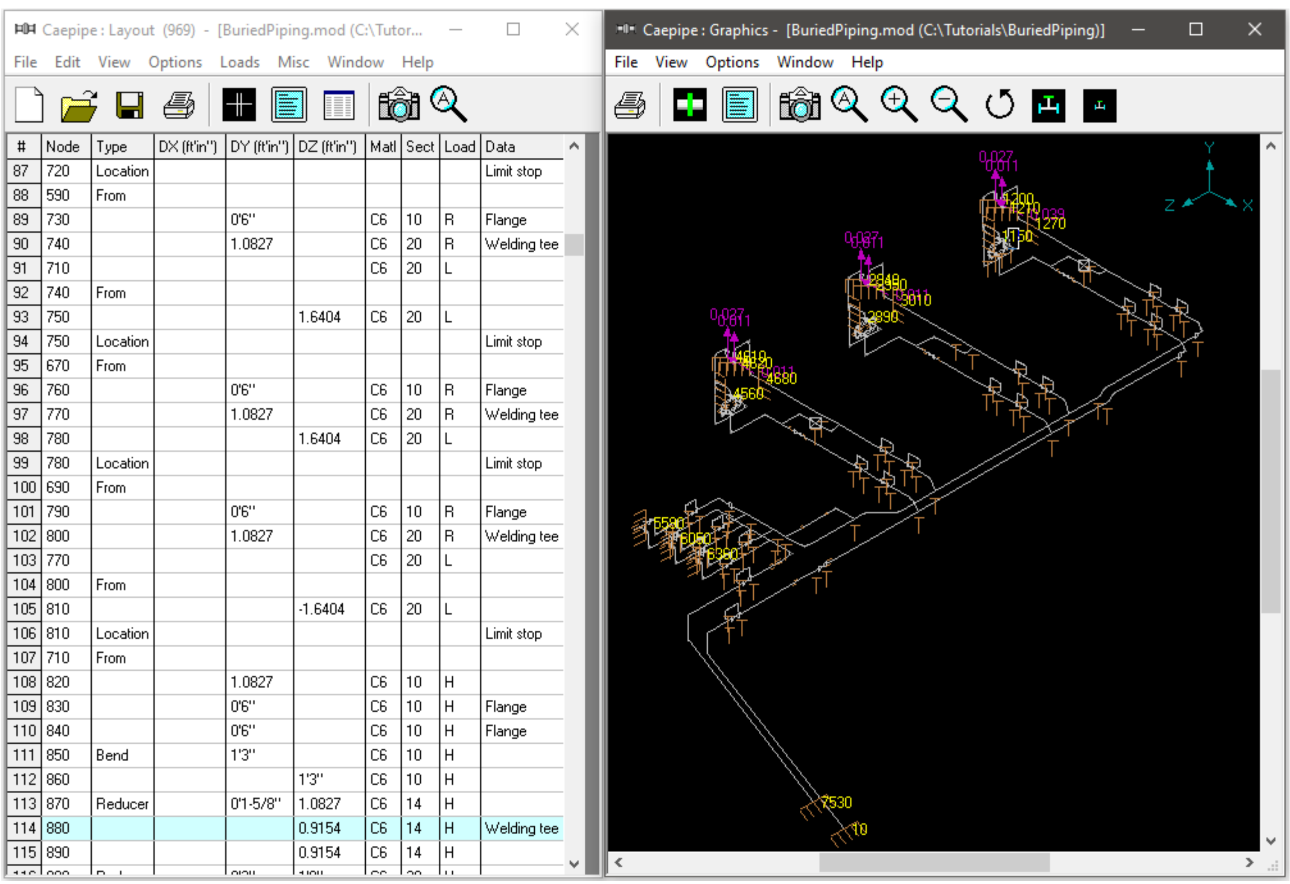
E = modulus of elasticity of pipe at reference temperature

I = moment of inertia of pipe cross section

k = modulus of subgrade reaction of soil as detailed above.

