SST SYSTEMS, INC.

The *FASTEST* Solutions for Piping Design and Analysis.

Readme Supplement

CAEPIPE

Version 7.50

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Annexure A

Code Compliance

EN 13480-3 (2012)

Allowable Pressure

The allowable pressure for straight pipes is calculated from Equation 6.1-1 or 6.1-3 depending on the ratio between inner and outer diameter.

For $D_o / D_i \leq 1.7$

$$P = \frac{2fze}{D_o - e}$$

For $D_o / D_i > 1.7$

$$P = fz\frac{(1-a^2)}{(1+a^2)}$$

where

P = allowable pressure

f = allowable stress

z = joint factor (input as material property in CAEPIPE)

e = nominal pipe thickness x [1 - mill tolerance %/100] - corrosion allowance “c”

(Any additional thickness required for threading, grooving, erosion, corrosion, etc. should be included in corrosion allowance in CAEPIPE)

D_o = outside diameter

D_i = inside diameter

$$a = 1 - \frac{2e}{D_o}$$

For pipe bends the maximum allowable pressure is calculated using the equivalent pipe wall thickness e_{equi}.

$$e_{equi} = \frac{e}{t_f}$$

Where

$$t_f = \frac{(R/D - 0.25)}{(R/D - 0.50)}$$

R = radius of bend

For closely spaced miter bends, the allowable pressure is calculated from Equations 6.3.4-1 and 6.3.4-2.

$$P = \min\left[\frac{fze^2}{r(e + 0.643\tan\theta\sqrt{re})}, \frac{fze(R_s - r)}{r(R_s - r/2)}\right] \text{ with } \theta \leq 22.5$$

For widely spaced miter bends, the allowable pressure is calculated from Equations 6.3.4-1, 6.3.4-2 and 6.3.5-1

$$P = \min\left[\frac{fze^2}{r(e + 0.643\tan\theta\sqrt{re})}, \frac{fze(R_s - r)}{r(R_s - r/2)}\right] \text{ with } \theta \leq 22.5$$

$$P = \frac{fze^2}{r(e + 1.25\tan\theta\sqrt{re})} \text{ with } \theta > 22.5$$

Where

r = mean radius of pipe = (D - t)/2

R_s = effective bend radius of the miter

θ = miter half angle

Sustained Stress

The stress (σ_1) due to sustained loads (pressure, weight and other sustained mechanical loads) is calculated from Equation (12.3.2-1)

$$\sigma_1 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} \le f_f$$

where

P = maximum of CAEPIPE input pressures [i.e., max(P1 through P10)]

D_o = outside diameter

e_n = nominal pipe thickness

$i =$ stress intensification factor; the product of 0.75i shall not be less than 1.0

$M_A =$ resulting bending moment due to sustained loads

Z = uncorroded section modulus; for reduced outlets / branch connections, effective section modulus

f_f = min(f; f_{cr}) = design stress for flexibility analysis at the maximum operating temperature under consideration [i.e., max(T1 through T10)], where

f = min($R_{p0.2t}$/1.5 ; R_m/2.4)

f_{cr} = design stress in creep range at max(T1 through T10)

$R_{p0.2t}$ = minimum 0.2% proof strength at max(T1 through T10)

R_m = Tensile Strength (= Tensile as shown in CAEPIPE material input)

Note:

Starting Version 7.50 of CAEPIPE, the value of "f_f" is no longer input in the material properties table. Instead, the value of "f" which is calculated as min($R_{p0.2t}$/1.5; R_m/2.4) is input for each temperature.

If a stress model created using an earlier version of CAEPIPE is read into Version 7.50 of CAEPIPE, then in the 7.50 model file, the material properties should be updated appropriately.

Sustained plus Occasional Stress

The stress (σ_2) due to sustained and occasional loads is calculated from Equation (12.3.3-1) as the sum of stress due to sustained loads such as due to pressure, weight and other sustained mechanical loads and stress due to occasional loads such as earthquake or wind. Wind and earthquake are not considered concurrently.

$$\sigma_2 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_B}{Z} \le kf_f$$

M_B=resultant bending moment due to occasional load

k = 1.2 if the occasional load is acting less than 1% in any 24 hour operating period. In CAEPIPE, the default value of k is 1.2.

This k value can be modified through CAEPIPE Options > Analysis > Code > Occasional load factor.

Expansion Stress

The stress (σ_3) due to thermal expansion is calculated from Equation (12.3.4-1)

$$\sigma_3 = \frac{iM_C}{Z} \leq f_a$$

where

M_C = resultant moment due to thermal expansion and alternating loads

Z = uncorroded section modulus; for reduced outlets / branch connections, effective section modulus

$f_a = U(1.25 f_C + 0.25 f_h) \frac{E_h}{E_c}$ as per Equation (12.1.3-1)

$U =$ cyclic stress range reduction factor taken from Table 12.1.3-1

E_c = modulus of elasticity at the minimum metal temperature consistent with the loading under consideration

E_h = modulus of elasticity at the maximum metal temperature consistent with the loading under consideration

f_C = min(R_m/3; f), where f = min($R_{p0.2t}$/1.5 ; R_m/2.4) at room temperature (T_{ref}) as per Equation (12.1.3-2)

f_h = basic allowable stress at maximum metal temperature consistent with the loading under consideration = min(f_c; f; f_{cr}) as per Equation 12.1.3-3,

> with f_c determined at minimum metal temperature consistent with the loading under consideration and f determined at maximum metal temperature consistent with the loading under consideration

For example, for the thermal range (T1-T2), with T1 = 300 ^{0}C, T2 = 100 ^{0}C and T_{ref} = 21 ^{0}C,

E_c is determined at T2 = 100 ^{0}C and E_h is determined at T1 =300 ^{0}C

f_c as per Equation (12.1.3-2) listed above is determined at T_{ref} = 21 ^{0}C,

the value of f_c used in calculating f_h is determined at T2 = 100 ^{0}C

the value of f used in calculating f_h is determined at T1 = 300 ^{0}C and

the value of f_{cr} is taken at T1 = 300 ^{0}C (if available)

If the above condition in Equation (12.3.4-1) is not met, Equation (12.3.4-2) may be used.

$$\sigma_4 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} + \frac{iM_C}{Z} \leq f_f + f_a$$

Additional Conditions for the Creep Range

For piping operating within the creep range, the stress, σ_5, due to sustained, thermal and alternating loadings shall satisfy the Equation (12.3.5-1) below.

$$\sigma_5 = \frac{PD_o}{4e_n} + \frac{0.75iM_A}{Z} + \frac{0.75iM_C}{3Z} \leq f_{cr}$$

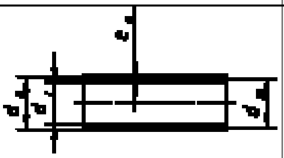
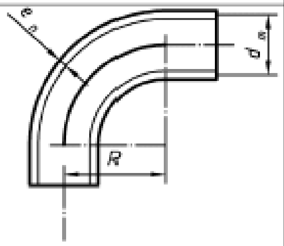
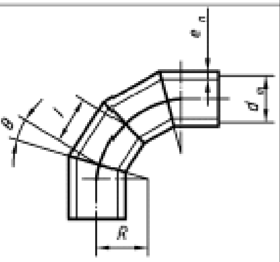
where

f_{cr} = design stress in creep range at max(T1 through T10)

Stresses due to single non-repeated Support Movement (settlement)

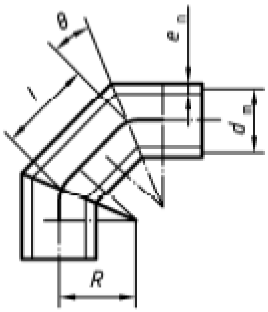
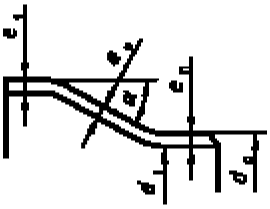
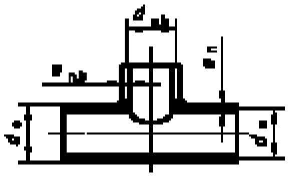
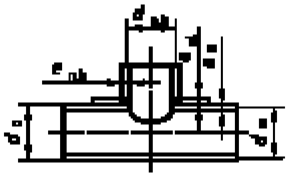
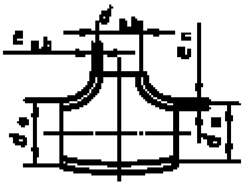
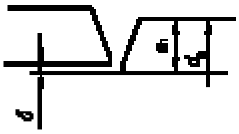
Settlement evaluation as per Equation (12.3.6-1) of EN 13480-3 (2012) is not yet implemented in Version 7.50 of CAEPIPE.

