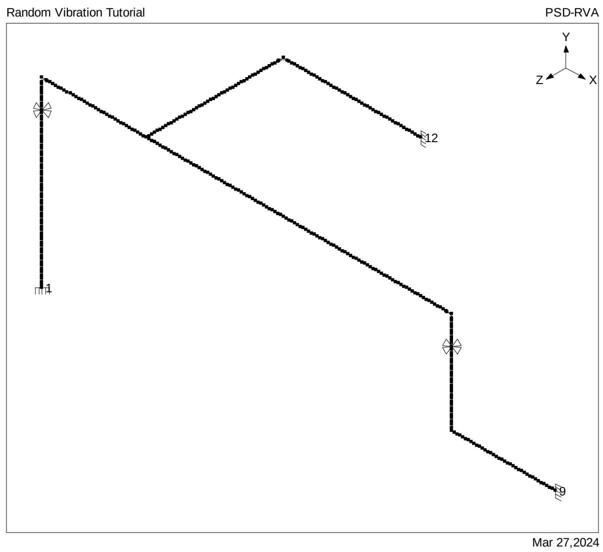
Tutorial on Random Vibration Analysis using CAEPIPE

General

Random vibration analysis for piping/tubing/ducting systems is a critical aspect of engineering design aimed at understanding and mitigating the effects of random dynamic loads on such systems. In essence, it involves evaluating how the systems respond to stationary stochastic excitations from surroundings, such as seismic events, flow induced vibrations or machinery vibrations, which are often unpredictable in nature.

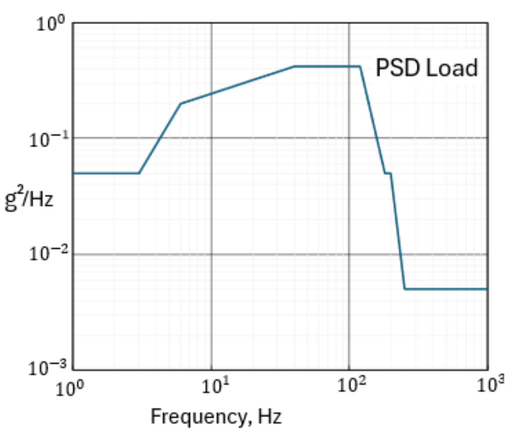
A Random Vibration Analysis in CAEPIPE can be used when a piping/tubing/ducting system is subjected to a non-deterministic, continuous uniform base excitation at supports. The solution is formulated in the frequency domain when the uniform support excitations are expressed by power spectral density (PSD) functions. Given below is a sample problem for Random Vibration analysis of a tubing system.

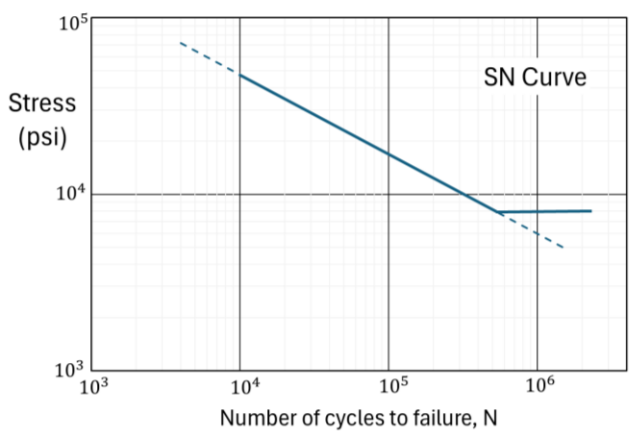
Sample Problem



Problem Definition

In this tutorial, a Random Vibration Analysis of a tubing layout as shown in the figure above measuring ¼ inch in size with STD Schedule and a material density of 0.403 lb/in³ is performed. This tubing layout is subjected to a PSD load as shown in the graph below for a duration of 60 hours with uniform base excitation at its supports. In order to calculate the damage factor, the required SN curve for Fatigue evaluation is provided below.