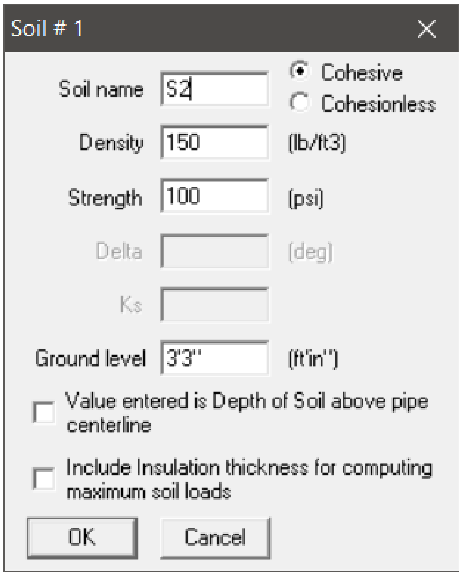
Tutorial

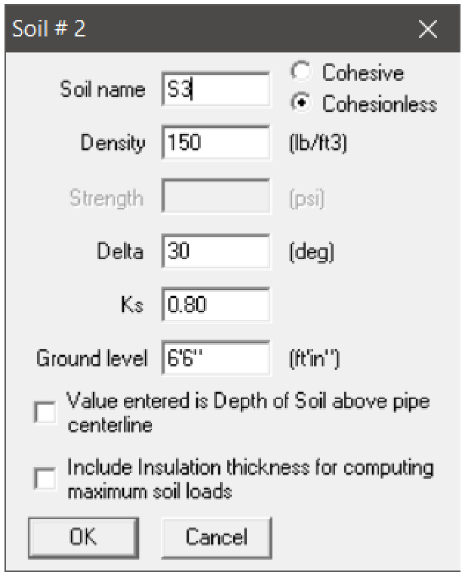
Snap shot shown below is a sample model for Buried Piping Modeling and Analysis.



Step 1:

First define soils 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.

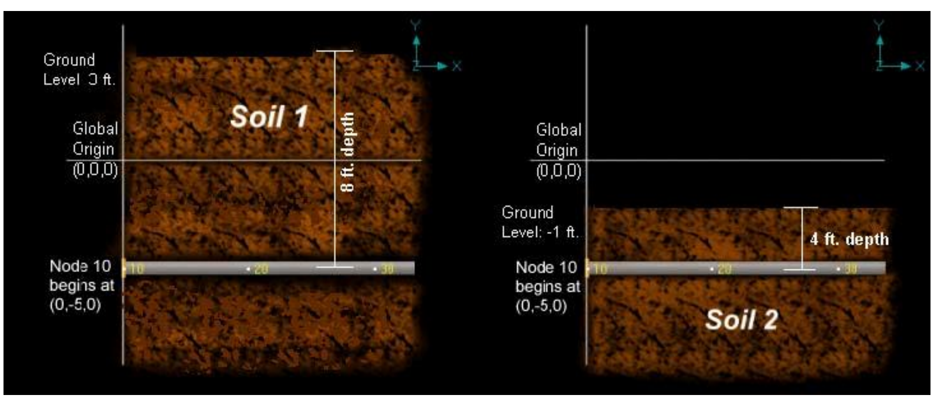
Soil density and **Ground level** are input for both cohesive and cohesionless soils. The **Ground level** is used to calculate depth of the buried section. For cohesive soil, **Strength** is the un-drained cohesive strength (Cs). For cohesionless soil, **Delta** is angle of friction between soil and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

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.

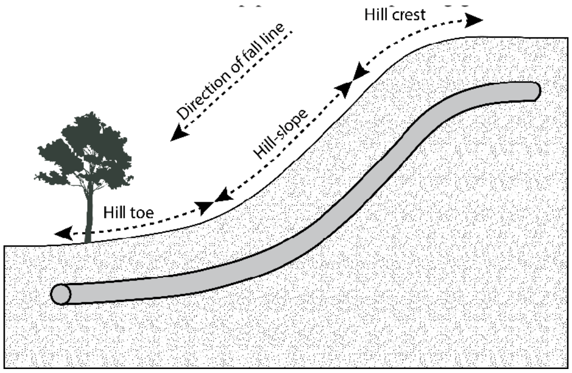
In the figure, the height of the soil surface for Soil 1 is 3 feet from the global origin. Pipe node 10 [model origin] is defined at (0,-5, 0). So, at Node 10, the pipe is buried 8' [= (3' – (-5'))] deep into the soil. Define similarly for the other soil.

