The *FASTEST* Solutions for Piping Design and Analysis.

Readme Supplement

CAEPIPE™

Version 7.60

Disclaimer

Please read the following carefully:

This software and this document have been developed and checked for correctness and accuracy by SST Systems, Inc. (SST). However, no warranty, expressed or implied, is made by SST as to the accuracy and correctness of this document or the functioning of the software and the accuracy, correctness and utilization of its calculations.

Users must carry out all necessary tests to assure the proper functioning of the software and the applicability of its results. All information presented by the software is for review, interpretation, approval and application by a Registered Professional Engineer.

CAEPIPE is a trademark of SST.

SST Systems, Inc.
1798 Technology Drive, Suite 236
San Jose, California 95110
USA

Tel: (408) 452-8111
Fax: (408) 452-8388
Email: info@sstusa.com
www.sstusa.com

Table of Contents

Annexure A

Refinement of Nodal Mesh
based on Mass Modeling Frequency

Refinement of Nodal Mesh based on Mass Modeling Frequency

The purpose of this feature is to ensure that there are a sufficient number of mass points for an accurate dynamic model for the dynamic loading under consideration.

Intermediate mass points along a span are generated based on the free vibration of an equivalent simply supported beam. Optimum element length is calculated from:

$$L_{opt} = \frac{1}{2}\sqrt{\frac{\pi}{2.f}}\,.\,\sqrt[4]{\frac{E.I.g}{w}}$$

L_{opt} = Optimum length required to capture the span dynamic behavior

f = mass modeling frequency

g = acceleration due to gravity

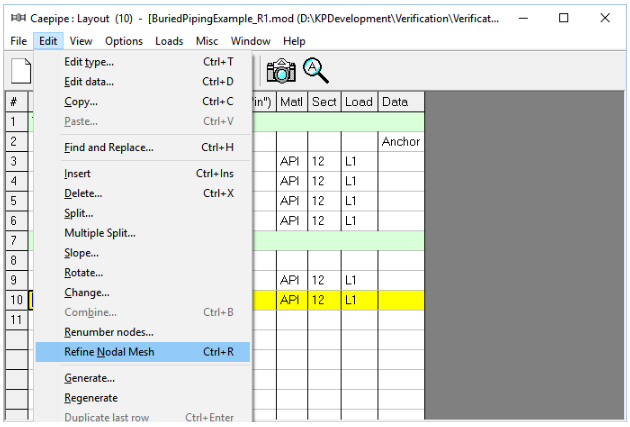
E = modulus of elasticity of pipe material

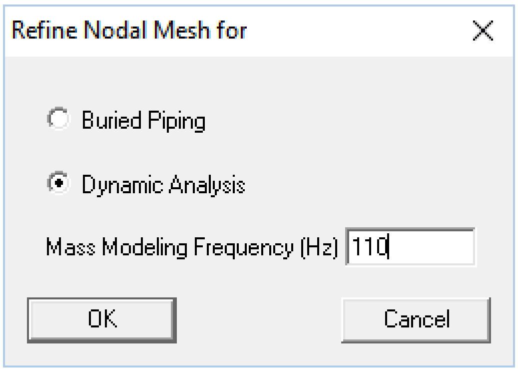
Although the above equation is valid for any temperature, to generate intermediate nodes, E is taken at the reference temperature entered in CAEPIPE.

I = moment of inertia of pipe cross section

w = weight per unit length of pipe (including insulation, lining and content)

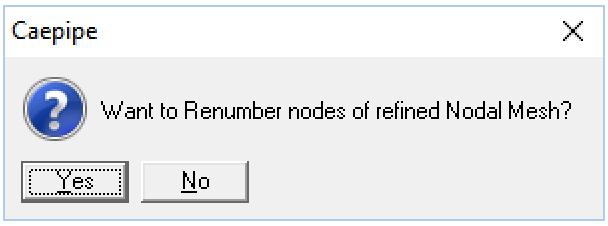
Intermediate mass points can be automatically generated in CAEPIPE by selecting the radio button “Dynamic Analysis” through Layout window > Edit > Refine Nodal Mesh. Enter the Mass modeling Frequency in the dialog box shown and press the button “OK”. See figures shown below for details.

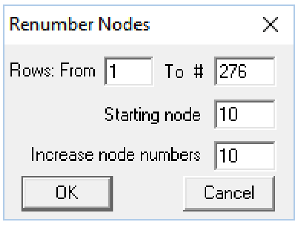




While refining the Nodal Mesh, the new node numbers will be generated by adding the node increment specified through Layout window > Options > Node increment to get the new node numbers (without affecting the original node numbers used in the Layout window). Hence, set the node increment value as required before refining the Nodal Mesh.

Upon refining the Nodal Mesh based on Mass modeling frequency, CAEPIPE will prompt for renumbering of nodes as shown below.

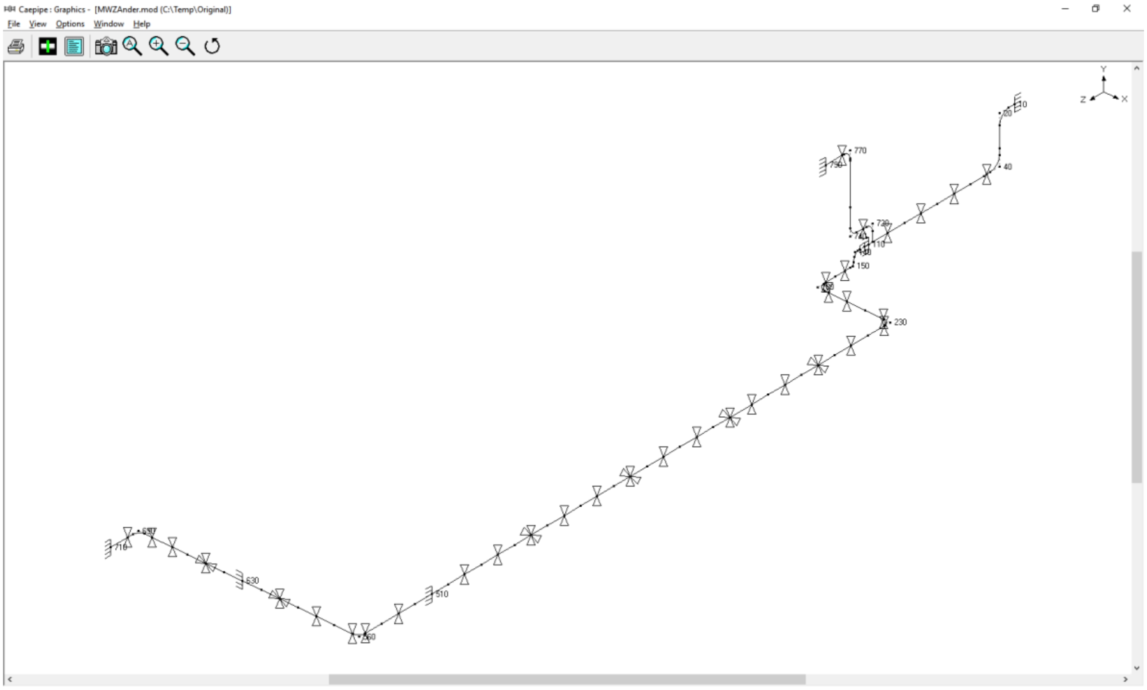




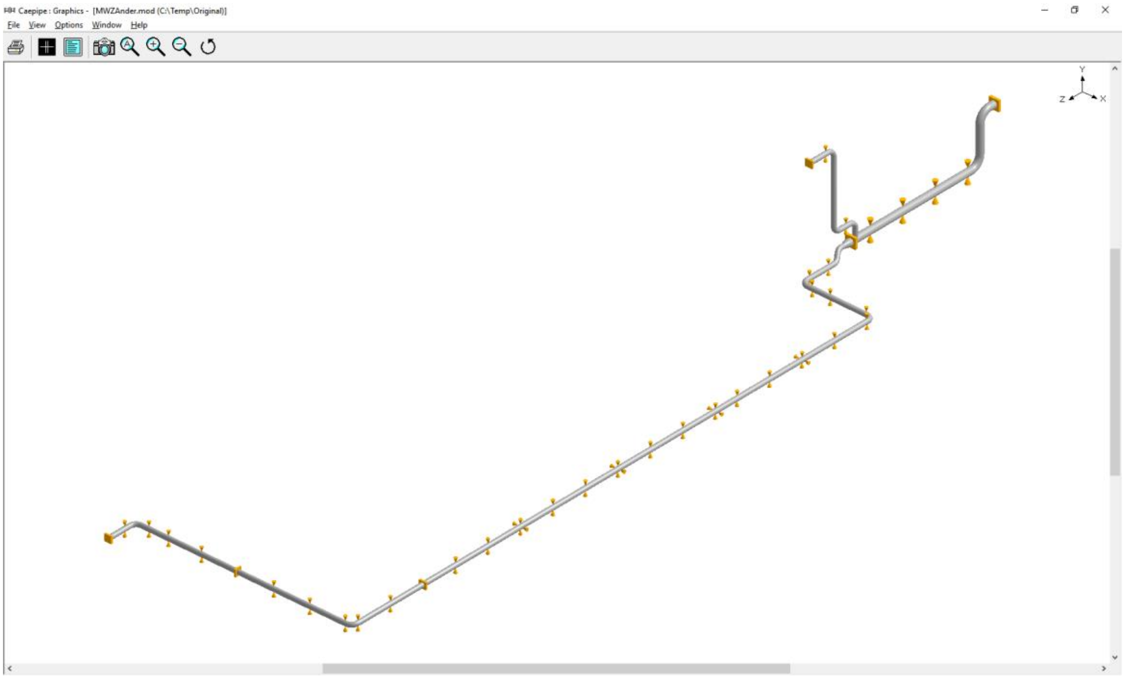
Press the button “Yes” to renumber the nodes and enter the details required by CAEPIPE in the dialog box. See snap shot shown above.

Example

A sample CAEPIPE model (with graphics and layout details as shown below) was chosen for verification of implementation. Modal analysis was then performed by defining the cut-off frequency and number of modes as “110 Hz” and 175 respectively in the CAEPIPE model through Layout window > Options > Analysis > Dynamics with the node points as defined by the stress analyst.



Wireframe layout without addition of mass points



Rendered layout without addition of mass points

Options

Piping code = B31.3 (2014)
Do not use liberal allowable stresses
Include axial force in stress calculations
Reference temperature = 40 (F)
Number of thermal cycles = 7000
Number of thermal loads = 1
Thermal = Operating - Sustained
Use modulus at reference temperature
Include hanger stiffness
Include Bourdon effect
Use pressure correction for bends
Pressure stress = PD / 4t
Peak pressure factor = 1.00
Cut off frequency = 110 Hz
Number of modes = 175
Include missing mass correction
Use friction in dynamic analysis
Vertical direction = Y

#	Node	Type	DX(ft'in")	DY(ft'in")	DZ(ft'in")	Mat	Sec	Load	Data
1	Title =								
2	10	From							Anchor
3	20	Bend			11'0"	API	54I	54I	
4	30			-20'0"		API	54I	54I	
5	40	Bend		-10'9"		API	54I	54I	
6	50				9'0"	API	54I	54I	Y restraint
7	60				2'0"	API	54O	54O	
8	65				10'0"	API	54O	54O	
9	70				12'0"	API	54O	54O	Y restraint
10	75				12'0"	API	54O	54O	
11	80				12'0"	API	54O	54O	Y restraint
12	85				12'0"	API	54O	54O	
13	90				12'0"	API	54O	54O	Y restraint
14	100				11'0"	API	54O	54O	
15	110				3'0"	API	54O	54O	Anchor
16	120				3'0"	API	54O	54O	
17	130	Reducer			3'0"	API	54O	54O	
18	140	Bend			3'8"	API	36I	36I	
19	150	Bend	2'11"	-4'6"	4'6"	API	36I	36I	
20	160				6'0"	API	36I	36I	Y restraint
21	165				7'0"	API	36I	36I	
22	170				7'0"	API	36I	36I	Y restraint
23	180	Bend			6'0"	API	36I	36I	
24	190		7'3"			API	36I	36I	Y restraint
25	200		12'0"			API	36I	36I	Y restraint
26	210		12'0"			API	36I	36I	
27	220		12'0"			API	36I	36I	Y restraint
28	230	Bend	4'5"			API	36I	36I	
29	240				4'5"	API	36I	36I	Y restraint
30	250				12'0"	API	36I	36I	
31	260				12'0"	API	36I	36I	Y restraint
32	270				12'0"	API	36I	36I	
33	280				12'0"	API	36I	36I	XY restraint

#	Node	Type	DX(ft'in")	DY(ft'in")	DZ(ft'in")	Mat	Sec	Load	Data
34	290				12'0"	API	36I	36I	
35	300				12'0"	API	36I	36I	Y restraint
36	310				12'0"	API	36I	36I	
37	320				12'0"	API	36I	36I	Y restraint
38	330				16'0"	API	36I	36I	XY restraint
39	340				12'0"	API	36I	36I	
40	350				12'0"	API	36I	36I	Y restraint
41	360				12'0"	API	36I	36I	
42	370				12'0"	API	36I	36I	Y restraint
43	380				12'0"	API	36I	36I	
44	390				12'0"	API	36I	36I	XY restraint
45	400				12'0"	API	36I	36I	
46	410				12'0"	API	36I	36I	Y restraint
47	420				12'0"	API	36I	36I	
48	430				12'0"	API	36I	36I	Y restraint
49	440				12'0"	API	36I	36I	
50	450				12'0"	API	36I	36I	XY restraint
51	460				12'0"	API	36I	36I	
52	470				12'0"	API	36I	36I	Y restraint
53	480				12'0"	API	36I	36I	
54	490				12'0"	API	36I	36I	Y restraint
55	500				12'0"	API	36I	36I	
56	510				12'0"	API	36I	36I	Anchor
57	520				12'0"	API	36I	36I	
58	530				12'0"	API	36I	36I	Y restraint
59	540				12'0"	API	36I	36I	
60	550				12'0"	API	36I	36I	Y restraint
61	560	Bend			4'5"	API	36I	36I	
62	570		-4'5"			API	36I	36I	Y restraint
63	580		-12'0"			API	36I	36I	
64	590		-11'7"			API	36I	36I	Y restraint
65	600		-12'0"			API	36I	36I	
66	610		-12'0"			API	36I	36I	XY restraint
67	620		-12'0"			API	36I	36I	
68	630		-12'0"			API	36I	36I	Anchor
69	640		-12'0"			API	36I	36I	
70	650		-12'0"			API	36I	36I	XY restraint
71	660		-12'0"			API	36I	36I	
72	670		-10'0"			API	36I	36I	Y restraint
73	680		-13'0"			API	36I	36I	Y restraint
74	690	Bend	-9'0"			API	36I	36I	
75	700				7'11"	API	36I	36I	Y restraint
76	710				12'0"	API	36I	36I	Anchor
77	100	From							
78	720	Bend		10'9"		API	36O	36O	
79	730				7'0"	API	36O	36O	Y restraint
80	740	Bend			9'0"	API	36O	36O	
81	750			16'9"		API	36O	36O	
82	760			26'11"		API	36O	36O	
83	770	Bend		5'8"		API	36O	36O	
84	780				6'0"	API	36O	36O	Y restraint
85	790				12'0"	API	36O	36O	Anchor

Anchors

Node	KX/kx (lb/inch)	KY/ky (lb/inch)	KZ/kz (lb/inch)	KXX/kxx (in-lb/deg)	KYY/kyy (in-lb/deg)	KZZ/kzz (in-lb/deg)	Releases X Y Z XXYYZZ	Anchor In Pipe
10	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
110	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
510	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
630	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
710	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
790	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS

Bends

Bend Node	Radius (inch)	Thickness (inch)	Bend Matl	Flex. Factor	Int. Node	Angle (deg)	Int. Node	Angle (deg)
20	81	L						
40	81	L						
140	54	L						
150	54	L						
180	54	L						
230	48	U						
560	48	U						
690	48	U						
720	54	L						
740	54	L						
770	54	L						

Reducers

From	To	OD1 (inch)	Thk1 (inch)	OD2 (inch)	Thk2 (inch)	Cone Angle (deg)	Knuckles	Delta (inch)
120	130	54	0.375	36	0.375			

Restraints

Node	X	Y	Z
50		Yes	
70		Yes	
80		Yes	
90		Yes	
160		Yes	
170		Yes	
190		Yes	
200		Yes	
220		Yes	
240		Yes	
260		Yes	
280	Yes	Yes	
300		Yes	
320		Yes	
330	Yes	Yes	
350		Yes	

Restraints

Node	X	Y	Z
370		Yes	
390	Yes	Yes	
410		Yes	
430		Yes	
450	Yes	Yes	
470		Yes	
490		Yes	
530		Yes	
550		Yes	
570		Yes	
590		Yes	
610	Yes	Yes	
650	Yes	Yes	
670		Yes	
680		Yes	
700		Yes	
730		Yes	
780		Yes	

Pipe material API: API 5L Grade B

Density = 0.283 (lb/in3), Nu = 0.300, Joint factor = 1.00, Type = CS
Yield strength = 35000 (psi)

Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
-325	31.4E+6	5.00E-6	20000
-200	30.8E+6	5.35E-6	20000
-100	30.2E+6	5.65E-6	20000
70	29.5E+6	6.07E-6	20000
200	28.8E+6	6.38E-6	20000
300	28.3E+6	6.60E-6	20000
400	27.7E+6	6.82E-6	19900
500	27.3E+6	7.02E-6	19000
600	26.7E+6	7.23E-6	17900
650	26.1E+6	7.33E-6	17300
700	25.5E+6	7.44E-6	16700
750	24.8E+6	7.54E-6	13900
800	24.2E+6	7.65E-6	11400
850	23.3E+6	7.75E-6	8700
900	22.4E+6	7.84E-6	5900
950	21.4E+6	7.91E-6	4000
1000	20.4E+6	7.97E-6	2500
1050	19.2E+6	8.05E-6	1600
1100	18.0E+6	8.12E-6	1000

Pipe Sections

Name	Nominal Dia.	Sch	O.D. (inch)	Thk (inch)	Cor.Al (inch)	M.Tol (%)	Ins.Dens (lb/ft3)	Ins.Th (inch)	Lin.Dens (lb/ft3)	Lin.Th (inch)
36I	36"	STD	36	0.375	0	0.0				
36O	36"	STD	36	0.375	0	0.0				
54O	Non Std		54	0.375	0	0.0				
54I	Non Std		54	0.375	0	0.0				

Loads

Static seismic load: X = -0.20, Y = -0.20, Z = -0.20 (g's)
Acceleration load combination = Square Root of Sum of Squares

X spectrum: Malta, NY_b Factor = 1.0000
Y spectrum: Malta, NY_b Factor = 0.0430
Z spectrum: Malta, NY_b Factor = 1.0000

Mode sum = SRSS Direction sum = SRSS

Wind Load 1

Shape factor = 0.60
Wind direction: X comp = 0.000, Y comp = 0.000, Z comp = 1.000

Elevation (feet)	Pressure (psf)
0	15
15	15
30	15
45	15
60	15

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
36O	100	125							Y
36I	100	125							
54O	100	125							Y
54I	100	125							

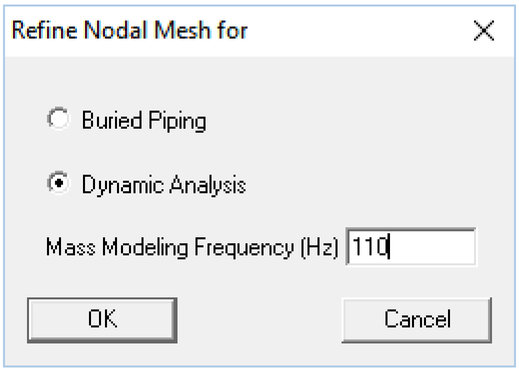
From the Modal Analysis results shown below, it was noted that the CAEPIPE was able to extract 92 modes with highest frequency being 95.967 Hz.