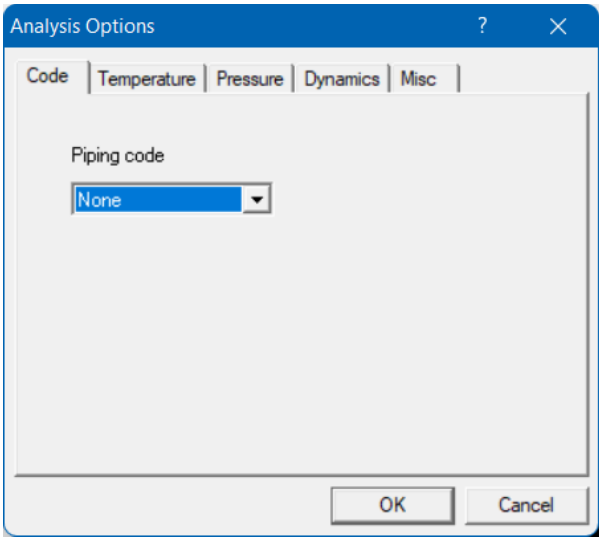


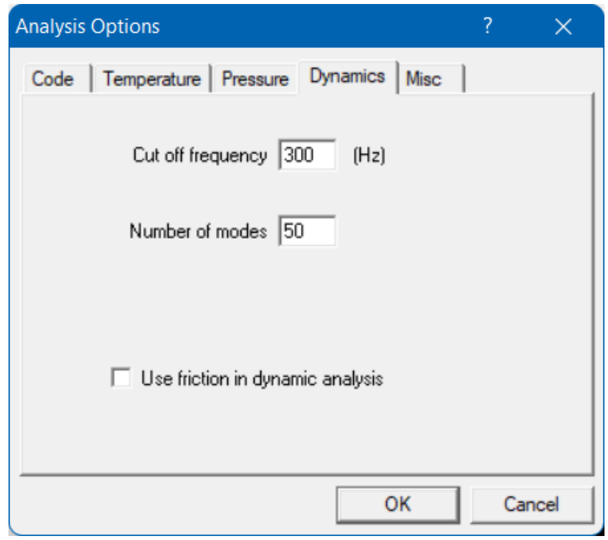


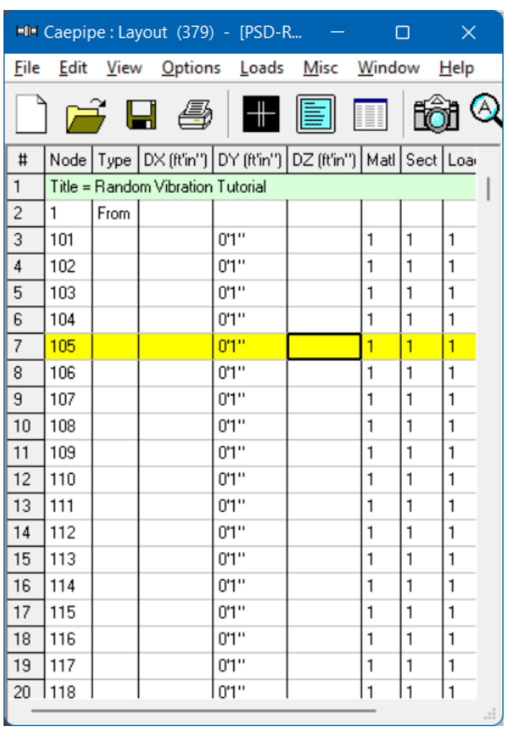
INPUT

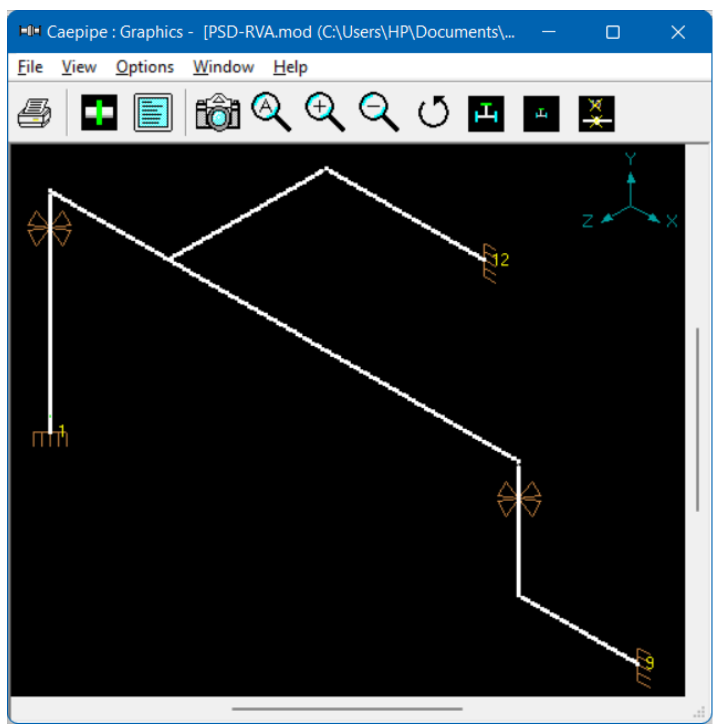
Step 1

At this time, the Random Vibration analysis is available only for NONE code in CAEPIPE. The Analysis Options chosen for this layout are shown below along with its Layout Window and Graphics Window.



