# **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 (C<sub>P</sub>/C<sub>V</sub>) at the outlet conditions
W = Flow rate of any gas or vapor, pound mass (lbm.)/hr
C<sub>P</sub> = Specific heat at constant pressure
C<sub>V</sub> = Specific heat at constant volume
T = Temperature at the outlet, ^{\circ}R
M = Molecular weight of the process fluid
A = Area of the outlet at the point of discharge, in<sub>2</sub>
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.

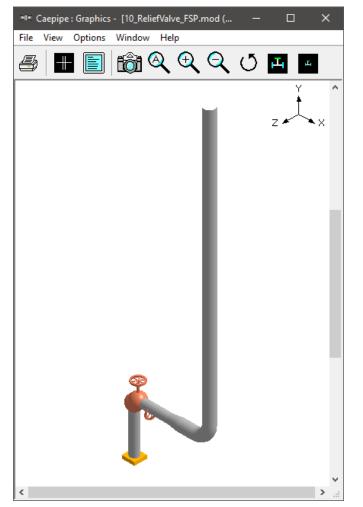
### **Tutorial**

#### Step 1:

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

- 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 =  $51^{\circ}F$

The steps followed in generating the model are given below.



							fsp.mod (	c:\tutorial	ls\reliefva	lvear	nalysis)]	-		×	
File	Edit	View	Option	s Miso		ow H	lelp								
#	Name	Nom Dia	Sch	OD (inch)	Thk (inch)	Cor.A (inch)		Ins.Der (lb/ft3)	ns Ins.T (inch		Lin.Den (lb/ft3)	is Lin.T (inch		1	
1 2	<mark>3</mark> 4	<mark>3"</mark> 4"	STD STD	3.5 4.5	0.216								, 		
				1	1	fsp.mod	d (c:\tutor	ials\relief	valveana	lysis)	]	_		×	
File	Edit	View	Option	_			lelp								
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#	Name	T1 (F)	P1 (psi)	Desg. (F)	T Des (psi)	- 1	Specific gravity	Add.W (lb/ft)	/gt. Win Loa		Wind Load 2	Wind Load	Wind 3 Load		
		51	475	51	475		0.01								
1 2	L2	51 51	1875	51	1875	5	0.01								
2	L2	51	1875	51			0.01 (c:\tutorial	ls\reliefval	veanalysis	;)]					×
2	L2 Caepipe :	51 Materia	1875	51 [10_reli Misc		sp.mod		ls\reliefval	veanalysis	;)]					×
2 F04	L2 Caepipe :	51 Materia	1875 als (1) -	51 · [10_reli	iefvalve_f	sp.mod		ls\reliefval	veanalysis	;)]			_		×
2 File	L2 Caepipe :	51 Materia /iew O	1875 als (1) -	51 [10_reli Misc	efvalve_f	sp.mod Help		■ 📫 Yield T	•	#		Ē (psi)	Alpha (in/in/F)	Allowat	
2 File #	L2 Caepipe : Edit V	51 Materia /iew O Des	1875 als (1) - ptions	51 Misc A Type	efvalve_f Window H Density	sp.mod Help	(c\tutorial	■ 📫	ensile psi)	#	(F) ( -20 (	(psi) 29.9E+6	(in/in/F) 6.25E-6	Allowat (psi) 17100	
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2 File #	L2 Caepipe : Edit V	51 Materia /iew O Des	1875 als (1) - ptions E	51 Misc A Type	efvalve_f Window H Density (Ib/in3)	sp.mod Help U	(c\tutorial	■ 📫	ensile psi)	# 1 2 3 4 5	(F) ( -20 2 70 2 200 2 300 2 400 2	(psi) 29.9E+6 29.5E+6 28.8E+6 28.3E+6 27.7E+6	(in/in/F) 6.25E-6 6.40E-6 6.70E-6 6.90E-6 7.10E-6	Allowat (psi) 17100 17100 17100 17100 17100	
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H0H	🕬 Caepipe : Layout (10) - [10_reliefvalve_fsp.mod (c:\tutorials\reliefval — 🛛 🛛 🛛											
File	File Edit View Options Loads Misc Window Help											
#	Node	Туре	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												

Caepipe : Valves (2) - [10_reliefvalve_fsp.mod (c:\tutorials\reliefvalveanalysis)] -											0	×
File	File Edit View Options Misc Window Help											
-#												
#	From	То	Weight	Length	Thick	Insul	Add.Wgt	Offs	ets of Add.	Wgt		
			(lb)	(inch)	Х	WgtX	(lb)	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.

