Tutorial for Pressure Relief Valve Load Analysis using CAEPIPE

General

[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.

Simplified Analysis Approach

American Petroleum Institute's API 520, Part II (1994), 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 2.4.1.1) in US Customary units from API 520, Part II (1994), for vapor relief devices discharging to the atmosphere, is shown below:

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

where,

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F = Reaction force at the point of discharge to the atmosphere,(lbf.)
k = Ratio of specific heats (CP/CV) at the outlet conditions
W = Flow rate of any gas or vapor, pound mass (lbm.)/hr
CP = Specific heat at constant pressure
CV = 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, in2
P = Static pressure within the outlet at the point of discharge, psig
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Using the reaction force computed from the above formula along with the following PRV parameters, namely

- 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 to perform a simplified analysis.

Detailed Analysis Approach

Section 2.4.2 of API 520, Part II (1994) also states the following.

"Pressure relief devices that relieve under steady-state flow conditions into a closed system usually do not create large forces and bending moments on the exhaust system. Only at points of sudden expansion will there be any significant reaction forces to be calculated. Closed discharge systems, however, do not lend themselves to simplified analytical techniques. A complex time history analysis of the piping system may be required to obtain the true values of the reaction forces and associated moments."

Such complex time history analysis of the piping system can be carried out as follows.

- Perform a fluid transient analysis on the piping system using a fluid dynamics software tool such as, “PipeNet”, “RELAP”, "ROLAST", etc.
- Apply the resulting output obtained (forces as a function of frequency) 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 and hence, not covered here.

Tutorial

Step 1:

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

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1. Reaction force (F) computed using the formula above = 6854 lb.
2. Relief Valve Opening time = 8 ms (milliseconds)
3. Relief Valve Closing time = 8 ms
4. Relief duration = 1 s
6. Pressure = 475 psig
7. Temperature = 51°F
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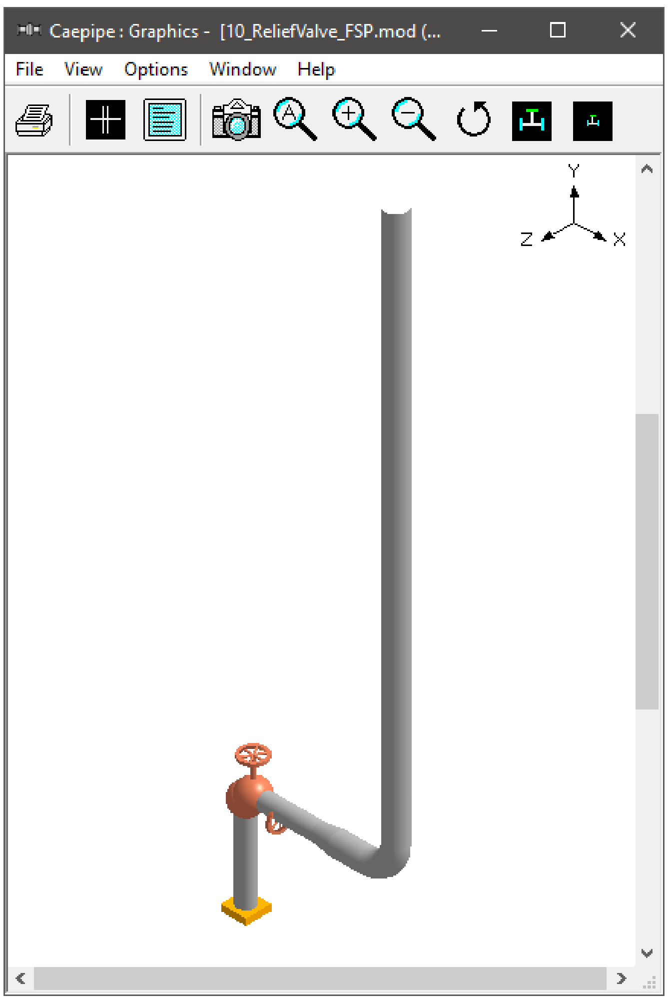
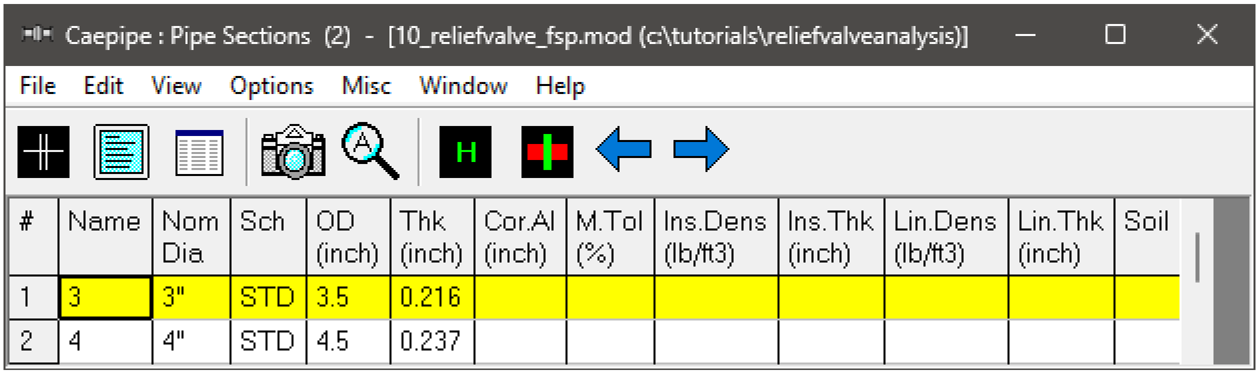
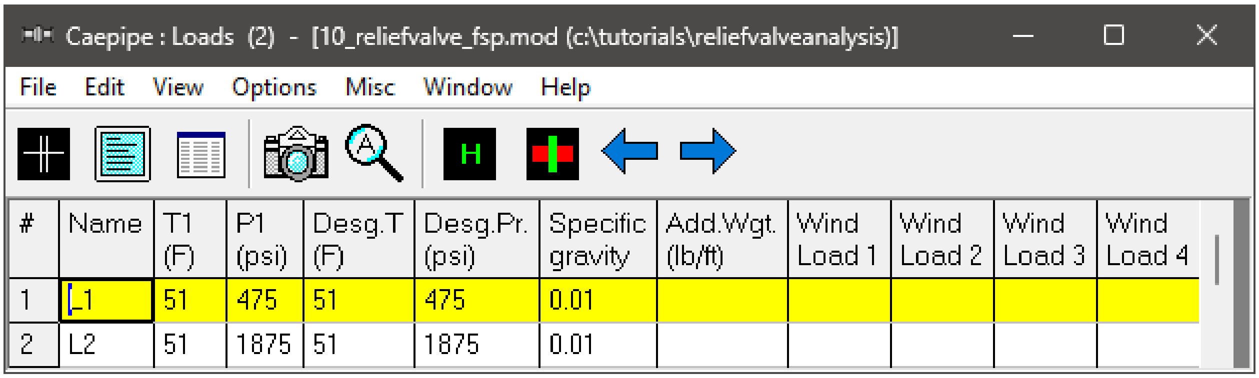
The steps followed in generating the model are given below.