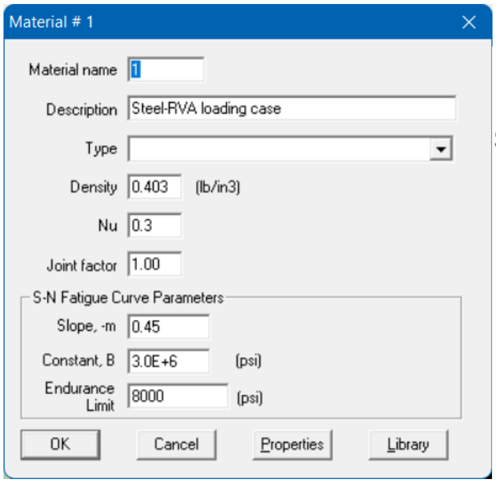


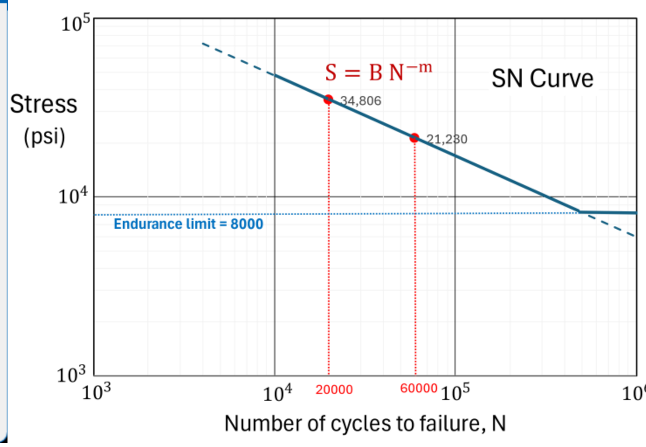




Step 2

The details on material properties, pipe sections and loads are given below.





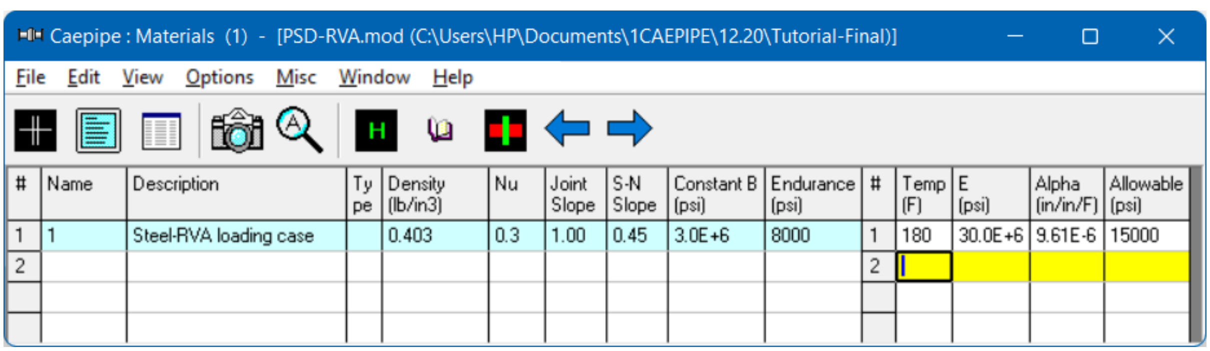
Input the slope m (must be a positive integer) of the S-N curve, -m. From two known data points (N1, S1) → (20000,34806) and (N2, S2) →(60000,21230), the slope of the S-N curve m can be calculated as:

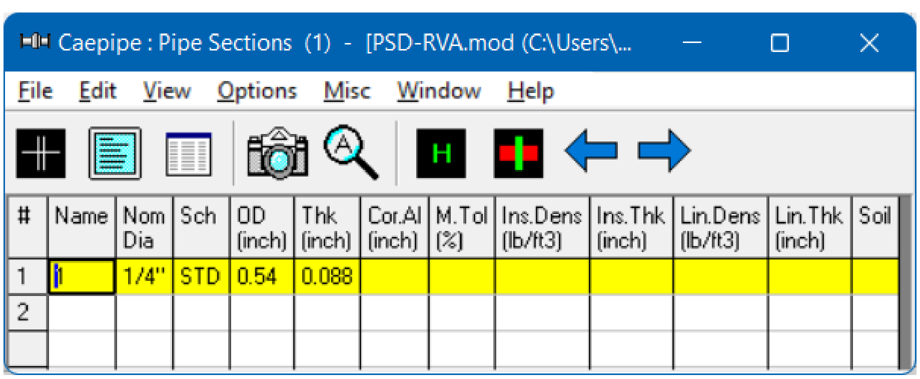
$$m = \frac{\log S_2 - \log S_1}{\log N_1 - \log N_2} = \frac{\log 21230 \ - \log 34806}{\log 20000 - \log 60000} = 0.45$$