Table H.1 — Flexibility characteristics, flexibility and stress intensification factors and section moduli for general cases

N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B [a]	Stress intensification factor i	Section modulus Z
1	straight pipe		1	1	1	$\frac{\pi}{32}\frac{d_o^4-d_i^4}{d_o}$
2	plain bend		$\frac{4Re_n}{d_m^2}$	$\frac{1,65}{h}$	$\frac{0,9}{h^{2/3}}$ [b c h l]	
3	Closely spaced mitre bend $l < r\,(1 + \tan\theta)$ $(l = 2\,R\tan\theta)$		$\frac{4Re_n}{d_m^2}$ with $R = \frac{l\cot\theta}{2}$	$\frac{1,52}{h^{5/6}}$	$\frac{0,9}{h^{2/3}}$ [b c h l]	

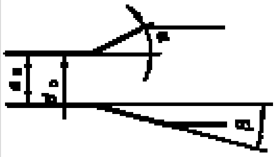
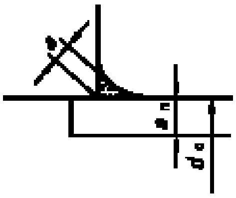
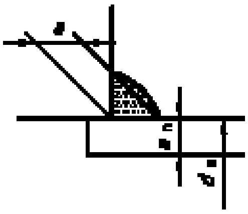
(to be continued)

Table H.1 *(continued)*

N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B [a]	Stress intensification factor i	Section modulus Z
4	Single mitre bend or widely spaced mitre bend $l \geq r\,(1 + \tan\theta)$		$\frac{4Re_n}{d_m^2}$ with $R = \frac{d_m(1+\cot\theta)}{4}$	$\frac{1{,}52}{h^{5/6}}$	$\frac{0{,}9}{h^{2/3}}$ [b h l]	
5	forged welded-in reducer		Shape conditions : $\alpha \leq 60°$ $e_n \geq d_o/100$ $e_2 \geq e_1$	1	$0{,}5 + \frac{\alpha}{100}\left(\frac{d_o}{e_n}\right)^{1/2}$ max. 2,0 (α in deg.) [d]	
6	tee with welded-on, welded-in or extruded nozzle		$\frac{2e_n}{d_m}$	1	$\frac{0{,}9}{h^{2/3}}$ [b e g]	Header $\frac{\pi}{32}\,\frac{d_o^4 - d_i^4}{d_o}$ Nozzle $\frac{\pi}{4} d_{m,b}^2\, e_x$ with e_x as smaller value of $e_{x1} = e_n$ and $e_{x2} = i\, e_{n,b}$ resp.
7	as above, however, with additional reinforcing ring		$\frac{2(e_n + 0{,}5e_{pl})^{5/2}}{d_m e_n^{3/2}}$ with $e_{pl} \leq e_n$	1	$\frac{0{,}9}{h^{2/3}}$ [b e g]	
8	forged welded-in tee with e_n and $e_{n,b}$ as connecting wall thickness		$\frac{8{,}8e_n}{d_m}$	1	$\frac{0{,}9}{h^{2/3}}$ [b g]	
9	butt weld		$e_n \geq 5$ mm and $\delta \leq 0{,}1\, e_n$ [f] $e_n < 5$ mm and $\delta > 0{,}1\, e_n$ [f]	1 1	1,0 [f] 1,8 [f]	

(to be continued)

Table H.1 *(concluded)*

N°	Designation	Sketch	Flexibility characteristic h	Flexibility factor k_B [a]	Stress intensification factor i	Section modulus Z
10	wall thickness transitions		$\alpha \leq 30°$ $\beta \leq 15°$ (without circumferential weld at transitions $\delta = 0$)	1	$1{,}3 + 0{,}0036 \dfrac{d_o}{e_n} + 3{,}6 \dfrac{\delta}{e_n}$ max 1,9 [f]	$\dfrac{\pi}{32} \dfrac{d_o^4 - d_i^4}{d_o}$
11	fillet welds at set-in connections		concave shape with continuous transition to pipe	1	1,3	smaller value of $\dfrac{\pi}{32} \dfrac{d_o^4 - d_i^4}{d_o}$ and $\dfrac{\pi}{4} d_o^2 a$
12				1	2,1	

[a] The flexibility factor k_B applies to bending in all planes. The factor related to torsion is equal to 1 in all cases.

[b] The factors k_B and i apply over the whole effective length of the elbows and bends and at the intersection of the axes in case of tees and nozzles.

[c] If these components are fitted with :

- flange at one extremity, k_B and i are multiplied by $h^{1/6}$;
- flange at each of the extremities, k_B and i are multiplied by $h^{1/3}$.

[d] The wall thickness of the reducer is not less than e_1 except in the vicinity of the small end where however the thickness is not less than e_n.

[e] Other values may be used subject to justification.

[f] The factor applies if the fabrication tolerances are met. Otherwise the determination of the factors is the responsibility of the designer.

[g] The factors only apply to nozzles with convergent axes, not applicable for instance for configurations according to Figure 8.4.3-5.

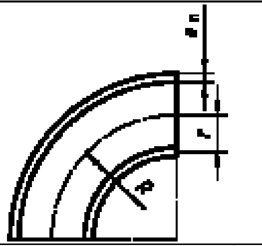
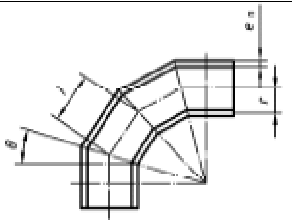
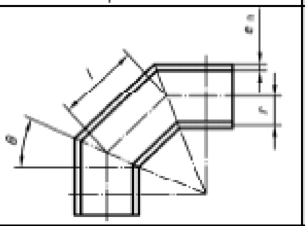
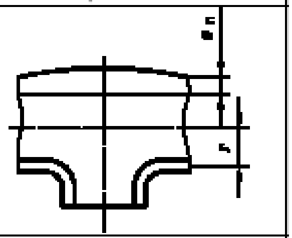
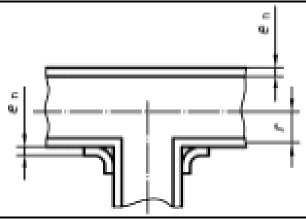
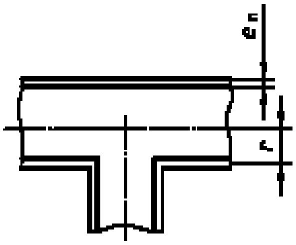
[h] If the pressure is likely to correct ovality (large diameter, small thickness), the factor i shall be divided by:

$1 + 3{,}25 \left(\dfrac{p_o}{E_c}\right)\left(\dfrac{d_m}{2e_n}\right)^{5/2} \left(\dfrac{2R}{d_m}\right)^{2/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20 °C).

[i] If the pressure is likely to correct ovality (large diameter, small thickness), the factor k shall be divided by:

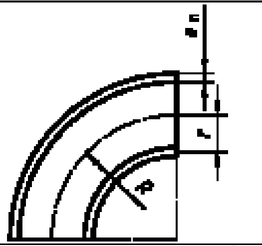
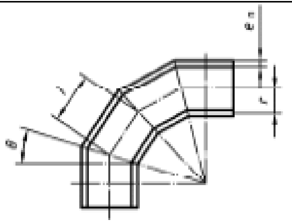
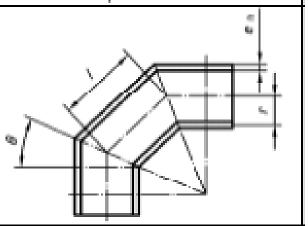
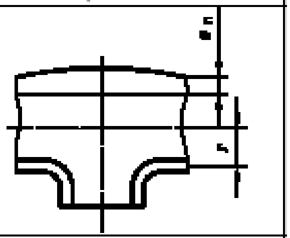
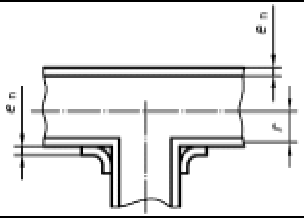
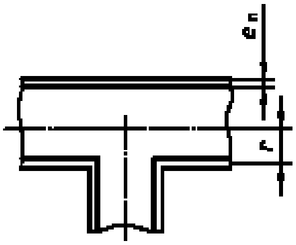
$1 + 6 \left(\dfrac{p_o}{E_c}\right)\left(\dfrac{d_m}{2e_n}\right)^{7/3} \left(\dfrac{2R}{d_m}\right)^{1/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20 °C).

Table H.3 — Flexibility characteristics and stress intensification factors for out-of-plane and in-plane bending

Component description	Out-of-plane i_o	In-plane i_i	Flexibility characteristic	Sketch
Welding elbow or pipe bend	$\frac{0{,}75}{h^{2/3}}$ [a, b, c, j]	$\frac{0{,}9}{h^{2/3}}$ [a, b, c, j]	$\frac{e_n R}{r^2}$	
Closely spaced mitre bend $l < r(1 + \tan\theta)$ $(l = 2\,R\tan\theta)$	$\frac{0{,}9}{h^{2/3}}$ [a, b, c, j]	$\frac{0{,}9}{h^{2/3}}$ [a, b, c, j]	$\frac{\cot\theta}{2}\,\frac{e_n l}{r^2}$	
Single mitre bend or widely spaced mitre bend $l \geq r(1 + \tan\theta)$	$\frac{0{,}9}{h^{2/3}}$ [a, b, c, j]	$\frac{0{,}9}{h^{2/3}}$ [a, b, c, j]	$\frac{e_n}{r}\left(\frac{1+\cot\theta}{2}\right)$	
Forged tee to be welded, designed with a burst pressure greater than or equal to the burst pressure of the connected pipes	$\frac{0{,}9}{h^{2/3}}$ [a, e, f, g, l]	$0{,}75 i_o + 0{,}25$ [a, e, f, g, l]	$\frac{4{,}4 e_n}{r}$	
Reinforced fabricated tee with pad or saddle	$\frac{0{,}9}{h^{2/3}}$ [a, d, e, l]	$0{,}75 i_o + 0{,}25$ [a, d, e, l]	$\frac{(e_n + 0{,}5 e_r)^{5/2}}{r\left(e_n{}^{3/2}\right)}$	
Unreinforced fabricated tee	$\frac{0{,}9}{h^{2/3}}$ [a, d, e, l]	$0{,}75 i_o + 0{,}25$ [a, d, e, l]	$\frac{e_n}{r}$	