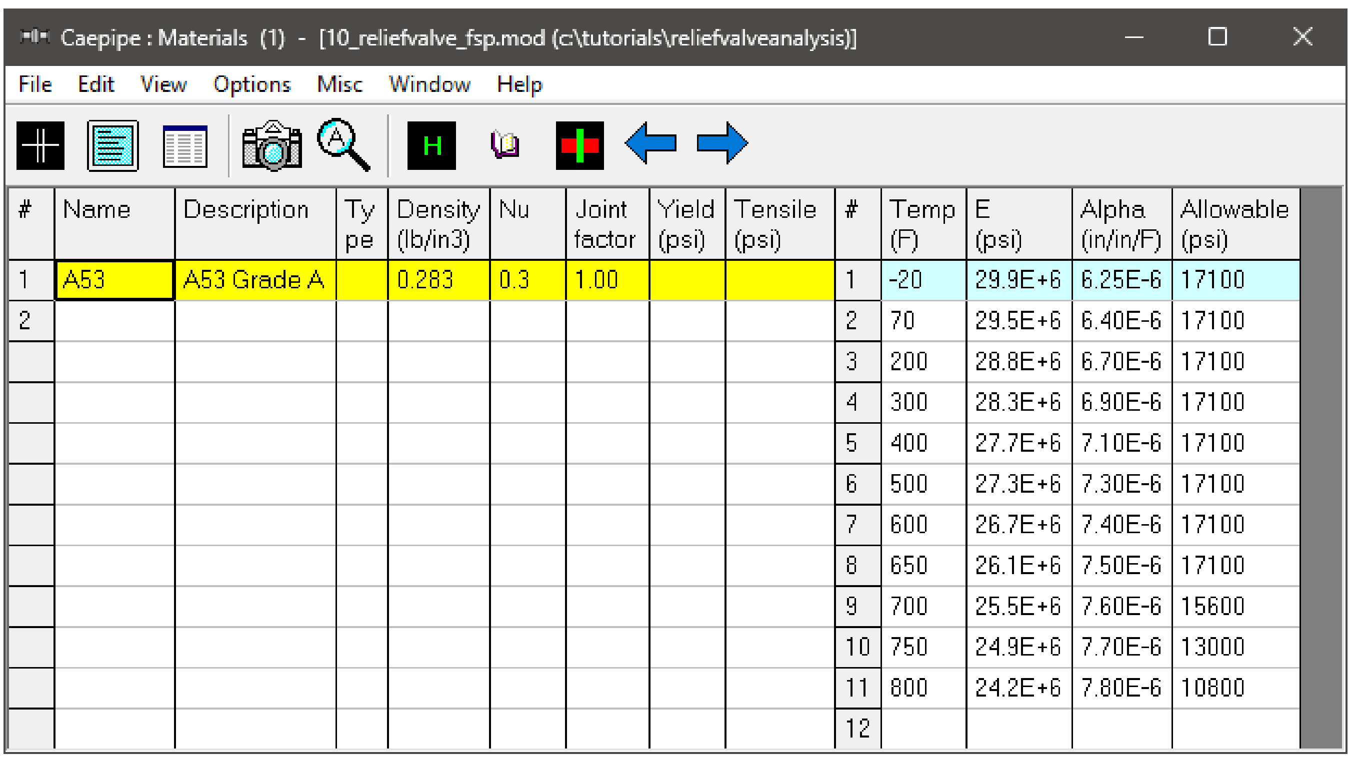




#	Name	Nom Dia	Sch	OD (inch)	Thk (inch)	Cor.Al (inch)	M.Tol (%)	Ins.Dens (lb/ft3)	Ins.Thk (inch)	Lin.Dens (lb/ft3)	Lin.Thk (inch)	Soil
1	3	3"	STD	3.5	0.216							
2	4	4"	STD	4.5	0.237							