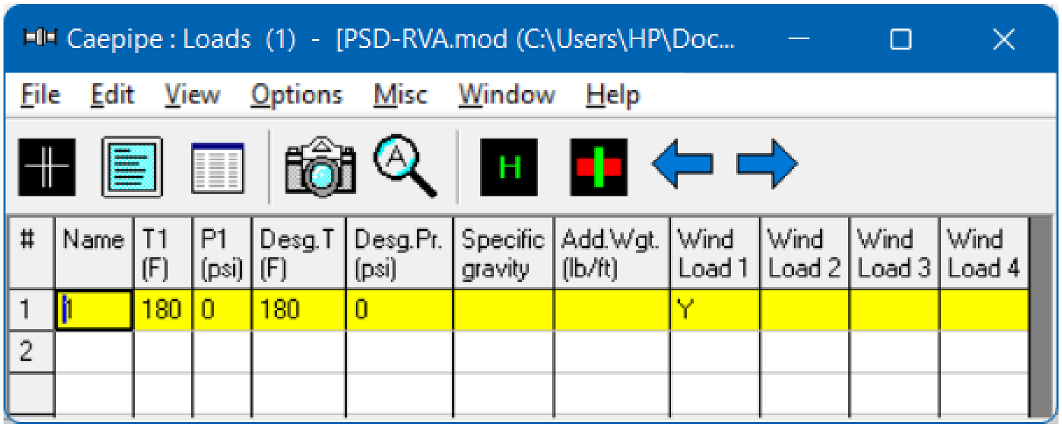
The constant "B" is the fatigue strength coefficient and can be calculated from any known data point and slope m, as

$$B = S_1 N_1^m = S_2 N_2^m = 34806 \ \times 20000^{0.45} = 3.0e + 06$$

Input the endurance limit of the material. The endurance limit is the stress limit below which there is no fatigue failure. Refer to the Section titled “Dynamic Analysis” in the CAEPIPE Technical Reference Manual for further details.

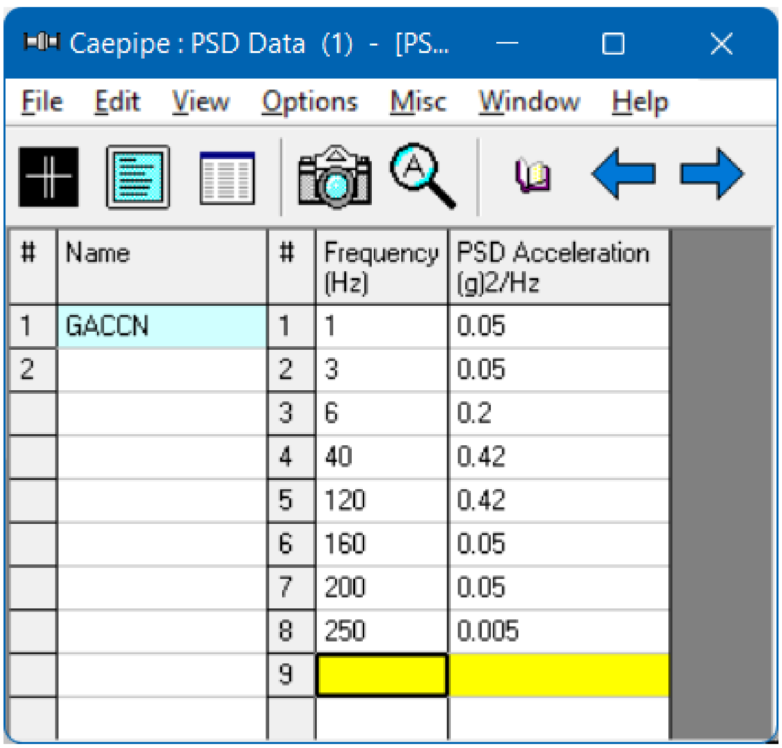






Step 3

Input the PSD Data through Layout window > Misc > PSD Data.

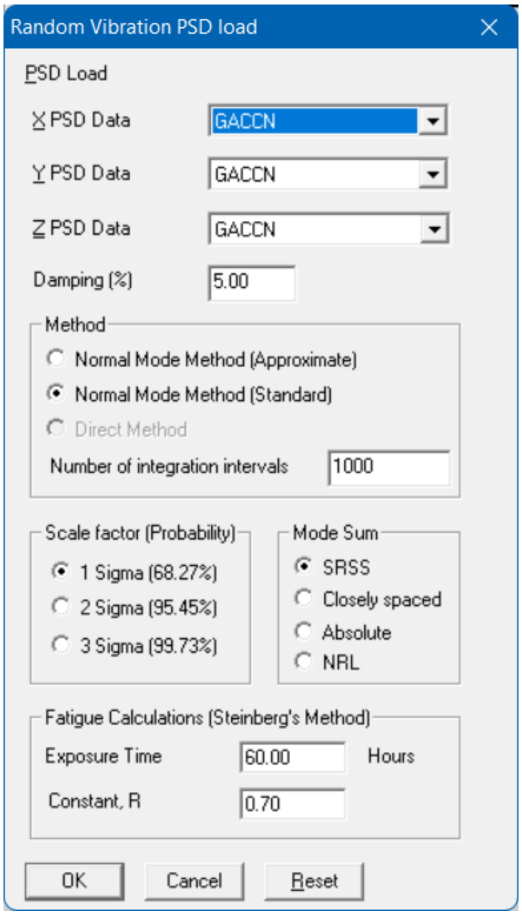


Note:

The variance/response of the system is evaluated in the frequency range specified in the above PSD Data table. The lowest and highest frequencies specified in the table are the lower and upper bounds of integration. The natural modes falling outside the frequency range of PSD Data table will not be considered in the analysis. It is users' responsibility to specify PSD Data across the desired range of frequency.

