Tutorial for Harmonic Analysis using CAEPIPE

The following are the Steps to perform Harmonic Analysis using CAEPIPE.

General

- A harmonic analysis is performed to determine the response of a piping system to sinusoidal loads. Harmonic forces can arise from unbalanced rotating equipment, acoustic vibrations caused by reciprocating equipment, flow impedance, and other sources. These forces can be damaging to a piping system if their frequency is close to the piping system's natural frequency, thereby introducing resonant conditions.

  It is feasible that multiple harmonic loads may be applied simultaneously at different locations of a piping system. More complex forms of vibration, such as those caused by the fluid flow, may be considered as superposition of several simple harmonics, each with its own frequency, magnitude, and phase.

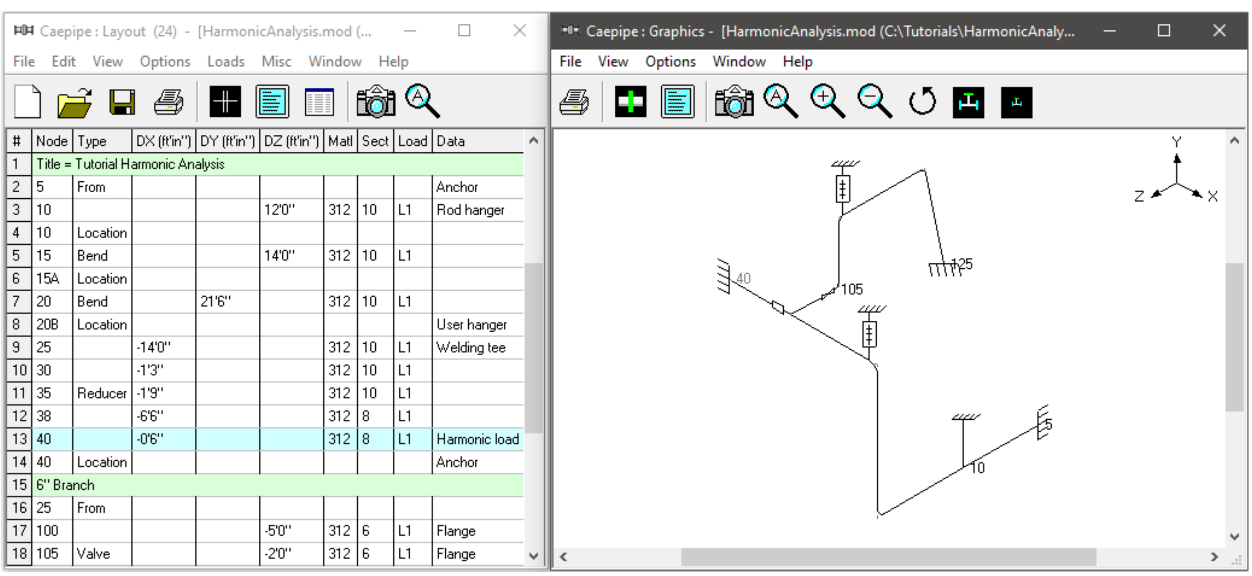
- A harmonic analysis uses the results from the modal analysis to obtain a solution. A single damping factor is used for all modes.

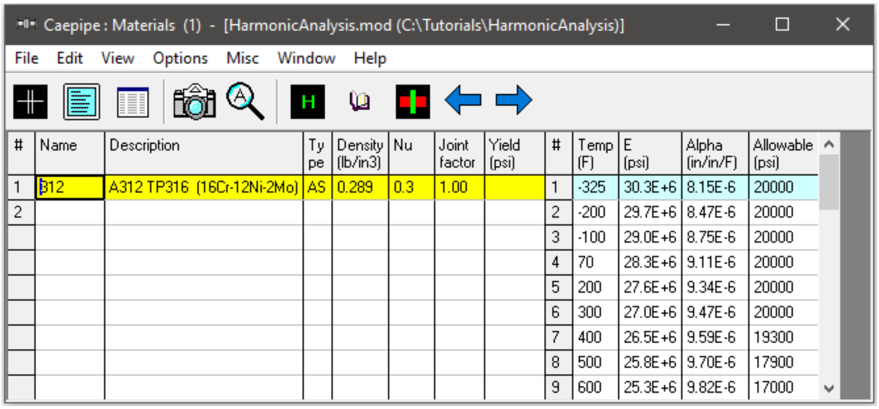
  First, the maximum response for each harmonic load is obtained separately. Then, the total response for multiple simultaneous harmonic loads is determined by combining the individual responses. The combination method may be specified as the Root Mean Square (RMS) or Absolute Sum. Even in the case of a system with a single harmonic load, the said combination is always carried out, so that the resulting solution becomes an "unsigned" case. For an unsigned case, the actual values for displacements, element forces and moments, etc. computed internally by CAEPIPE prior to such combination can be +ve or -ve for the dynamic event.