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.

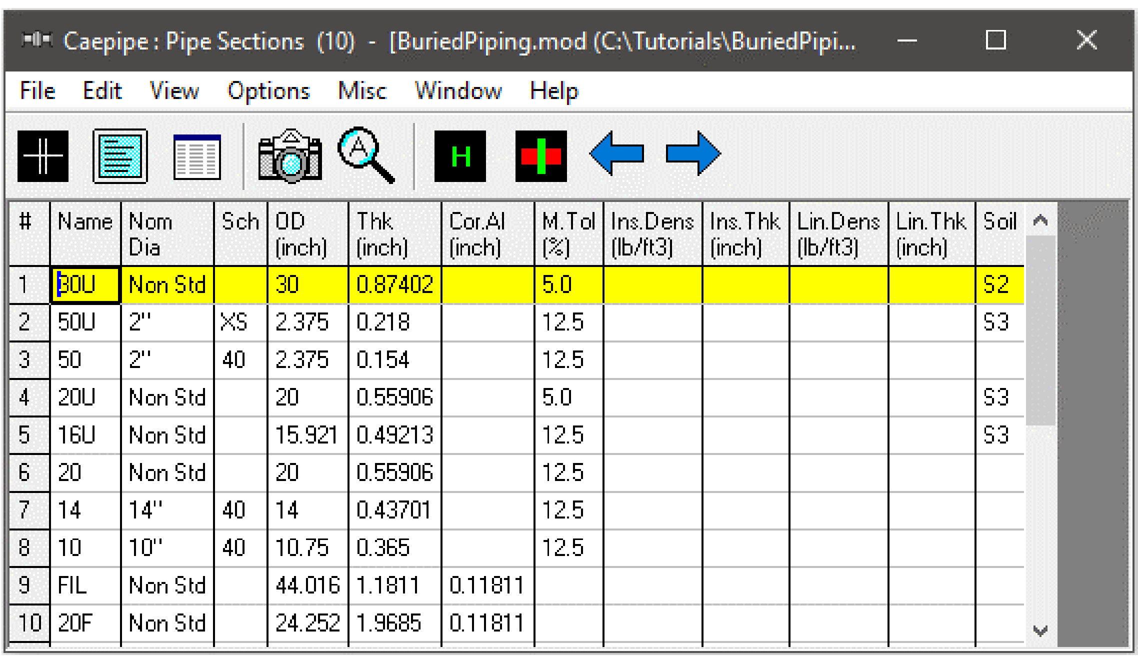


Warning:

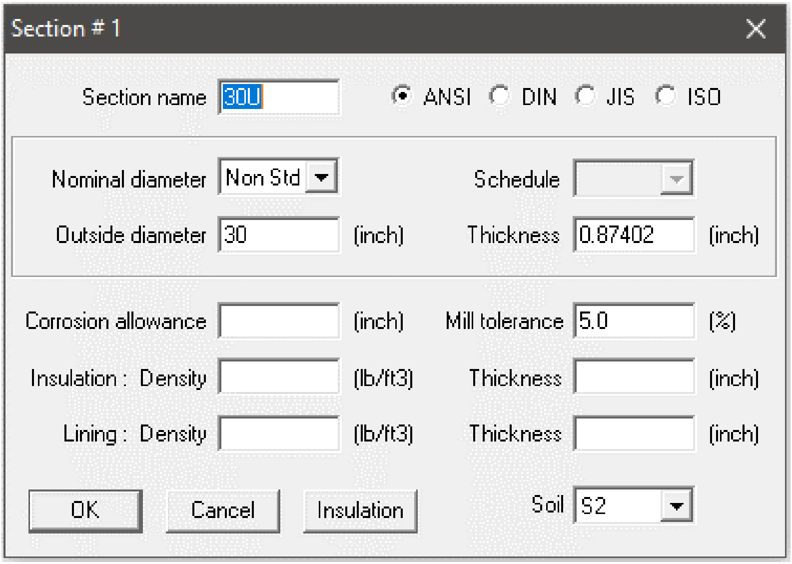
Assign Soil only to those elements that are really buried in soil when the option "Value entered is Depth of Soil above pipe centerline" is turned ON.