(to be continued)

Table H.3 — Flexibility characteristics and stress intensification factors for out-of-plane and in-plane bending

Component description	Out-of-plane i_o	In-plane i_i	Flexibility characteristic	Sketch
Welding elbow or pipe bend	$\frac{0,75}{h^{2/3}}$ [a,b,c,j]	$\frac{0,9}{h^{2/3}}$ [a,b,c,j]	$\frac{e_n R}{r^2}$	
Closely spaced mitre bend $l < r(1 + \tan\theta)$ $(l = 2\,R \tan\theta)$	$\frac{0,9}{h^{2/3}}$ [a,b,c,j]	$\frac{0,9}{h^{2/3}}$ [a,b,c,j]	$\frac{\cot\theta}{2}\frac{e_n l}{r^2}$	
Single mitre bend or widely spaced mitre bend $l \geq r(1 + \tan\theta)$	$\frac{0,9}{h^{2/3}}$ [a,b,c,j]	$\frac{0,9}{h^{2/3}}$ [a,b,c,j]	$\frac{e_n}{r}\left(\frac{1+\cot\theta}{2}\right)$	
Forged tee to be welded, designed with a burst pressure greater than or equal to the burst pressure of the connected pipes	$\frac{0,9}{h^{2/3}}$ [a,e,f,g,l]	$0,75 i_o + 0,25$ [a,e,f,g,l]	$\frac{4,4 e_n}{r}$	
Reinforced fabricated tee with pad or saddle	$\frac{0,9}{h^{2/3}}$ [a,d,e,l]	$0,75 i_o + 0,25$ [a,d,e,l]	$\frac{(e_n + 0,5 e_r)^{5/2}}{r\left(e_n{}^{3/2}\right)}$	
Unreinforced fabricated tee	$\frac{0,9}{h^{2/3}}$ [a,d,e,l]	$0,75 i_o + 0,25$ [a,d,e,l]	$\frac{e_n}{r}$	

(to be continued)

Table H.3 (*continued*)

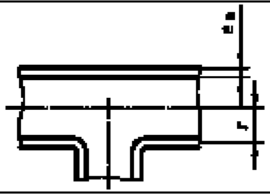
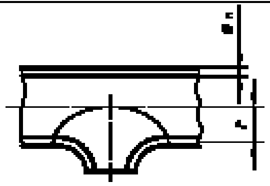
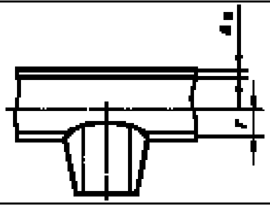
Component description	Out-of-plane i_o	In-plane i_i	Flexibility characteristic	Sketch
Extruded welding tee	$\frac{0,9}{h^{2/3}}$ [a][e][i]	$0,75 i_o + 0,25$ [a][e][i]	$\left(1+\frac{r_1}{r}\right)\frac{e_n}{r}$	
Welded in contour insert	$\frac{0,9}{h^{2/3}}$ [a][e][f][g][i]	$0,75 i_o + 0,25$ [a][e][f][g][i]	$\frac{4,4 e_n}{r}$	
Branch welded on fitting (integrally reinforced)	$\frac{0,9}{h^{2/3}}$ [a][d][f][h]	$0,75 i_o + 0,25$ [a][d][f][h]	$\frac{3,3 e_n}{r}$	

Table H.3 (*concluded*)

[a] The factors i_o and i_i apply over the whole effective length of the elbows and bends and at the intersection of the axes in case of tees and nozzles.

[b] If these components are fitted with :

- flange at one extremity, i_o and i_i are multiplied by $h^{1/6}$;
- flange at each of the extremities, i_o and i_i are multiplied by $h^{1/3}$.

[c] If the pressure is likely to correct ovality (large diameter, small thickness), the factors i_o and i_i shall be divided by:

$1 + 3,25\left(\frac{p_o}{E_c}\right)\left(\frac{r}{e_n}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20°C).

[d] For a nozzle with a ratio of branch diameter to pipe diameter exceeding 0,5, the out-of-plane stress intensification factor may be non-conservative. In addition a smooth transition by a concave shaped weld is proved to reduce the value of this factor. Consequently the selection of an appropriate value for this factor remains the responsibility of the designer.

[e] The stress intensification factors regarding the branch connections are based on tests carried out with at least two diameters of straight pipe on either side of the branch axis. The case of closer branches requires a particular attention.

[f] The forgings shall be suitable with regard to the operating conditions.

[g] When the limitations with respect to radius and thickness are not met and reliable data are not available, the flexibility characteristic is taken as $\frac{e_n}{r}$.

[h] The designer shall check that the design against pressure is at least equivalent to that for a straight pipe.

[i] The factors only apply to nozzles with convergent axes, and is not applicable for instance for configurations according to Figure 8.4.3-5.

[j] If the pressure is likely to correct ovality (large diameter, small thickness), the factor k shall be devided by:

$1+6\left(\frac{p_o}{E_c}\right)\left(\frac{r}{e_n}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}$, where p_o is the operating pressure and E_c the modulus of elasticity at room temperature (20°C).

Annexure B

Pressure Relief Valve Analysis

Pressure Relief Valve Analysis

A Simplified Approach

[Abbreviation: Pressure relief valve = PRV]

During an overpressure event, the discharge of a PRV imposes a load, referred to as a reaction force, on the collective installation. The flowrate and associated reaction force increase from nominally zero to some value, remain relatively constant at that value for the duration of the release, and then decrease to zero again, i.e., when the relief valve opens, the discharge fluid creates a jet force that acts on the piping system. This force increases from zero to its full value over a time frame similar to the opening time of the valve. The relief valve remains open until sufficient fluid is vented to relieve the overpressure situation. As the valve closes, the reduction in flow reduces the jet force to zero.

Detailed Analysis Approach

- Perform a fluid transient analysis on the piping system using some software tool such as “FlowMaster”, “PipeNet”, “RELAP”, "ROLAST", etc.
- Apply the resulting output obtained (forces as a function of time) at the bend node after the relief valve in a pipe stress analysis software (CAEPIPE).
- Compute forces, moments and stresses in the piping system due to this loading.

As one can see, this method is detailed, time consuming and expensive.

Alternate Analysis Approach

American Petroleum Institute’s API 520, Part II, provides a basis for calculation of the reaction force in the event of a vapor or a two-phase release directly to the atmosphere. There is no discussion in this section of API 520, Part II, about the reaction force developed during a liquid release. Furthermore, no guidance is presented with respect to applying these results or determining if an installation is acceptable; instead, the burden is placed on the designer to ensure that the installation is appropriately designed. While this may be reasonable for the design of new facilities, evaluating the adequacy of existing facilities becomes much more complicated.

The formula (section 4.4.1.1) in US Customary units from API 520, Part II, for vapor relief devices discharging to the atmosphere, is shown below:

$$F = \frac{W}{366}\sqrt{\frac{kT}{(k+1)M}} + (AP)$$

where,

F = Reaction force at the point of discharge to the atmosphere,(lbf.)
k = Ratio of specific heats (C_P/C_V) at the outlet conditions
W = Flow rate of any gas or vapor, pound mass (lbm.)/hr
C_P = Specific heat at constant pressure
C_V = Specific heat at constant volume
T = Temperature at the outlet, °R
M = Molecular weight of the process fluid
A = Area of the outlet at the point of discharge, in^2
P = Static pressure within the outlet at the point of discharge, psig

Using the reaction force computed from the above formula along with the PRV parameters mentioned below:

- Valve Opening Time
- Valve Closing Time and
- Relief duration (all obtained from the PRV manufacturer)

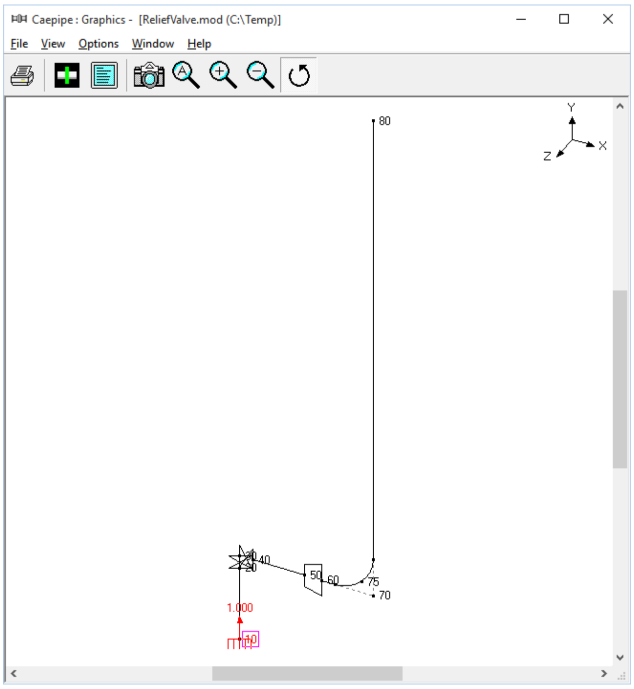
One can generate a PRV load profile and apply it in CAEPIPE for further analysis.