Step 1:

Attached is a CAEPIPE model for Harmonic Analysis. For this model, let us assume the following.

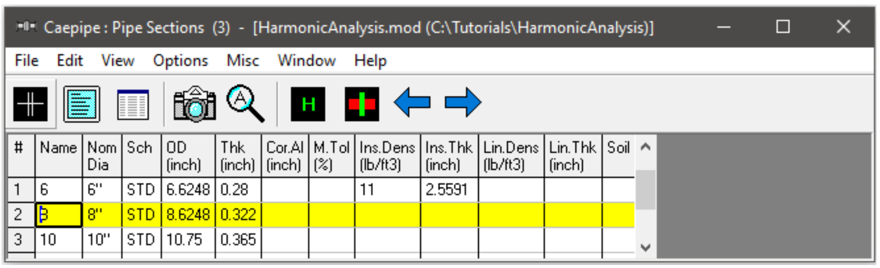
1. Node 5 is connected to a Tank.
2. Node 40 is connected to a Pump Suction Nozzle.



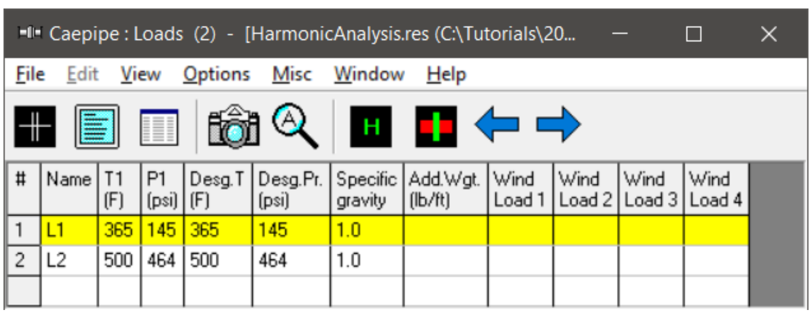


#	Name	Description	Type	Density (lb/in3)	Nu	Joint factor	Yield (psi)
1	312	A312 TP316 (16Cr-12Ni-2Mo)	AS	0.289	0.3	1.00	
2							

#	Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
1	-325	30.3E+6	8.15E-6	20000
2	-200	29.7E+6	8.47E-6	20000
3	-100	29.0E+6	8.75E-6	20000
4	70	28.3E+6	9.11E-6	20000
5	200	27.6E+6	9.34E-6	20000
6	300	27.0E+6	9.47E-6	20000
7	400	26.5E+6	9.59E-6	19300
8	500	25.8E+6	9.70E-6	17900
9	600	25.3E+6	9.82E-6	17000



#	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	6	6"	STD	6.6248	0.28			11	2.5591			
2	8	8"	STD	8.6248	0.322							
3	10	10"	STD	10.75	0.365							



#	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	365	145	365	145	1.0					
2	L2	500	464	500	464	1.0					

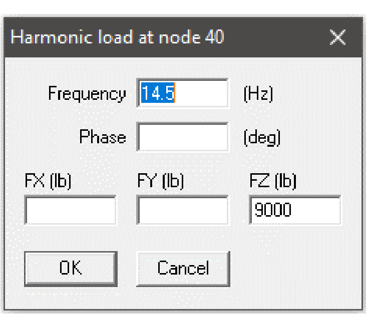
Step 2:

The harmonic load can be imposed as a Force (FX/FY/FZ) at a specified frequency and phase angle. You may be able to get more information on the harmonic loading (mass, rpm, etc.) from the manufacturer of the equipment.