Step 2:

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	30U	Non Std		30	0.87402		5.0					S2
2	50U	2"	XS	2.375	0.218		12.5					S3
3	50	2"	40	2.375	0.154		12.5					
4	20U	Non Std		20	0.55906		5.0					S3
5	16U	Non Std		15.921	0.49213		12.5					S3
6	20	Non Std		20	0.55906		12.5					
7	14	14"	40	14	0.43701		12.5					
8	10	10"	40	10.75	0.365		12.5					
9	FIL	Non Std		44.016	1.1811	0.11811						
10	20F	Non Std		24.252	1.9685	0.11811						



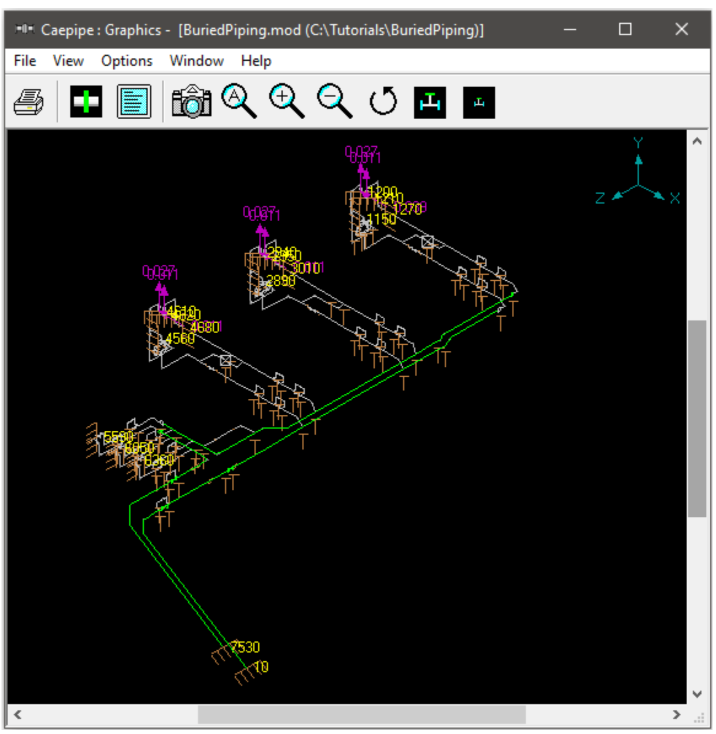
If a part of a piping system uses a certain pipe section with some portion of it buried and the balance not buried, then two separate sections have to be defined, with one of them without soil and the other with soil.

Step 3:

Use the appropriate section for each element on the Layout window that is buried with this soil around it.

Step 4:

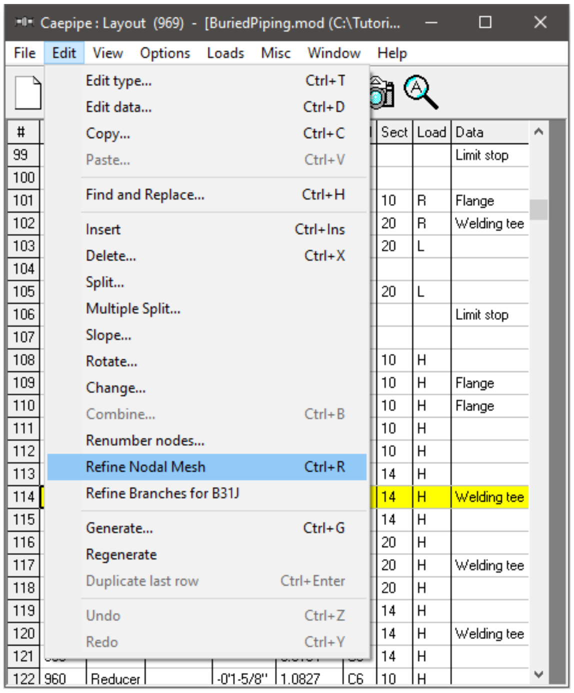
Review the stress layout by highlighting the buried sections of the model in graphics. If your model contains sections that are above ground and buried, then you can selectively see only the buried sections of piping in CAEPIPE graphics by highlighting the section that is tied to the soil. Use the Highlight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