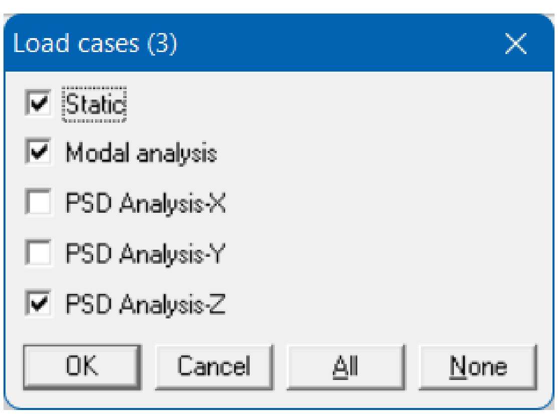
Step 4

Define the Random Vibration load through Layout window > Loads > Random Vibration. Select the PSD Load Data for Global X, Y and Z directions from the list. Enter the Damping (in %) as shown in the below snapshot. Choose the Method as “Normal Mode Method (Standard)”, Scale factor (Probability) as “1 Sigma (68.27%)”; and Mode sum as “SRSS”. For further details on the input parameters and the analysis type, refer to the Section titled “Random Vibration” in CAEPIPE User’s Manual.



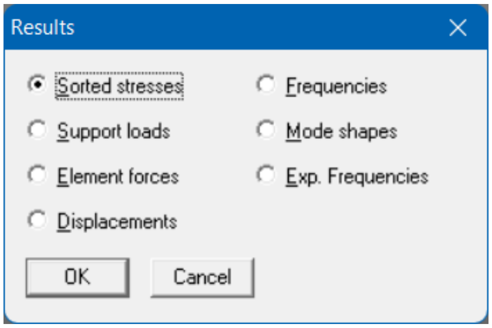
Step 5

After defining the directional PSD loads, the Load cases corresponding to the Random Vibration analysis will appear in Load Cases dialog seen through Layout Window > Loads > Load Cases. Select the preferred load cases, save the model and perform the analysis through Layout window > File > Analyze.