For this Tutorial, the following assumptions are made.

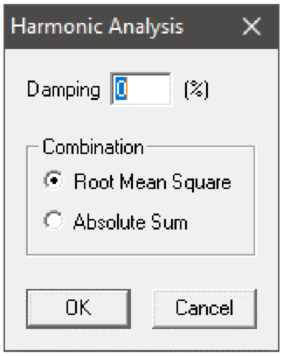
1. Frequency of the rotating equipment = 14.5 Hz.
2. Force in Global Z Direction = FZ = 9000 lb.

The above parameters are entered for analysis by creating a "Data" type called "Harmonic Load" through Layout window > Misc > Data types… at Node 40. See snap shot below for details.



Step 3:

Define “Percentage of Damping” and “Combination” method for Harmonic analysis through CAEPIPE Layout window > Loads > Harmonic...



Step 4:

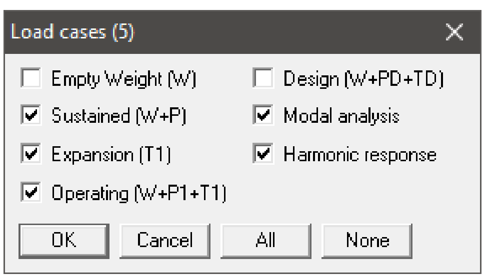
Then, include “Harmonic response” for analysis through Layout window > Loads > Load cases.

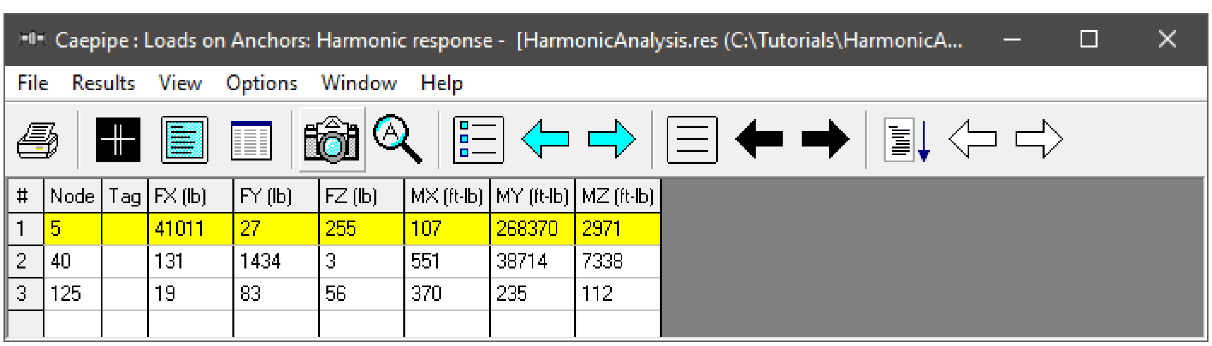
Step 5:

Save the model and perform the analysis through Layout window > File > Analyze. CAEPIPE will apply these loads to compute the response of the piping system by performing a Harmonic analysis along with other load cases defined in the piping system.

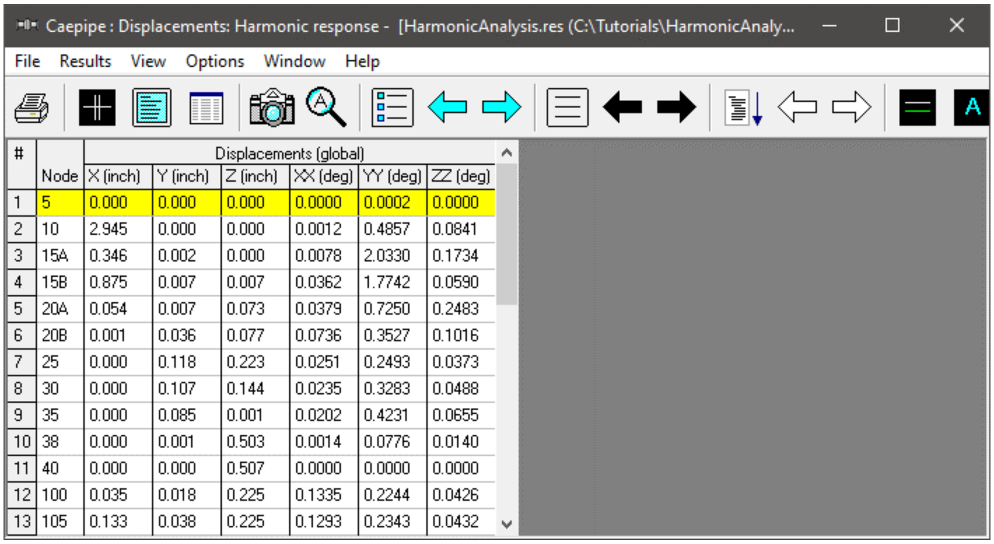
Step 6:

Upon successful analysis, CAEPIPE will now show a “Load case” with name “Harmonic response” under “Support Loads”, “Displacements”, “Element forces” and “Support load summary” results.

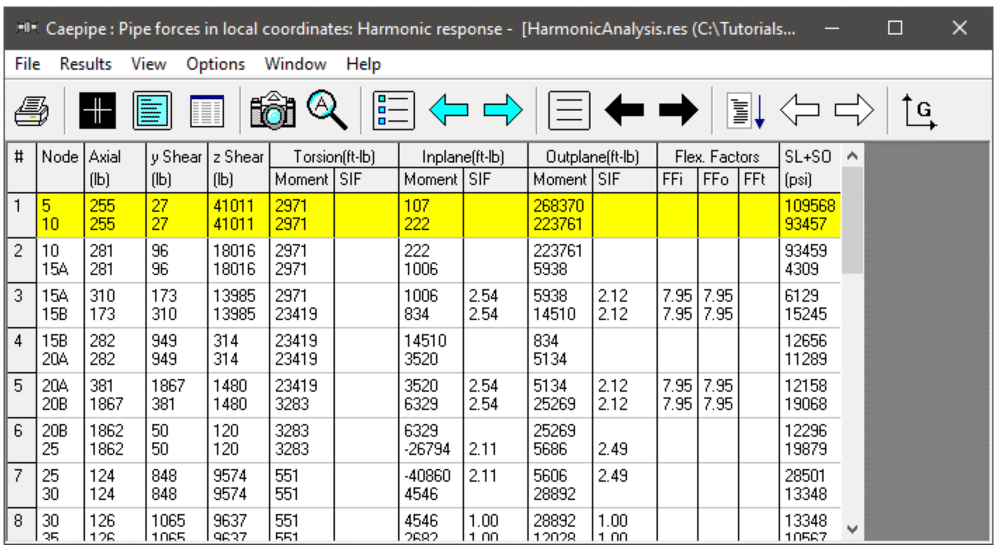




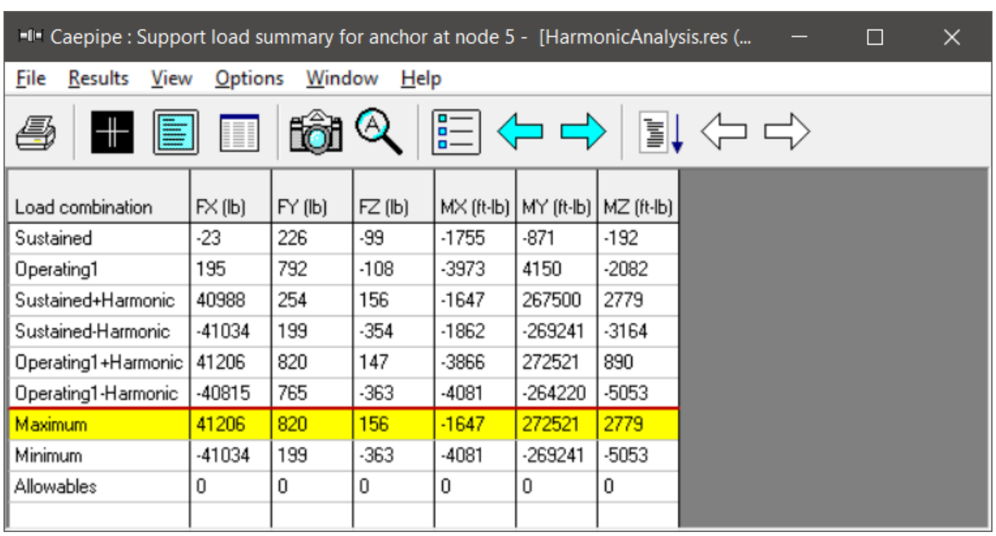
#	Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	5		41011	27	255	107	268370	2971
2	40		131	1434	3	551	38714	7338
3	125		19	83	56	370	235	112