Mode	Frequency (Hz)	Period (sec)	Participation factors X	Participation factors Y	Participation factors Z	Modal mass / Total mass X	Modal mass / Total mass Y	Modal mass / Total mass Z
1	1.875	0.5335	-5.7615	-0.0004	0.5255	0.0979	0.0000	0.0008
2	3.288	0.3041	-6.7721	-0.0000	0.0003	0.1353	0.0000	0.0000
3	5.971	0.1675	-4.1919	0.0000	-0.0001	0.0518	0.0000	0.0000
4	6.147	0.1627	0.0909	-0.0000	-0.1021	0.0000	0.0000	0.0000
5	7.800	0.1282	-0.4240	-0.0000	4.5032	0.0005	0.0000	0.0598
6	8.102	0.1234	0.0029	0.0001	0.3321	0.0000	0.0000	0.0003
7	9.933	0.1007	0.0861	-0.0000	-4.2655	0.0000	0.0000	0.0537
8	10.146	0.0986	-0.6501	0.0002	1.6688	0.0012	0.0000	0.0082
9	10.241	0.0976	-2.1689	-0.0000	0.0048	0.0139	0.0000	0.0000
10	11.279	0.0887	3.2684	-0.0002	-7.9718	0.0315	0.0000	0.1874
11	11.628	0.0860	6.7199	-0.0002	5.8034	0.1332	0.0000	0.0993
12	13.116	0.0762	-0.0013	1.4576	-3.8221	0.0000	0.0063	0.0431
13	13.276	0.0753	2.6364	0.0000	-0.0001	0.0205	0.0000	0.0000
14	13.931	0.0718	3.3527	0.0030	-3.2879	0.0332	0.0000	0.0319
15	16.027	0.0624	-3.6866	0.0000	-0.3181	0.0401	0.0000	0.0003
16	16.038	0.0624	-2.9281	-0.0001	-0.7810	0.0253	0.0000	0.0018
17	17.802	0.0562	-1.8832	0.0179	2.3004	0.0105	0.0000	0.0156
18	21.780	0.0459	0.0000	2.7930	3.3879	0.0000	0.0230	0.0339
19	22.412	0.0446	-0.0006	-3.2159	-1.3274	0.0000	0.0305	0.0052
20	22.683	0.0441	-0.3117	-0.0005	0.0747	0.0003	0.0000	0.0000
21	24.003	0.0417	-0.5955	-0.0000	0.1696	0.0010	0.0000	0.0001
22	24.910	0.0401	2.7763	-0.0000	-0.0070	0.0227	0.0000	0.0000
23	26.421	0.0378	-0.2314	0.0001	0.1348	0.0002	0.0000	0.0001
24	27.698	0.0361	-1.3316	0.0000	-0.0002	0.0052	0.0000	0.0000
25	29.713	0.0337	-1.2585	-0.0000	-0.0049	0.0047	0.0000	0.0000
26	30.079	0.0332	-0.3437	0.0000	-0.1955	0.0003	0.0000	0.0001
27	30.146	0.0332	0.0215	-0.0001	0.3494	0.0000	0.0000	0.0004
28	31.946	0.0313	-0.6062	0.0012	-1.6290	0.0011	0.0000	0.0078
29	33.670	0.0297	0.9928	-0.0040	2.8297	0.0029	0.0000	0.0236
30	36.072	0.0277	0.0014	1.4997	-2.1277	0.0000	0.0066	0.0134
31	37.812	0.0264	-0.4989	-0.0074	2.1572	0.0007	0.0000	0.0137
32	39.097	0.0256	1.2371	-0.0000	-0.0086	0.0045	0.0000	0.0000
33	41.172	0.0243	-0.0001	1.2001	-6.2487	0.0000	0.0042	0.1152
34	41.250	0.0242	-0.3414	-0.0000	1.6185	0.0003	0.0000	0.0077
35	42.488	0.0235	0.7544	-0.0001	-0.0047	0.0017	0.0000	0.0000
36	43.804	0.0228	-0.4830	0.0108	1.2389	0.0007	0.0000	0.0045
37	46.065	0.0217	-0.0011	0.0686	-0.0001	0.0000	0.0000	0.0000
38	46.766	0.0214	-0.0098	-0.5622	-0.0023	0.0000	0.0009	0.0000
39	47.504	0.0211	-0.2337	-0.0029	-0.2475	0.0002	0.0000	0.0002
40	49.063	0.0204	0.0015	0.3511	0.0007	0.0000	0.0004	0.0000
41	49.295	0.0203	-0.0000	-1.0018	-0.0000	0.0000	0.0030	0.0000
42	49.985	0.0200	1.3732	-0.0000	-1.3809	0.0056	0.0000	0.0056
43	50.052	0.0200	-0.1938	0.0000	-1.9635	0.0001	0.0000	0.0114
44	52.178	0.0192	-0.9811	-0.0281	-0.6345	0.0028	0.0000	0.0012
45	52.335	0.0191	0.0000	-0.8918	-0.0000	0.0000	0.0023	0.0000
46	53.313	0.0188	-0.0715	-1.0283	-0.1169	0.0000	0.0031	0.0000
47	53.496	0.0187	-1.0974	-0.0751	-1.8548	0.0036	0.0000	0.0101
48	54.481	0.0184	0.0407	-1.8917	0.0845	0.0000	0.0106	0.0000
49	56.408	0.0177	0.4159	-1.3502	0.0358	0.0005	0.0054	0.0000
50	56.457	0.0177	2.6140	0.2176	-0.1253	0.0202	0.0001	0.0000
51	56.920	0.0176	1.8036	0.0012	0.0177	0.0096	0.0000	0.0000
52	57.929	0.0173	-0.2764	-0.0033	-0.0311	0.0002	0.0000	0.0000
53	58.372	0.0171	-1.1204	0.0366	0.3623	0.0037	0.0000	0.0004

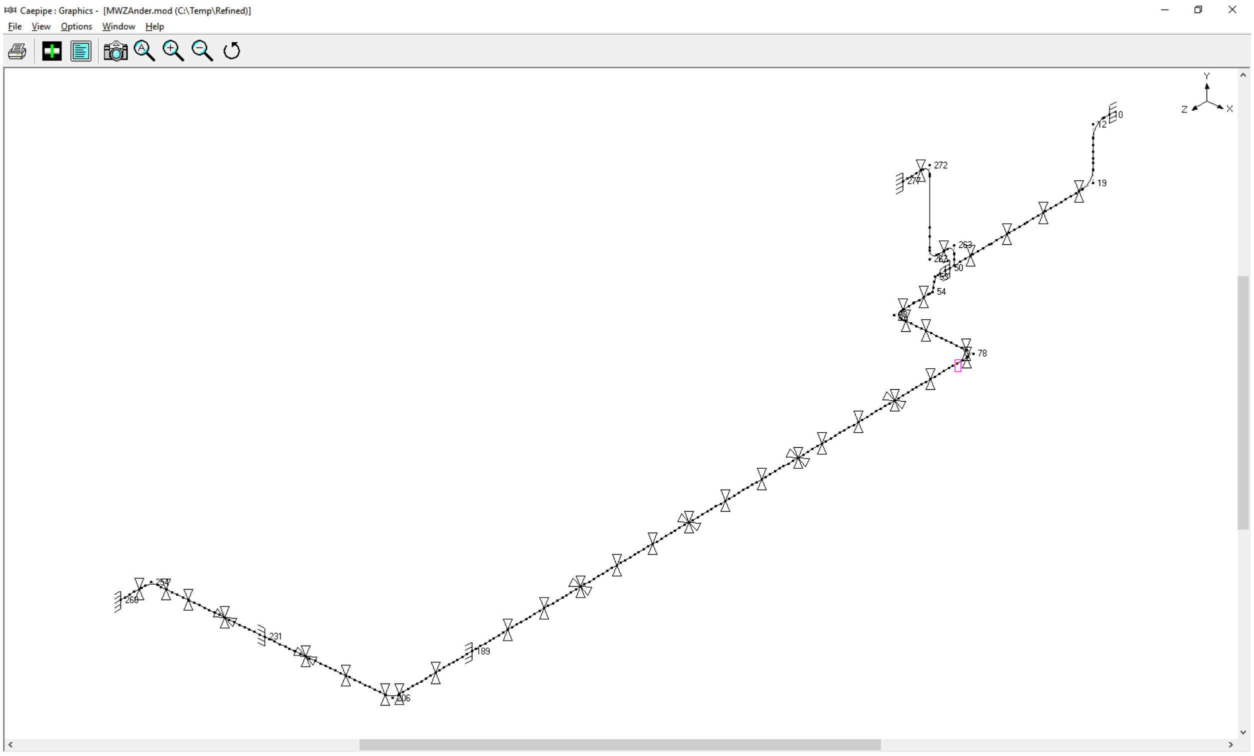
Caepipe dynamic_model_original Page 2
Version 7.60 May 30,2016

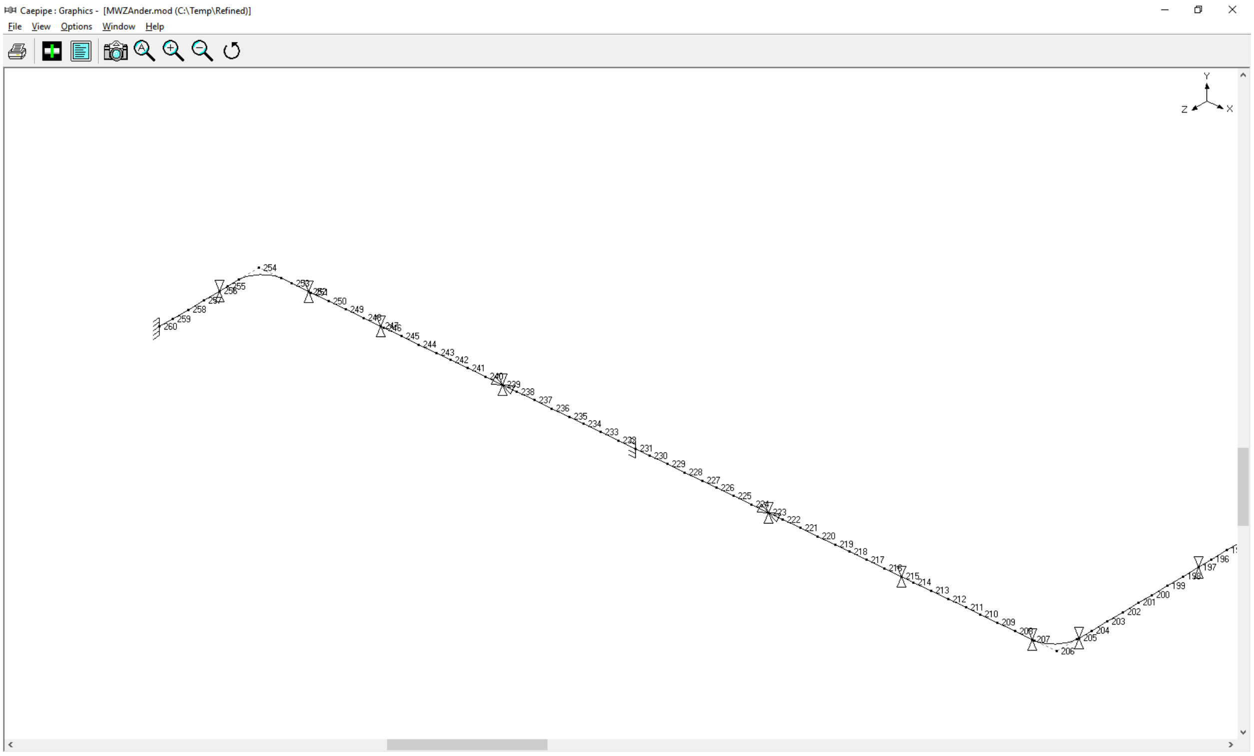
Mode	Frequency (Hz)	Period (sec)	Participation factors X	Participation factors Y	Participation factors Z	Modal mass / Total mass X	Modal mass / Total mass Y	Modal mass / Total mass Z
54	58.736	0.0170	0.0013	-0.4068	0.0005	0.0000	0.0005	0.0000
55	62.338	0.0160	-0.0004	1.7473	2.3502	0.0000	0.0090	0.0163
56	63.166	0.0158	1.4680	0.0042	1.3132	0.0064	0.0000	0.0051
57	63.180	0.0158	1.1531	0.0001	-1.1840	0.0039	0.0000	0.0041
58	63.512	0.0157	0.0000	-0.1612	0.0000	0.0000	0.0001	0.0000
59	64.003	0.0156	-0.0020	-0.5988	0.0007	0.0000	0.0011	0.0000
60	64.339	0.0155	-0.0000	-1.1254	0.0000	0.0000	0.0037	0.0000
61	65.107	0.0154	-1.0551	-0.0210	1.1888	0.0033	0.0000	0.0042
62	65.192	0.0153	0.0016	0.3043	0.5961	0.0000	0.0003	0.0010
63	65.893	0.0152	-0.0078	-0.0572	0.0105	0.0000	0.0000	0.0000
64	69.245	0.0144	-0.0005	-0.9214	0.0006	0.0000	0.0025	0.0000
65	70.044	0.0143	-2.3140	-0.0000	-1.0324	0.0158	0.0000	0.0031
66	70.911	0.0141	-3.2315	-0.0000	-1.9392	0.0308	0.0000	0.0111
67	73.355	0.0136	-0.9182	0.2454	0.2391	0.0025	0.0002	0.0002
68	73.445	0.0136	-0.0085	1.5999	0.0018	0.0000	0.0075	0.0000
69	74.015	0.0135	0.0021	1.9142	0.0703	0.0000	0.0108	0.0000
70	74.156	0.0135	-0.0000	2.9214	-0.0000	0.0000	0.0252	0.0000
71	74.905	0.0134	0.0017	-3.8949	0.0017	0.0000	0.0447	0.0000
72	76.249	0.0131	-0.1108	0.0489	0.0287	0.0000	0.0000	0.0000
73	76.553	0.0131	0.0001	1.4453	0.0002	0.0000	0.0062	0.0000
74	76.599	0.0131	0.0000	3.2442	0.0000	0.0000	0.0310	0.0000
75	78.151	0.0128	-0.0001	-5.7802	-0.0001	0.0000	0.0985	0.0000
76	78.399	0.0128	0.1428	-1.8259	0.2005	0.0001	0.0098	0.0001
77	79.572	0.0126	-0.0000	-3.1388	-0.0000	0.0000	0.0291	0.0000
78	80.352	0.0124	-0.0611	-0.0303	0.0321	0.0000	0.0000	0.0000
79	80.590	0.0124	-0.4718	0.0055	-0.0030	0.0007	0.0000	0.0000
80	81.366	0.0123	0.0014	-1.7246	1.7171	0.0000	0.0088	0.0087
81	81.537	0.0123	-0.6787	0.0000	2.6001	0.0014	0.0000	0.0199
82	83.538	0.0120	2.6049	-0.0000	0.2580	0.0200	0.0000	0.0002
83	83.555	0.0120	0.0186	0.0064	-0.0224	0.0000	0.0000	0.0000
84	85.143	0.0117	-0.9456	0.0093	-0.0136	0.0026	0.0000	0.0000
85	86.260	0.0116	-0.0033	-0.7082	1.6260	0.0000	0.0015	0.0078
86	86.553	0.0116	0.1187	-0.0708	1.3196	0.0000	0.0000	0.0051
87	87.389	0.0114	-0.0038	-0.2207	-0.7108	0.0000	0.0001	0.0015
88	87.678	0.0114	1.8995	-0.0000	-1.1843	0.0106	0.0000	0.0041
89	90.219	0.0111	-0.3088	-0.2777	-0.2039	0.0003	0.0002	0.0001
90	93.121	0.0107	-0.5735	-0.1326	0.4279	0.0010	0.0001	0.0005
91	95.224	0.0105	0.0000	4.5908	0.5409	0.0000	0.0622	0.0009
92	95.967	0.0104	0.7252	-0.0000	-0.6981	0.0016	0.0000	0.0014
					Total	0.7887	0.4496	0.8526

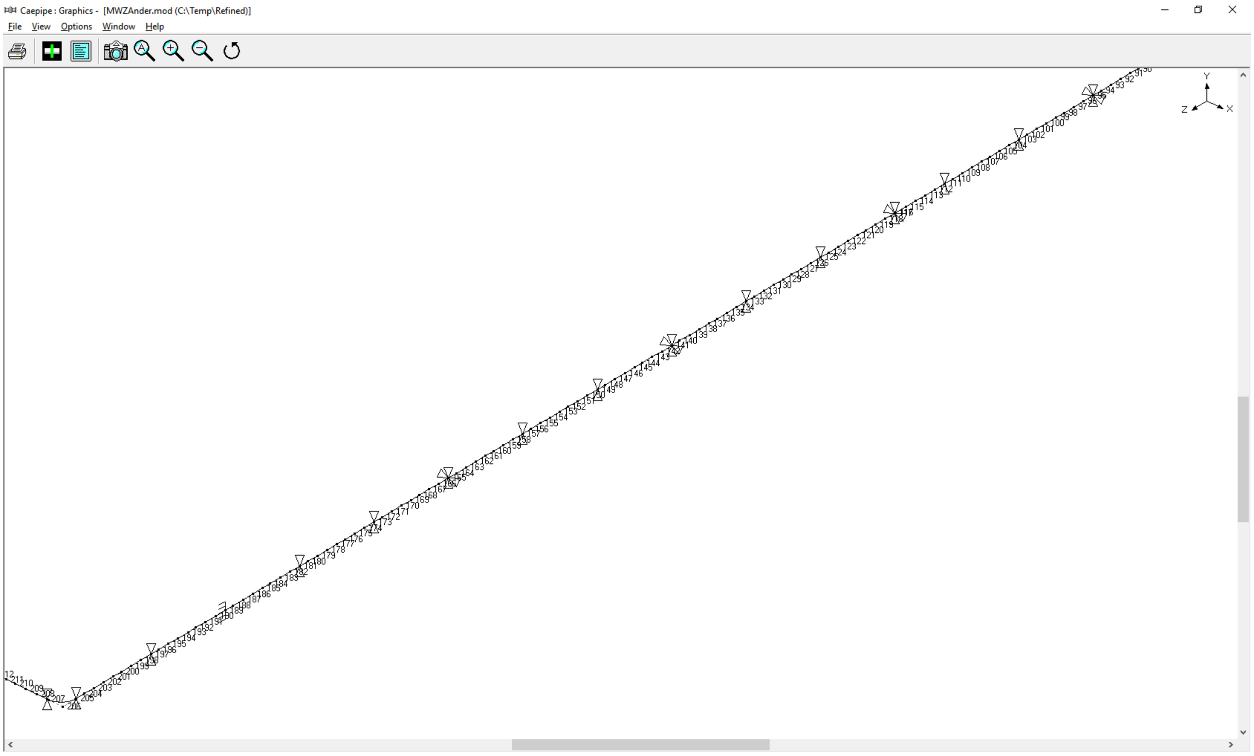
Now, the original model shown above was refined through the feature Layout window > Edit > Refine Nodal Mesh. The Mass modeling frequency was set to 110 Hz for refining the mesh for “Dynamic Analysis” as shown below.