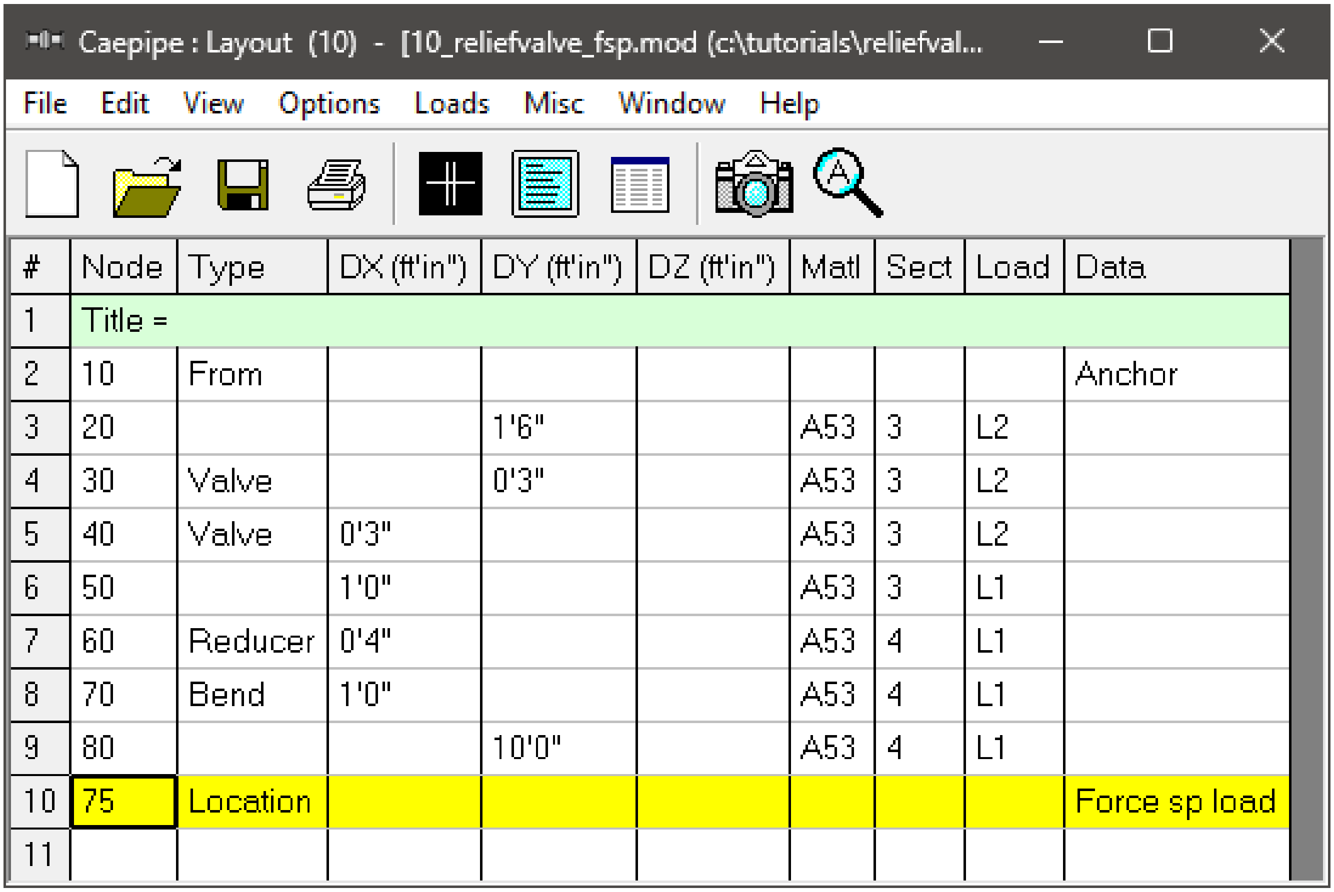


#	Name	T1 (F)	P1 (psi)	Desg.T (F)	Desg.Pr. (psi)	Specific gravity	Add.Wgt. (lb/ft)	Wind Load 1	Wind Load 2	Wind Load 3	Wind Load 4
1	L1	51	475	51	475	0.01					
2	L2	51	1875	51	1875	0.01					