#	Node	Displacements (global)					
		X (inch)	Y (inch)	Z (inch)	XX (deg)	YY (deg)	ZZ (deg)
1	5	0.000	0.000	0.000	0.0000	0.0002	0.0000
2	10	2.945	0.000	0.000	0.0012	0.4857	0.0841
3	15A	0.346	0.002	0.000	0.0078	2.0330	0.1734
4	15B	0.875	0.007	0.007	0.0362	1.7742	0.0590
5	20A	0.054	0.007	0.073	0.0379	0.7250	0.2483
6	20B	0.001	0.036	0.077	0.0736	0.3527	0.1016
7	25	0.000	0.118	0.223	0.0251	0.2493	0.0373
8	30	0.000	0.107	0.144	0.0235	0.3283	0.0488
9	35	0.000	0.085	0.001	0.0202	0.4231	0.0655
10	38	0.000	0.001	0.503	0.0014	0.0776	0.0140
11	40	0.000	0.000	0.507	0.0000	0.0000	0.0000
12	100	0.035	0.018	0.225	0.1335	0.2244	0.0426
13	105	0.133	0.038	0.225	0.1293	0.2343	0.0432



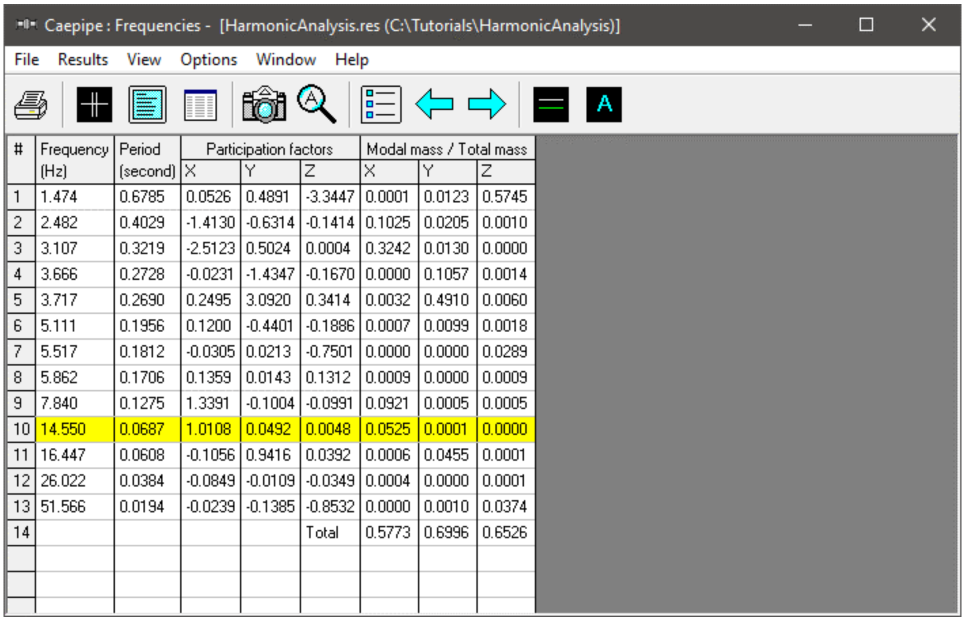
#	Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torsion(ft-lb)		Inplane(ft-lb)		Outplane(ft-lb)		Flex. Factors			SL+SO (psi)
					Moment	SIF	Moment	SIF	Moment	SIF	FFi	FFo	FFt	
1	5 10	255 255	27 27	41011 41011	2971 2971		107 222		268370 223761					109568 93457
2	10 15A	281 281	96 96	18016 18016	2971 2971		222 1006		223761 5938					93459 4309
3	15A 15B	310 173	173 310	13985 13985	2971 23419		1006 834	2.54 2.54	5938 14510	2.12 2.12	7.95 7.95	7.95 7.95		6129 15245
4	15B 20A	282 282	949 949	314 314	23419 23419		14510 3520		834 5134					12656 11289
5	20A 20B	381 1867	1867 381	1480 1480	23419 3283		3520 6329	2.54 2.54	5134 25269	2.12 2.12	7.95 7.95	7.95 7.95		12158 19068
6	20B 25	1862 1862	50 50	120 120	3283 3283		6329 -26794	 2.11	25269 5686	 2.49				12296 19879
7	25 30	124 124	848 848	9574 9574	551 551		-40860 4546	2.11	5606 28892	2.49				28501 13348
8	30 35	126 126	1065 1065	9637 9637	551 551		4546 2682	1.00 1.00	28892 12028	1.00 1.00				13348 10567