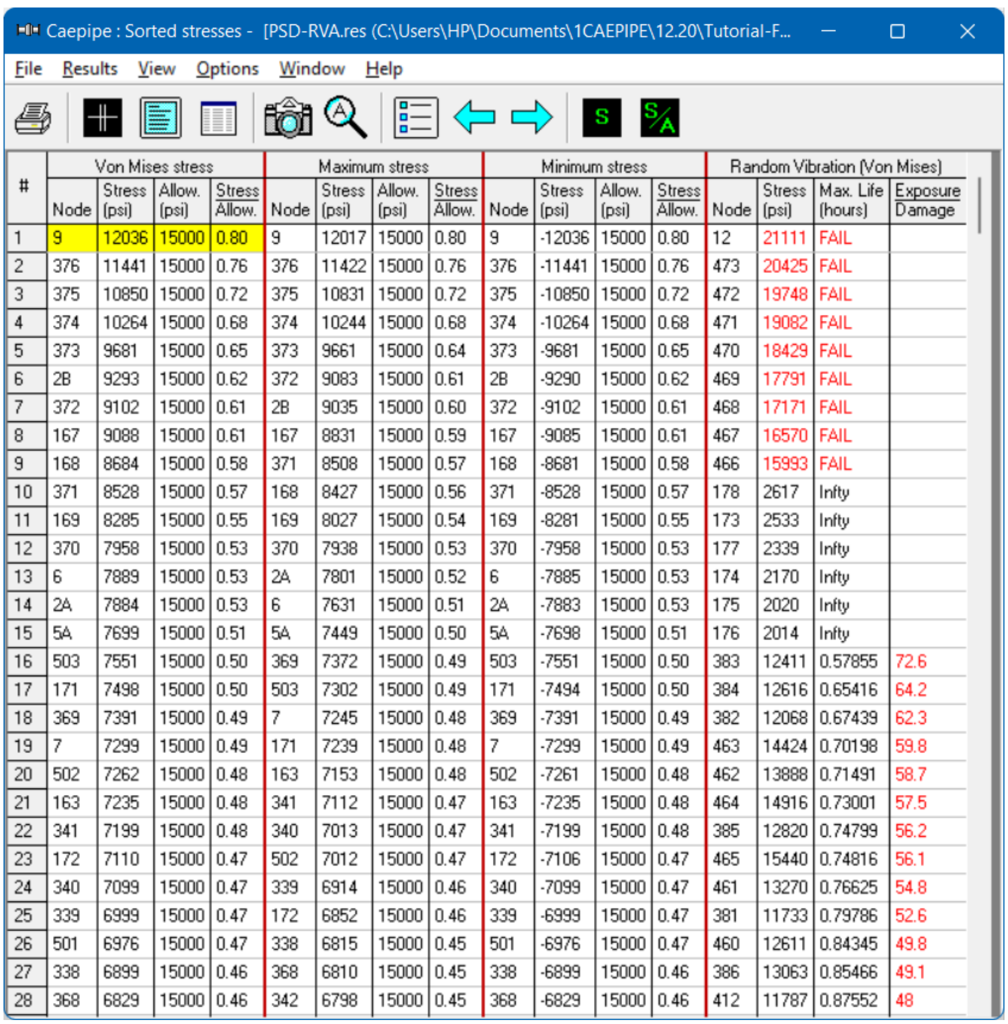
RESULTS

After finishing the analysis and choosing to see the results or by opening the results file (.res), the results window is displayed. The “Results” dialog is opened automatically as shown below.



Sorted Stresses

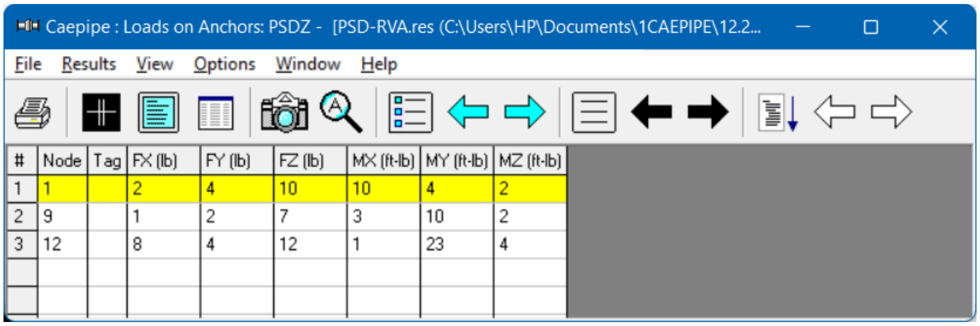
The computed stresses (“Von Mises”, “Maximum stress”, “Minimum stress” are sorted in descending order by stress ratios for Static load case. On the other hand, Von Mises stresses corresponding to Random Vibration analysis are sorted in descending order of the damage factor when the exposure time is input, or else the sorting will be based on stress intensity alone.



#	Von Mises stress				Maximum stress				Minimum stress				Random Vibration (Von Mises)			
	Node	Stress (psi)	Allow. (psi)	Stress Allow.	Node	Stress (psi)	Allow. (psi)	Stress Allow.	Node	Stress (psi)	Allow. (psi)	Stress Allow.	Node	Stress (psi)	Max. Life (hours)	Exposure Damage
1	9	12036	15000	0.80	9	12017	15000	0.80	9	-12036	15000	0.80	12	21111	FAIL	
2	376	11441	15000	0.76	376	11422	15000	0.76	376	-11441	15000	0.76	473	20425	FAIL	
3	375	10850	15000	0.72	375	10831	15000	0.72	375	-10850	15000	0.72	472	19748	FAIL	
4	374	10264	15000	0.68	374	10244	15000	0.68	374	-10264	15000	0.68	471	19082	FAIL	
5	373	9681	15000	0.65	373	9661	15000	0.64	373	-9681	15000	0.65	470	18429	FAIL	
6	2B	9293	15000	0.62	372	9083	15000	0.61	2B	-9290	15000	0.62	469	17791	FAIL	
7	372	9102	15000	0.61	2B	9035	15000	0.60	372	-9102	15000	0.61	468	17171	FAIL	
8	167	9088	15000	0.61	167	8831	15000	0.59	167	-9085	15000	0.61	467	16570	FAIL	
9	168	8684	15000	0.58	371	8508	15000	0.57	168	-8681	15000	0.58	466	15993	FAIL	
10	371	8528	15000	0.57	168	8427	15000	0.56	371	-8528	15000	0.57	178	2617	Infty	
11	169	8285	15000	0.55	169	8027	15000	0.54	169	-8281	15000	0.55	173	2533	Infty	
12	370	7958	15000	0.53	370	7938	15000	0.53	370	-7958	15000	0.53	177	2339	Infty	
13	6	7889	15000	0.53	2A	7801	15000	0.52	6	-7885	15000	0.53	174	2170	Infty	
14	2A	7884	15000	0.53	6	7631	15000	0.51	2A	-7883	15000	0.53	175	2020	Infty	
15	5A	7699	15000	0.51	5A	7449	15000	0.50	5A	-7698	15000	0.51	176	2014	Infty	
16	503	7551	15000	0.50	369	7372	15000	0.49	503	-7551	15000	0.50	383	12411	0.57855	72.6
17	171	7498	15000	0.50	503	7302	15000	0.49	171	-7494	15000	0.50	384	12616	0.65416	64.2
18	369	7391	15000	0.49	7	7245	15000	0.48	369	-7391	15000	0.49	382	12068	0.67439	62.3
19	7	7299	15000	0.49	171	7239	15000	0.48	7	-7299	15000	0.49	463	14424	0.70198	59.8
20	502	7262	15000	0.48	163	7153	15000	0.48	502	-7261	15000	0.48	462	13888	0.71491	58.7
21	163	7235	15000	0.48	341	7112	15000	0.47	163	-7235	15000	0.48	464	14916	0.73001	57.5
22	341	7199	15000	0.48	340	7013	15000	0.47	341	-7199	15000	0.48	385	12820	0.74799	56.2
23	172	7110	15000	0.47	502	7012	15000	0.47	172	-7106	15000	0.47	465	15440	0.74816	56.1
24	340	7099	15000	0.47	339	6914	15000	0.46	340	-7099	15000	0.47	461	13270	0.76625	54.8
25	339	6999	15000	0.47	172	6852	15000	0.46	339	-6999	15000	0.47	381	11733	0.79786	52.6
26	501	6976	15000	0.47	338	6815	15000	0.45	501	-6976	15000	0.47	460	12611	0.84345	49.8
27	338	6899	15000	0.46	368	6810	15000	0.45	338	-6899	15000	0.46	386	13063	0.85466	49.1
28	368	6829	15000	0.46	342	6798	15000	0.45	368	-6829	15000	0.46	412	11787	0.87552	48