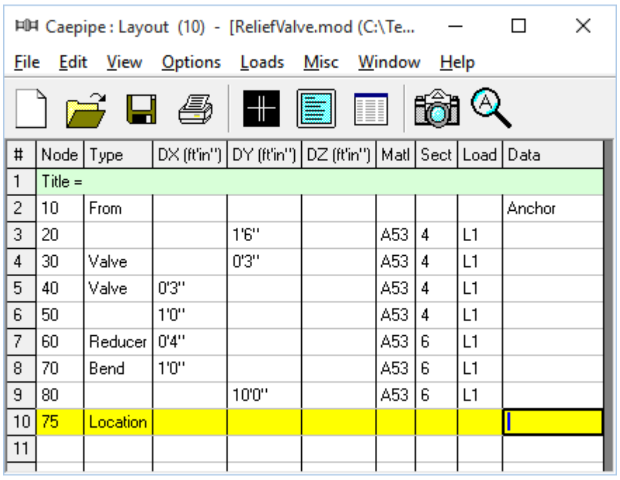
Example

By assuming the following data, one can apply the relief valve loading in CAEPIPE. Please see the model below for details.

```
1. Reaction force (F) computed = 6,700 lb.
2. Relief Valve Opening time = 8 ms (milliseconds)
3. Relief Valve Closing time = 8 ms
4. Relief duration = 1 s
5. Thermal Anchor Movement at Node 10 = 1” in (vertical) Y-direction
6. Pressure = 450 psig
7. Temperature = 650°F
```

A sample model, “ReliefValve.mod” is available with this document (and @ www.sstusa.com) for your reference. The steps followed in generating the model are given below.

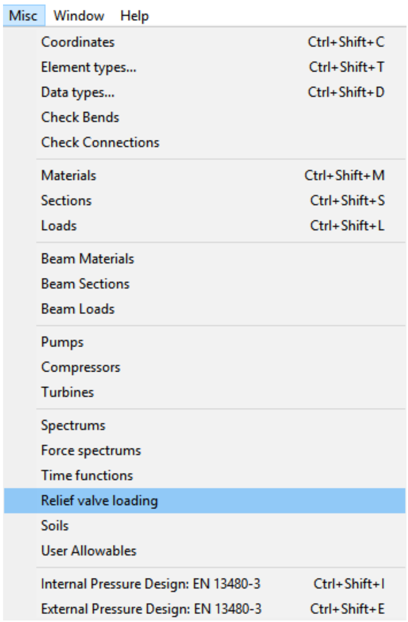


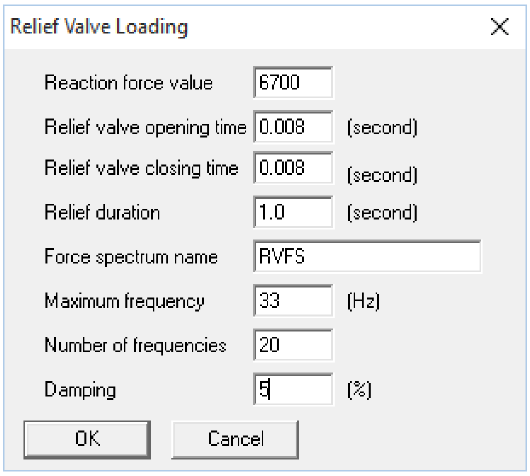


#	Node	Type	DX (ft'in")	DY (ft'in")	DZ (ft'in")	Matl	Sect	Load	Data
1	Title =								
2	10	From							Anchor
3	20			1'6"		A53	4	L1	
4	30	Valve		0'3"		A53	4	L1	
5	40	Valve	0'3"			A53	4	L1	
6	50		1'0"			A53	4	L1	
7	60	Reducer	0'4"			A53	6	L1	
8	70	Bend	1'0"			A53	6	L1	
9	80			10'0"		A53	6	L1	
10	75	Location							
11									

After creating your piping model (with node 75 being the center node of the discharge bend where the PRV reaction force will be applied),

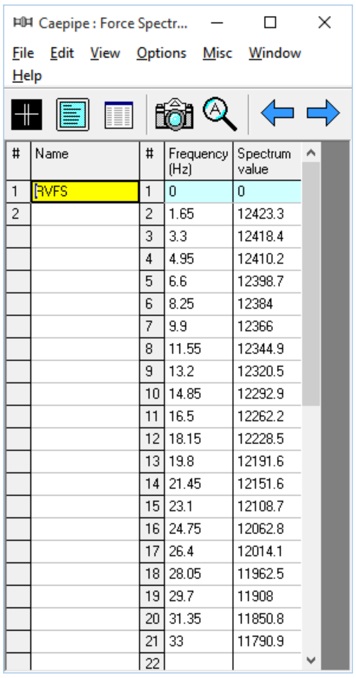
a. Select “Relief valve loading” from CAEPIPE Layout window > Misc and enter the data in the dialog box as shown in the figure below.




Relief Valve Loading

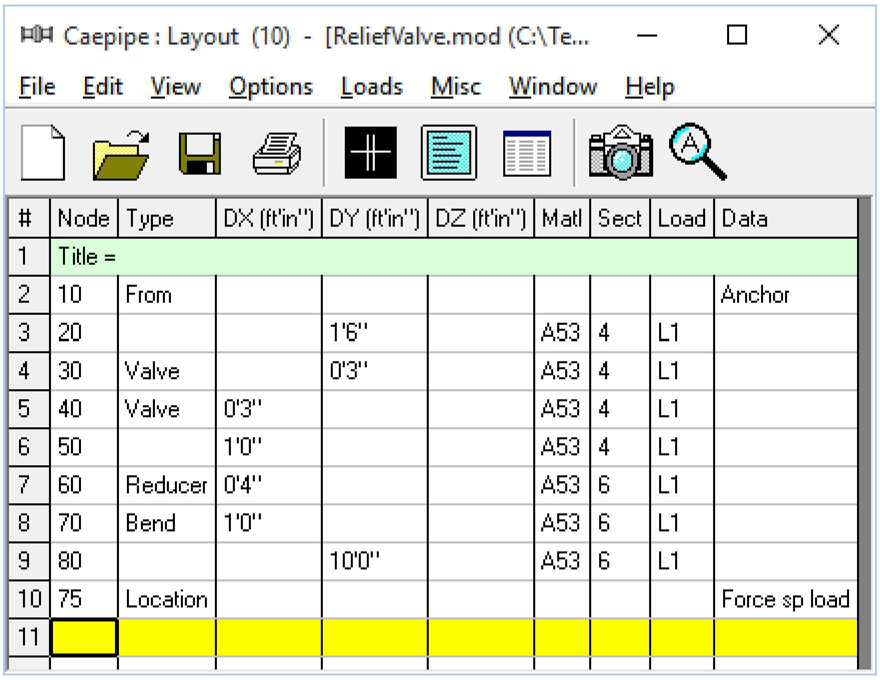
Reaction force value: 6700
Relief valve opening time: 0.008 (second)
Relief valve closing time: 0.008 (second)
Relief duration: 1.0 (second)
Force spectrum name: RVFS
Maximum frequency: 33 (Hz)
Number of frequencies: 20
Damping: 5 (%)

b. After entering the data as shown in the dialog above, press the button “OK”. This will generate a “Force Spectrum Load” as shown in the figure below.

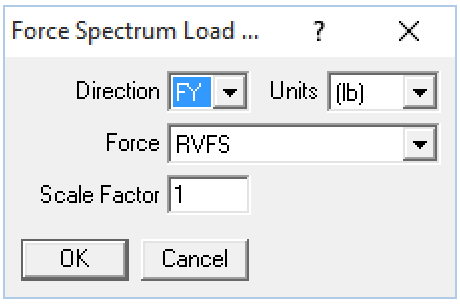


#	Name	#	Frequency (Hz)	Spectrum value
1	RVFS	1	0	0
2		2	1.65	12423.3
		3	3.3	12418.4
		4	4.95	12410.2
		5	6.6	12398.7
		6	8.25	12384
		7	9.9	12366
		8	11.55	12344.9
		9	13.2	12320.5
		10	14.85	12292.9
		11	16.5	12262.2
		12	18.15	12228.5
		13	19.8	12191.6
		14	21.45	12151.6
		15	23.1	12108.7
		16	24.75	12062.8
		17	26.4	12014.1
		18	28.05	11962.5
		19	29.7	11908
		20	31.35	11850.8
		21	33	11790.9
		22		

c. Apply the Force Spectrum Load thus generated at the bend center node 75 after the relief valve in vertical direction (FY) as shown below.