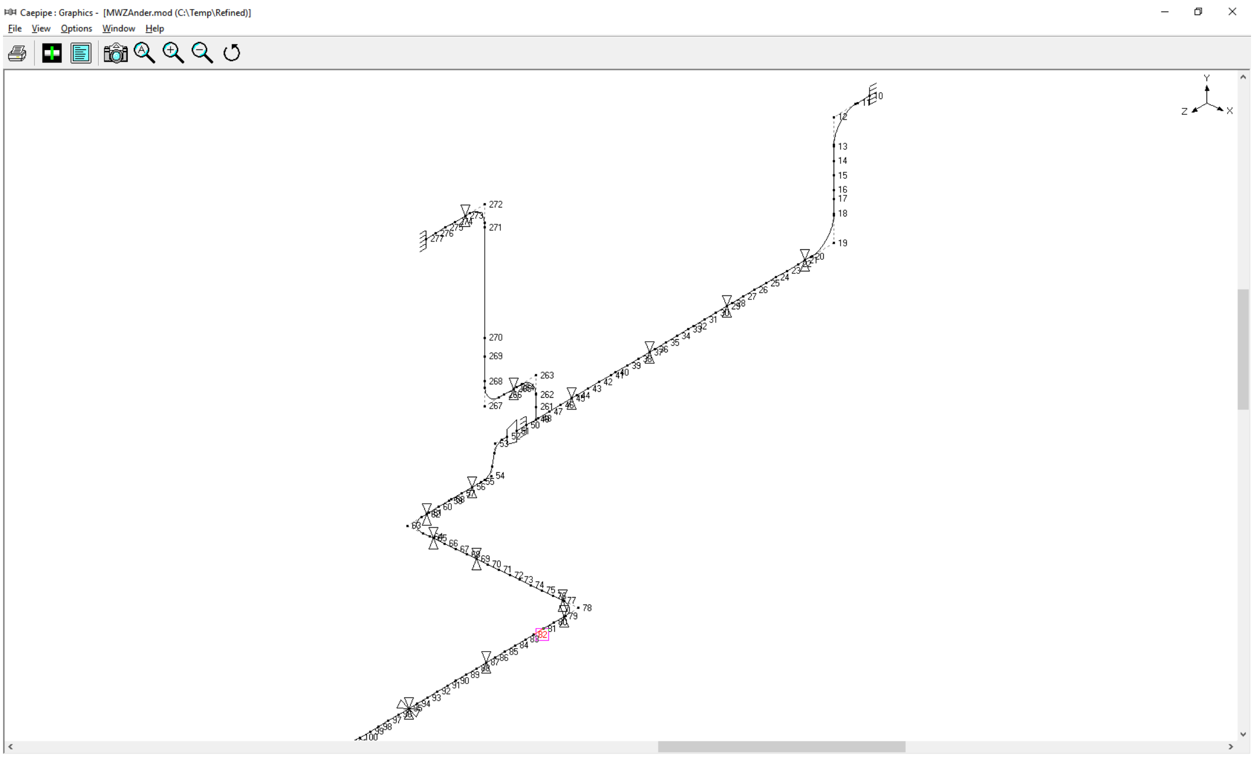


The resulting refined model with additional mass points added by CAEPIPE is shown in the snap shots below.









Modal analysis was then performed using CAEPIPE for the refined model (with additional mass points automatically added) for mass modeling frequency 110 Hz and found that the CAEPIPE was able to extract all the modes below the cut-off frequency 110 Hz specified in the analysis options. Please see the modal analysis results obtained from CAEPIPE shown below.

Mode	Frequency (Hz)	Period (sec)	Participation factors X	Participation factors Y	Participation factors Z	Modal mass / Total mass X	Modal mass / Total mass Y	Modal mass / Total mass Z
1	1.755	0.5698	-5.7696	-0.0003	0.5155	0.0982	0.0000	0.0008
2	2.855	0.3502	6.7662	0.0000	-0.0002	0.1350	0.0000	0.0000
3	5.521	0.1811	-4.1344	0.0000	-0.0001	0.0504	0.0000	0.0000
4	6.151	0.1626	0.0878	-0.0000	-0.1088	0.0000	0.0000	0.0000
5	7.722	0.1295	0.4309	0.0000	-4.5502	0.0005	0.0000	0.0611
6	8.119	0.1232	0.0315	0.0001	0.3840	0.0000	0.0000	0.0004
7	9.824	0.1018	0.0839	-0.0000	-4.3165	0.0000	0.0000	0.0550
8	10.063	0.0994	2.3014	0.0000	0.0054	0.0156	0.0000	0.0000
9	10.134	0.0987	-0.6185	0.0003	2.3174	0.0011	0.0000	0.0158
10	11.111	0.0900	2.0288	0.0003	-8.3004	0.0121	0.0000	0.2032
11	11.613	0.0861	-7.1492	0.0006	-4.4135	0.1508	0.0000	0.0575
12	12.635	0.0791	-0.0006	1.5513	-3.8503	0.0000	0.0071	0.0437
13	13.233	0.0756	2.6877	0.0000	-0.0007	0.0213	0.0000	0.0000
14	13.640	0.0733	2.9690	0.0034	-4.0182	0.0260	0.0000	0.0476
15	15.725	0.0636	3.7891	-0.0000	0.3498	0.0423	0.0000	0.0004
16	15.805	0.0633	3.1354	0.0024	0.9356	0.0290	0.0000	0.0026
17	16.409	0.0609	2.2658	-0.0169	-2.5046	0.0151	0.0000	0.0185
18	17.349	0.0576	-0.0000	-2.7191	-3.1311	0.0000	0.0218	0.0289
19	20.661	0.0484	0.0007	3.2479	1.4079	0.0000	0.0311	0.0058
20	22.737	0.0440	0.2479	0.0001	-0.0877	0.0002	0.0000	0.0000
21	23.733	0.0421	0.7055	-0.0000	-0.0963	0.0015	0.0000	0.0000
22	23.782	0.0420	-2.9878	0.0000	0.0053	0.0263	0.0000	0.0000
23	26.507	0.0377	0.1027	0.0005	-0.1910	0.0000	0.0000	0.0001
24	27.187	0.0368	-0.6336	0.0000	-0.0045	0.0012	0.0000	0.0000
25	29.021	0.0345	-1.1191	0.0000	0.0002	0.0037	0.0000	0.0000
26	29.061	0.0344	0.3323	-0.0000	0.1679	0.0003	0.0000	0.0001
27	30.289	0.0330	-0.4261	0.0036	-1.0079	0.0005	0.0000	0.0030
28	31.215	0.0320	1.0457	-0.0087	2.3123	0.0032	0.0000	0.0158
29	33.583	0.0298	0.4478	-0.0064	1.5750	0.0006	0.0000	0.0073
30	36.362	0.0275	-1.1690	0.0000	-0.0052	0.0040	0.0000	0.0000
31	37.505	0.0267	-0.0033	1.4151	-2.1430	0.0000	0.0059	0.0135
32	37.885	0.0264	0.4183	0.0121	-2.4989	0.0005	0.0000	0.0184
33	40.194	0.0249	0.1951	-0.0000	-1.5005	0.0001	0.0000	0.0066
34	40.968	0.0244	0.0001	-1.1979	6.4128	0.0000	0.0042	0.1213
35	43.038	0.0232	0.3511	-0.0019	-1.2983	0.0004	0.0000	0.0050
36	43.372	0.0231	-0.4795	0.0000	-0.0105	0.0007	0.0000	0.0000
37	46.870	0.0213	0.0021	-0.0008	0.0010	0.0000	0.0000	0.0000
38	47.541	0.0210	-0.0144	-0.7462	-0.0080	0.0000	0.0016	0.0000
39	48.377	0.0207	-0.2963	-0.0021	-0.3487	0.0003	0.0000	0.0004
40	50.010	0.0200	-0.4830	0.0001	-1.8955	0.0007	0.0000	0.0106
41	50.132	0.0199	-0.0043	-0.3850	-0.0040	0.0000	0.0004	0.0000
42	50.285	0.0199	0.0000	1.2526	0.0000	0.0000	0.0046	0.0000
43	51.219	0.0195	1.2828	0.0000	-1.6462	0.0049	0.0000	0.0080
44	51.778	0.0193	1.4654	0.0565	1.8643	0.0063	0.0000	0.0103
45	53.561	0.0187	0.0000	-1.1367	-0.0000	0.0000	0.0038	0.0000
46	53.672	0.0186	-0.1396	0.0329	0.4238	0.0001	0.0000	0.0005
47	54.731	0.0183	0.0027	-1.2178	0.0180	0.0000	0.0044	0.0000
48	56.221	0.0178	-0.0024	-2.0037	0.0429	0.0000	0.0118	0.0000
49	57.051	0.0175	-1.6501	-0.0050	-0.0543	0.0080	0.0000	0.0000
50	57.365	0.0174	-0.2648	-0.0208	0.4221	0.0002	0.0000	0.0005
51	58.161	0.0172	-0.0620	-1.7053	0.0076	0.0000	0.0086	0.0000
52	58.480	0.0171	-2.8218	0.0672	0.2197	0.0235	0.0000	0.0001
53	59.590	0.0168	0.0011	-1.6797	-2.3900	0.0000	0.0083	0.0168

Mode	Frequency (Hz)	Period (sec)	Participation factors X	Y	Z	Modal mass / Total mass X	Y	Z
54	59.697	0.0168	1.3631	-0.0003	-0.0002	0.0055	0.0000	0.0000
55	60.969	0.0164	-0.0001	1.4746	0.5326	0.0000	0.0064	0.0008
56	61.166	0.0163	-0.0003	0.3240	-0.0009	0.0000	0.0003	0.0000
57	63.791	0.0157	1.1014	-0.0167	1.6815	0.0036	0.0000	0.0083
58	65.476	0.0153	0.0000	-0.0239	-0.0000	0.0000	0.0000	0.0000
59	66.097	0.0151	-2.0302	-0.0513	0.5933	0.0122	0.0000	0.0010
60	66.996	0.0149	0.6629	0.0000	-1.1896	0.0013	0.0000	0.0042
61	67.413	0.0148	0.0051	-0.4949	-0.0031	0.0000	0.0007	0.0000
62	67.702	0.0148	0.0000	-1.4164	-0.0000	0.0000	0.0059	0.0000
63	69.973	0.0143	-0.0065	-0.2969	0.0052	0.0000	0.0003	0.0000
64	70.117	0.0143	0.0002	-2.2385	0.7487	0.0000	0.0148	0.0017
65	70.175	0.0143	-2.4152	-0.0000	-0.9261	0.0172	0.0000	0.0025
66	74.234	0.0135	3.4185	0.0003	1.5639	0.0345	0.0000	0.0072
67	74.560	0.0134	0.0042	1.0701	-0.0017	0.0000	0.0034	0.0000
68	74.843	0.0134	-1.3329	0.8236	0.1534	0.0052	0.0020	0.0001
69	76.927	0.0130	-0.4107	-1.5744	0.2386	0.0005	0.0073	0.0002
70	78.576	0.0127	-0.1023	0.0017	-0.0013	0.0000	0.0000	0.0000
71	80.082	0.0125	0.0006	-0.5746	1.6438	0.0000	0.0010	0.0080
72	80.485	0.0124	0.0002	-2.1498	0.0002	0.0000	0.0136	0.0000
73	81.701	0.0122	-0.2466	-0.0537	0.0757	0.0002	0.0000	0.0000
74	81.749	0.0122	-0.0002	3.4973	0.0000	0.0000	0.0361	0.0000
75	82.787	0.0121	-0.0004	4.3124	-0.0023	0.0000	0.0549	0.0000
76	84.316	0.0119	1.6969	0.0000	-3.1197	0.0085	0.0000	0.0287
77	85.065	0.0118	-0.0026	-0.4712	0.8256	0.0000	0.0007	0.0020
78	85.440	0.0117	0.0000	3.7852	-0.0000	0.0000	0.0423	0.0000
79	85.507	0.0117	-0.0001	1.4996	0.0009	0.0000	0.0066	0.0000
80	87.100	0.0115	-0.0680	0.0853	-1.2077	0.0000	0.0000	0.0043
81	87.358	0.0114	-0.0000	3.5186	-0.0000	0.0000	0.0365	0.0000
82	87.548	0.0114	1.1884	-0.0035	-0.0409	0.0042	0.0000	0.0000
83	87.820	0.0114	0.1975	-0.0174	0.6688	0.0001	0.0000	0.0013
84	88.217	0.0113	-0.0001	6.8293	-0.0003	0.0000	0.1376	0.0000
85	88.587	0.0113	0.0003	-0.6062	-1.1192	0.0000	0.0011	0.0037
86	89.553	0.0112	2.9233	-0.0000	0.1706	0.0252	0.0000	0.0001
87	91.995	0.0109	-0.2639	-0.2144	-0.3238	0.0002	0.0001	0.0003
88	92.948	0.0108	0.1126	0.0508	0.0909	0.0000	0.0000	0.0000
89	93.055	0.0107	1.1698	-0.0041	0.6341	0.0040	0.0000	0.0012
90	102.283	0.0098	0.0000	-0.0302	-0.0000	0.0000	0.0000	0.0000
91	103.208	0.0097	0.0131	5.0475	0.3381	0.0000	0.0751	0.0003
92	103.322	0.0097	-0.6291	-0.0242	0.3139	0.0012	0.0000	0.0003
93	109.288	0.0092	-0.7946	-0.1550	0.6055	0.0019	0.0001	0.0011
94	110.299	0.0091	1.2405	-0.0000	0.3050	0.0045	0.0000	0.0003
					Total	0.8148	0.5606	0.8574

Annexure B

Verification for Export of Local Element Forces and Moments contributed by each Mode participating in Response Spectrum Analysis

Verification for Export of Local Element Forces and Moments contributed by each Mode participating in Response Spectrum Analysis

A new feature is added in CAEPIPE Version 7.60 to automatically export in .csv format element forces and moments in Local coordinate system contributed by each mode participating in Response Spectrum. These will be exported only when the option "Analyze" is selected through Layout Window > File > Analyze. CAEPIPE will name the .CSV file automatically by appending "_MFM" with the model name specified.

The above implementation is verified by combining the forces and moments manually for each Mode Sum manually (using Excel) and compared against the CAEPIPE element forces and moments for Response Spectrum load case for the models described below along with their respective path shown in bracket.

1. RespSpectrumSRSS_NoMissMass_NoSeisDisp.mod (.\Verification\MFM\Model-1)
2. RespSpectrumSRSS_WithMissMass_NoSeisDisp.mod (.\Verification\MFM\Model-2)
3. RespSpectrumSRSS_WithMissMass_WithSeisDisp.mod (.\Verification\MFM\Model-3)
4. RespSpectrumCSM_NoMissMass_NoSeisDisp.mod (.\Verification\MFM\Model-4)
5. RespSpectrumCSM_WithMissMass_WithSeisDisp.mod (.\Verification\MFM\Model-5)
6. RespSpectrumABSS_NoMissMass_NoSeisDisp.mod (.\Verification \MFM\Model-6)

Model 1: RespSpectrumSRSS_NoMissMass_NoSeisDisp.mod

In this model, Response Spectrum load is defined and included in the analysis with **Mode Sum = SRSS**. In addition, the option "**Include Missing Mass**" was turned "**OFF**" and **NO Seismic Displacements** were entered at Anchor Nodes.

File "RespSpectrumSRSS_NoMissMass_NoSeisDisp_MFM.csv" contains the element forces and moments for each mode exported from CAEPIPE. The element forces and moments are then manually combined and compared against the CAEPIPE element forces and moments for Response Spectrum load case. The manually combined results are found to be identical to CAEPIPE computed results.

Please see the file RespSpectrumSRSS_NoMissMass_NoSeisDisp_MFM.xlsx for details.

Model 2: RespSpectrumSRSS_WithMissMass_NoSeisDisp.mod

In this model, Response Spectrum load is defined and included in the analysis with **Mode Sum = SRSS**. In addition, the option "**Include Missing Mass**" was turned "**ON**" and **NO Seismic Displacements** were entered at Anchor Nodes.

File "RespSpectrumSRSS_WithMissMass_NoSeisDisp_MFM.csv" contains the element forces and moments for each mode exported from CAEPIPE. The element forces and moments are then manually combined and compared against the CAEPIPE element forces and moments for Response Spectrum load case. The manually combined results are found to be identical to CAEPIPE computed results.

Please see the file RespSpectrumSRSS_WithMissMass_NoSeisDisp_MFM.xlsx for details.

Model 3: RespSpectrumSRSS_WithMissMass_WithSeisDisp.mod

In this model, Response Spectrum load is defined and included in the analysis with **Mode Sum = SRSS**. In addition, the option "**Include Missing Mass**" was turned "**ON**" and **Seismic Displacements** were entered as given below.

Seismic Displacements at Anchor @ **Node 10: X = Y = 0.5** inch & Anchor @ **Node 90: X = Y = -0.5 inch**

File "RespSpectrumSRSS_WithMissMass_WithSeisDisp_MFM.csv" contains the element forces and moments for each mode exported from CAEPIPE. The element forces and moments are then manually combined and compared against the CAEPIPE element forces and moments for Response Spectrum load case. The manually combined results are found to be identical to CAEPIPE computed results.

