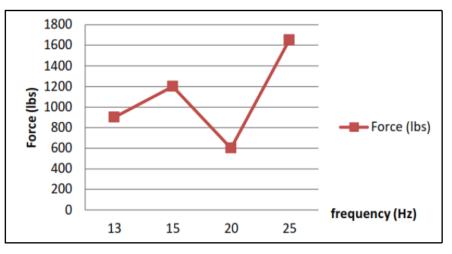
# **Tutorial for Force Spectrum Analysis using CAEPIPE**

#### The following are the Steps for performing the Force Spectrum Analysis using CAEPIPE.

# General

Force spectrum analyses are generally performed to determine the response of the piping system to shortduration impulsive loads such as fluid hammer, safety relief valve (SRV) and slug flow loads. For an actual shortduration impulsive dynamic load exerted on a piping system, a fluid transient analysis is first carried out in order to arrive at the "time-history loads" (i.e., force vs. time) acting in the three global directions (namely global X, Y and Z) at all affected points in the piping system. The time-history load sets so computed are then applied, one time-history load set at a time, on a single degree-of-freedom (dof) spring-mass system with a pre-set natural frequency, to determine the maximum dynamic response of this single dof system with that natural frequency. Such dynamic analysis for that time-history load is repeated on the same single dof system with different pre-set natural frequencies. The force spectrum for that time-history load would then be a table of maximum dynamic response computed for the single dof system with different natural frequencies. In other words, the force spectrum is a table of force spectral values vs frequencies that captures the maximum intensity and frequency content of that time-history load. Similarly, force spectrum tables are determined for all other time-history load sets. The above force spectrum tables (i.e., maximum dynamic force vs frequency) are then applied as inputs at the respective piping nodes of the CAEPIPE stress model to compute displacements, forces and stresses.

For any piping system, there are as many natural modes of vibrations as the number of dynamic degrees of freedom for that system. The force spectral value corresponding to a natural frequency of the piping system is arrived at by interpolating the force spectrum vs frequency table as determined above. For better understanding, as an example, refer to the graph shown next as well as the natural frequencies computed for a piping system at 10 Hz, 14 Hz, 21 Hz, 29 Hz and 33.8 Hz.



From the above graph, to arrive at a force value corresponding to a natural frequency of 14 Hz, CAEPIPE interpolates the force spectral values between 13 and 15 Hz. Similarly, to arrive at a force value corresponding to a natural frequency of 21 Hz, CAEPIPE interpolates the force spectral values between 20 Hz & 25 Hz. Since force spectral values above 25 Hz are not defined in the graph shown above, CAEPIPE arrives at a force value of 1650 lb. (i.e., the spectral value corresponding to the maximum frequency of 25 Hz in the above plot) even for natural frequencies of 29 and 33.8 Hz. Similarly, CAEPIPE arrives at a force value of 900 lb. for a natural frequency of 10 Hz (i.e., the spectral value corresponding to the minimum frequency of 13 Hz in the above plot).

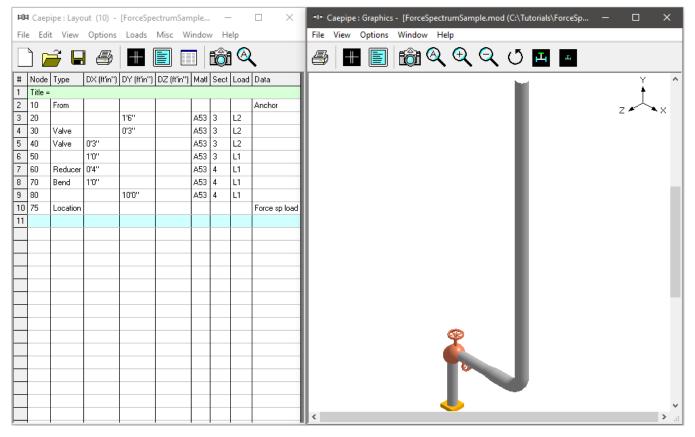
The results of the modal analysis are used with force spectrum loads to calculate the response (displacements, support loads and stresses) of the piping system. It is often used in place of a time-history analysis to determine the response of the piping system to sudden impulsive loads such as water hammer, relief valve and slug flow.