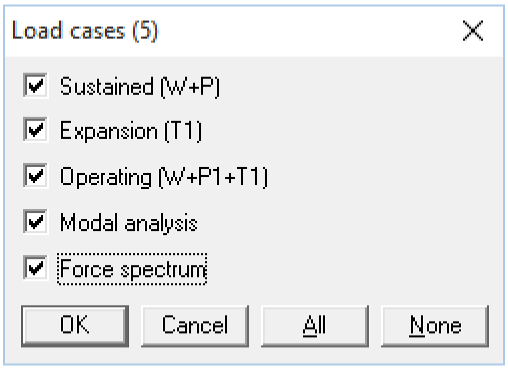


#	Node	Type	DX (ft'in")	DY (ft'in")	DZ (ft'in")	Matl	Sect	Load	Data
1	Title =								
2	10	From							Anchor
3	20			1'6"		A53	4	L1	
4	30	Valve		0'3"		A53	4	L1	
5	40	Valve	0'3"			A53	4	L1	
6	50		1'0"			A53	4	L1	
7	60	Reducer	0'4"			A53	6	L1	
8	70	Bend	1'0"			A53	6	L1	
9	80			10'0"		A53	6	L1	
10	75	Location							Force sp load
11									



Direction FY
Units (lb)
Force RVFS
Scale Factor 1

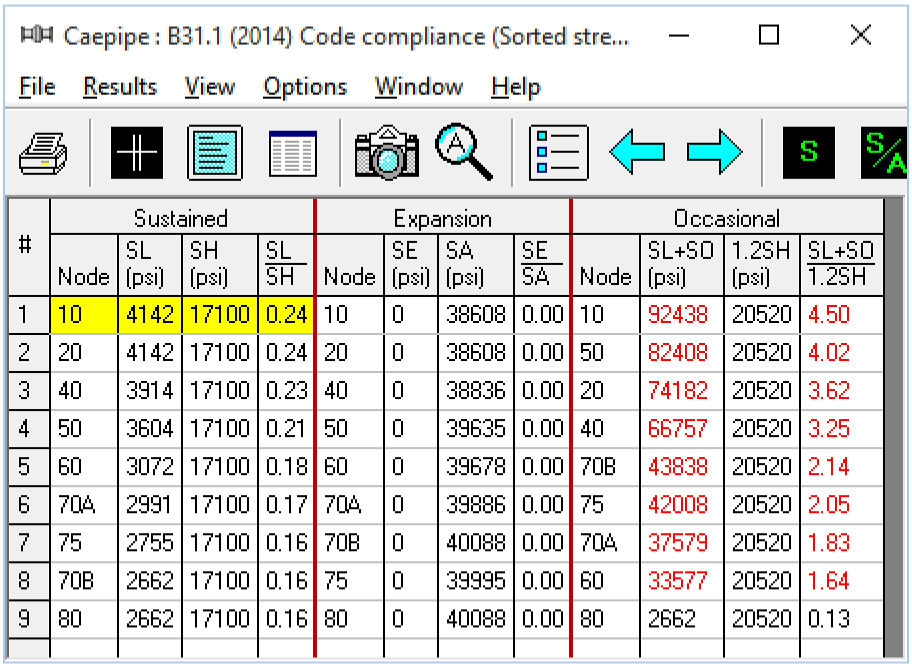
d. Check “Force Spectrum” for analysis through Layout window > Load cases. Click on OK.



☑ Sustained (W+P)
☑ Expansion (T1)
☑ Operating (W+P1+T1)
☑ Modal analysis
☑ Force spectrum

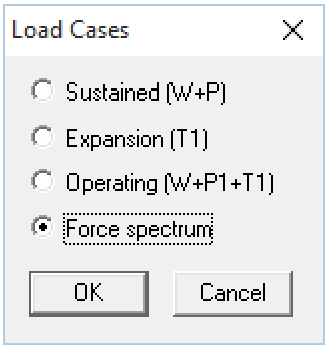
e. Save and Analyze the model.

After analysis, CAEPIPE displays Occasional stresses which include the effects of the PRV load.

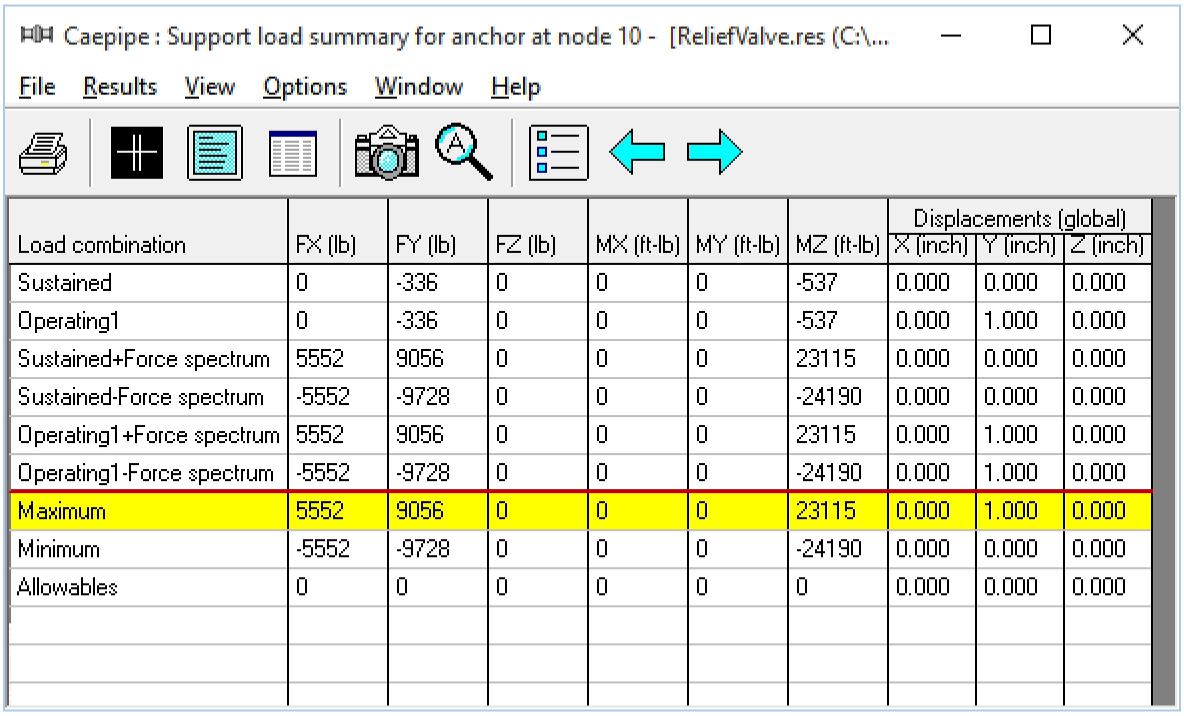


#	Sustained				Expansion				Occasional			
	Node	SL (psi)	SH (psi)	SL/SH	Node	SE (psi)	SA (psi)	SE/SA	Node	SL+SO (psi)	1.2SH (psi)	SL+SO/1.2SH
1	10	4142	17100	0.24	10	0	38608	0.00	10	92438	20520	4.50
2	20	4142	17100	0.24	20	0	38608	0.00	50	82408	20520	4.02
3	40	3914	17100	0.23	40	0	38836	0.00	20	74182	20520	3.62
4	50	3604	17100	0.21	50	0	39635	0.00	40	66757	20520	3.25
5	60	3072	17100	0.18	60	0	39678	0.00	70B	43838	20520	2.14
6	70A	2991	17100	0.17	70A	0	39886	0.00	75	42008	20520	2.05
7	75	2755	17100	0.16	70B	0	40088	0.00	70A	37579	20520	1.83
8	70B	2662	17100	0.16	75	0	39995	0.00	60	33577	20520	1.64
9	80	2662	17100	0.16	80	0	40088	0.00	80	2662	20520	0.13

Another load case called “Force Spectrum” will be available for which you can study displacements, support loads, support load summary (for sizing supports), etc.



○ Sustained (W+P)
○ Expansion (T1)
○ Operating (W+P1+T1)
● Force spectrum



Load combination	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)	Displacements (global) X (inch)	Y (inch)	Z (inch)
Sustained	0	-336	0	0	0	-537	0.000	0.000	0.000
Operating1	0	-336	0	0	0	-537	0.000	1.000	0.000
Sustained+Force spectrum	5552	9056	0	0	0	23115	0.000	0.000	0.000
Sustained-Force spectrum	-5552	-9728	0	0	0	-24190	0.000	0.000	0.000
Operating1+Force spectrum	5552	9056	0	0	0	23115	0.000	1.000	0.000
Operating1-Force spectrum	-5552	-9728	0	0	0	-24190	0.000	1.000	0.000
Maximum	5552	9056	0	0	0	23115	0.000	1.000	0.000
Minimum	-5552	-9728	0	0	0	-24190	0.000	0.000	0.000
Allowables	0	0	0	0	0	0	0.000	0.000	0.000

Annexure C

Generation of Mesh for Buried Piping Layout

(Automatic Discretization of Buried Piping Layout)