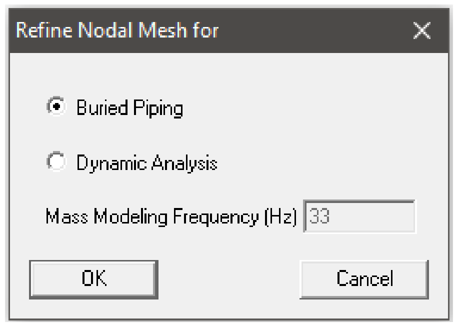


Step 5:

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 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 CAEPIPE User’s Manual for details on “Nodal mesh generation”.





Step 6:

Now, to best simulate Winkler’s soil model, discretize even the remaining long straight buried pipe sections in the stress layout as detailed below.

Starting CAEPIPE Version 10.30, a feature was included to discretize the long straight buried pipe sections through Layout Window > Edit > Refine Nodal Mesh > Buried Piping. In other words, the procedure listed below in this step is done automatically using this command.

In CAEPIPE Version 10.20 or earlier, long straight buried pipe sections in the stress layout need to be discretized manually using “Multiple Split…” command available through Layout Window > Edit.

For example, a long pipe section at row #3 is split as given below. Since the split length is not known, Influence Length is calculated as explained above by obtaining the properties required from the CAEPIPE model. The resulting length is then used to split the long pipe section.

Density of soil S2 = 150 lb/ft3 = **0.087 lb/in3**

As explained above, dimensionless factor (Ck) is taken as 80 for cohesive and cohesionless soil.

Pipe OD (D) for element at row #3 = **30”**

Pipe ID (d) for element at row #3 = 30”- (2 x 0.874) = **28.252”**

being a sloped pipe, the average height at the middle of the pipe is considered as given below

H = Depth of Pipe below grade = 3’3” + (11’ + 3’)/2 = 10’3” = **125”**

N_h = (0.285H)/D) + 4.3 = (0.285 x 125”/30”) + 4.3 = **5.4875**

Modulus Subgrade Reaction = k = $C_k.N_h.w.D$ = 80 x 5.4875 x 0.087 x 30 = **1145.79 psi**

Moment of Inertia (I) = PI()/64 x (D^4 – D^4) = (3.14/64.0) x (30^4 – 28.252^4) = **8487.99 in4**

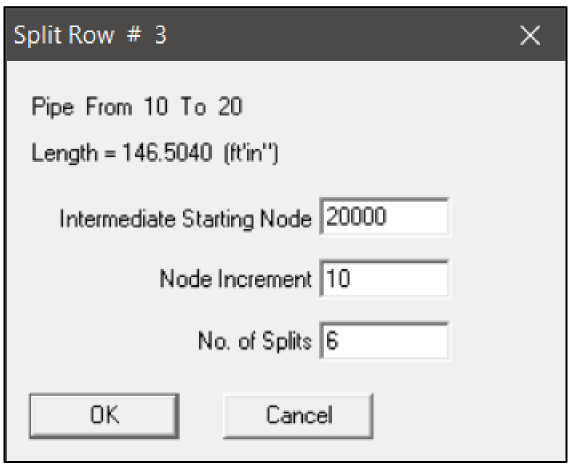
Modulus of elasticity of Pipe at Reference Temperature (E) = **30.8E+6 psi**

Pipe / Soil System Characteristics = $\beta = \left[\dfrac{k}{4EI}\right]^{1/4}$ = [1145.79 / (4 x 30.8E+6 x 8487.99)]^1/4 = **0.0057**

Influence Length (L_k) = $L_k = \dfrac{3\pi}{4\beta}$ = 3 x 3.14 / (4 x 0.0057) = **413 in**

Based on the above, number of splits = (Total Length / 413) + 1 = (1758 / 413) + 1 = 5.25 = 6