Elle         Edit         View         Options         Loads         Misc         Window         Help           I         Image: Coordinates         Ctrl+Shift+C         Element types         Ctrl+Shift+T           I         Tritle =         Dat types         Ctrl+Shift+T         Dat types         Ctrl+Shift+C           1         Tritle =         Check Bends         Check Bends         Check Bends         Check Bends           2         10         From         Check Bends         Check Bends         Check Bends         Check Bends           2         10         From         Materials         Ctrl+Shift+D         Check Bends         Check Bends           2         10         From         Materials         Ctrl+Shift+M         Sections         Ctrl+Shift+S           2         0         0'3"         Sections         Ctrl+Shift+S         Loads         Ctrl+Shift+S           4         30         Valve         0'3"         Beam Materials         Ctrl+Shift+S         Loads         Ctrl+Shift+S           4         70         Bend         1'0"         Beam Materials         Ctrl+Shift+S         Relief Valve Loading         68554           8         80         1         Beam Sections <th></th>	
Image: Constraint type         Image: Constraint type         Ctrl+Shift+T           #         Node         Type         DX (ft'in')         Data types         Ctrl+Shift+D           1         Title =         Check Bends         Check Bends         Check Bends           2         10         From         Check Bends         Check Bends           3         20         1         Check Bends         Check Bends           4         30         Valve         0         Materials         Ctrl+Shift+M           5         40         Valve         0'3"         Sections         Ctrl+Shift+S           Loads         Ctrl+Shift+L         Sections         Ctrl+Shift+L         Beam Materials           7         60         Reducer 0'4"         Beam Materials         Ctrl+Shift+L           8         70         Bend         1'0"         Beam Materials         Beam Sections           9         80         1         Beam Sections         Beam Loads         Felief valve opening time         0.0008         (second)	
#       Node       Type       DX (ftin")       DX         1       Title =       Data types       Ctrl+shift+D         2       10       From       Data types       Ctrl+shift+D         3       20       1       Check Banch SIF         4       30       Valve       0         5       40       Valve       0's"         5       40       Valve       0's"         5       60       1'0"       Materials       Ctrl+Shift+S         Loads       Ctrl+Shift+L       Beam Materials       Ctrl+Shift+L         8       70       Bend       1'0"       Beam Materials         8       80       1       Beam Sections       Beam Loads         10       75       Location       Beam Loads       Felief valve opening time       0.008       (second)	
1       Title =       Check Bends         2       10       From       Check Bends         3       20       1         4       30       Valve       0         5       40       Valve       0'3"         5       50       1'0"         7       60       Reducer       0'4"         8       70       Bend       1'0"         8       70       Bend       1'0"         9       80       1       1         75       Location       1       Beam Loads	
2       100       From       Image: Constraint of the constrated of the constraint of the constraint of the constrai	
3       20	
4       30       Valve       0         5       40       Valve       0'3"         5       50       10"         6       50       10"         7       60       Reducer       0'4"         8       70       Bend       1'0"         8       70       Bend       1'0"         9       80       1       1         10       75       Location       Loads	
5       40       Valve       0'3"       Materials       Ctrl+Shift+M         6       50       10"       Sections       Ctrl+Shift+S       Loads       Ctrl+Shift+S         7       60       Reducer       0'4"       Sections       Ctrl+Shift+S       Loads       Ctrl+Shift+S         8       70       Bend       1'0"       Beam Materials       Beam Sections       Beam Sections       Beam Loads       Relief Valve Loading         10       75       Location       1       Beam Loads       Beam Loads       Relief valve opening time       0.008       (second)	
6     50     10"     Sections     Ctri+shift+S       7     60     Reducer     0'4"       8     70     Bend     10"       9     80      1       10     75     Location       10     75     Location	
7       60       Reducer       0'4"       Loads       Ctri+Shift+L         8       70       Bend       1'0"       Beam Materials       Reaction force value       6854         9       80       -       1       Beam Sections       Relief valve opening time       0.008       (second)	$\times$
8     70     Bend     1'0"     Beam Materials     Reaction force value     6854       9     80     -     1     Beam Sections     -       10     75     Location     -     Beam Loads     Relief valve opening time     0.008	
Image: 10 to the second sec	
11 Pumps	
Compressors Relief valve closing time 0.008 (second)	
Turbines	
Spectrums Relief duration 1 (second)	
Time functions Force spectrum name RVFS	
Relief valve loading	
Soils Maximum frequency 33 (Hz)	
User Allowables Number of frequencies 20	
Internal Pressure Design: EN 13480-3 Ctrl+Shift+1	
External Pressure Design: EN 13480-3 Ctrl+Shift+E Damping 5 (%)	
Wind - ASCE/SEI 7-16	
Wind - EN 1991-1-4 (2010) OK Cancel	

#### 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.

-	Caepipe : Force Spect	rums	(2) - [10_reli	e —		×			
File	Edit View Option	ns I	Misc Window	v Help					
#	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.

-0-0	Caepipe	e:Layout (1	10) - [10_re	liefvalve_fsp	.mod (c:\tute	orials\r	eliefval	veanaly	sis)] —		×
File	Edit	View Opt	ions Load	s Misc V	Vindow He	elp					
#	Node	Туре	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											

Force Spectrum Load	?	$\times$
Direction F 💌	Units (Ib)	•
Force RVFS		-
Scale Factor -1		
OK Cancel		

### Step 5:

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

Load cases (5)	×				
☑ Sustained (W+P)	🔲 Design (W+PD+TD)				
🔲 Empty Weight (W)	🔽 Modal analysis				
💌 Expansion (T1)	Force spectrum				
✓ Operating (W+P1+T1)					
OK Cancel	All None				

### Step 6:

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

-0-1	📲 Caepipe : B31.1 (2022) Code compliance (Sorted stresses) - [10_reliefvalve_fsp.res — 🛛 🛛 🗡													
File	File Results View Options Window Help													
		Susta	ained			Expa	nsion			Occas	sional			
#	Node	SL (psi)	SH (psi)	SL SH	Node	SE (psi)	SA (psi)	<u>SE</u> 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.

=1= Caepipe : Support load summary for anchor at node 10 - [10_reliefvalve_fsp.res (c $ \Box$ $ imes$											
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					