Support loads

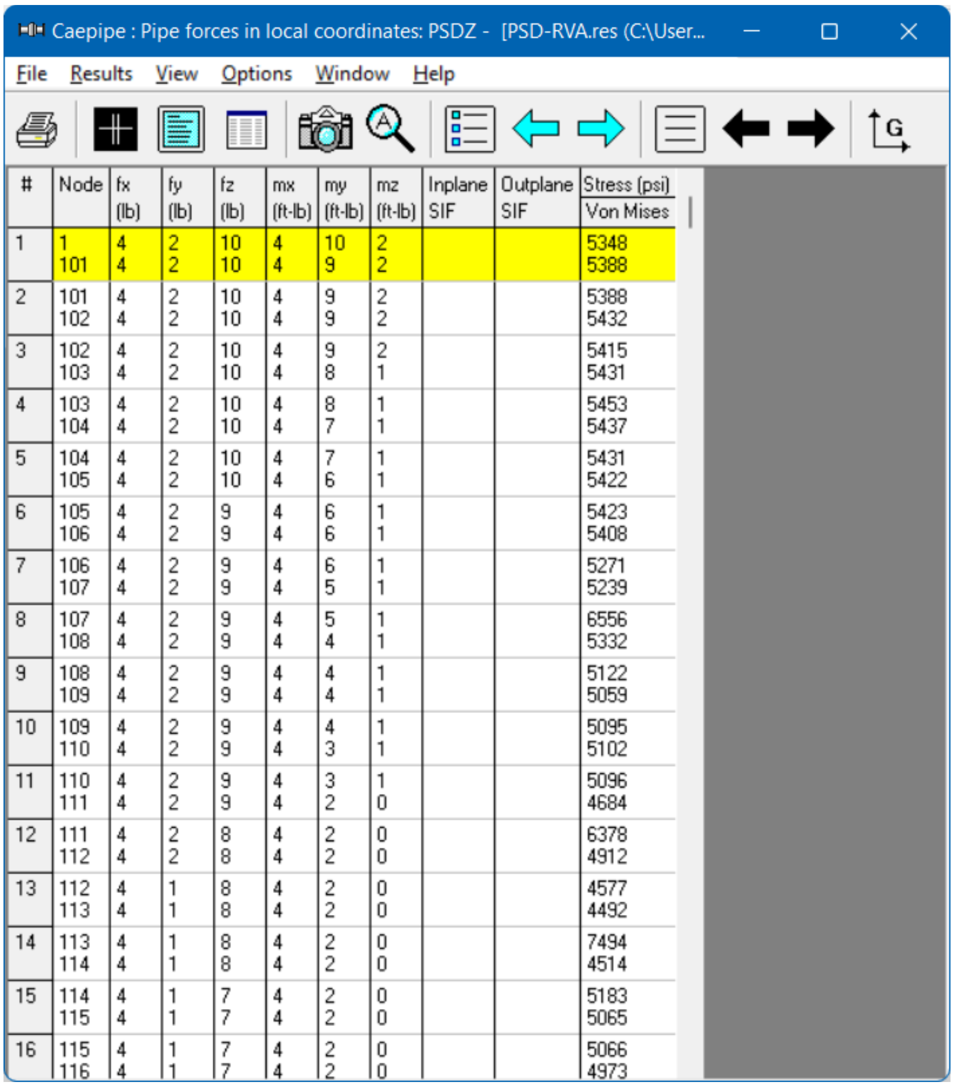
Support loads are the loads acting on the supports by the tubing system for the selected load case. The loads on anchors for the “PSDZ Load” case are shown below.