The force spectrum is a table of force spectral values versus frequencies that captures the intensity and frequency content of the time-history loads. It is a table of Dynamic Load Factors (DLF) versus natural frequencies. DLF is the ratio of the maximum dynamic displacement divided by the maximum static displacement. Note that Force spectrum is a non-dimensional function (since it is a ratio) defining a curve representing force versus frequency. The actual force spectrum load at a node is defined using this force spectrum in addition to the direction (FX, FY, FZ, MX, MY, MZ), units (Ib, N, kg, ft-lb, in-lb, Nm, kg-m) and a scale factor.

# Tutorial

#### Step 1:

Attached is a sample CAEPIPE model with Force Spectrum. The steps followed in generating the model are shown in the snap shot below.



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		-									e.mod	(C:\Tuto	ri —		×
File	e Edit	Vie	ew O	ption	s	Misc	Wi	ndov	v H	lelp					
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2	4	4''	STD	4.5		237									
3														~	
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#	Name	T1 (F)	P1 (psi)	Des (F)	g. T	Des (psi)	g.Pr.	Spe grav	cific vitu	Add.\ (lb/ft)				ind Win ad 3 Loa	_
1	L1	51	475	51		475		0.01	-	,					
2	L2	51	1875	51		187	5	0.01	1						
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#	e Edit			ion	s	-	ity N	ndov	v H	lelp		4	•	Allowable	
		<b>]</b> [		ion	<b>і</b> Ту	Misc A Dens	ity N	ndov	v H U	Help	Temp	<b>E</b>	Alpha (in/in/F)	Allowable	
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#	Name	<b>]</b> [	escripti	ion	<b>і</b> Ту	Misc A Dens (Ib/in	ity N	ndov H	v H U Joint facto	Help	Temp (F) -20 70 200 300	E (psi) 29.9E+6 29.5E+6 28.8E+6 28.3E+6	Alpha (in/in/F) 6.25E-6 6.40E-6 6.70E-6 6.90E-6	Allowable (psi) 17100 17100 17100 17100	
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#	Name	<b>]</b> [	escripti	ion	<b>і</b> Ту	Misc A Dens (Ib/in	ity N	ndov H	v H U Joint facto	Help , # , 1 2 3 4 5 6 7 8 9 10	Temp (F) -20 200 300 400 500 500 650 700 750	E (psi) 29.9E+6 29.5E+6 28.8E+6 28.3E+6 27.7E+6 27.7E+6 26.7E+6 26.7E+6 26.1E+6 25.5E+6 24.9E+6	Alpha (in/in/F) 6.25E-6 6.40E-6 6.40E-6 6.90E-6 7.10E-6 7.30E-6 7.40E-6 7.50E-6 7.50E-6 7.70E-6	Allowable (psi) 17100 17100 17100 17100 17100 17100 17100 17100 17600 13600 13000	
# 1 2	Name A53		escripti	de A	Ty pe	Misc Dens (Ib/in 0.283	, N iity N 3) 3 0, 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	H Iu 3	v H	Help , # , 1 2 3 4 5 6 7 8 9 10 11 12 10 11 12	Temp (F) -20 200 200 300 400 500 600 650 600 650 700 750 800	E (psi) 29.9E+6 29.5E+6 28.3E+6 28.3E+6 27.7E+6 26.7E+6 26.7E+6 26.5E+6 24.9E+6 24.9E+6 24.2E+6	Alpha (in/in/F) 6.25E-6 6.40E-6 6.40E-6 6.90E-6 7.10E-6 7.30E-6 7.40E-6 7.50E-6 7.50E-6 7.70E-6	Allowable (psi) 17100 17100 17100 17100 17100 17100 17100 17100 17100 17100 17100 17100 17100	
# 1 2	Name A53	D A	escripti	de A de A	Ту ре	Misc Dens (Ib/in 0.283	kity N N 3 0.	H Iu 3	v H	Help , # , 1 2 3 4 5 6 7 8 9 10 11 12 10 11 12	Temp (F) -20 200 200 300 400 500 600 650 600 650 700 750 800	E (psi) 29.9E+6 29.5E+6 28.8E+6 28.3E+6 27.7E+6 27.7E+6 26.7E+6 26.7E+6 26.1E+6 25.5E+6 24.9E+6	Alpha (in/in/F) 6.25E-6 6.40E-6 6.40E-6 6.90E-6 7.10E-6 7.30E-6 7.40E-6 7.50E-6 7.50E-6 7.70E-6	Allowable (psi) 17100 17100 17100 17100 17100 17100 17100 17100 17600 13600 13000	
# 1 2	Name A53	D A	escripti	de A	Ту ре	Misc Dens (Ib/in 0.283	kity N N 3 0.	H Iu 3	v H	Help , # , 1 2 3 4 5 6 7 8 9 10 11 12 10 11 12	Temp (F) -20 70 200 300 400 500 600 650 650 700 750 800 800 s (C:\T	E (psi) 29.9E+6 29.5E+6 28.3E+6 28.3E+6 27.7E+6 26.7E+6 26.7E+6 26.5E+6 24.9E+6 24.9E+6 24.2E+6	Alpha (in/in/F) 6.25E-6 6.40E-6 6.40E-6 6.90E-6 7.10E-6 7.30E-6 7.40E-6 7.50E-6 7.50E-6 7.70E-6	Allowable (psi) 17100 17100 17100 17100 17100 17100 17100 17100 17100 17100 17100 17100 17100	