Generation of Mesh for Buried Piping Layout

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

w = soil density

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

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

where

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

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

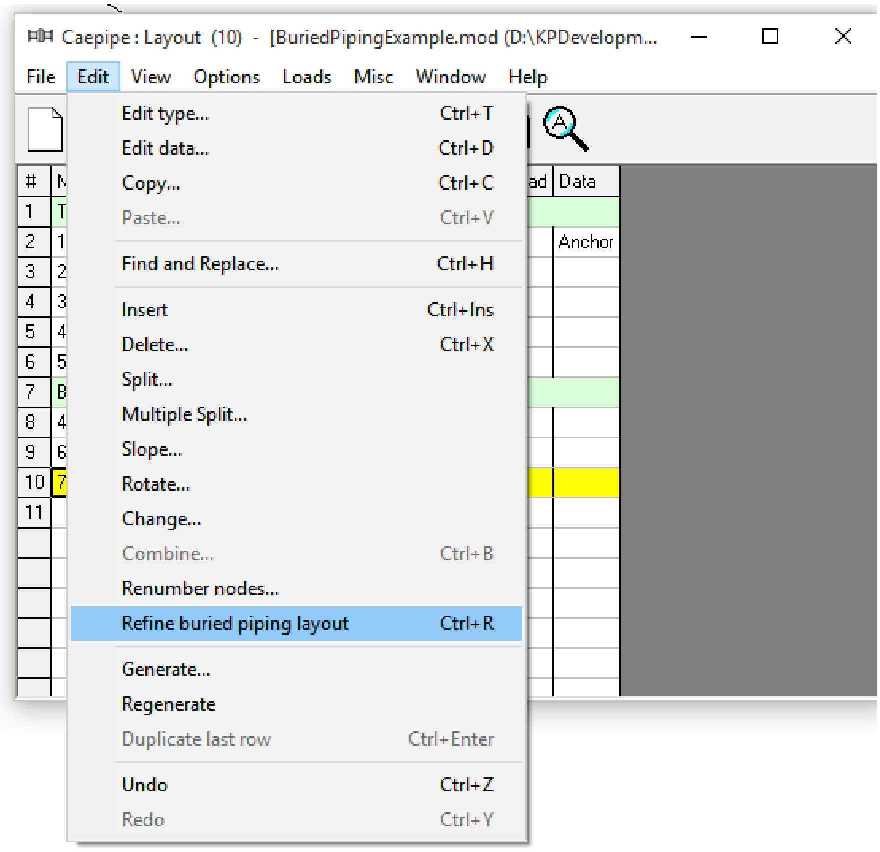
I = moment of inertia of pipe cross section

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

Implementation in CAEPIPE

It is in 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 element at the junction of bend, elbow and branch connection is to be refined in the stress layout.

This can be performed through Layout Window > Edit > Refine buried piping layout.



When the command is selected, CAEPIPE will refine the piping layout as detailed below.

1. Calculate modulus of subgrade reaction (k) as detailed above. While calculating k, the value of C_k is taken as 80 for both cohesive and cohesionless soil.
2. Calculate influence length (L_k) for the element that is fully buried.
3. If the length of the pipe element near bend / elbow / branch connection is greater than or equal to the influence length (L_k), then the pipe element will be split into a number of short elements with length of each short element being equal to 2 x OD of that pipe section until the Influence length (L_k).

   On the other hand, if the length of the pipe element near bend / elbow / branch connection is less than the influence length (L_k) and greater than 2 x OD of the pipe, then the pipe element will be split into a number of short elements with length of each short element being equal to 2 x OD of that pipe section.

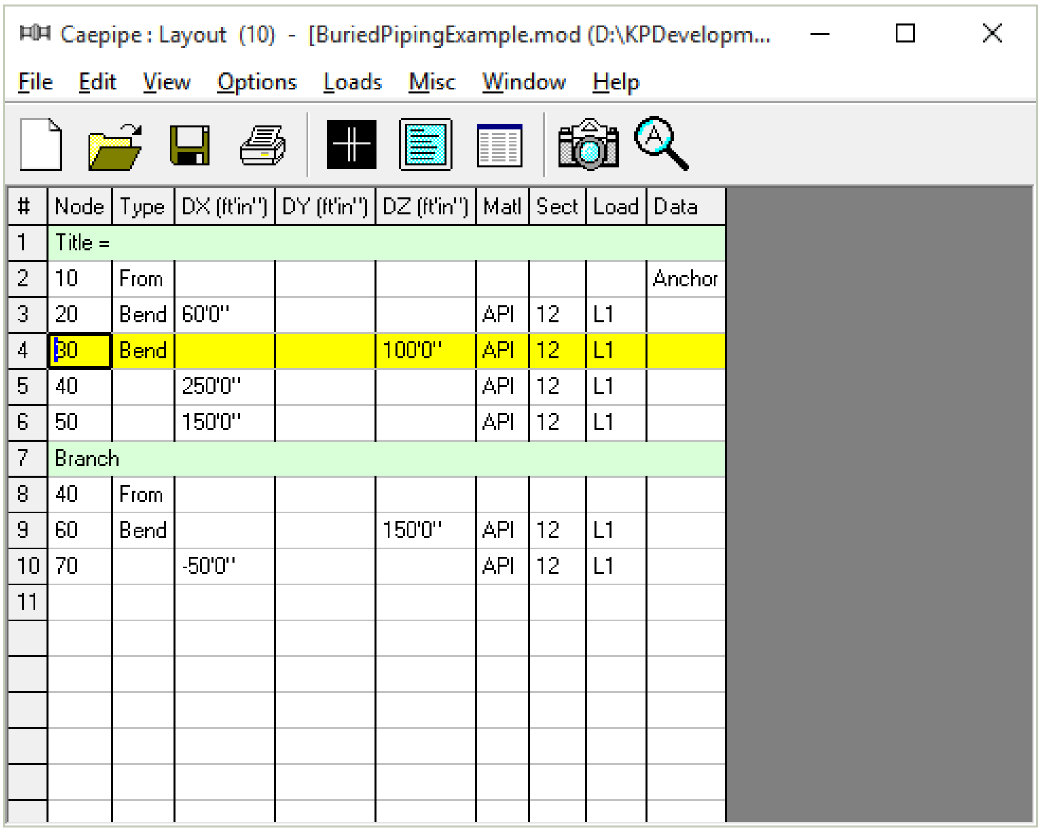
Note: while refining the layout, the new node number will be generated by adding the node increment specified (through Layout Window > Options > Node increment) to the available free node number. Hence, set the node increment value as required before refining the buried piping layout.

Sample buried piping model

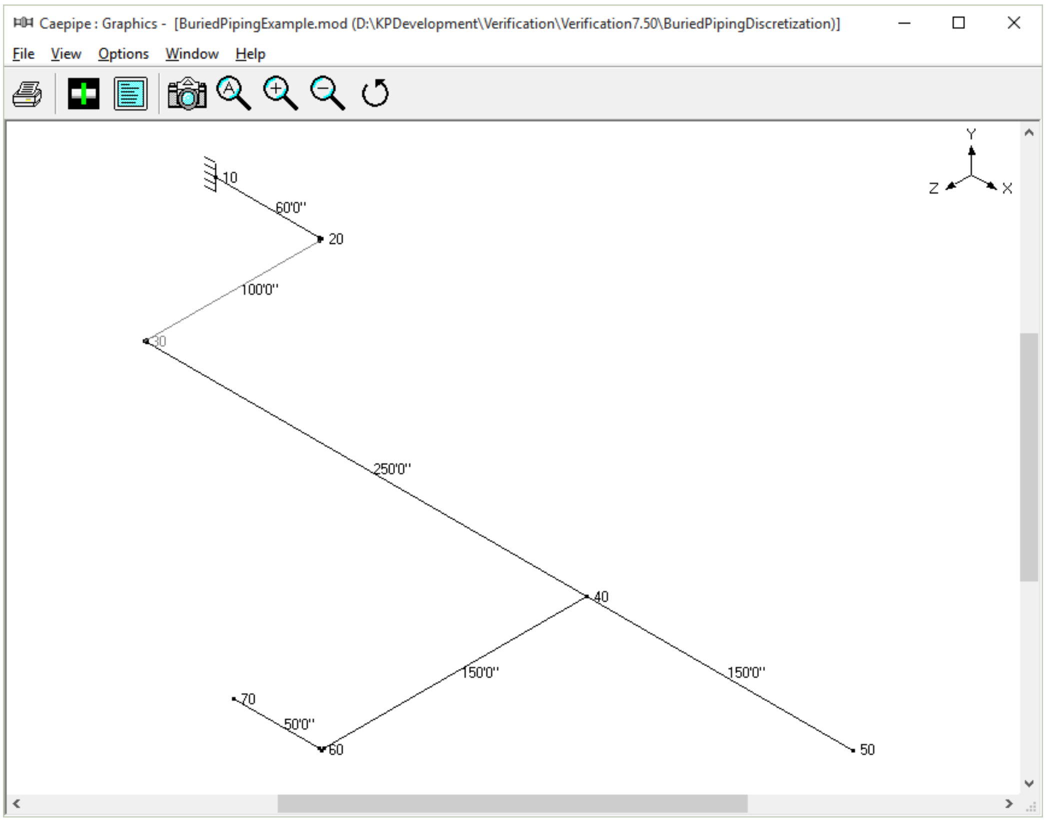
The following data are used to generate the sample buried piping model.

```
  Piping code = B31.1 (2014)
  Use liberal allowable stresses
  Do not include axial force in stress calculations
  Reference temperature = 70 (F)
  Number of thermal cycles = 7000
  Number of thermal loads = 1
  Thermal = Operating - Sustained
  Use modulus at reference temperature
  Include hanger stiffness
  Include Bourdon effect
  Use pressure correction for bends
  Pressure stress = PD / 4t
  Peak pressure factor = 1.00
  Cut off frequency = 33 Hz
  Number of modes = 20
  Include missing mass correction
  Use friction in dynamic analysis
  Vertical direction = Y
-----------------------------------------------------------------------------------
                          Pipe material API: API 5L
-----------------------------------------------------------------------------------
  Density = 0.283 (lb/in3),  Nu = 0.300,  Joint factor = 0.85, Type = CS

    Temp       E         Alpha     Allowable
    (F)      (psi)     (in/in/F)     (psi)
  -------------------------------------------
    -20     27.9E+6     6.25E-6      10900
    100     27.9E+6     6.47E-6      10900
    200     26.8E+6     6.70E-6      10900
    300     25.3E+6     6.90E-6      10900
    400     24.7E+6     7.10E-6      10900
-----------------------------------------------------------------------------------
                                Pipe Sections
-----------------------------------------------------------------------------------
      Nominal      O.D.   Thk   Cor.Al M.Tol Ins.Dens Ins.Th Lin.Dens Lin.Th
Name   Dia.   Sch (inch) (inch) (inch)  (%)  (lb/ft3) (inch) (lb/ft3) (inch)
-----------------------------------------------------------------------------------
12    12"     STD 12.75   0.375  0      0.0
-----------------------------------------------------------------------------------
                                    Soils
-----------------------------------------------------------------------------------
Name     Type       Density    Strength     Delta        Ks     Ground Level
                    (lb/ft3)    (psi)       (deg)                  (ft'in")
-----------------------------------------------------------------------------------
S1   Cohesionless   130                     30         0.30       12'0"
-----------------------------------------------------------------------------------
                                 Pipe Loads
-----------------------------------------------------------------------------------
  Load    T1    P1       T2    P2       T3    P3   Specific  Add.Wgt  Wind
  Name   (F)  (psi)     (F)  (psi)     (F)  (psi)   gravity  (lb/ft)  Load
-----------------------------------------------------------------------------------
  L1     140   100
-----------------------------------------------------------------------------------
```