#	Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	1		2	4	10	10	4	2
2	9		1	2	7	3	10	2
3	12		8	4	12	1	23	4

Element Forces

For pipe (also bend and reducer), element forces in local coordinates, “Stress Intensification Factors” (SIF) and Von Mises stresses are shown by default for the selected load case.



#	Node	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)	Inplane SIF	Outplane SIF	Stress (psi) Von Mises
1	1 101	4 4	2 2	10 10	4 4	10 9	2 2			5348 5388
2	101 102	4 4	2 2	10 10	4 4	9 9	2 2			5388 5432
3	102 103	4 4	2 2	10 10	4 4	9 8	2 1			5415 5431
4	103 104	4 4	2 2	10 10	4 4	8 7	1 1			5453 5437
5	104 105	4 4	2 2	10 10	4 4	7 6	1 1			5431 5422
6	105 106	4 4	2 2	9 9	4 4	6 6	1 1			5423 5408
7	106 107	4 4	2 2	9 9	4 4	6 5	1 1			5271 5239
8	107 108	4 4	2 2	9 9	4 4	5 4	1 1			6556 5332
9	108 109	4 4	2 2	9 9	4 4	4 4	1 1			5122 5059
10	109 110	4 4	2 2	9 9	4 4	4 3	1 1			5095 5102
11	110 111	4 4	2 2	9 9	4 4	3 2	1 0			5096 4684
12	111 112	4 4	2 2	8 8	4 4	2 2	0 0			6378 4912
13	112 113	4 4	1 1	8 8	4 4	2 2	0 0			4577 4492
14	113 114	4 4	1 1	8 8	4 4	2 2	0 0			7494 4514
15	114 115	4 4	1 1	7 7	4 4	2 2	0 0			5183 5065
16	115 116	4 4	1 1	7 7	4 4	2 2	0 0			5066 4973

Displacements

The nodal displacements for “PSDZ load” case are shown below.

Caepipe : Displacements: PSDZ - [PSD-RVA.res (C:\Users\HP\Documents\1CAEPIPE\12.20\Tutorial-Final)]

File Results View Options Window Help

#		Displacements (global)					
	Node	X (inch)	Y (inch)	Z (inch)	XX (deg)	YY (deg)	ZZ (deg)
132	232	0.036	0.094	2.160	0.4443	0.7515	0.2808
133	233	0.036	0.093	2.171	0.4493	0.6961	0.2846
134	234	0.036	0.093	2.180	0.4546	0.6421	0.2883
135	235	0.036	0.093	2.189	0.4600	0.5905	0.2917
136	236	0.036	0.094	2.196	0.4656	0.5425	0.2948
137	237	0.036	0.094	2.202	0.4714	0.4994	0.2974
138	238	0.036	0.094	2.207	0.4773	0.4632	0.2995
139	239	0.036	0.094	2.211	0.4834	0.4359	0.3010
140	240	0.036	0.095	2.214	0.4896	0.4194	0.3019
141	241	0.036	0.096	2.215	0.4960	0.4151	0.3022
142	242	0.036	0.096	2.216	0.5025	0.4236	0.3019
143	243	0.036	0.097	2.215	0.5091	0.4441	0.3009
144	244	0.036	0.098	2.213	0.5159	0.4749	0.2993
145	245	0.036	0.099	2.209	0.5228	0.5140	0.2971
146	246	0.036	0.100	2.205	0.5297	0.5596	0.2943
147	247	0.036	0.101	2.199	0.5368	0.6100	0.2910
148	248	0.036	0.103	2.192	0.5440	0.6640	0.2873
149	249	0.036	0.104	2.184	0.5514	0.7206	0.2832

Expected Frequencies

The Expected Frequencies for vibration displacement in Global X, Y and Z directions corresponding to “PSDZ Load” case for each Node is shown below.

Caepipe : Expected Frequencies: PSDZ - [PSD-RVA.res (C:\Users\...

File Results View Options Window Help

#		Frequencies (Hz)		
	Node	X	Y	Z
1	1	34.568	38.496	54.029
2	101	29.314	38.496	33.178
3	102	29.114	38.496	32.486
4	103	28.942	38.495	31.902
5	104	28.771	38.495	31.334
6	105	28.594	38.495	30.766
7	106	28.411	38.495	30.194
8	107	28.220	38.494	29.621
9	108	28.021	38.494	29.049
10	109	27.812	38.494	28.481
11	110	27.594	38.493	27.923
12	111	27.366	38.492	27.377
13	112	27.129	38.492	26.850
14	113	26.880	38.491	26.345
15	114	26.622	38.490	25.866
16	115	26.352	38.490	25.415