Load combination	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
Sustained	-23	226	-99	-1755	-871	-192
Operating1	195	792	-108	-3973	4150	-2082
Sustained+Harmonic	40988	254	156	-1647	267500	2779
Sustained-Harmonic	-41034	199	-354	-1862	-269241	-3164
Operating1+Harmonic	41206	820	147	-3866	272521	890
Operating1-Harmonic	-40815	765	-363	-4081	-264220	-5053
Maximum	41206	820	156	-1647	272521	2779
Minimum	-41034	199	-363	-4081	-269241	-5053
Allowables	0	0	0	0	0	0

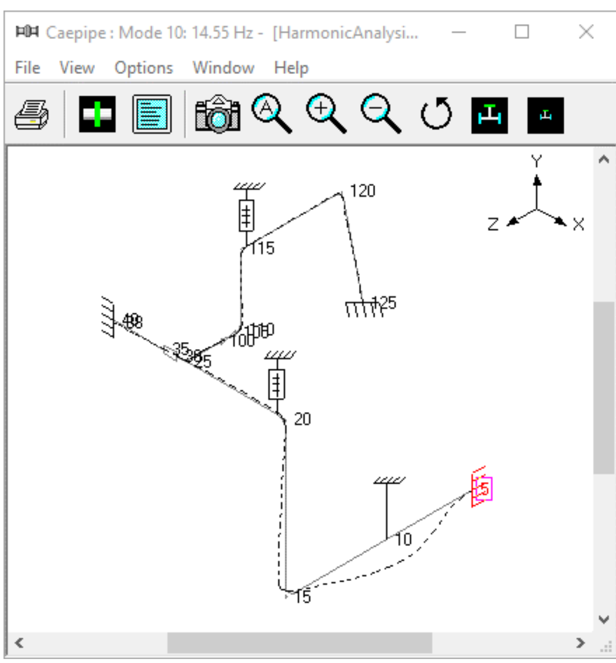
Step 7:

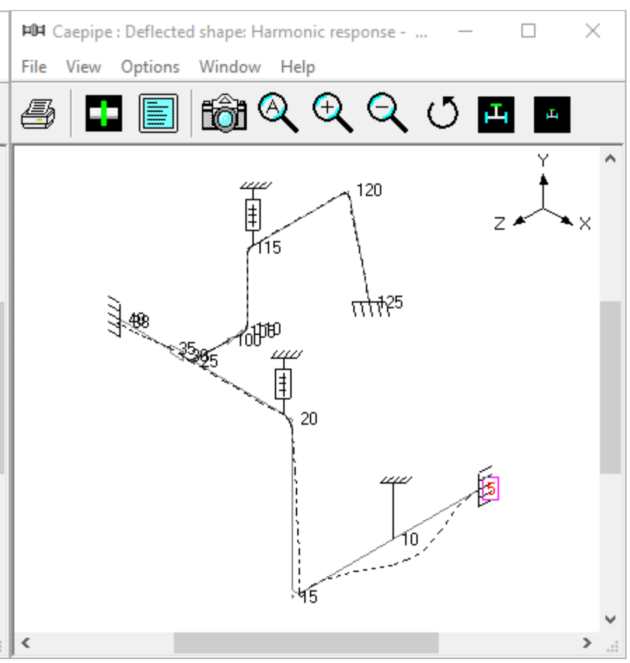
From the review of frequency results of CAEPIPE, it is noted that one of the natural frequencies of this piping system (i.e., frequency for Mode 10 shown in yellow highlight in the snap shot below) is close to the rotating equipment frequency of 14.5 Hz.