Please see the file RespSpectrumSRSS_WithMissMass_WithSeisDisp_MFM.xlsx for details.

Model 4: RespSpectrumCSM_NoMissMass_NoSeisDisp.mod

In this model, Response Spectrum load is defined and included in the analysis with **Mode Sum = Closely Spaced**. In addition, the option "**Include Missing Mass**" was turned "**OFF**" and **NO Seismic Displacements** were entered.

File "RespSpectrumCSM_NoMissMass_NoSeisDisp_MFM.csv" contains the element forces and moments for each mode exported from CAEPIPE. The element forces and moments are then manually combined and compared against the CAEPIPE element forces and moments for Response Spectrum load case. The manually combined results are found to be identical to CAEPIPE computed results.

Please see the file RespSpectrumCSM_NoMissMass_NoSeisDisp_MFM.xlsx for details.

Model 5: RespSpectrumCSM_WithMissMass_WithSeisDisp.mod

In this model, Response Spectrum load is defined and included in the analysis with **Mode Sum = Closely Spaced**. In addition, the option "**Include Missing Mass**" was turned "**On**" and **Seismic Displacements** were entered as given below.

Seismic Displacements at Anchor @ **Node 10: X = Y = 0.5** inch & Anchor @ **Node 90: X = Y = -0.5 inch**

File "RespSpectrumCSM_WithMissMass_WithSeisDisp_MFM.csv" contains the element forces and moments for each mode exported from CAEPIPE. The element forces and moments are then manually combined and compared against the CAEPIPE element forces and moments for Response Spectrum load case. The manually combined results are found to be identical to CAEPIPE computed results.

Please see the file RespSpectrumCSM_WithMissMass_WithSeisDisp_MFM.xlsx for details.

Model 6: RespSpectrumABSS_NoMissMass_NoSeisDisp.mod

In this model, Response Spectrum load is defined and included in the analysis with **Mode Sum = Absolute**. In addition, the option "**Include Missing Mass**" was turned "**OFF**" and No **Seismic Displacements** were entered at Anchor Nodes.

File "RespSpectrumABSS_NoMissMass_NoSeisDisp_MFM.csv" contains the element forces and moments for each mode exported from CAEPIPE. The element forces and moments are then manually combined and compared against the CAEPIPE element forces and moments for Response Spectrum load case. The manually combined results are found to be identical to CAEPIPE computed results.

Please see the file RespSpectrumCSM_WithMissMass_WithSeisDisp_MFM.xlsx for details.

From the comparison results of the above models, it was noted that the values obtained by manual combinations are exactly matching the CAEPIPE computed element forces and moments for Response Spectrum loadings.

CAEPIPE Input file for Model **"Model 1 - RespSpectrumSRSS_NoMissMass_NoSeisDisp.mod"** along with CAEPIPE Response Spectrum Element Forces and Moments results as well as the Forces and Moments manually combined from .CSV results is given below.

For rest of the models, CAEPIPE Response Spectrum Element Forces and Moments and the Forces and Moments manually combined from .csv results are presented in this section.

Similar verification is also carried out for a complex model (BIGMODEL_SRSS_MM_SD.mod – model with 650+ elements). The CAEPIPE input file, results file, modal element forces and moments output file and the modal element forces and moments manually combined using excel are available in the folder ".\Verification\MFM\Big Model" for reference. As the reports run into a few hundred pages (425+), they are not presented in this section.

Caepipe RespSpectrumSRSS_NoMissMass_NoSeisDisp Page 1
Version 7.60 Verification of Modal Forces and Moments Jul 14,2016

Options

```
Piping code = B31.1 (2014)
Do not use liberal allowable stresses
Do not include axial force in stress calculations
Reference temperature = 40 (F)
Number of thermal cycles = 7000
Number of thermal loads = 1
Thermal = Operating - Sustained
Use modulus at reference temperature
Include hanger stiffness
Include Bourdon effect
Use pressure correction for bends
Pressure stress = PD / 4t
Peak pressure factor = 1.00
Cut off frequency = 100 Hz
Number of modes = 5
Do not include missing mass correction
Use friction in dynamic analysis
Vertical direction = Y
```

#	Node	Type	DX(ft'in")	DY(ft'in")	DZ(ft'in")	Mat	Sec	Load	Data
1	Title = Verification of Modal Forces and Moments								
2									
3	Spectrum = SpecXYZ								
4	Mode Sum Combination = SRSS								
5	Direction Sum Combination = SRSS								
6	Include Missing Mass = No								
7	Seismic Displacements at Anchors								
8	Node 10: X = Y = Z = 0.0 inch								
9	Node 90: X = Y = Z = 0.0 inch								
10									
11	10	From							Anchor
12	20	Bend			11'0"	API	54I	54I	
13	30			-20'0"		API	54I	54I	
14	40	Bend		-10'9"		API	54I	54I	
15	50				9'0"	API	54I	54I	
16	60	Valve			2'0"	API	54O	54O	
17	70				6'0"	API	54O	54O	
18	80	Valve			2'0"	API	54O	54O	
19	90				9'0"	API	54O	54O	Anchor

Anchors

	(lb/inch)			(in-lb/deg)			Releases	Anchor
Node	KX/kx	KY/ky	KZ/kz	KXX/kxx	KYY/kyy	KZZ/kzz	X Y Z XXYYZZ	In Pipe
10	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
90	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS

Bends

Bend Node	Radius (inch)	Thickness (inch)	Bend Matl	Flex. Factor	Int. Node	Angle (deg)	Int. Node	Angle (deg)
20	81	L						
40	81	L						

Valves

From	To	Weight (lb)	Length (inch)	Thick X	Insul Wgt X	Add Wght (lb)	DX (inch)	DY (inch)	DZ (inch)
50	60	1000		3.00	1.75				
70	80	1000		3.00	1.75				

Pipe material API: API 5L Grade B

Density = 0.283 (lb/in3), Nu = 0.300, Joint factor = 1.00, Type = CS

Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
-325	31.4E+6	5.00E-6	20000
-200	30.8E+6	5.35E-6	20000
-100	30.2E+6	5.65E-6	20000
70	29.5E+6	6.07E-6	20000
200	28.8E+6	6.38E-6	20000
300	28.3E+6	6.60E-6	20000
400	27.7E+6	6.82E-6	19900
500	27.3E+6	7.02E-6	19000
600	26.7E+6	7.23E-6	17900
650	26.1E+6	7.33E-6	17300
700	25.5E+6	7.44E-6	16700
750	24.8E+6	7.54E-6	13900
800	24.2E+6	7.65E-6	11400
850	23.3E+6	7.75E-6	8700
900	22.4E+6	7.84E-6	5900
950	21.4E+6	7.91E-6	4000
1000	20.4E+6	7.97E-6	2500
1050	19.2E+6	8.05E-6	1600
1100	18.0E+6	8.12E-6	1000

Pipe Sections

Name	Nominal Dia.	Sch	O.D. (inch)	Thk (inch)	Cor.Al (inch)	M.Tol (%)	Ins.Dens (lb/ft3)	Ins.Th (inch)	Lin.Dens (lb/ft3)	Lin.Th (inch)
36I	36"	STD	36	0.375	0.075	0.0	13	2		
36O	36"	STD	36	0.375	0.075	0.0	13	2.5		
54O	Non Std		54	0.375	0.075	0.0	13	2.5		
54I	Non Std		54	0.375	0.075	0.0	13	2		

Loads

X spectrum: SpecXYZ Factor = 1.0000
Y spectrum: SpecXYZ Factor = 1.0000
Z spectrum: SpecXYZ Factor = 1.0000

Mode sum = SRSS Direction sum = SRSS

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
36O	100	125					1.000	77.2	Y
36I	100	125					1.000		
54O	100	125					1.000	111.1	Y
54I	100	125					1.000		

Spectrum = SpecXYZ, Interpolation: 1 = Linear, 2 = Linear

Frequency (Hz)	Displacement (inch)
8	0.2
30	0.2

Local & Global Element Forces and Moments for Response Spectrum from CAEPIPE

Caepipe RespSpectrumSRSS_NoMissMass_NoSeisDisp Page 4
Version 7.60 Verification of Modal Forces and Moments Jul 14,2016

Pipe element forces in local coordinates: Response spectrum

Node	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)	SIF	SL+SO (psi)
10	39153	65201	36207	158859	273116	493301		18158
20A	39153	65201	36207	158859	129233	229101		11228
20A	38957	62931	34542	158859	129233	229101	3.31	21220
20B	62931	38957	34542	139680	126821	169876	3.31	16525
20B	45042	14930	24342	139680	169876	126821		9338
30	45042	14930	24342	139680	367995	123498		10740
30	33037	13589	20162	139680	367995	123498		10740
40A	33037	13589	20162	139680	291622	103656		9439
40A	25357	55799	26790	139680	103656	291622	3.31	16774
40B	55799	25357	26790	117501	100429	249924	3.31	15090
40B	56897	8965	20867	117501	100429	249924		8761
50	56897	8965	20867	117501	118001	235518		8628
60	57946	39621	28915	117501	139344	202524		8510
70	57946	39621	28915	117501	253383	128460		9896
80	58894	63171	40310	117501	308558	200221		11476
90	58894	63171	40310	117501	632830	741756		23014

Other forces in local coordinates: Response spectrum

Node	Type	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)
50	Valve	57271	20158	22496	117501	118001	235518
60		57271	20158	22496	117501	139344	202524
70	Valve	58365	51089	34094	117501	253383	128460
80		58365	51089	34094	117501	308558	200221

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
10	36207	65201	39153	493301	273116	158859
20A	36207	65201	39153	229101	129233	158859

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
20A	34542	62931	38957	229101	129233	158859
20B	34542	62931	38957	169876	139680	126821
20B	14930	45042	24342	169876	139680	126821
30	14930	45042	24342	367995	139680	123498
30	13589	33037	20162	367995	139680	123498
40A	13589	33037	20162	291622	139680	103656
40A	26790	25357	55799	291622	139680	103656
40B	26790	25357	55799	249924	100429	117501
40B	20867	8965	56897	249924	100429	117501
50	20867	8965	56897	235518	118001	117501
60	28915	39621	57946	202524	139344	117501
70	28915	39621	57946	128460	253383	117501
80	40310	63171	58894	200221	308558	117501
90	40310	63171	58894	741756	632830	117501

Other forces in global coordinates: Response spectrum

Node	Type	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
50	Valve	22496	20158	57271	235518	118001	117501
60		22496	20158	57271	202524	139344	117501
70	Valve	34094	51089	58365	128460	253383	117501
80		34094	51089	58365	200221	308558	117501

Local Element Forces and Moment results obtained by combining forces and moments from each mode using SRSS

Combined Local Element Forces and Moments using SRSS							
Node	**Type**	**fx**	**fy**	**fz**	**mx**	**my**	**mz**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		39153	65201	36207	158859	273116	493301
20A		39153	65201	36207	158859	129233	229101
20A	Bend	38957	62931	34542	158859	129233	229101
20B		62931	38957	34542	139680	126821	169876
20B		45042	14930	24343	139680	169876	126821
30		45042	14930	24343	139680	367995	123498
30		33037	13589	20162	139680	367995	123498
40A		33037	13589	20162	139680	291622	103656
40A	Bend	25357	55799	26790	139680	103656	291622
40B		55799	25357	26790	117501	100429	249924
40B		56897	8965	20867	117501	100429	249924
50		56897	8965	20867	117501	118001	235518
50	Valve	57271	20158	22496	117501	118001	235518
60		57271	20158	22496	117501	139344	202524
60		57946	39621	28915	117501	139344	202524
70		57946	39621	28915	117501	253383	128460
70	Valve	58365	51089	34094	117501	253383	128460
80		58365	51089	34094	117501	308558	200221
80		58894	63171	40310	117501	308558	200221
90		58894	63171	40310	117501	632830	741756

Transformation of Local Element Forces and Moments to Global Forces and Moments

Transformation to Global Element Forces and Moments							
Node	**Type**	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		36207	65201	39153	493301	273116	158859
20A		36207	65201	39153	229101	129233	158859
20A	Bend	34542	62931	38957	229101	129233	158859
20B		34542	62931	38957	169876	139680	126821
20B		14930	45042	24343	169876	139680	126821
30		14930	45042	24343	367995	139680	123498
30		13589	33037	20162	367995	139680	123498
40A		13589	33037	20162	291622	139680	103656
40A	Bend	26790	25357	55799	291622	139680	103656
40B		26790	25357	55799	249924	100429	117501
40B		20867	8965	56897	249924	100429	117501
50		20867	8965	56897	235518	118001	117501
50	Valve	22496	20158	57271	235518	118001	117501
60		22496	20158	57271	202524	139344	117501
60		28915	39621	57946	202524	139344	117501
70		28915	39621	57946	128460	253383	117501
70	Valve	34094	51089	58365	128460	253383	117501
80		34094	51089	58365	200221	308558	117501
80		40310	63171	58894	200221	308558	117501
90		40310	63171	58894	741756	632830	117501

Local Element Forces and Moments from .CSV file for each Mode

Modal Local Forces & Moments: Mode = 1; Frequency = 6.434 Hz							
Node	Type	fx	fy	fz	mx	my	mz
		(lb)	(lb)	(lb)	(ft-lb)	(ft-lb)	(ft-lb)
10		0	0	-10641	108595.9	33473.79	0
20A		0	0	-10641	108595.9	-11750.4	0
20A	Bend	0	0	10566.63	108595.9	11750.42	0
20B		0	0	10566.63	83075.18	-37271.1	0
20B		0	-7473.5	0	83075.18	0	-37271.1
30		0	-7473.5	0	83075.18	0	61752.78
30		0	2485.93	0	83075.18	0	61752.78
40A		0	2485.93	0	83075.18	0	51809.06
40A	Bend	0	0	12722.87	83075.18	-51809.1	0
40B		0	0	12722.87	34070.34	2804.21	0
40B		0	0	19977.83	34070.33	2804.21	0
50		0	0	19977.83	34070.33	47754.34	0
50	Valve	0	0	22374.04	34070.33	47754.34	0
60		0	0	22374.04	34070.33	92502.43	0
60		0	0	26211.24	34070.33	92502.43	0
70		0	0	26211.24	34070.33	249769.9	0
70	Valve	0	0	28168.48	34070.33	249769.9	0
80		0	0	28168.48	34070.33	306106.8	0
80		0	0	30118.99	34070.33	306106.8	0
90		0	0	30118.99	34070.33	577177.8	0
Modal Local Forces & Moments: Mode = 2; Frequency = 8.302 Hz							
Node	Type	fx	fy	fz	mx	my	mz
		(lb)	(lb)	(lb)	(ft-lb)	(ft-lb)	(ft-lb)
10		12180.86	45587.7	0	0	0	409591.7
20A		12180.86	45587.7	0	0	0	215844
20A	Bend	12159.84	-44656.1	0	0	0	-215844
20B		-44656.1	-12159.8	0	0	0	167663.3
20B		-25920.2	0	3360.05	0	-167663	0
30		-25920.2	0	3360.05	0	-123143	0

30		-12208.8	0	11896.31	0	-123143	0
40A		-12208.8	0	11896.31	0	-75557.5	0
40A	Bend	-582	-17643	0	0	0	-75557.5
40B		-17643	582	0	0	0	39604.56
40B		-17759.8	-4969.95	0	0	0	39604.56
50		-17759.8	-4969.95	0	0	0	50786.95
50	Valve	-17799.5	-6794.15	0	0	0	50786.95
60		-17799.5	-6794.15	0	0	0	64375.24
60		-17871	-9697.85	0	0	0	64375.24
70		-17871	-9697.85	0	0	0	122562.3
70	Valve	-17915.1	-11163.9	0	0	0	122562.3
80		-17915.1	-11163.9	0	0	0	144890.1
80		-17970.9	-12618.6	0	0	0	144890.1
90		-17970.9	-12618.6	0	0	0	258457.6
Modal Local Forces & Moments: Mode = 3; Frequency = 13.461 Hz							
Node	Type	fx	fy	fz	mx	my	mz
		(lb)	(lb)	(lb)	(ft-lb)	(ft-lb)	(ft-lb)
10		0	0	-33841.1	97010.05	270865.2	0
20A		0	0	-33841.1	97010.05	127040.6	0
20A	Bend	0	0	32154.39	97010.05	-127041	0
20B		0	0	32154.39	90001.5	120032.1	0
20B		0	8925.33	0	90001.5	0	120032.1
30		0	8925.33	0	90001.5	0	1771.47
30		0	11317.81	0	90001.5	0	1771.47
40A		0	11317.81	0	90001.5	0	-43499.8
40A	Bend	0	0	5896.04	90001.5	43499.78	0
40B		0	0	5896.04	83298.08	-50203.2	0
40B		0	0	2966.17	83298.09	-50203.2	0
50		0	0	2966.17	83298.09	-43529.3	0
50	Valve	0	0	2038.89	83298.09	-43529.3	0
60		0	0	2038.89	83298.09	-39451.5	0

60		0	0	624.41	83298.09	-39451.5	0
70		0	0	624.41	83298.09	-35705.1	0
70	Valve	0	0	-25.07	83298.09	-35705.1	0
80		0	0	-25.07	83298.09	-35755.2	0
80		0	0	-642	83298.09	-35755.2	0
90		0	0	-642	83298.09	-41533.2	0
Modal Local Forces & Moments: Mode = 4; Frequency = 14.598 Hz							
Node	Type	fx	fy	fz	mx	my	mz
		(lb)	(lb)	(lb)	(ft-lb)	(ft-lb)	(ft-lb)
10		37209.57	-46615.4	0	0	0	-274919
20A		37209.57	-46615.4	0	0	0	-76803.5
20A	Bend	37011.06	44340.69	0	0	0	76803.53
20B		44340.68	-37011.1	0	0	0	27328.54
20B		36836.52	0	-24109.5	0	-27328.5	0
30		36836.52	0	-24109.5	0	-346779	0
30		30698.08	0	16278.78	0	-346779	0
40A		30698.08	0	16278.78	0	-281664	0
40A	Bend	25350.07	-52935.9	0	0	0	-281664
40B		-52935.9	-25350.1	0	0	0	246766.1
40B		-54054.1	7461.62	0	0	0	246766.1
50		-54054.1	7461.62	0	0	0	229977.4
50	Valve	-54435.3	18978.66	0	0	0	229977.4
60		-54435.3	18978.66	0	0	0	192020.1
60		-55121.4	38416.12	0	0	0	192020.1
70		-55121.4	38416.12	0	0	0	-38476.7
70	Valve	-55547.3	49854.82	0	0	0	-38476.7
80		-55547.3	49854.82	0	0	0	-138186
80		-56085.1	61898.24	0	0	0	-138186
90		-56085.1	61898.24	0	0	0	-695271
Modal Local Forces & Moments: Mode = 5; Frequency = 19.091 Hz							
Node	Type	fx	fy	fz	mx	my	mz
		(lb)	(lb)	(lb)	(ft-lb)	(ft-lb)	(ft-lb)