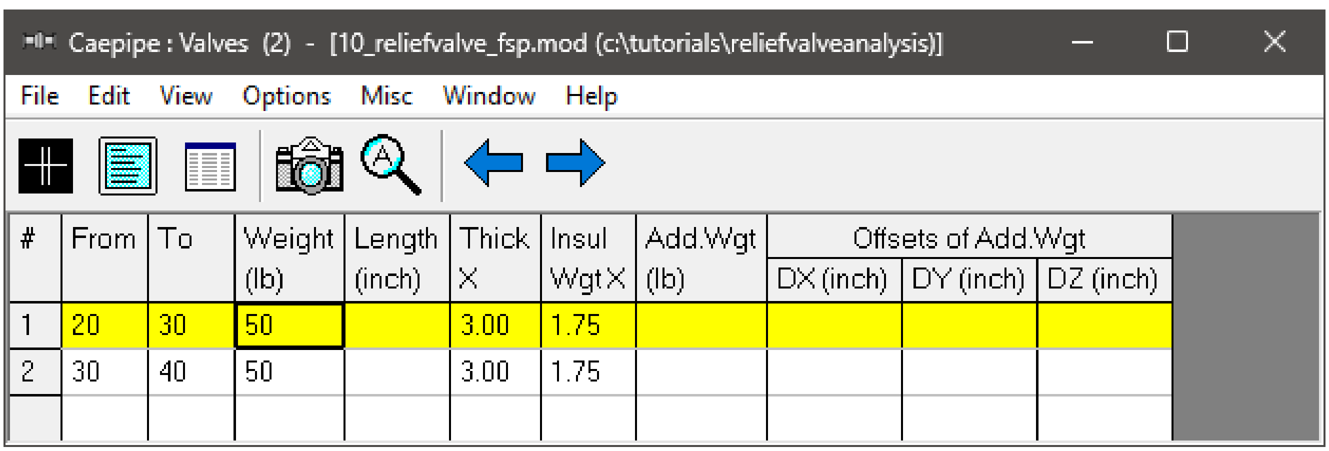


#	Name	Description	Type	Density (lb/in3)	Nu	Joint factor	Yield (psi)	Tensile (psi)
1	A53	A53 Grade A		0.283	0.3	1.00		
2								

#	Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
1	-20	29.9E+6	6.25E-6	17100
2	70	29.5E+6	6.40E-6	17100
3	200	28.8E+6	6.70E-6	17100
4	300	28.3E+6	6.90E-6	17100
5	400	27.7E+6	7.10E-6	17100
6	500	27.3E+6	7.30E-6	17100
7	600	26.7E+6	7.40E-6	17100
8	650	26.1E+6	7.50E-6	17100
9	700	25.5E+6	7.60E-6	15600
10	750	24.9E+6	7.70E-6	13000
11	800	24.2E+6	7.80E-6	10800
12				



#	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	3	L2	
4	30	Valve		0'3"		A53	3	L2	
5	40	Valve	0'3"			A53	3	L2	
6	50		1'0"			A53	3	L1	
7	60	Reducer	0'4"			A53	4	L1	
8	70	Bend	1'0"			A53	4	L1	
9	80			10'0"		A53	4	L1	
10	75	Location							Force sp load
11									