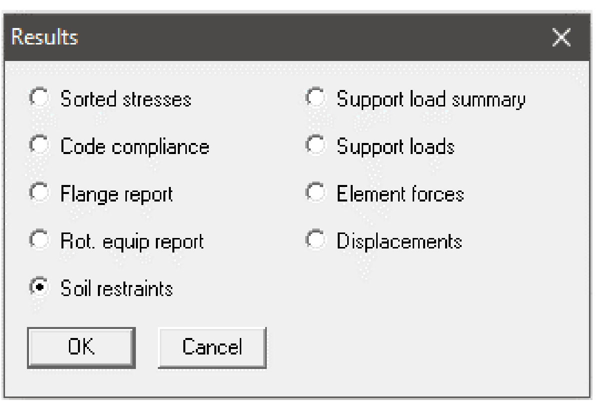
Now, split the long pipe element using the command Layout Window > Edit > Multiple Split… by highlighting the pipe element at row #3.

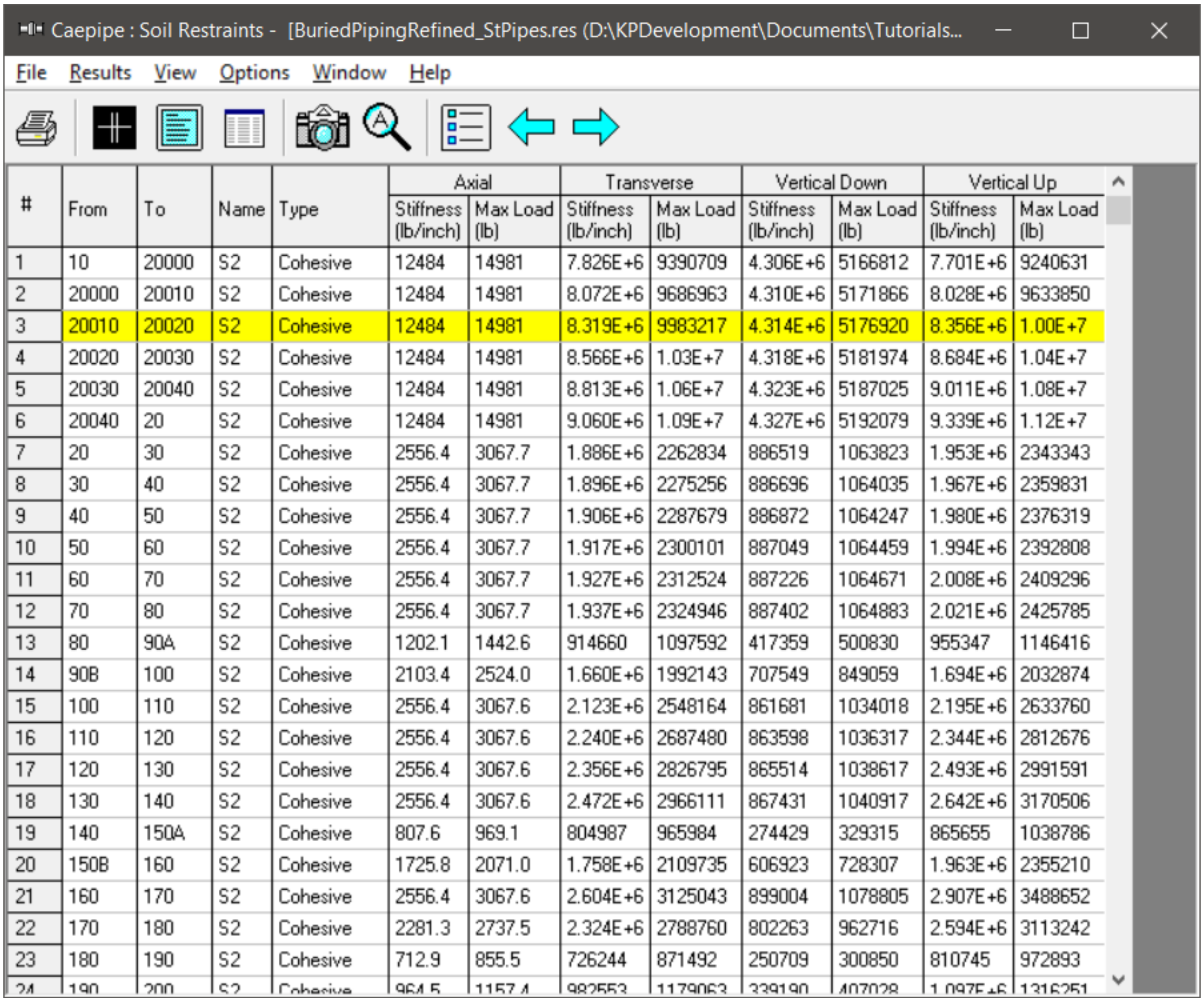


Follow the same procedure to split other long buried straight pipe sections in the stress model.