10		0	0	7243.81	-63500.5	-10203.3	0
20A		0	0	7243.81	-63500.5	20582.93	0
20A	Bend	0	0	-6898.47	-63500.5	-20582.9	0
20B		0	0	-6898.47	-67147.6	16935.89	0
20B		0	9348.74	0	-67147.6	0	16935.89
30		0	9348.74	0	-67147.6	0	-106935
30		0	-7099.32	0	-67147.6	0	-106935
40A		0	-7099.32	0	-67147.6	0	-78537.7
40A	Bend	0	0	-22827.2	-67147.6	78537.69	0
40B		0	0	-22827.2	-75545.6	-86935.7	0
40B		0	0	-5244.73	-75545.6	-86935.7	0
50		0	0	-5244.73	-75545.6	-98736.4	0
50	Valve	0	0	1140.18	-75545.6	-98736.4	0
60		0	0	1140.18	-75545.6	-96456	0
60		0	0	12191.44	-75545.6	-96456	0
70		0	0	12191.44	-75545.6	-23307.4	0
70	Valve	0	0	19207.2	-75545.6	-23307.4	0
80		0	0	19207.2	-75545.6	15107.05	0
80		0	0	26782.85	-75545.6	15107.05	0
90		0	0	26782.85	-75545.6	256152.7	0

Local & Global Element Forces and Moments for Response Spectrum from CAEPIPE for Model 2: RespSpectrumSRSS_WithMissMass_NoSeisDisp.mod

```
Caepipe            RespSpectrumSRSS_WithMissMass_NoSeisDisp       Page 1
Version 7.60       Verification of Modal Forces and Moments       Jul 14,2016
```

Pipe element forces in local coordinates: Response spectrum

Node	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)	SIF	SL+SO (psi)
10	132689	118937	70303	159112	363212	683223		21071
20A	132689	118937	70303	159112	130305	240453		11358
20A	78282	83746	34672	159112	130305	240453	3.31	21544
20B	83746	78282	34672	139726	127325	230779	3.31	18101
20B	49613	15034	27879	139726	230779	127325		9973
30	49613	15034	27879	139726	379204	124085		10886
30	38742	13590	24973	139726	379204	124085		10886
40A	38742	13590	24973	139726	298847	104373		9531
40A	46612	64462	26889	139726	104373	298847	3.31	17003
40B	64462	46612	26889	117549	102242	267522	3.31	15648
40B	101966	25798	25878	117549	102242	267522		8985
50	101966	25798	25878	117549	118984	270115		9046
60	157621	43752	34345	117549	148840	257247		9182
70	157621	43752	34345	117549	301564	234097		11209
80	250547	78402	52625	117549	348739	265998		12446
90	250547	78402	52625	117549	648558	783679		23613

Other forces in local coordinates: Response spectrum

Node	Type	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)
50	Valve	120517	29154	29139	117549	118984	270115
60		120517	29154	29139	117549	148840	257247
70	Valve	196540	53966	34097	117549	301564	234097
80		196540	53966	34097	117549	348739	265998

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
10	70303	118937	132689	683223	363212	159112
20A	70303	118937	132689	240453	130305	159112
20A	34672	83746	78282	240453	130305	159112
20B	34672	83746	78282	230779	139726	127325
20B	15034	49613	27879	230779	139726	127325
30	15034	49613	27879	379204	139726	124085

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
30	13590	38742	24973	379204	139726	124085
40A	13590	38742	24973	298847	139726	104373
40A	26889	46612	64462	298847	139726	104373
40B	26889	46612	64462	267522	102242	117549
40B	25878	25798	101966	267522	102242	117549
50	25878	25798	101966	270115	118984	117549
60	34345	43752	157621	257247	148840	117549
70	34345	43752	157621	234097	301564	117549
80	52625	78402	250547	265998	348739	117549
90	52625	78402	250547	783679	648558	117549

Other forces in global coordinates: Response spectrum

Node	Type	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
50	Valve	29139	29154	120517	270115	118984	117549
60		29139	29154	120517	257247	148840	117549
70	Valve	34097	53966	196540	234097	301564	117549
80		34097	53966	196540	265998	348739	117549

Combination of Local Element Forces and Moments using SRSS (Missing Mass included and Seismic Displacements NOT defined)							
Node	**Type**	**fx**	**fy**	**fz**	**mx**	**my**	**mz**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		132689	118937	70303	159112	363212	683223
20A		132689	118937	70303	159112	130305	240453
20A	Bend	78282	83746	34672	159112	130305	240453
20B		83746	78282	34672	139726	127325	230779
20B		49613	15034	27879	139726	230779	127325
30		49613	15034	27879	139726	379204	124085
30		38742	13589	24973	139726	379204	124085
40A		38742	13589	24973	139726	298847	104373
40A	Bend	46612	64462	26889	139726	104373	298847
40B		64462	46612	26889	117549	102242	267522
40B		101966	25798	25878	117549	102242	267522
50		101966	25798	25878	117549	118984	270115
50	Valve	120517	29154	29139	117549	118984	270115
60		120517	29154	29139	117549	148840	257247
60		157621	43752	34345	117549	148840	257247
70		157621	43752	34345	117549	301564	234097
70	Valve	196540	53966	34097	117549	301564	234097
80		196540	53966	34097	117549	348739	265998
80		250547	78402	52625	117549	348739	265998
90		250547	78402	52625	117549	648558	783679

Transformation to Global Element Forces and Moments (Missing Mass included and Seismic Displacements NOT defined)							
Node	Type	FX	FY	FZ	MX	MY	MZ
		(lb)	(lb)	(lb)	(ft-lb)	(ft-lb)	(ft-lb)
10		70303	118937	132689	683223	363212	159112
20A		70303	118937	132689	240453	130305	159112
20A	Bend	34672	83746	78282	240453	130305	159112
20B		34672	83746	78282	230779	139726	127325
20B		15034	49613	27879	230779	139726	127325
30		15034	49613	27879	379204	139726	124085
30		13589	38742	24973	379204	139726	124085
40A		13589	38742	24973	298847	139726	104373
40A	Bend	26889	46612	64462	298847	139726	104373
40B		26889	46612	64462	267522	102242	117549
40B		25878	25798	101966	267522	102242	117549
50		25878	25798	101966	270115	118984	117549
50	Valve	29139	29154	120517	270115	118984	117549
60		29139	29154	120517	257247	148840	117549
60		34345	43752	157621	257247	148840	117549
70		34345	43752	157621	234097	301564	117549
70	Valve	34097	53966	196540	234097	301564	117549
80		34097	53966	196540	265998	348739	117549
80		52625	78402	250547	265998	348739	117549
90		52625	78402	250547	783679	648558	117549

Local & Global Element Forces and Moments for Response Spectrum from CAEPIPE for Model 3: RespSpectrumSRSS_WithMissMass_WithSeisDisp.mod

```
Caepipe             RespSpectrumSRSS_WithMissMass_NoSeisDisp       Page 1
Version 7.60        Verification of Modal Forces and Moments       Jul 14,2016
```

Pipe element forces in local coordinates: Response spectrum

Node	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)	SIF	SL+SO (psi)
10	148402	179646	76537	258926	436164	1137906		27575
20A	148402	179646	76537	258926	176764	437125		14518
20A	93996	144455	40906	258926	176764	437125	3.31	29398
20B	144455	93996	40906	144108	185063	337825	3.31	22106
20B	110322	21268	43592	144108	337825	185063		11584
30	110322	21268	43592	144108	480361	148942		12318
30	99451	19823	40686	144108	480361	148942		12318
40A	99451	19823	40686	144108	462859	154165		11852
40A	107321	80175	33123	144108	154165	462859	3.31	22771
40B	80175	107321	33123	209418	139937	407228	3.31	21649
40B	117679	86507	32112	209418	139937	407228		11400
50	117679	86507	32112	209418	170705	546415		13210
60	173335	104461	40578	209418	213028	654964		14893
70	173335	104461	40578	209418	403154	996067		21130
80	266261	139110	58859	209418	462796	1149385		23896
90	266261	139110	58859	209418	818717	2213445		42806

Other forces in local coordinates: Response spectrum

Node	Type	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)
50	Valve	136230	89863	35373	209418	170705	546415
60		136230	89863	35373	209418	213028	654964
70	Valve	212254	114675	40331	209418	403154	996067
80		212254	114675	40331	209418	462796	1149385

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
10	76537	179646	148402	1137906	436164	258926
20A	76537	179646	148402	437125	176764	258926
20A	40906	144455	93996	437125	176764	258926
20B	40906	144455	93996	337825	144108	185063
20B	21268	110322	43592	337825	144108	185063
30	21268	110322	43592	480361	144108	148942

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
30	19823	99451	40686	480361	144108	148942
40A	19823	99451	40686	462859	144108	154165
40A	33123	107321	80175	462859	144108	154165
40B	33123	107321	80175	407228	139937	209418
40B	32112	86507	117679	407228	139937	209418
50	32112	86507	117679	546415	170705	209418
60	40578	104461	173335	654964	213028	209418
70	40578	104461	173335	996067	403154	209418
80	58859	139110	266261	1149385	462796	209418
90	58859	139110	266261	2213445	818717	209418

Other forces in global coordinates: Response spectrum

Node	Type	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
50	Valve	35373	89863	136230	546415	170705	209418
60		35373	89863	136230	654964	213028	209418
70	Valve	40331	114675	212254	996067	403154	209418
80		40331	114675	212254	1149385	462796	209418

Combination of Local Element Forces and Moments using SRSS (Missing Mass included and Seismic Displacements defined)							
Node	**Type**	**fx**	**fy**	**fz**	**mx**	**my**	**mz**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		148402	179646	76537	258926	436164	1137906
20A		148402	179646	76537	258926	176764	437124
20A	Bend	93996	144455	40906	258926	176764	437124
20B		144455	93996	40906	144108	185063	337825
20B		110322	21268	43592	144108	337825	185063
30		110322	21268	43592	144108	480361	148942
30		99451	19823	40686	144108	480361	148942
40A		99451	19823	40686	144108	462859	154165
40A	Bend	107321	80175	33123	144108	154165	462859
40B		80175	107321	33123	209418	139937	407228
40B		117679	86507	32112	209418	139937	407228
50		117679	86507	32112	209418	170705	546415
50	Valve	136230	89863	35373	209418	170705	546415
60		136230	89863	35373	209418	213028	654964
60		173335	104461	40578	209418	213028	654964
70		173335	104461	40578	209418	403154	996067
70	Valve	212254	114674	40331	209418	403154	996067
80		212254	114674	40331	209418	462796	1149385
80		266261	139110	58859	209418	462796	1149385
90		266261	139110	58859	209418	818717	2213444

Transformation to Global Element Forces and Moments (Missing Mass included and Seismic Displacements defined)							
Node	**Type**	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		76537	179646	148402	1137906	436164	258926
20A		76537	179646	148402	437124	176764	258926
20A	Bend	40906	144455	93996	437124	176764	258926
20B		40906	144455	93996	337825	144108	185063
20B		21268	110322	43592	337825	144108	185063
30		21268	110322	43592	480361	144108	148942
30		19823	99451	40686	480361	144108	148942
40A		19823	99451	40686	462859	144108	154165
40A	Bend	33123	107321	80175	462859	144108	154165
40B		33123	107321	80175	407228	139937	209418
40B		32112	86507	117679	407228	139937	209418
50		32112	86507	117679	546415	170705	209418
50	Valve	35373	89863	136230	546415	170705	209418
60		35373	89863	136230	654964	213028	209418
60		40578	104461	173335	654964	213028	209418
70		40578	104461	173335	996067	403154	209418
70	Valve	40331	114674	212254	996067	403154	209418
80		40331	114674	212254	1149385	462796	209418
80		58859	139110	266261	1149385	462796	209418
90		58859	139110	266261	2213444	818717	209418

Local & Global Element Forces and Moments for Response Spectrum from CAEPIPE for Model 4: RespSpectrumCSM_NoMissMass_NoSeisDisp.mod

```
Caepipe            RespSpectrumCSM_NoMissMass_NoSeisDisp         Page 1
Version 7.60      Verification of Modal Forces and Moments       Jul 14,2016
```

Pipe element forces in local coordinates: Response spectrum

Node	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)	SIF	SL+SO (psi)
10	39153	65201	36207	158859	273116	493301		18158
20A	39153	65201	36207	158859	129233	229101		11228
20A	38957	62931	34542	158859	129233	229101	3.31	21220
20B	62931	38957	34542	139680	126821	169876	3.31	16525
20B	45042	14930	24342	139680	169876	126821		9338
30	45042	14930	24342	139680	367995	123498		10740
30	33037	13589	20162	139680	367995	123498		10740
40A	33037	13589	20162	139680	291622	103656		9439
40A	25357	55799	26790	139680	103656	291622	3.31	16774
40B	55799	25357	26790	117501	100429	249924	3.31	15090
40B	56897	8965	20867	117501	100429	249924		8761
50	56897	8965	20867	117501	118001	235518		8628
60	57946	39621	28915	117501	139344	202524		8510
70	57946	39621	28915	117501	253383	128460		9896
80	58894	63171	40310	117501	308558	200221		11476
90	58894	63171	40310	117501	632830	741756		23014

Other forces in local coordinates: Response spectrum

Node	Type	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)
50	Valve	57271	20158	22496	117501	118001	235518
60		57271	20158	22496	117501	139344	202524
70	Valve	58365	51089	34094	117501	253383	128460
80		58365	51089	34094	117501	308558	200221

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
10	36207	65201	39153	493301	273116	158859
20A	36207	65201	39153	229101	129233	158859
20A	34542	62931	38957	229101	129233	158859
20B	34542	62931	38957	169876	139680	126821
20B	14930	45042	24342	169876	139680	126821
30	14930	45042	24342	367995	139680	123498

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
30	13589	33037	20162	367995	139680	123498
40A	13589	33037	20162	291622	139680	103656
40A	26790	25357	55799	291622	139680	103656
40B	26790	25357	55799	249924	100429	117501
40B	20867	8965	56897	249924	100429	117501
50	20867	8965	56897	235518	118001	117501
60	28915	39621	57946	202524	139344	117501
70	28915	39621	57946	128460	253383	117501
80	40310	63171	58894	200221	308558	117501
90	40310	63171	58894	741756	632830	117501

Other forces in global coordinates: Response spectrum

Node	Type	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
50	Valve	22496	20158	57271	235518	118001	117501
60		22496	20158	57271	202524	139344	117501
70	Valve	34094	51089	58365	128460	253383	117501
80		34094	51089	58365	200221	308558	117501

Combination of Local Element Forces and Moments using CSM (Missing Mass NOT included and Seismic Displacements NOT defined)							
Node	**Type**	**fx**	**fy**	**fz**	**mx**	**my**	**mz**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		39153	65201	36207	158859	273116	493301
20A		39153	65201	36207	158859	129233	229101
20A	Bend	38957	62931	34542	158859	129233	229101
20B		62931	38957	34542	139680	126821	169876
20B		45042	14930	24343	139680	169876	126821
30		45042	14930	24343	139680	367995	123498
30		33037	13589	20162	139680	367995	123498
40A		33037	13589	20162	139680	291622	103656
40A	Bend	25357	55799	26790	139680	103656	291622
40B		55799	25357	26790	117501	100429	249924
40B		56897	8965	20867	117501	100429	249924
50		56897	8965	20867	117501	118001	235518
50	Valve	57271	20158	22496	117501	118001	235518
60		57271	20158	22496	117501	139344	202524
60		57946	39621	28915	117501	139344	202524
70		57946	39621	28915	117501	253383	128460
70	Valve	58365	51089	34094	117501	253383	128460
80		58365	51089	34094	117501	308558	200221
80		58894	63171	40310	117501	308558	200221
90		58894	63171	40310	117501	632830	741756

Transformation to Global Element Forces and Moments (Missing Mass NOT included and Seismic Displacements NOT defined)							
Node	**Type**	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		36207	65201	39153	493301	273116	158859
20A		36207	65201	39153	229101	129233	158859
20A	Bend	34542	62931	38957	229101	129233	158859
20B		34542	62931	38957	169876	139680	126821
20B		14930	45042	24343	169876	139680	126821
30		14930	45042	24343	367995	139680	123498
30		13589	33037	20162	367995	139680	123498
40A		13589	33037	20162	291622	139680	103656
40A	Bend	26790	25357	55799	291622	139680	103656
40B		26790	25357	55799	249924	100429	117501
40B		20867	8965	56897	249924	100429	117501
50		20867	8965	56897	235518	118001	117501
50	Valve	22496	20158	57271	235518	118001	117501
60		22496	20158	57271	202524	139344	117501
60		28915	39621	57946	202524	139344	117501
70		28915	39621	57946	128460	253383	117501
70	Valve	34094	51089	58365	128460	253383	117501
80		34094	51089	58365	200221	308558	117501
80		40310	63171	58894	200221	308558	117501
90		40310	63171	58894	741756	632830	117501

Local & Global Element Forces and Moments for Response Spectrum from CAEPIPE for Model 5: RespSpectrumCSM_WithMissMass_WithSeisDisp.mod

```
Caepipe            RespSpectrumCSM_WithMissMass_WithSeisDisp       Page 1
Version 7.60        Verification of Modal Forces and Moments       Jul 14,2016
```

Pipe element forces in local coordinates: Response spectrum

Node	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)	SIF	SL+SO (psi)
10	148402	179646	76537	258926	436164	1137906		27575
20A	148402	179646	76537	258926	176764	437125		14518
20A	93996	144455	40906	258926	176764	437125	3.31	29398
20B	144455	93996	40906	144108	185063	337825	3.31	22106
20B	110322	21268	43592	144108	337825	185063		11584
30	110322	21268	43592	144108	480361	148942		12318
30	99451	19823	40686	144108	480361	148942		12318
40A	99451	19823	40686	144108	462859	154165		11852
40A	107321	80175	33123	144108	154165	462859	3.31	22771
40B	80175	107321	33123	209418	139937	407228	3.31	21649
40B	117679	86507	32112	209418	139937	407228		11400
50	117679	86507	32112	209418	170705	546415		13210
60	173335	104461	40578	209418	213028	654964		14893
70	173335	104461	40578	209418	403154	996067		21130
80	266261	139110	58859	209418	462796	1149385		23896
90	266261	139110	58859	209418	818717	2213445		42806

Other forces in local coordinates: Response spectrum

Node	Type	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)
50	Valve	136230	89863	35373	209418	170705	546415
60		136230	89863	35373	209418	213028	654964
70	Valve	212254	114675	40331	209418	403154	996067
80		212254	114675	40331	209418	462796	1149385