#	Node	Type	DX (ft'in")	DY (ft'in")	DZ (ft'in")	Matl	Sect	Load	Data
1	Title =								
2	10	From							Anchor
3	20	Bend	60'0"			API	12	L1	
4	30	Bend			100'0"	API	12	L1	
5	40		250'0"			API	12	L1	
6	50		150'0"			API	12	L1	
7	Branch								
8	40	From							
9	60	Bend			150'0"	API	12	L1	
10	70		-50'0"			API	12	L1	
11									



Soil characteristics

Soil density, w = 130 lb/ft3 = 0.075 lb/in^3

Pipe depth below grade, H = 12 ft (144 in)

Type of backfill, dense sand (cohesion less soil)

C_k = 80

Calculation of Modulus of subgrade reaction (k)

N_h = 0.285H/D + 4.3

N_h = (0.285 x 144 / 12.75) + 4.3 = **7.518**

$k = C_k N_h w D$ = 80 x 7.518 x 0.075 x 12.75 = **575.127 psi**

Calculation of Influence Length (L_k)

Moment of inertia, I = 279.3 in^4

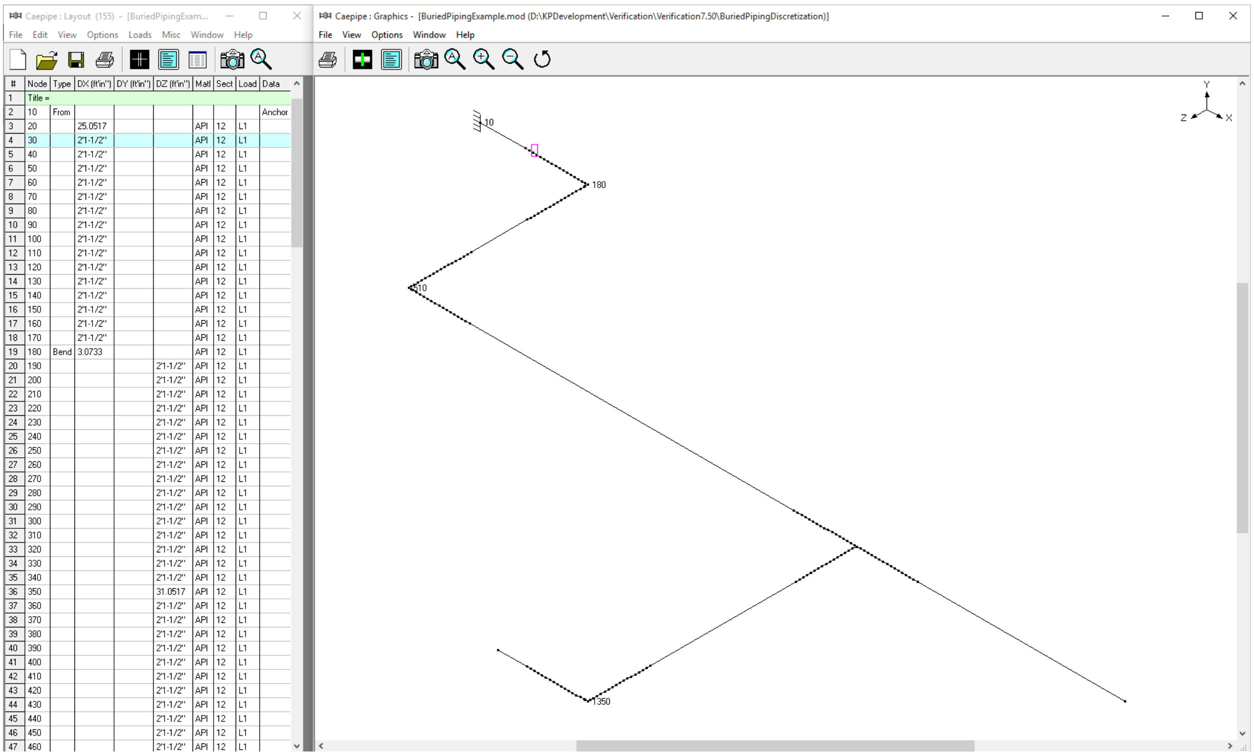
Modulus of elasticity, E = 27.9 x 10^6 psi

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

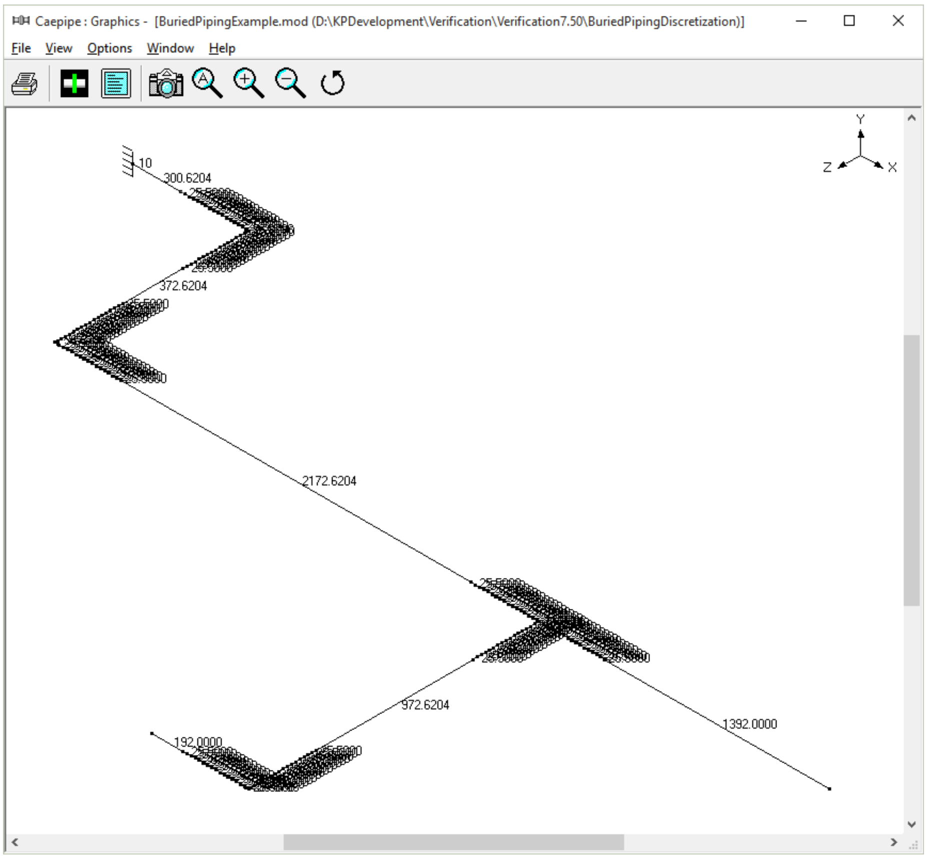
Pipe / Soil System Characteristics = $\beta = \left[\frac{k}{4EI}\right]^{1/4}$ = [575.127 / (4 x 27.9 x 106 x 279.3)] $^{1/4}$ = **0.01165**

Influence Length (Lk) = 3 x 3.14 / (4 x 0.01165) = **202.145 in**

As the length of pipe element near the bend and branch connection is greater than the influence length (L_k = 202.145 in), the pipe elements near the bends and branch connection are split into a number of short elements with length of each short element being equal to 2 x OD = 2 x 12.75 = 25.5 in until the influence length (L_k). See figures given below for details.