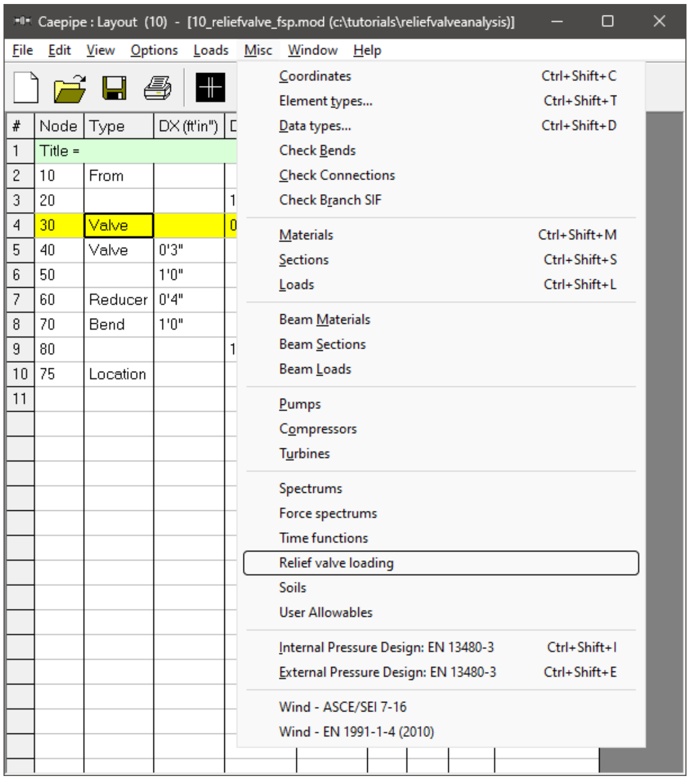


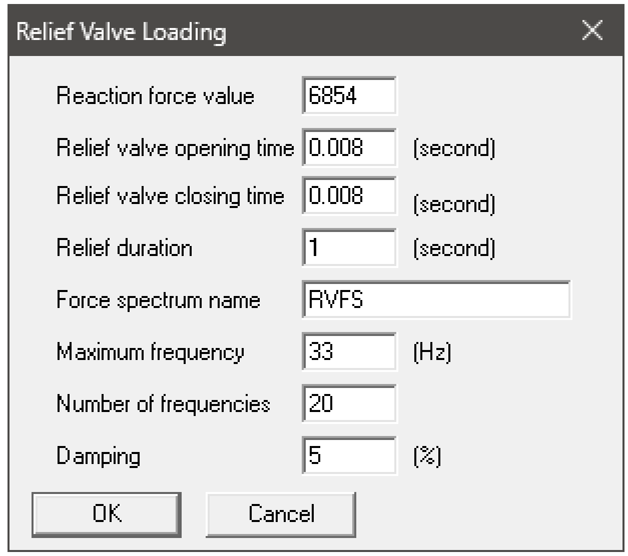
#	From	To	Weight (lb)	Length (inch)	Thick X	Insul Wgt X	Add.Wgt (lb)	Offsets of Add.Wgt DX (inch)	DY (inch)	DZ (inch)
1	20	30	50		3.00	1.75				
2	30	40	50		3.00	1.75				

Step 2:

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

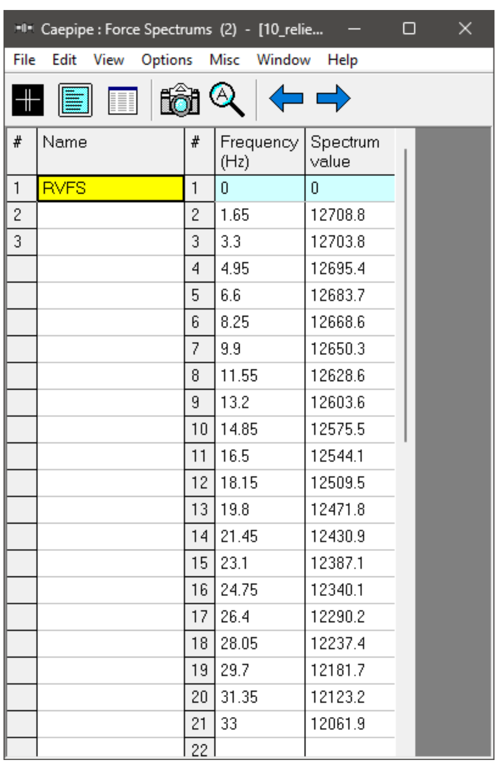
Select “Relief valve loading” from CAEPIPE Layout window > Misc and enter the data in the dialog box as shown in the figure below.