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
10	76537	179646	148402	1137906	436164	258926
20A	76537	179646	148402	437125	176764	258926
20A	40906	144455	93996	437125	176764	258926
20B	40906	144455	93996	337825	144108	185063
20B	21268	110322	43592	337825	144108	185063
30	21268	110322	43592	480361	144108	148942

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
30	19823	99451	40686	480361	144108	148942
40A	19823	99451	40686	462859	144108	154165
40A	33123	107321	80175	462859	144108	154165
40B	33123	107321	80175	407228	139937	209418
40B	32112	86507	117679	407228	139937	209418
50	32112	86507	117679	546415	170705	209418
60	40578	104461	173335	654964	213028	209418
70	40578	104461	173335	996067	403154	209418
80	58859	139110	266261	1149385	462796	209418
90	58859	139110	266261	2213445	818717	209418

Other forces in global coordinates: Response spectrum

Node	Type	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
50	Valve	35373	89863	136230	546415	170705	209418
60		35373	89863	136230	654964	213028	209418
70	Valve	40331	114675	212254	996067	403154	209418
80		40331	114675	212254	1149385	462796	209418

Combination of Local Element Forces and Moments using CSM (Missing Mass included and Seismic Displacements defined)							
Node	**Type**	**fx**	**fy**	**fz**	**mx**	**my**	**mz**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		148402	179646	76537	258926	436164	1137906
20A		148402	179646	76537	258926	176764	437124
20A	Bend	93996	144455	40906	258926	176764	437124
20B		144455	93996	40906	144108	185063	337825
20B		110322	21268	43592	144108	337825	185063
30		110322	21268	43592	144108	480361	148942
30		99451	19823	40686	144108	480361	148942
40A		99451	19823	40686	144108	462859	154165
40A	Bend	107321	80175	33123	144108	154165	462859
40B		80175	107321	33123	209418	139937	407228
40B		117679	86507	32112	209418	139937	407228
50		117679	86507	32112	209418	170705	546415
50	Valve	136230	89863	35373	209418	170705	546415
60		136230	89863	35373	209418	213028	654964
60		173335	104461	40578	209418	213028	654964
70		173335	104461	40578	209418	403154	996067
70	Valve	212254	114674	40331	209418	403154	996067
80		212254	114674	40331	209418	462796	1149385
80		266261	139110	58859	209418	462796	1149385
90		266261	139110	58859	209418	818717	2213444

Transformation to Global Element Forces and Moments (Missing Mass included and Seismic Displacements defined)							
Node	**Type**	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		76537	179646	148402	1137906	436164	258926
20A		76537	179646	148402	437124	176764	258926
20A	Bend	40906	144455	93996	437124	176764	258926
20B		40906	144455	93996	337825	144108	185063
20B		21268	110322	43592	337825	144108	185063
30		21268	110322	43592	480361	144108	148942
30		19823	99451	40686	480361	144108	148942
40A		19823	99451	40686	462859	144108	154165
40A	Bend	33123	107321	80175	462859	144108	154165
40B		33123	107321	80175	407228	139937	209418
40B		32112	86507	117679	407228	139937	209418
50		32112	86507	117679	546415	170705	209418
50	Valve	35373	89863	136230	546415	170705	209418
60		35373	89863	136230	654964	213028	209418
60		40578	104461	173335	654964	213028	209418
70		40578	104461	173335	996067	403154	209418
70	Valve	40331	114674	212254	996067	403154	209418
80		40331	114674	212254	1149385	462796	209418
80		58859	139110	266261	1149385	462796	209418
90		58859	139110	266261	2213444	818717	209418

Local & Global Element Forces and Moments for Response Spectrum from CAEPIPE for Model 6: RespSpectrumABSS_NoMissMass_NoSeisDisp.mod

```
Caepipe              RespSpectrumABSS_NoMissMass_NoSeisDisp        Page 1
Version 7.60        Verification of Modal Forces and Moments       Jul 14,2016
```

Pipe element forces in local coordinates: Response spectrum

Node	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)	SIF	SL+SO (psi)
10	49390	92203	51726	269107	314542	684511		21213
20A	49390	92203	51726	269107	159374	292648		12954
20A	49171	88997	49619	269107	159374	292648	3.31	25512
20B	88997	49171	49619	240224	174239	194992	3.31	20114
20B	62757	25748	27470	240224	194992	174239		10782
30	62757	25748	27470	240224	469922	170459		12767
30	42907	20903	28175	240224	469922	170459		12767
40A	42907	20903	28175	240224	357222	173847		11218
40A	25932	70579	41446	240224	173847	357222	3.31	21196
40B	70579	25932	41446	192914	139943	286371	3.31	17881
40B	71814	12432	28189	192914	139943	286371		9884
50	71814	12432	28189	192914	190020	280764		10078
60	72992	48114	39027	192914	228410	256395		10241
70	72992	48114	39027	192914	308782	161039		11190
80	74056	74517	57544	192914	356969	283076		13026
90	74056	74517	57544	192914	874864	953728		27672

Other forces in local coordinates: Response spectrum

Node	Type	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)
50	Valve	72235	25773	25553	192914	190020	280764
60		72235	25773	25553	192914	228410	256395
70	Valve	73462	61019	47401	192914	308782	161039
80		73462	61019	47401	192914	356969	283076

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
10	51726	92203	49390	684511	314542	269107
20A	51726	92203	49390	292648	159374	269107
20A	49619	88997	49171	292648	159374	269107
20B	49619	88997	49171	194992	240224	174239
20B	25748	62757	27470	194992	240224	174239
30	25748	62757	27470	469922	240224	170459

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
30	20903	42907	28175	469922	240224	170459
40A	20903	42907	28175	357222	240224	173847
40A	41446	25932	70579	357222	240224	173847
40B	41446	25932	70579	286371	139943	192914
40B	28189	12432	71814	286371	139943	192914
50	28189	12432	71814	280764	190020	192914
60	39027	48114	72992	256395	228410	192914
70	39027	48114	72992	161039	308782	192914
80	57544	74517	74056	283076	356969	192914
90	57544	74517	74056	953728	874864	192914

Other forces in global coordinates: Response spectrum

Node	Type	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
50	Valve	25553	25773	72235	280764	190020	192914
60		25553	25773	72235	256395	228410	192914
70	Valve	47401	61019	73462	161039	308782	192914
80		47401	61019	73462	283076	356969	192914

Combination of Local Element Forces and Moments using Absolute Sum (Missing Mass NOT included and Seismic Displacements NOT defined)							
Node	**Type**	**fx**	**fy**	**fz**	**mx**	**my**	**mz**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		49390	92203	51726	269106	314542	684511
20A		49390	92203	51726	269106	159374	292648
20A	Bend	49171	88997	49619	269106	159374	292648
20B		88997	49171	49619	240224	174239	194992
20B		62757	25748	27470	240224	194992	174239
30		62757	25748	27470	240224	469922	170459
30		42907	20903	28175	240224	469922	170459
40A		42907	20903	28175	240224	357222	173847
40A	Bend	25932	70579	41446	240224	173847	357222
40B		70579	25932	41446	192914	139943	286371
40B		71814	12432	28189	192914	139943	286371
50		71814	12432	28189	192914	190020	280764
50	Valve	72235	25773	25553	192914	190020	280764
60		72235	25773	25553	192914	228410	256395
60		72992	48114	39027	192914	228410	256395
70		72992	48114	39027	192914	308782	161039
70	Valve	73462	61019	47401	192914	308782	161039
80		73462	61019	47401	192914	356969	283076
80		74056	74517	57544	192914	356969	283076
90		74056	74517	57544	192914	874864	953728

Transformation to Global Element Forces and Moments (Missing Mass NOT included and Seismic Displacements NOT defined)							
Node	**Type**	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		51726	92203	49390	684511	314542	269106
20A		51726	92203	49390	292648	159374	269106
20A	Bend	49619	88997	49171	292648	159374	269106
20B		49619	88997	49171	194992	240224	174239
20B		25748	62757	27470	194992	240224	174239
30		25748	62757	27470	469922	240224	170459
30		20903	42907	28175	469922	240224	170459
40A		20903	42907	28175	357222	240224	173847
40A	Bend	41446	25932	70579	357222	240224	173847
40B		41446	25932	70579	286371	139943	192914
40B		28189	12432	71814	286371	139943	192914
50		28189	12432	71814	280764	190020	192914
50	Valve	25553	25773	72235	280764	190020	192914
60		25553	25773	72235	256395	228410	192914
60		39027	48114	72992	256395	228410	192914
70		39027	48114	72992	161039	308782	192914
70	Valve	47401	61019	73462	161039	308782	192914
80		47401	61019	73462	283076	356969	192914
80		57544	74517	74056	283076	356969	192914
90		57544	74517	74056	953728	874864	192914

Annexure C

NRL procedure for combing modes

NRL Method

The following NRL Sum formula developed by the Naval Research Laboratory (NRL) is used for calculating the total response (displacements and forces).

$$R_i = |R_{ia}| + \sqrt{\left(\sum_{b=1}^{N} R_{ib}^2\right) - R_{ia}^2}$$

where,

R_i = Total (combined) response
R_{ia}= value of the largest response among all the modes
R_{ib} = value of the response due to the nth mode
N = Number of significant modes

Verification of NRL Method

A new feature is added in CAEPIPE Version 7.60 to automatically export in csv format Element Forces and Moments in Local coordinate system contributed by each mode participating in Response Spectrum analysis.

In order to verify the implementation of modal summation by NRL method, a CAEPIPE model has been created with name "**RespSpectrumNRL.mod**". A Response Spectrum load was defined and included in the analysis with **Mode Sum = NRL**. In addition, the option "**Include Missing Mass**" was turned "**ON**" and "**Seismic Displacements"** were entered at Anchor Nodes.

Analysis was then performed to export the modal Element Forces and Moments in CSV format as stated above. The Element Forces and Moments thus contributed by each mode are then combined manually using the NRL method equation listed above and compared against the Element Forces and Moments obtained from CAEPIPE by selecting NRL method.

From the comparison results, it was noted that the values obtained by manual combinations are exactly matching with the CAEPIPE computed element forces and moments for Response Spectrum loadings.

CAEPIPE Input file for the model **"RespSpectrumNRL.mod"** along with CAEPIPE Response Spectrum Element Forces and Moments results for NRL summation as well as the Forces and Moments manually combined from .CSV results are given below in this section.

In addition to the above, the displacement and acceleration results obtained from CAEPIPE for NRL summation for the model "ResSpec_NRLSum_DISP_ACC.mod" (available in the folder ".\Verification\NRL\Model_1\DISP_ACC") are verified against the manually combined displacements and accelerations using NRL summation and presented in this section.

CAEPIPE input file, results file, modal forces and moments output file (.csv) and element forces and moments combined manually using NRM summation are available in the folder "\NRL\Model_1\MFM" for reference. Similarly, CAEPIPE input file, results file and displacements & accelerations combined manually using NRM summation are available in the folder ".\Verification\NRL\Model_1\DISP_ACC " for reference.

Similar verification is also carried out for a complex model with 650+ elements. The CAEPIPE input file, results file, modal element forces and moments output file in csv format, modal element forces and moments manually combined using excel, modal displacements and accelerations manually combined using excel for NRL summation are available in the folder ".\Verification\NRL\Bigmodel" for reference. As the reports run into a few hundred pages (425+), they are not presented in this section.

Options

Piping code = B31.1 (2014)
Do not use liberal allowable stresses
Do not include axial force in stress calculations
Reference temperature = 40 (F)
Number of thermal cycles = 7000
Number of thermal loads = 1
Thermal = Operating - Sustained
Use modulus at reference temperature
Include hanger stiffness
Include Bourdon effect
Use pressure correction for bends
Pressure stress = PD / 4t
Peak pressure factor = 1.00
Cut off frequency = 110 Hz
Number of modes = 5
Include missing mass correction
Use friction in dynamic analysis
Vertical direction = Y

#	Node	Type	DX(ft'in")	DY(ft'in")	DZ(ft'in")	Mat	Sec	Load	Data
1	Title = Verification of NRL Modal Summation								
2									
3	Spectrum = Test								
4	Mode Sum Combination = NRL								
5	Direction Sum Combination = SRRS								
6	Include Missing Mass = Yes								
7	Seismic Displacements at Anchors								
8	Node 10: X = Y = 0.5 inch Z = 0								
9	Node 65: X = Y = -0.5 inch Z = 0								
10									
11	10	From							Anchor
12	20	Bend			11'0"	API	54I	54I	
13	30			-20'0"		API	54I	54I	
14	40	Bend		-10'9"		API	54I	54I	
15	50				9'0"	API	54I	54I	
16	60	Valve			2'0"	API	54O	54O	
17	62	Valve			1'0"	API	54O	54O	
18	65				9'0"	API	54O	54O	Anchor

Anchors

	(lb/inch)			(in-lb/deg)			Releases	Anchor
Node	KX/kx	KY/ky	KZ/kz	KXX/kxx	KYY/kyy	KZZ/kzz	X Y Z XXYYZZ	In Pipe
10	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
65	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS

Bends

Bend Node	Radius (inch)	Thickness (inch)	Bend Matl	Flex. Factor	Int. Node	Angle (deg)	Int. Node	Angle (deg)
20	81 L							

Bends

Bend Node	Radius (inch)	Thickness (inch)	Bend Matl	Flex. Factor	Int. Node	Angle (deg)	Int. Node	Angle (deg)
40	81	L						

Specified Displacements

Node	Type	Load	X(inch)	Y(inch)	Z(inch)	XX(deg)	YY(deg)	ZZ(deg)	In Pipe
10	Anchor	T1							
		Seis	0.5	0.5	0.0				GCS
65	Anchor	T1							
		Seis	-0.5	-0.5	0.0				GCS

Valves

From	To	Weight (lb)	Length (inch)	Thick X	Insul Wgt X	Add Wght (lb)	DX (inch)	DY (inch)	DZ (inch)
50	60	0		3.00	1.75				
60	62	0		3.00	1.75				

Pipe material API: API 5L Grade B

Density = 0.283 (lb/in3), Nu = 0.300, Joint factor = 1.00, Type = CS

Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
-325	31.4E+6	5.00E-6	20000
-200	30.8E+6	5.35E-6	20000
-100	30.2E+6	5.65E-6	20000
70	29.5E+6	6.07E-6	20000
200	28.8E+6	6.38E-6	20000
300	28.3E+6	6.60E-6	20000
400	27.7E+6	6.82E-6	19900
500	27.3E+6	7.02E-6	19000
600	26.7E+6	7.23E-6	17900
650	26.1E+6	7.33E-6	17300
700	25.5E+6	7.44E-6	16700
750	24.8E+6	7.54E-6	13900
800	24.2E+6	7.65E-6	11400
850	23.3E+6	7.75E-6	8700
900	22.4E+6	7.84E-6	5900
950	21.4E+6	7.91E-6	4000
1000	20.4E+6	7.97E-6	2500
1050	19.2E+6	8.05E-6	1600
1100	18.0E+6	8.12E-6	1000

Pipe Sections

Name	Nominal Dia.	Sch	O.D. (inch)	Thk (inch)	Cor.Al (inch)	M.Tol (%)	Ins.Dens (lb/ft3)	Ins.Th (inch)	Lin.Dens (lb/ft3)	Lin.Th (inch)
36I	36"	STD	36	0.375	0.075	0.0	13	2		
36O	36"	STD	36	0.375	0.075	0.0	13	2.5		
54O	Non Std		54	0.375	0.075	0.0	13	2.5		
54I	Non Std		54	0.375	0.075	0.0	13	2		

Loads

X spectrum: Test Factor = 1.0000
Y spectrum: Test Factor = 1.0000
Z spectrum: Test Factor = 1.0000

Mode sum = NRL Direction sum = SRSS

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
36O	100	125					1.000	77.2	Y
36I	100	125					1.000		
54O	100	125					1.000	111.1	Y
54I	100	125					1.000		

Spectrum = Test, Interpolation: 1 = Linear, 2 = Linear

Frequency (Hz)	Displacement (inch)
8	2
30	2

Local & Global Element Forces and Moments for Response Spectrum from CAEPIPE using NRL modal summation for Model: RespSpectrumNRL.mod

Caepipe RespSpectrumNRL Page 1
Version 7.60 Verification of NRL Modal Summation Jul 19,2016

Pipe element forces in local coordinates: Response spectrum

Node	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)	SIF	SL+SO (psi)
10	2886158	2646215	1436041	3069679	6915296	14183467		238085
20A	2886158	2646215	1436041	3069679	1670216	3943230		81538
20A	1738090	1702378	551336	3069679	1670216	3943230	3.31	195966
20B	1702378	1738090	551336	2779195	1657014	4525448	3.31	204141
20B	888282	299416	614246	2779195	4525448	1657014		84828
30	888282	299416	614246	2779195	6719519	2974994		117064
30	594051	278063	535978	2779195	6719519	2974994		117064
40A	594051	278063	535978	2779195	5136839	2255935		94153
40A	840381	1389294	665007	2779195	2255935	5136839	3.31	227318
40B	1389294	840381	665007	2733141	2250682	3971821	3.31	194241
40B	2248750	982361	687818	2733141	2250683	3971821		80844
50	2248750	982361	687818	2733141	2740630	3483326		79588
62	3632871	1645451	1202054	2733141	3960584	4631168		101199
65	3632871	1645451	1202054	2733141	13732266	16749208		320218

Other forces in local coordinates: Response spectrum

Node	Type	fx (lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)
50	Valve	2570557	1089285	818815	2733141	2740630	3483326
60		2570557	1089285	818815	2733141	3431691	3953386
60	Valve	2791102	1153208	885884	2733141	3431691	3953386
62		2791102	1153208	885884	2733141	3960584	4631168

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
10	1436041	2646215	2886158	14183467	6915296	3069679
20A	1436041	2646215	2886158	3943230	1670216	3069679
20A	551336	1702378	1738090	3943230	1670216	3069679
20B	551336	1702378	1738090	4525448	2779195	1657014
20B	299416	888282	614246	4525448	2779195	1657014
30	299416	888282	614246	6719519	2779195	2974994
30	278063	594051	535978	6719519	2779195	2974994
40A	278063	594051	535978	5136839	2779195	2255935

Element forces in global coordinates: Response spectrum

Node	FX (lb)	FY (lb)	FZ (lb)	MX(ft-lb)	MY(ft-lb)	MZ(ft-lb)
40A	665007	840381	1389294	5136839	2779195	2255935
40B	665007	840381	1389294	3971821	2250682	2733141
40B	687818	982361	2248750	3971821	2250683	2733141
50	687818	982361	2248750	3483326	2740630	2733141
62	1202054	1645451	3632871	4631168	3960584	2733141
65	1202054	1645451	3632871	16749208	13732266	2733141