#	Node	Type	DX (ft'in")	DY (ft'in")	DZ (ft'in")	Matl	Sect	Load	Data
1	Title =								
2	10	From							Anchor
3	20		25.0517			API	12	L1	
4	30		2'1-1/2"			API	12	L1	
5	40		2'1-1/2"			API	12	L1	
6	50		2'1-1/2"			API	12	L1	
7	60		2'1-1/2"			API	12	L1	
8	70		2'1-1/2"			API	12	L1	
9	80		2'1-1/2"			API	12	L1	
10	90		2'1-1/2"			API	12	L1	
11	100		2'1-1/2"			API	12	L1	
12	110		2'1-1/2"			API	12	L1	
13	120		2'1-1/2"			API	12	L1	
14	130		2'1-1/2"			API	12	L1	
15	140		2'1-1/2"			API	12	L1	
16	150		2'1-1/2"			API	12	L1	
17	160		2'1-1/2"			API	12	L1	
18	170		2'1-1/2"			API	12	L1	
19	180	Bend	3.0733			API	12	L1	
20	190				2'1-1/2"	API	12	L1	
21	200				2'1-1/2"	API	12	L1	
22	210				2'1-1/2"	API	12	L1	
23	220				2'1-1/2"	API	12	L1	
24	230				2'1-1/2"	API	12	L1	
25	240				2'1-1/2"	API	12	L1	
26	250				2'1-1/2"	API	12	L1	
27	260				2'1-1/2"	API	12	L1	
28	270				2'1-1/2"	API	12	L1	
29	280				2'1-1/2"	API	12	L1	
30	290				2'1-1/2"	API	12	L1	
31	300				2'1-1/2"	API	12	L1	
32	310				2'1-1/2"	API	12	L1	
33	320				2'1-1/2"	API	12	L1	
34	330				2'1-1/2"	API	12	L1	
35	340				2'1-1/2"	API	12	L1	
36	350				31.0517	API	12	L1	
37	360				2'1-1/2"	API	12	L1	
38	370				2'1-1/2"	API	12	L1	
39	380				2'1-1/2"	API	12	L1	
40	390				2'1-1/2"	API	12	L1	
41	400				2'1-1/2"	API	12	L1	
42	410				2'1-1/2"	API	12	L1	
43	420				2'1-1/2"	API	12	L1	
44	430				2'1-1/2"	API	12	L1	
45	440				2'1-1/2"	API	12	L1	
46	450				2'1-1/2"	API	12	L1	
47	460				2'1-1/2"	API	12	L1	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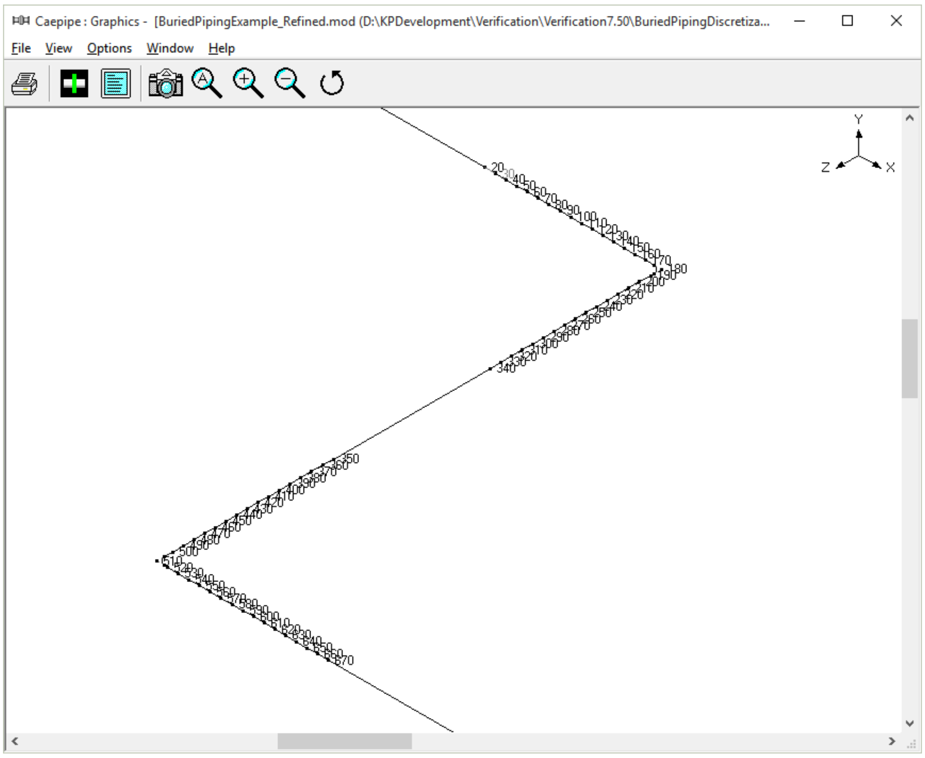
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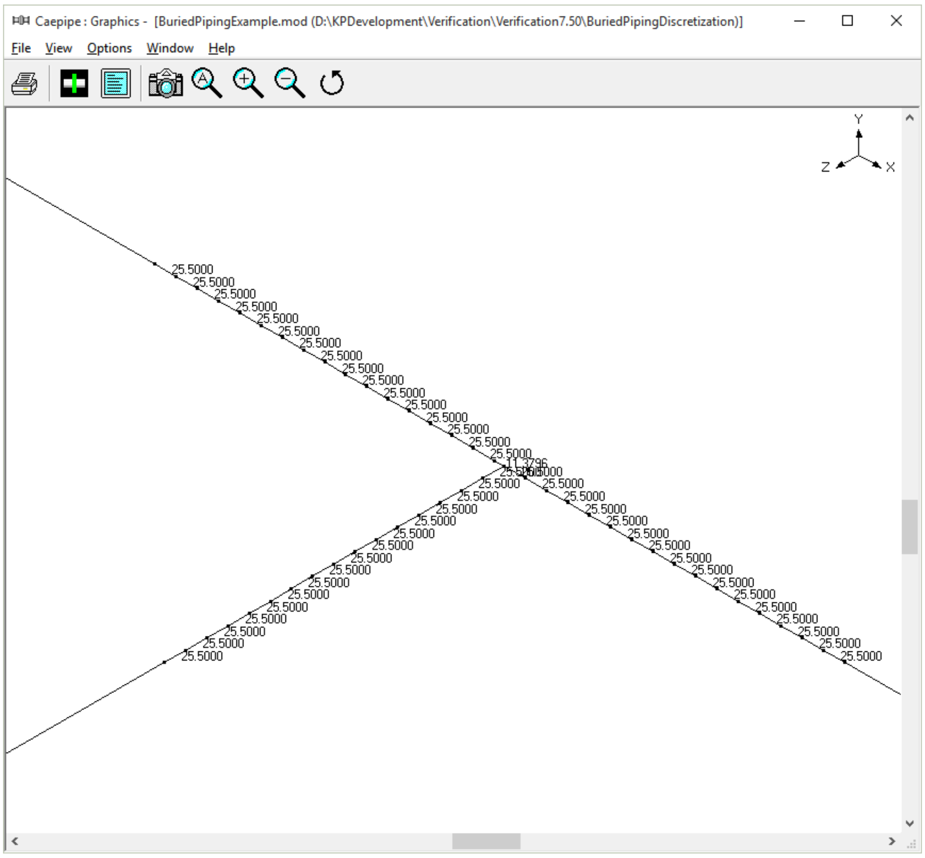
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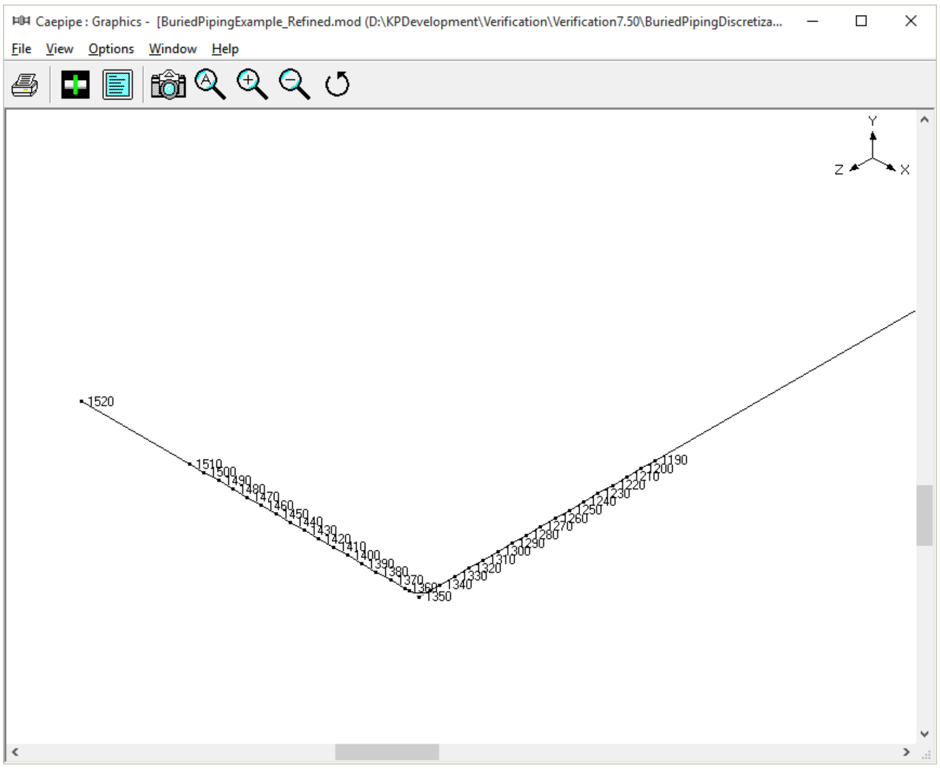
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