#	Frequency (Hz)	Period (second)	Participation factors X	Y	Z	Modal mass / Total mass X	Y	Z
1	1.474	0.6785	0.0526	0.4891	-3.3447	0.0001	0.0123	0.5745
2	2.482	0.4029	-1.4130	-0.6314	-0.1414	0.1025	0.0205	0.0010
3	3.107	0.3219	-2.5123	0.5024	0.0004	0.3242	0.0130	0.0000
4	3.666	0.2728	-0.0231	-1.4347	-0.1670	0.0000	0.1057	0.0014
5	3.717	0.2690	0.2495	3.0920	0.3414	0.0032	0.4910	0.0060
6	5.111	0.1956	0.1200	-0.4401	-0.1886	0.0007	0.0099	0.0018
7	5.517	0.1812	-0.0305	0.0213	-0.7501	0.0000	0.0000	0.0289
8	5.862	0.1706	0.1359	0.0143	0.1312	0.0009	0.0000	0.0009
9	7.840	0.1275	1.3391	-0.1004	-0.0991	0.0921	0.0005	0.0005
10	14.550	0.0687	1.0108	0.0492	0.0048	0.0525	0.0001	0.0000
11	16.447	0.0608	-0.1056	0.9416	0.0392	0.0006	0.0455	0.0001
12	26.022	0.0384	-0.0849	-0.0109	-0.0349	0.0004	0.0000	0.0001
13	51.566	0.0194	-0.0239	-0.1385	-0.8532	0.0000	0.0010	0.0374
14					Total	0.5773	0.6996	0.6526

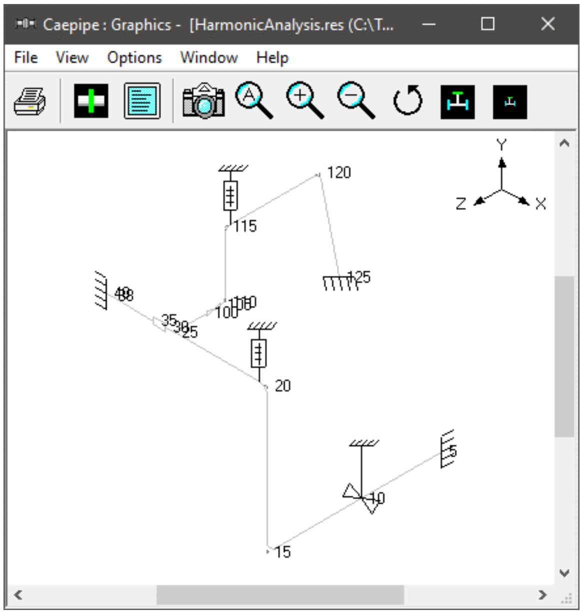
Due to closeness of Mode 10 frequency to the equipment frequency, it is observed that Mode 10 is excited on the piping system by the harmonic load, thereby creating a resonance. This can be seen graphically by plotting the mode shape corresponding to Mode 10 with frequency of "14.55 Hz" (figure shown on the left below) and the deflected shape for "harmonic response" case (figure shown on the right below). See snap shots for details.