Other forces in global coordinates: Response spectrum

Node	Type	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
50	Valve	818815	1089285	2570557	3483326	2740630	2733141
60		818815	1089285	2570557	3953386	3431691	2733141
60	Valve	885884	1153208	2791102	3953386	3431691	2733141
62		885884	1153208	2791102	4631168	3960584	2733141

Local Element Forces and Moments using NRL Modal Sum (Missing Mass included and Seismic Displacements defined)							
Node	**Type**	**fx**	**fy**	**fz**	**mx**	**my**	**mz**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		2886159	2646215	1436040	3069678	6915297	14183469
20A		2886159	2646215	1436040	3069678	1670216	3943229
20A	Bend	1738090	1702377	551335	3069678	1670216	3943229
20B		1702377	1738090	551335	2779195	1657015	4525448
20B		888282	299415	614247	2779195	4525448	1657015
30		888282	299415	614247	2779195	6719519	2974994
30		594052	278064	535977	2779195	6719519	2974994
40A		594052	278064	535977	2779195	5136838	2255936
40A	Bend	840381	1389294	665007	2779195	2255936	5136838
40B		1389294	840381	665007	2733142	2250682	3971821
40B		2248751	982362	687818	2733142	2250682	3971821
50		2248751	982362	687818	2733142	2740630	3483326
50	Valve	2570557	1089286	818815	2733142	2740630	3483326
60		2570557	1089286	818815	2733142	3431690	3953385
60	Valve	2791103	1153208	885884	2733142	3431690	3953385
62		2791103	1153208	885884	2733142	3960584	4631168
62		3632872	1645451	1202054	2733142	3960584	4631168
65		3632872	1645451	1202054	2733142	13732267	16749209

Transformation to Global Element Forces and Moments (Missing Mass included and Seismic Displacements defined)							
Node	**Type**	**FX**	**FY**	**FZ**	**MX**	**MY**	**MZ**
		(lb)	**(lb)**	**(lb)**	**(ft-lb)**	**(ft-lb)**	**(ft-lb)**
10		1436040	2646215	2886159	14183469	6915297	3069678
20A		1436040	2646215	2886159	3943229	1670216	3069678
20A	Bend	551335	1702377	1738090	3943229	1670216	3069678
20B		551335	1702377	1738090	4525448	2779195	1657015
20B		299415	888282	614247	4525448	2779195	1657015
30		299415	888282	614247	6719519	2779195	2974994
30		278064	594052	535977	6719519	2779195	2974994
40A		278064	594052	535977	5136838	2779195	2255936
40A	Bend	665007	840381	1389294	5136838	2779195	2255936
40B		665007	840381	1389294	3971821	2250682	2733142
40B		687818	982362	2248751	3971821	2250682	2733142
50		687818	982362	2248751	3483326	2740630	2733142
50	Valve	818815	1089286	2570557	3483326	2740630	2733142
60		818815	1089286	2570557	3953385	3431690	2733142
60	Valve	885884	1153208	2791103	3953385	3431690	2733142
62		885884	1153208	2791103	4631168	3960584	2733142
62		1202054	1645451	3632872	4631168	3960584	2733142
65		1202054	1645451	3632872	16749209	13732267	2733142

Global Displacements & Accelerations for Response Spectrum from CAEPIPE using NRL modal summation for Model: RespSpec_NRLSum_DISP_ACC.mod

```
Caepipe                    ResSpec_NRLSum_DISP_ACC                  Page 1
Version 7.60                                                        Jul 19,2016
```

Options

- Piping code = B31.3 (2014)
- Do not use liberal allowable stresses
- Include axial force in stress calculations
- Reference temperature = 40 (F)
- Number of thermal cycles = 7000
- Number of thermal loads = 1
- Thermal = Operating - Sustained
- Use modulus at reference temperature
- Include hanger stiffness
- Include Bourdon effect
- Use pressure correction for bends
- Pressure stress = PD / 4t
- Peak pressure factor = 1.00
- Cut off frequency = 110 Hz
- Number of modes = 5
- Do not include missing mass correction
- Use friction in dynamic analysis
- Vertical direction = Y

#	Node	Type	DX(ft'in")	DY(ft'in")	DZ(ft'in")	Mat	Sec	Load	Data
1	Title =								
2	10	From							Anchor
3	20	Bend			11'0"	API	54I	54I	
4	30			-20'0"		API	54I	54I	
5	40	Bend		-10'9"		API	54I	54I	
6	50				9'0"	API	54I	54I	
7	60	Valve			2'0"	API	54O	54O	
8	62	Valve			1'0"	API	54O	54O	
9	65				9'0"	API	54O	54O	Anchor

Anchors

Node	KX/kx (lb/inch)	KY/ky (lb/inch)	KZ/kz (lb/inch)	KXX/kxx (in-lb/deg)	KYY/kyy (in-lb/deg)	KZZ/kzz (in-lb/deg)	Releases X Y Z XXYYZZ	Anchor In Pipe
10	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
65	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS

Bends

Bend Node	Radius (inch)	Thickness (inch)	Bend Matl	Flex. Factor	Int. Node	Angle (deg)	Int. Node	Angle (deg)
20	81 L							
40	81 L							

Valves

From	To	Weight (lb)	Length (inch)	Thick X	Insul Wgt X	Add Wght (lb)	DX (inch)	DY (inch)	DZ (inch)
50	60	0		3.00	1.75				
60	62	0		3.00	1.75				

Pipe material API: API 5L Grade B

Density = 0.283 (lb/in3), Nu = 0.300, Joint factor = 1.00, Type = CS
Yield strength = 35000 (psi)

Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
-325	31.4E+6	5.00E-6	20000
-200	30.8E+6	5.35E-6	20000
-100	30.2E+6	5.65E-6	20000
70	29.5E+6	6.07E-6	20000
200	28.8E+6	6.38E-6	20000
300	28.3E+6	6.60E-6	20000
400	27.7E+6	6.82E-6	19900
500	27.3E+6	7.02E-6	19000
600	26.7E+6	7.23E-6	17900
650	26.1E+6	7.33E-6	17300
700	25.5E+6	7.44E-6	16700
750	24.8E+6	7.54E-6	13900
800	24.2E+6	7.65E-6	11400
850	23.3E+6	7.75E-6	8700
900	22.4E+6	7.84E-6	5900
950	21.4E+6	7.91E-6	4000
1000	20.4E+6	7.97E-6	2500
1050	19.2E+6	8.05E-6	1600
1100	18.0E+6	8.12E-6	1000

Pipe Sections

Name	Nominal Dia.	Sch	O.D. (inch)	Thk (inch)	Cor.Al (inch)	M.Tol (%)	Ins.Dens (lb/ft3)	Ins.Th (inch)	Lin.Dens (lb/ft3)	Lin.Th (inch)
36I	36"	STD	36	0.375	0.075	0.0	13	2		
36O	36"	STD	36	0.375	0.075	0.0	13	2.5		
54O	Non Std		54	0.375	0.075	0.0	13	2.5		
54I	Non Std		54	0.375	0.075	0.0	13	2		

Loads

X spectrum: Test Factor = 1.0000
Y spectrum: Test Factor = 1.0000
Z spectrum: Test Factor = 1.0000

Mode sum = NRL Direction sum = SRSS

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
36O	100	125					1.000	77.2	Y
36I	100	125					1.000		
54O	100	125					1.000	111.1	Y

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
54I	100	125					1.000		

Spectrum = Test, Interpolation: 1 = Linear, 2 = Linear

Frequency (Hz)	Displacement (inch)
8	2
30	2

Displacements: Response spectrum

Node	X (inch)	Y (inch)	Z (inch)	XX(deg)	YY(deg)	ZZ(deg)
10	0.000	0.000	0.000	0.0053	0.0023	0.0020
20A	0.142	0.299	0.017	0.2903	0.1186	0.2013
20B	2.062	2.293	1.718	0.7323	1.0475	1.1207
30	2.761	2.336	3.176	0.4478	1.2040	1.0978
40A	3.380	2.340	3.082	0.3125	1.2663	1.0228
40B	2.524	2.584	0.087	0.9512	0.9503	0.5132
50	2.032	2.078	0.072	0.9630	0.9482	0.4190
60	1.620	1.657	0.067	0.9533	0.9368	0.3922
62	1.416	1.448	0.065	0.9433	0.9264	0.3788
65	0.000	0.000	0.000	0.0095	0.0093	0.0018

Response spectrum accelerations

Node	X	(g's) Y	Z
10	0.000	0.000	0.000
20A	3.290	6.853	0.458
20B	33.414	33.650	19.805
30	45.930	34.728	72.447
40A	50.400	34.833	74.225
40B	81.290	71.012	2.534
50	67.308	57.609	2.076
60	54.988	46.344	1.941
62	48.766	40.716	1.873
65	0.000	0.000	0.000

Manually Combined Displacement Results using NRL Summation		
X	Y	Z
0	0	0
0.138	0.289	0.019
2.07	2.285	1.71
2.754	2.342	3.183
3.383	2.342	3.072
2.53	2.579	0.094
2.029	2.086	0.076
1.624	1.648	0.076
1.428	1.458	0.076
0	0	0

Manually Combined Accelerations Results using NRL Summation		
X	Y	Z
0	0	0
3.101	6.536	0.635
33.547	33.544	19.547
45.813	34.937	72.467
50.592	34.937	73.986
81.55	71.087	2.631
67.383	57.73	2.029
54.906	46.211	2.029
49.071	40.909	2.029
0	0	0

Annexure D

Generation of Mesh for Buried Piping Layout

(Automatic Discretization of Buried Piping Layout)

Note: This feature was implemented in CAEPIPE Version 7.50. Minor changes incorporated in this Version 7.60 related to this feature are highlighted by the vertical line along the margin in this write-up.

Generation of Mesh for Buried Piping Layout

Modulus of Subgrade Reaction (k)

This factor k defines the resistance of the soil or backfill to pipe movement due to the bearing pressure at the pipe/soil interface. Several methods for calculating modulus of subgrade reaction (k) have been developed in recent years.

As per Trautmann, C.H., and O'Rourke, T.D., "Lateral Force-Displacement Response of Buried Pipes," Journal of Geotechnical Engineering, ASCE, Vol. 111, No. 9 Sep 1985, pp. 1077-1092, the modulus of subgrade reaction, k, can be calculated as per Eq. (2) in Appendix VII of ASME B31.1-2014 code.

$$k = C_k N_h w D$$

where,

C_k = a dimensionless factor for estimating horizontal stiffness of compacted backfill. C_k may be estimated at 20 for loose soil, 30 for medium soil, and 80 for dense or compacted soil. *In the current version of CAEPIPE, the value of C_k is internally set as 80 for both cohesive and cohesionless soil.*

D = pipe outside diameter

w = soil density

N_h = a dimensionless horizontal force factor from Fig. 8 of above stated technical paper. For a typical value where the soil internal friction angle is 30 deg. the curve from Fig. 8 may be approximated by a straight line defined by

$$N_h = 0.285H/D + 4.3$$

where

H = the depth of pipe below grade at the pipe centerline

Influence Length (L_k)

The influence length is defined as the portion of a transverse pipe run which is deflected or "influenced" by pipe thermal expansion along the axis of the longitudinal run.

From Hetenyi's theory, (*Beams on Elastic Foundation, The University of Michigan Press, Ann Arbor, Michigan 1967*) (also, see Section VII-3.3.2 of Appendix VII of ASME B31.1-2014 code)

$$L_k = \frac{3\pi}{4\beta}$$

where,

Pipe / Soil System Characteristics = $\beta = \left[\frac{k}{4EI}\right]^{1/4}$

E = modulus of elasticity of pipe at reference temperature

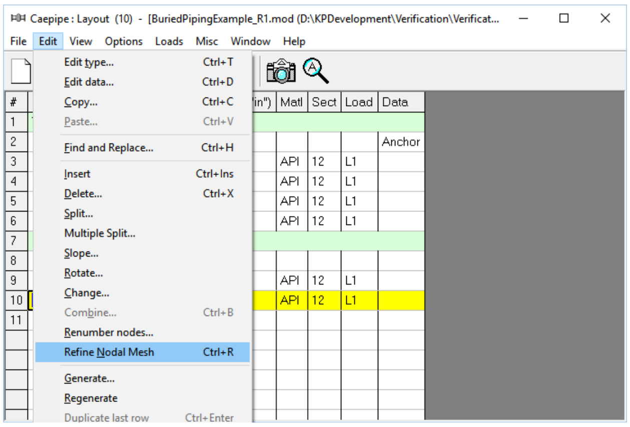
I = moment of inertia of pipe cross section

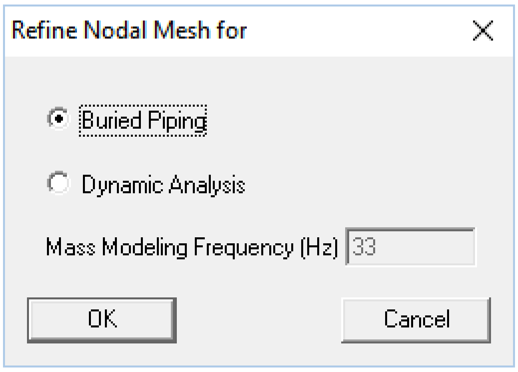
k = modulus of subgrade reaction of soil as detailed above.

Implementation in CAEPIPE

It is in the bends, elbows, and branch connections that the highest stresses are found in buried piping subjected to thermal expansion of the pipe. These stresses are due to the soil forces that bear against the transverse run. The stresses are proportional to the amount of soil deformation at the elbow or branch connection. Hence, piping element at the junction of bend, elbow and branch connection is to be refined in the stress layout.

This can be performed through Layout Window > Edit > Refine Nodal Mesh. Select the radio button "Buried piping" from the dialog box shown.





When the command is selected, CAEPIPE will refine the Nodal Mesh as detailed below.

1. Calculate modulus of subgrade reaction (k) as detailed above. While calculating k, the value of C_k is taken as 80 for both cohesive and cohesionless soil.
2. Calculate influence length (L_k) for the element that is fully buried.
3. If the length of the pipe element near bend / elbow / branch connection is greater than or equal to the influence length (L_k), then the pipe element will be split into a number of short elements with length of each short element being equal to 2 x OD of that pipe section until the Influence length (L_k).

   On the other hand, if the length of the pipe element near bend / elbow / branch connection is less than the influence length (L_k) and greater than 2 x OD of the pipe, then the pipe element will be split into a number of short elements with length of each short element being equal to 2 x OD of that pipe section.

Note: while refining the Nodal Mesh, the new node numbers will be generated by adding the node increment specified through Layout window > Options > Node increment to get the new node numbers (without affecting the original node numbers used in the Layout window). Hence, set the node increment value as required before refining the Nodal Mesh.

Sample buried piping model

The following data are used to generate the sample buried piping model.

```
Piping code = B31.1 (2014)
Use liberal allowable stresses
Do not include axial force in stress calculations
Reference temperature = 70 (F)
Number of thermal cycles = 7000
Number of thermal loads = 1
Thermal = Operating - Sustained
Use modulus at reference temperature
Include hanger stiffness
Include Bourdon effect
Use pressure correction for bends
Pressure stress = PD / 4t
Peak pressure factor = 1.00
Cut off frequency = 33 Hz
Number of modes = 20
Include missing mass correction
Use friction in dynamic analysis
Vertical direction = Y
```

Pipe material API: API 5L

Density = 0.283 (lb/in3), Nu = 0.300, Joint factor = 0.85, Type = CS

Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
-20	27.9E+6	6.25E-6	10900
100	27.9E+6	6.47E-6	10900
200	26.8E+6	6.70E-6	10900
300	25.3E+6	6.90E-6	10900
400	24.7E+6	7.10E-6	10900

Pipe Sections

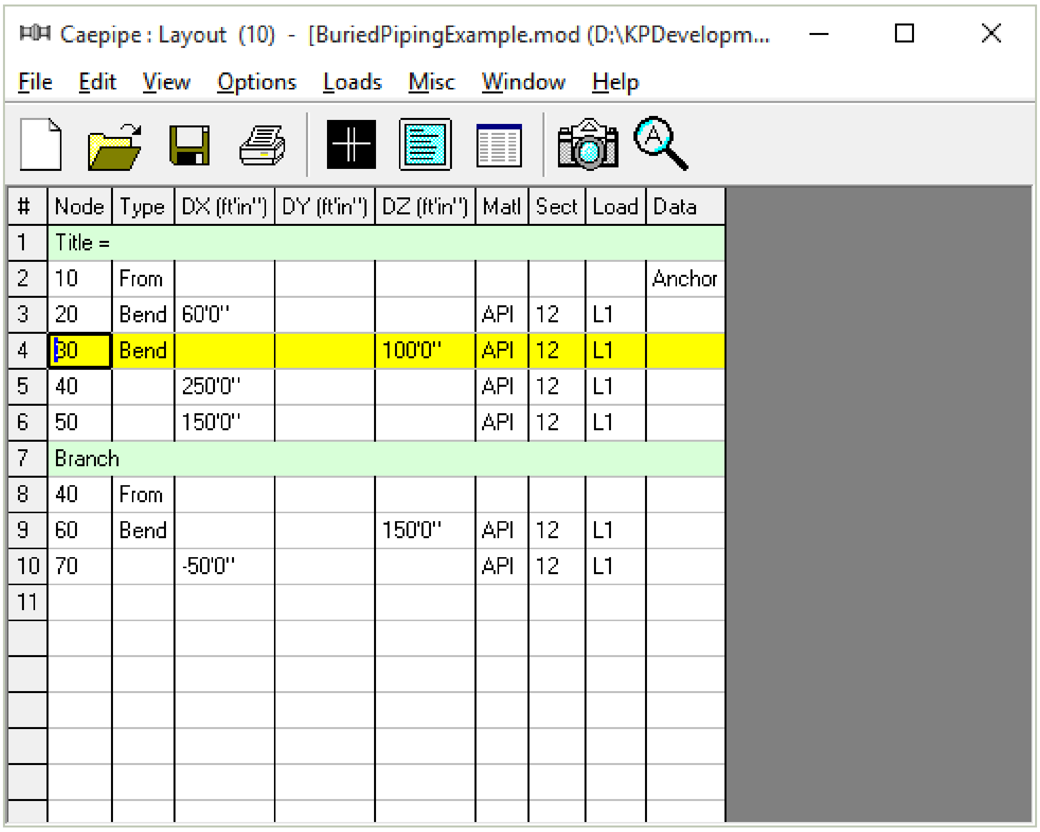
Name	Nominal Dia.	Sch	O.D. (inch)	Thk (inch)	Cor.Al (inch)	M.Tol (%)	Ins.Dens (lb/ft3)	Ins.Th (inch)	Lin.Dens (lb/ft3)	Lin.Th (inch)
12	12"	STD	12.75	0.375	0	0.0				