╡					Q					
#	From	To	Weight	Length	Thick	Insul	Add.Wgt		ets of Add.	
			(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 Force Spectrum will be applied), input Force spectrums through Layout or List menu: Misc > Force spectrums.

												_
-1-	Caep	ipe : La	iyou	ıt (10) -	[ForceSp	ectrum	nSample.mo	d (C:\Tuto	rials\Force	eSpectrum)	-	
File	e Edit	t Viev	w	Options	Loads	Misc	Window	Help				
	٦ 🗠	2 I		/Eb			Coordinates	;			Ctrl+Shift+C	
				4	+		Element typ	es			Ctrl+Shift+T	
#	Node	Туре	1	DX (ft'in'')	DY (ft'in'')		Data types				Ctrl+Shift+D	
1	Title =						Check Bend	s				
2	10	From					Check Conr	nections				
3	20				1'6''		Check Bran	-h SIE				
4	30	Valve			0'3''							
5	40	Valve		D'3''			Materials				Ctrl+Shift+M	
6 7	50	Dedu		1'0'' D'4''			Sections				Ctrl+Shift+S	
7 8	60 70	Reduc Bend		J4 1'0''			Loads				Ctrl+Shift+L	
9	80	Dena		10	10'0''		Beam Mater	rials				
10	75	Locatio	on				Beam Sectio	ons				
11							Beam Loads					
							Pumps					
							Compressor	s				
							Turbines					
							Spectrums					
_							Force spect	rums				
							Time function	ons				
							Relief valve	loading				
							Soils					
							User Allowa	bles				
							Internal Pres	cure Deci	ID: EN 124	00.2	Ctrl+Shift+I	
			_								Ctrl+Shift+E	
_							External Pre	ssure Desi	gn: EN 154	60-5	Cur+Shirt+E	-
_							Wind - ASC	E/SEI 7-10				
-0-	Саер	ipe : Lo	oads	(2) - [F	orceSpec	trumS	ample.mod	(C:\Tutori	als\ForceS	pectrum)]		
File	e Edi	t Viev	w	Options	Misc	Windo	w Help					
-#				1	C	oordin	ates	Ctrl+S	hift+C			
					M	laterial	s	Ctrl+Sł	ift+M		_	_
#	Name		P1 (psi)	Desg.T (F)	Se	ections		Ctrl+S	hift+S			
1	[_1			51	Lo	oads		Ctrl+S	hift+L			
2	L2			5 51	D.	aano M	aterials					
3					_		ections					
					Be	eam Lo	ads					
					P	umps						
					C	ompre	ssors					
					Т	urbines	;					
					Sp	pectrur	ms					
							ectrums					
							nctions					
						oils						
					50							

#### Step 3:

The Force spectrum list appears.

Enter a name for the force spectrum and spectrum values versus frequencies table.

10	Caepipe : Force	Spe	ctrums (2)	- [ForceSp	ectrumSample	. –	[
Fil	e Edit View	Opti	ions Misc	Window	Help		
			<u>ê</u> n Q		➡		
#	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			
			19.8	12471.8			
		<u> </u>	21.45	12430.9			
		15		12387.1			
			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			

In addition to inputting the force spectrum directly, it can also be read from a text file. This can be done through List menu: File > Read force spectrum.

HIN.	Caepipe :	Force S	peo	trum	s (2) -	[ForceSp	ectrumS	ample		×
File	Edit V	iew O	pti	ons	Misc	Window	Help			
	Read For	ce spec	tru	m			-			
	Convert	time fu	nct	ion						
	Export									
	Print				C	Ctrl+P				
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				

The text file should be in the following format:

.