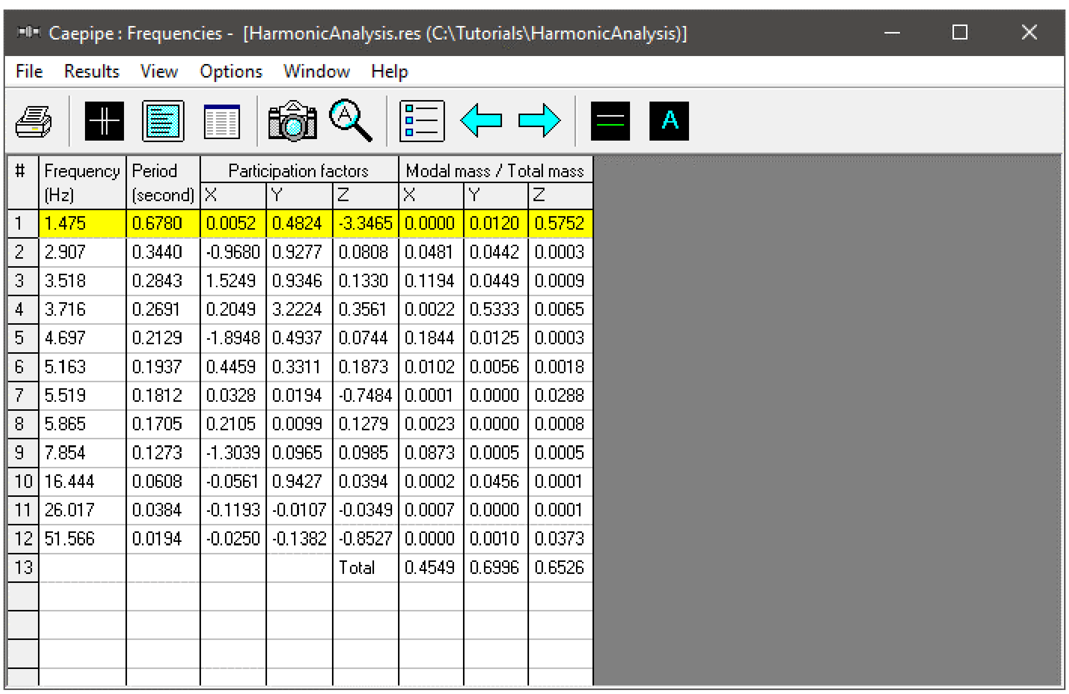




Step 8:

In order to prevent piping failure due to resonance, it is important to suppress relevant modes by changing the stiffness of the piping system either by adding or by moving the existing piping supports. For example, for the layout shown above, a lateral restraint in X direction is added at Node 10 as the displacement in X direction is about 3” for Harmonic Response case prior to adding this X restraint. By adding this new support, the stiffness of the piping system is altered. This, in turn, removed the 10th frequency with “14.55 Hz”, thereby ensuring that the natural frequency of the piping system is not close to the operating equipment frequency. See snap shots below.




Caepipe : Frequencies - [HarmonicAnalysis.res (C:\Tutorials\HarmonicAnalysis)]

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#	Frequency (Hz)	Period (second)	Participation factors X	Y	Z	Modal mass / Total mass X	Y	Z
1	1.475	0.6780	0.0052	0.4824	-3.3465	0.0000	0.0120	0.5752
2	2.907	0.3440	-0.9680	0.9277	0.0808	0.0481	0.0442	0.0003
3	3.518	0.2843	1.5249	0.9346	0.1330	0.1194	0.0449	0.0009
4	3.716	0.2691	0.2049	3.2224	0.3561	0.0022	0.5333	0.0065
5	4.697	0.2129	-1.8948	0.4937	0.0744	0.1844	0.0125	0.0003
6	5.163	0.1937	0.4459	0.3311	0.1873	0.0102	0.0056	0.0018
7	5.519	0.1812	0.0328	0.0194	-0.7484	0.0001	0.0000	0.0288
8	5.865	0.1705	0.2105	0.0099	0.1279	0.0023	0.0000	0.0008
9	7.854	0.1273	-1.3039	0.0965	0.0985	0.0873	0.0005	0.0005
10	16.444	0.0608	-0.0561	0.9427	0.0394	0.0002	0.0456	0.0001
11	26.017	0.0384	-0.1193	-0.0107	-0.0349	0.0007	0.0000	0.0001
12	51.566	0.0194	-0.0250	-0.1382	-0.8527	0.0000	0.0010	0.0373
13					Total	0.4549	0.6996	0.6526