Step 3:

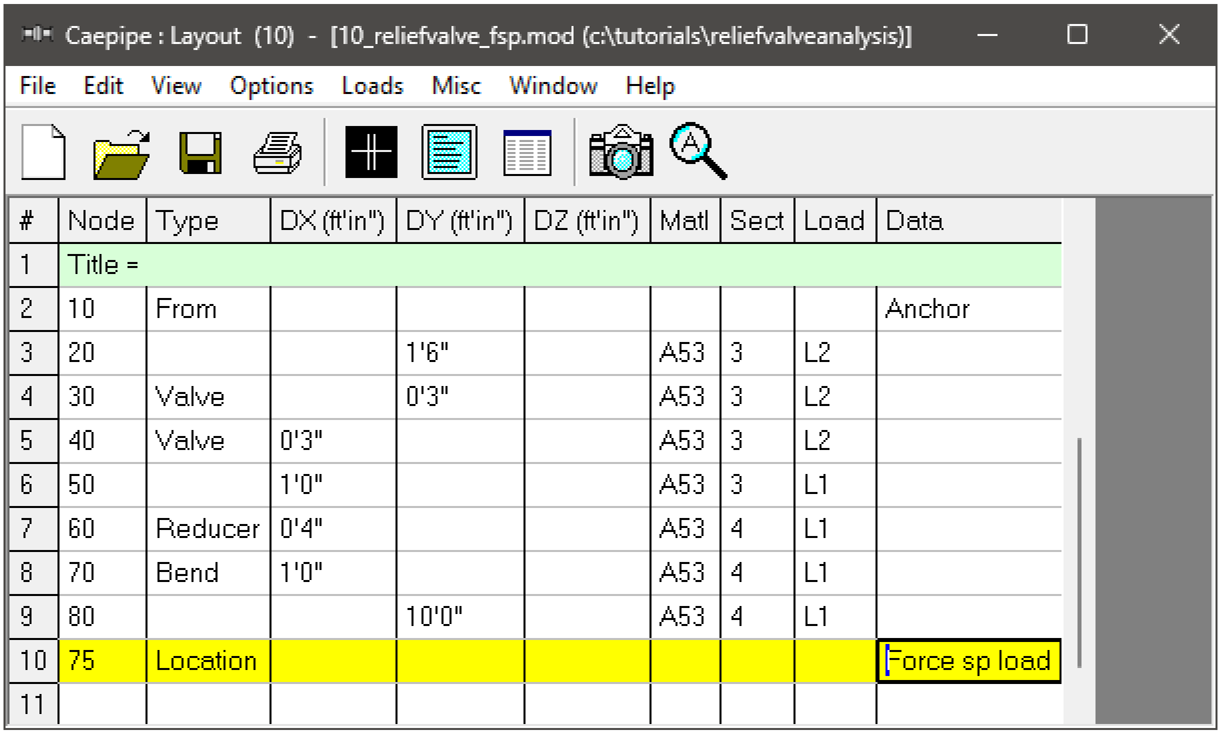
After entering the data as shown in the dialog above, press the button “OK”. Using the above input values for Relief Valve Loading, CAEPIPE internally generates a time-history loading function, which is then applied on a single degree-freedom spring-mass system with each intermediate frequency (between 0.0 Hz and the maximum frequency) to generate the “Force Spectrum Load” shown below.