Step 7:

Save the refined model as "BuriedPipingRefined_StPipes.mod". Analyze the model through File > Analyze. Upon successful analysis, CAEPIPE displays an option "Soil Restraints" in addition to other analysis results.





#	From	To	Name	Type	Axial		Transverse		Vertical Down		Vertical Up	
					Stiffness (lb/inch)	Max Load (lb)	Stiffness (lb/inch)	Max Load (lb)	Stiffness (lb/inch)	Max Load (lb)	Stiffness (lb/inch)	Max Load (lb)
1	10	20000	S2	Cohesive	12484	14981	7.826E+6	9390709	4.306E+6	5166812	7.701E+6	9240631
2	20000	20010	S2	Cohesive	12484	14981	8.072E+6	9686963	4.310E+6	5171866	8.028E+6	9633850
3	20010	20020	S2	Cohesive	12484	14981	8.319E+6	9983217	4.314E+6	5176920	8.356E+6	1.00E+7
4	20020	20030	S2	Cohesive	12484	14981	8.566E+6	1.03E+7	4.318E+6	5181974	8.684E+6	1.04E+7
5	20030	20040	S2	Cohesive	12484	14981	8.813E+6	1.06E+7	4.323E+6	5187025	9.011E+6	1.08E+7
6	20040	20	S2	Cohesive	12484	14981	9.060E+6	1.09E+7	4.327E+6	5192079	9.339E+6	1.12E+7
7	20	30	S2	Cohesive	2556.4	3067.7	1.886E+6	2262834	886519	1063823	1.953E+6	2343343
8	30	40	S2	Cohesive	2556.4	3067.7	1.896E+6	2275256	886696	1064035	1.967E+6	2359831
9	40	50	S2	Cohesive	2556.4	3067.7	1.906E+6	2287679	886872	1064247	1.980E+6	2376319
10	50	60	S2	Cohesive	2556.4	3067.7	1.917E+6	2300101	887049	1064459	1.994E+6	2392808
11	60	70	S2	Cohesive	2556.4	3067.7	1.927E+6	2312524	887226	1064671	2.008E+6	2409296
12	70	80	S2	Cohesive	2556.4	3067.7	1.937E+6	2324946	887402	1064883	2.021E+6	2425785
13	80	90A	S2	Cohesive	1202.1	1442.6	914660	1097592	417359	500830	955347	1146416
14	90B	100	S2	Cohesive	2103.4	2524.0	1.660E+6	1992143	707549	849059	1.694E+6	2032874
15	100	110	S2	Cohesive	2556.4	3067.6	2.123E+6	2548164	861681	1034018	2.195E+6	2633760
16	110	120	S2	Cohesive	2556.4	3067.6	2.240E+6	2687480	863598	1036317	2.344E+6	2812676
17	120	130	S2	Cohesive	2556.4	3067.6	2.356E+6	2826795	865514	1038617	2.493E+6	2991591
18	130	140	S2	Cohesive	2556.4	3067.6	2.472E+6	2966111	867431	1040917	2.642E+6	3170506
19	140	150A	S2	Cohesive	807.6	969.1	804987	965984	274429	329315	865655	1038786
20	150B	160	S2	Cohesive	1725.8	2071.0	1.758E+6	2109735	606923	728307	1.963E+6	2355210
21	160	170	S2	Cohesive	2556.4	3067.6	2.604E+6	3125043	899004	1078805	2.907E+6	3488652
22	170	180	S2	Cohesive	2281.3	2737.5	2.324E+6	2788760	802263	962716	2.594E+6	3113242
23	180	190	S2	Cohesive	712.9	855.5	726244	871492	250709	300850	810745	972893
24	190	200	S2	Cohesive	964.5	1157.4	982553	1179063	339190	407028	1.097E+6	1316251