Soils

Name	Type	Density (lb/ft3)	Strength (psi)	Delta (deg)	Ks	Ground Level (ft'in")
S1	Cohesionless	130		30	0.30	12'0"

Pipe Loads

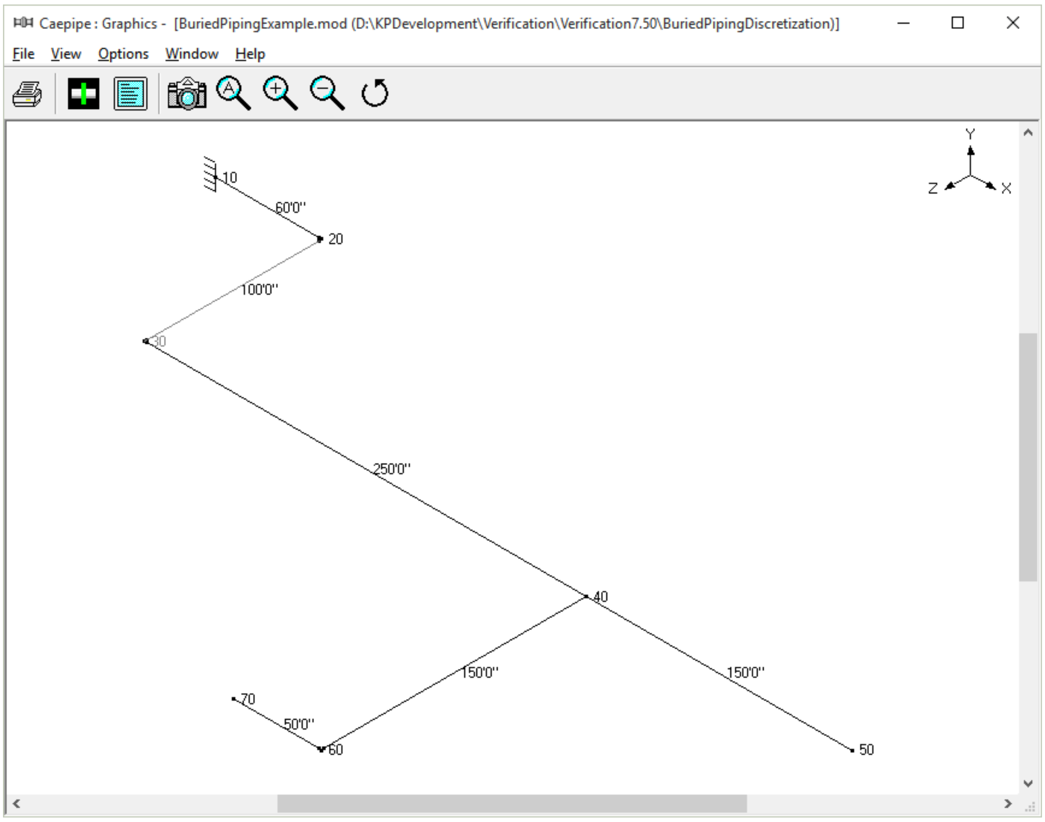
Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
L1	140	100							



Caepipe : Layout (10) - [BuriedPipingExample.mod (D:\KPDevelopm...

File Edit View Options Loads Misc Window Help

#	Node	Type	DX (ft'in")	DY (ft'in")	DZ (ft'in")	Matl	Sect	Load	Data
1	Title =								
2	10	From							Anchor
3	20	Bend	60'0"			API	12	L1	
4	30	Bend			100'0"	API	12	L1	
5	40		250'0"			API	12	L1	
6	50		150'0"			API	12	L1	
7	Branch								
8	40	From							
9	60	Bend			150'0"	API	12	L1	
10	70		-50'0"			API	12	L1	
11									



Soil characteristics

Soil density, w = 130 lb/ft3 = 0.075 lb/in^3

Pipe depth below grade, H = 12 ft (144 in)

Type of backfill, dense sand (cohesion less soil)

C_k = 80

Calculation of Modulus of subgrade reaction (k)

N_h = 0.285H/D + 4.3

N_h = (0.285 x 144 / 12.75) + 4.3 = **7.518**

$k = C_k N_h w D$ = 80 x 7.518 x 0.075 x 12.75 = **575.127 psi**

Calculation of Influence Length (L_k)

Moment of inertia, I = 279.3 in^4

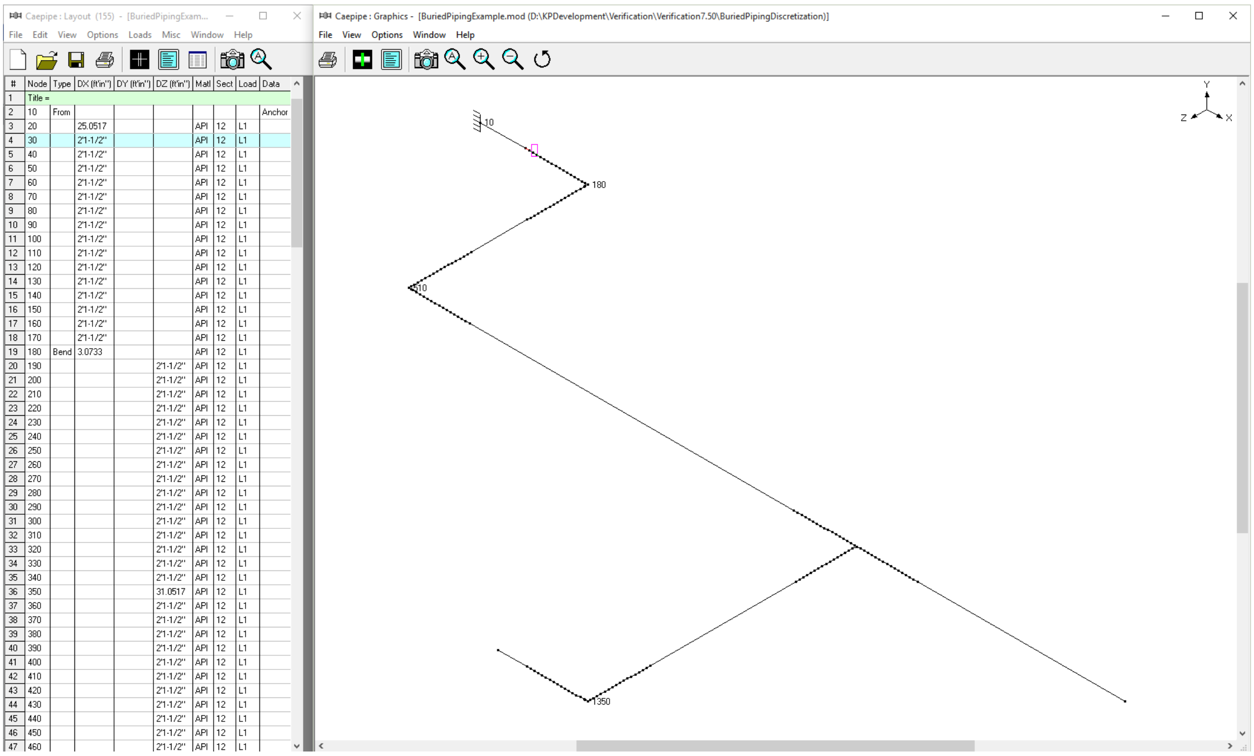
Modulus of elasticity, E = 27.9 x 10^6 psi

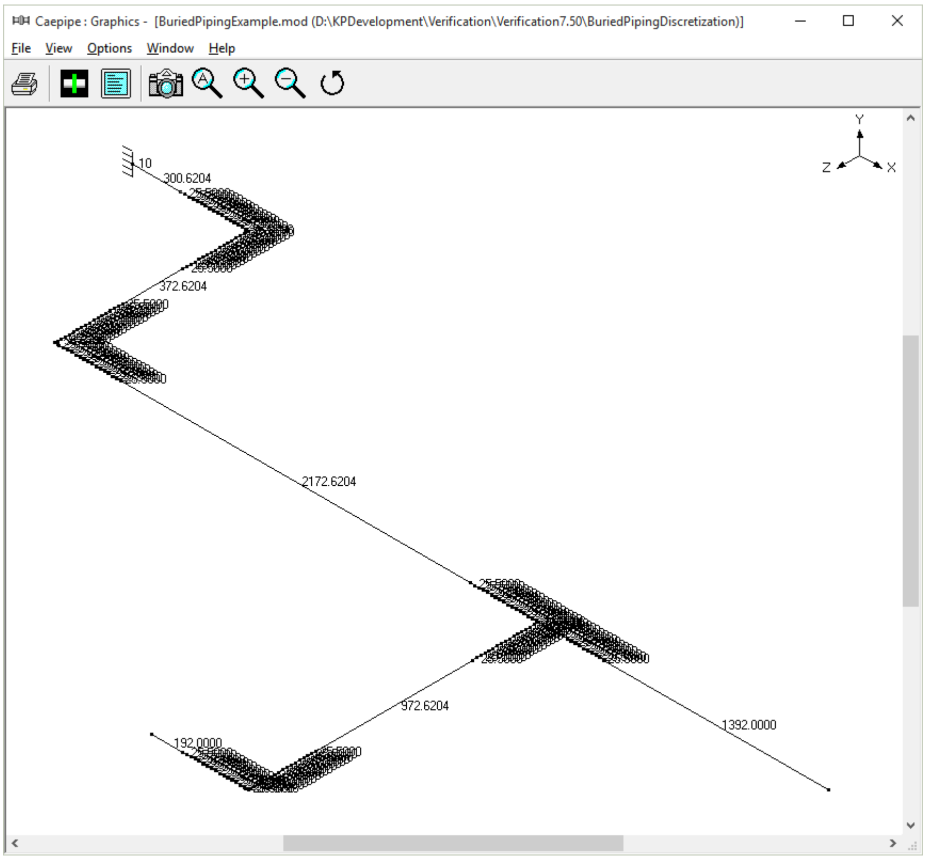
$$L_k = \frac{3\pi}{4\beta}$$

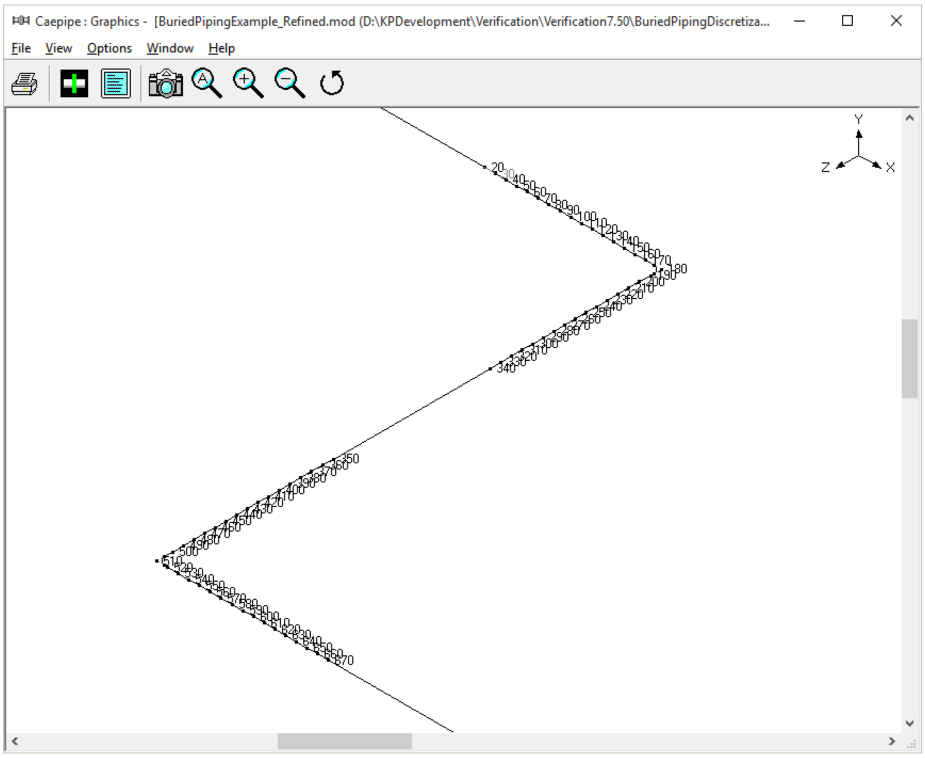
Pipe / Soil System Characteristics = $\beta = \left[\frac{k}{4EI}\right]^{1/4}$ = [575.127 / (4 x 27.9 x 106 x 279.3)] $^{1/4}$ = **0.01165**

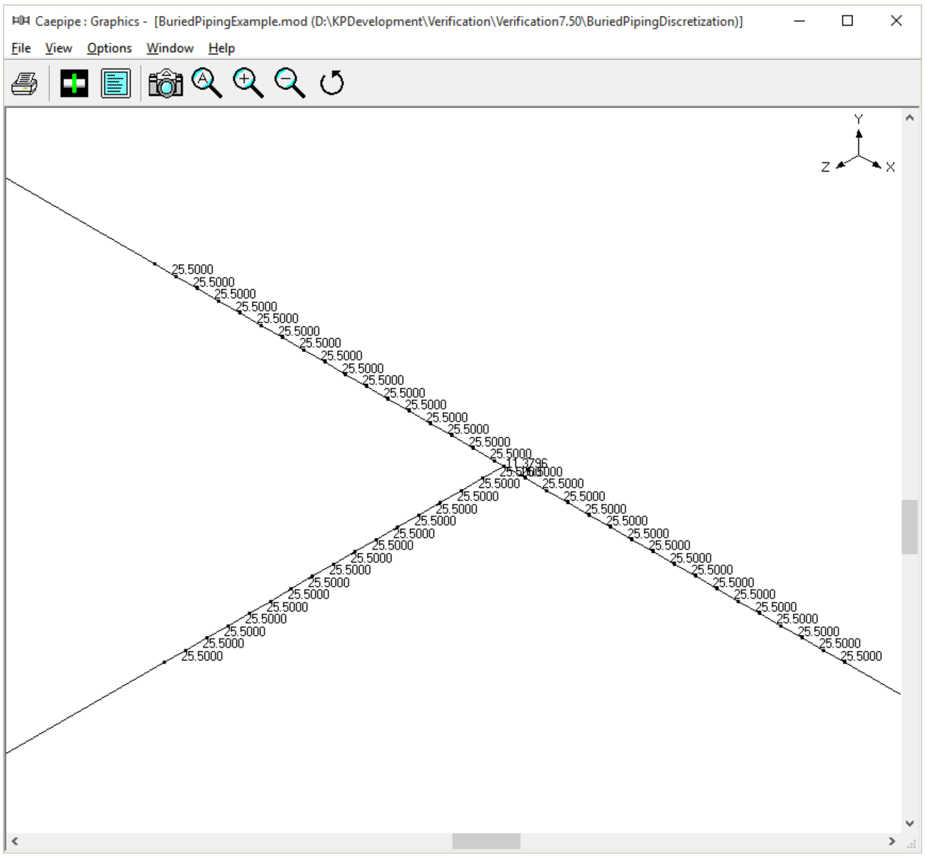
Influence Length (Lk) = 3 x 3.14 / (4 x 0.01165) = **202.145 in**

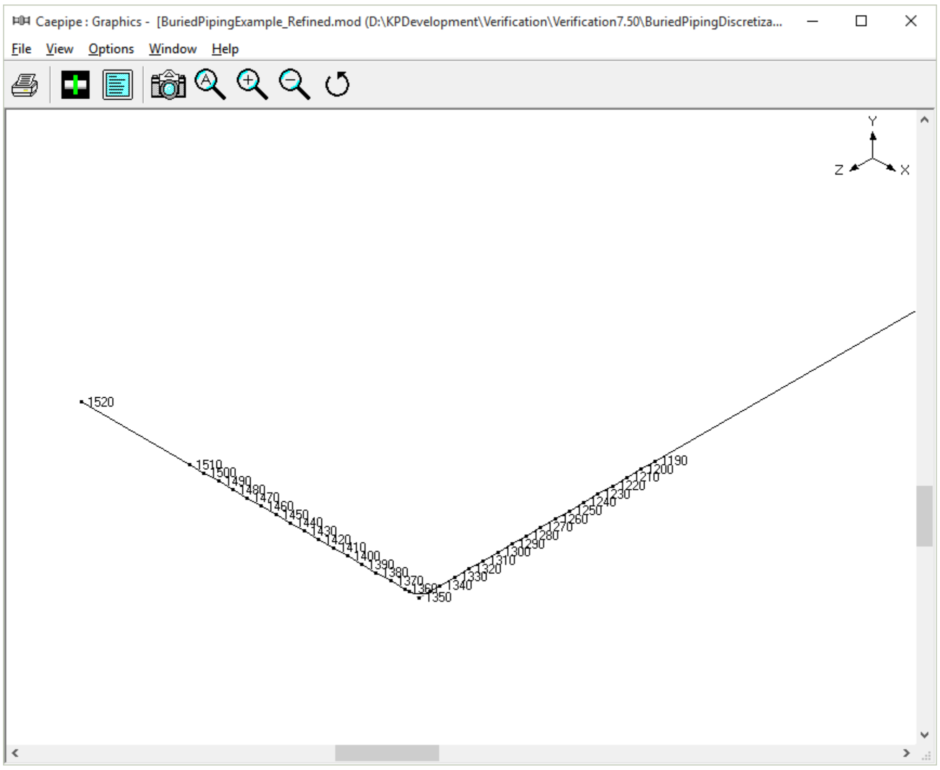
As the length of pipe element near the bend and branch connection is greater than the influence length (L_k = 202.145 in), the pipe elements near the bends and branch connection are split into a number of short elements with length of each short element being equal to 2 x OD = 2 x 12.75 = 25.5 in until the influence length (L_k). See figures given below for details.




Caepipe : Graphics - [BuriedPipingExample.mod (D:\KPDevelopment\Verification\Verification7.50\BuriedPipingDiscretization)]
File View Options Window Help
Y
Z
X
10
300.6204
372.6204
2172.6204
972.6204
192.0000
1392.0000


Caepipe : Graphics - [BuriedPipingExample_Refined.mod (D:\KPDevelopment\Verification\Verification7.50\BuriedPipingDiscretiza...
File View Options Window Help
Y
Z
X


Caepipe : Graphics - [BuriedPipingExample.mod (D:\KPDevelopment\Verification\Verification7.50\BuriedPipingDiscretization)]
File View Options Window Help
Y
Z
X
25.5000
11.3796


Caepipe : Graphics - [BuriedPipingExample_Refined.mod (D:\KPDevelopment\Verification\Verification7.50\BuriedPipingDiscretiza...
File View Options Window Help
Y
Z
X
1520
1510
1350
1340
1190