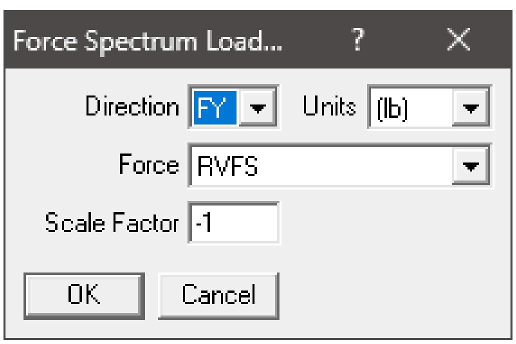


#	Name	#	Frequency (Hz)	Spectrum value
1	RVFS	1	0	0
2		2	1.65	12708.8
3		3	3.3	12703.8
		4	4.95	12695.4
		5	6.6	12683.7
		6	8.25	12668.6
		7	9.9	12650.3
		8	11.55	12628.6
		9	13.2	12603.6
		10	14.85	12575.5
		11	16.5	12544.1
		12	18.15	12509.5
		13	19.8	12471.8
		14	21.45	12430.9
		15	23.1	12387.1
		16	24.75	12340.1
		17	26.4	12290.2
		18	28.05	12237.4
		19	29.7	12181.7
		20	31.35	12123.2
		21	33	12061.9
		22		

Step 4:

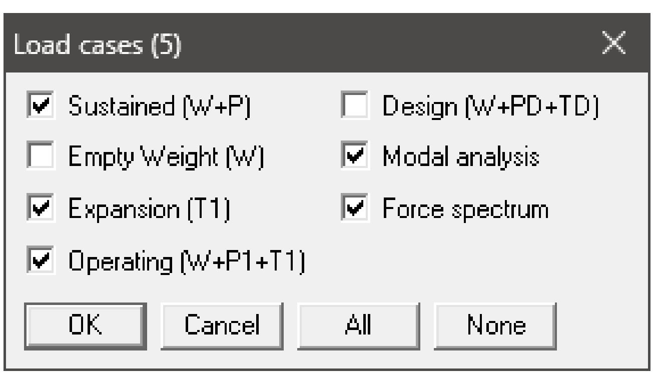
Apply the Force Spectrum Load thus generated at the bend center node 75 after the relief valve in downward direction (-FY by specifying negative Scale Factor) as shown below.





Step 5:

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



Step 6:

Save and Analyze the model. After analysis, CAEPIPE displays Occasional stresses which include the effects of the PRV load.

Caepipe : B31.1 (2022) Code compliance (Sorted stresses) - [10_reliefvalve_fsp.res...

File Results View Options Window Help

#	Sustained				Expansion				Occasional			
	Node	SL (psi)	SH (psi)	SL/SH	Node	SE (psi)	SA (psi)	SE/SA	Node	SO (psi)	1.2SH (psi)	SO/1.2SH
1	20	9669	17100	0.57	10	0	26195	0.00	10	191113	20520	9.31
2	10	9664	17100	0.57	20	0	26195	0.00	20	148596	20520	7.24
3	40	3834	17100	0.22	40	0	26195	0.00	40	122523	20520	5.97
4	50	3209	17100	0.19	50	0	26195	0.00	50	120658	20520	5.88
5	60	2763	17100	0.16	60	0	26195	0.00	70B	99118	20520	4.83
6	70A	2544	17100	0.15	70A	0	26195	0.00	75	95035	20520	4.63
7	75	2313	17100	0.14	70B	0	26195	0.00	70A	85517	20520	4.17
8	80	2255	17100	0.13	75	0	26195	0.00	60	67037	20520	3.27
9	70B	2222	17100	0.13	80	0	26195	0.00	80	3562	20520	0.17

Step 7:

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

Caepipe : Support load summary for anchor at node 10 - [10_reliefvalve_fsp.res (c...

File Results View Options Window Help

Load combination	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
Sustained	0	-239	0	0	0	-313
Operating1	0	-239	0	0	0	-313
Sustained+Force spectrum	4501	9517	0	0	0	25128
Sustained-Force spectrum	-4501	-9994	0	0	0	-25753
Operating1+Force spectrum	4501	9517	0	0	0	25128
Operating1-Force spectrum	-4501	-9994	0	0	0	-25753
Maximum	4501	9517	0	0	0	25128
Minimum	-4501	-9994	0	0	0	-25753
Allowables	0	0	0	0	0	0