.

Name (up to 31 characters)

Frequency (Hz) Spectrum value

Frequency (Hz) Spectrum value

Frequency (Hz) Spectrum value

.

.

The frequencies can be in any order. They will be sorted in ascending order after reading from the file.

#### Step 4:

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

-0-	💷 Caepipe : Layout (10) - [ForceSpectrumSample.mod (C:\Tutorials\ForceSpectrum)] — 🛛 🗙														
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															

Force Spectrum Load	?	×
Direction 🔽 💌	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)	×
🔲 Empty Weight (W)	🔲 Design (W+PD+TD)
🔽 Sustained (W+P)	🔽 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 Force Spectrum load.

📲 Caepipe : B31.1 (2020) Code compliance (Sorted stresses) - [ForceSpectrumSam — 🛛 🛛 🗙																
Eile	<u>F</u> ile <u>R</u> esults <u>V</u> iew <u>O</u> ptions <u>W</u> indow <u>H</u> elp															
4																
		Susta	ained													
#	Sustained         Expansion         Occasional           SL         SH         SL         SE         SA         SE         SO         1.2SH         SO           Node         (psi)         (psi)         SH         Node         (psi)         (psi)         (psi)         (psi)         1.2SH         SO															
1	20	9669	17100	0.57	10	0	25650	0.00	10	191113	20520	9.31				
2	10	9664	17100	0.57	20	0	25650	0.00	20	148596	20520	7.24				
3	40	3834	17100	0.22	40	0	25650	0.00	40	122523	20520	5.97				
4	50	3209	17100	0.19	50	0	25650	0.00	50	120658	20520	5.88				
5	60	2763	17100	0.16	60	0	25650	0.00	70B	99117	20520	4.83				
6	70A	2544	17100	0.15	70A	0	25650	0.00	75	95035	20520	4.63				
7	75	2313	17100	0.14	70B	0	25650	0.00	70A	85516	20520	4.17				
8	80	2255	17100	0.13	75	0	25650	0.00	60	67037	20520	3.27				
9	70B	2222	17100	0.13	80	0	25650	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.

-0-	-II- Caepipe : Displacements: Sustained (W+P) - [ForceSpectrumSample.res (C:\Tuto — 🛛 🗙														
<u>F</u> ile	<u>File Results View Options Window H</u> elp														
4	$ = \boxed{\blacksquare} \boxed{\blacksquare} \boxed{} \boxed{ \boxed{} \boxed{ \boxed{} \boxed{} \boxed{ \boxed{} \boxed{ \end{array}{} \boxed{  \boxed{ \end{array}{} \boxed{ \end{array}{} \boxed{  \end{array}{} \boxed{    \boxed{ \end{array}{} \boxed{  \end{array}{}     \boxed{    \boxed{         \boxed{           \blacksquare$														
#															
	Node	X (inch)	Y (inch)	Z (inch)	XX (deg)	YY (deg)	ZZ (deg)		Load Cases X						
1	10	0.000	0.000	0.000	0.0000	0.0000	0.0000		Load Cases X						
2	20	0.007	0.000	0.000	0.0000	0.0000	-0.0435		C Sustained (W+P)						
3	30	0.009	0.000	0.000	0.0000	0.0000	-0.0451		C Expansion (T1)						
4	40	0.009	-0.002	0.000	0.0000	0.0000	-0.0466								
5	50	0.009	-0.015	0.000	0.0000	0.0000	-0.0662		C Operating (W+P1+T1)						
6	60	0.009	-0.019	0.000	0.0000	0.0000	-0.0688		<ul> <li>Force spectrum</li> </ul>						
7	70A	0.009	-0.027	0.000	0.0000	0.0000	-0.0704		OK Cancel						
8	70B	0.017	-0.034	0.000	0.0000	0.0000	-0.0734								
9	75	0.011	-0.032	0.000	0.0000	0.0000	-0.0730								
10	80	0.163	-0.034	0.000	0.0000	0.0000	-0.0734								

Caepipe : Support loa	ad summa	ry for and	hor at no	de 10 - [f	orceSpec	trumSam	pl	_		×			
<u>File Results View O</u>	ptions <u>V</u>	Vindow	<u>H</u> elp										
Load combination	FX (Ib)	FY (Ib)	FZ (Ib)	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	۷						