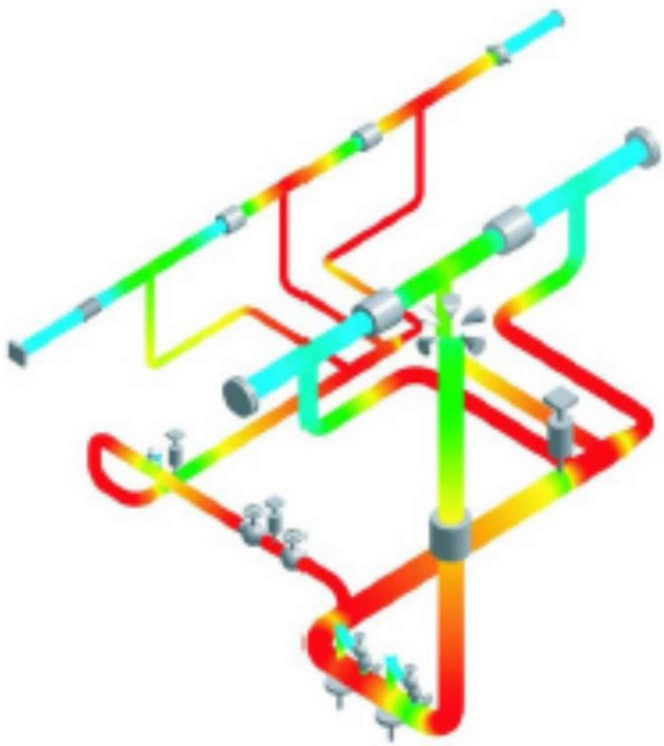
CAEPIPE™

Verification Manual



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CAEPIPE Verification Manual (Program Version 10.51)

Document Revision 27

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How to use this Manual?

START HERE	Look up tables that contain lists of features verified. List of CAEPIPE Statics features verified (Table P0-1). List of CAEPIPE Dynamics features verified (Table P0-2). From these tables, pick the problem number of interest and turn to the indicated page number.
MAIN SECTIONS	1. Statics 2. Dynamics 3. Rotating Equipment Reports 4. Verification for Export of Local Element Forces and Moments contributed by each Mode participating in Response Spectrum Analysis 5. Verification of NRL procedure for combining modes 6. Verification of Code Compliance Each section deals with verification of its respective features.

We have tried to make this manual an easy one to use. We welcome your suggestions for improvement. Thank you for using CAEPIPE.

Revision Control Sheet

Document Title				CAEPIPE Verification Manual (Program Version 10.50)		
Document Revision				24		
Program Version	**Revision Number**	**Date**	**Prepared By**	**Checked By**	**Corrected Pages**	**Remarks**
7.50	13	05/26/16	MSK	PBK	ALL	New Version
7.70	14	10/28/16	MSK	PBK	ALL	New Version
7.80	15	05/31/17	PBK	YWW GVR	ALL	New Version
7.90	16	11/20/17	PBK	GVR	ALL	New Version
7.90	17	12/12/17	PBK	GVR	ALL	New Version
8.00	18	06/22/18	PBK	GVR	ALL	New Version
9.00	19	10/10/2018	PBK	GVR	ALL	New Version
9.01	20	01/23/2019	PBK	GVR	178-191	Update
10.00	21	05/06/2019	PBK	GVR	All	New Version
10.10	22	10/23/2019	PBK	GVR	All	Update
10.20	23	04/27/2020	PBK	GVR	All	Update
10.30	24	10/26/2020	PBK	AS	All	Update
10.40	25	06/03/2021	PBK	AS	All	Update
10.50	26	01/06/2022	PBK AS	AS PBK	All	Update
10.51	27	02/04/2022	PBK AS	AS PBK	All	Update

Note: This manual is not published for every program version released. Every major program version, however, is verified before release. See summary of changes section.

Revision Control Sheet related information for Program Versions earlier than Version 7.50 can be provided upon request.

Certification for CAEPIPE Verification

In Revision 27 of the Verification Manual, the following is updated.

1. Reverification of Code Compliance Stresses as per EN 13480-3 (2020).

Program Version	Document Revision Number	Document Revision Date	Prepared by	Checked by	Approved by
10.51	27	02/04/2022	**(P B Karthick)** **(Dr. A Seena)**	**(Dr. A Seena)** **(P B Karthick)**	**(Dr. G V Ranjan)**

Contents

Nomenclature

ADL	ADLPIPE computer program
ANS	ANSYS computer program
API	American Petroleum Institute. Publishers for Centrifugal Pumps (API 610) and Centrifugal Compressors (API 617)
CAE	CAEPIPE computer program
DW	Deadweight load case
DYN	DYNAFLEX computer program
MMC	Missing mass correction feature
NEMA	National Electric Manufacturers Association publication for Steam Turbines (NEMA SM-23)
NUP	NUPIPE computer program
PS	PIPESTRESS computer program (previously known as PS+CAEPIPE)
Ref.	Reference number given under the section *References*
Rot	Rotational direction (X, Y and Z directions)
SE	Expansion stress
SIF	Stress Intensification Factor
SL	Sustained stress
T1,T2,T3	Thermal expansion load cases
TPE	TPIPE computer program
Tran	Translational direction (X, Y and Z directions)
W+P+T	Operating load case

List of Tables

Introduction

CAEPIPE is an integrated system of computer software that performs design and static and dynamic analyses of three dimensional piping systems in accordance with US and international piping codes such as ASME B31.1, B31.3, B31.4, B31.5, B31.8, B31.9, B31.12, BS 806, IGEM, RCC-M, SNCT, Norwegian, Swedish, Stoomwezen, ASME Section III Classes 2 and 3, Canadian (Z183, Z184 and Z662) and EN 13480 codes.

CAEPIPE may be used to design and analyze piping systems of any complexity encountered in fossil power plants, gas and liquid transmission systems, nuclear plants (non-safety related piping), chemical and other process plants, petroleum refineries, paper and pulp plants, aircraft and aerospace industries, and many other heavy industries. Users must perform their own nuclear quality assurance procedures on CAEPIPE before using it for safety-related piping systems in nuclear power plants.

CAEPIPE is developed using advanced software development tools and techniques. It is designed to execute interactively on a personal computer running a 32-bit/64-bit version of Microsoft Windows®. It is based on classical engineering concepts and documented finite element and numerical analysis techniques. The data built into the program have been taken from standard References [see ref. 1, 2 & 3].

This manual describes and documents the verification process every major CAEPIPE program version undergoes before release.

Program Description

CAEPIPE performs linear and non-linear static analyses and linear dynamic analyses of three-dimensional piping systems. It employs the finite element method to perform these analyses. It treats the piping as a series of elastic elements, generates the stiffness matrix for each element, assembles them into an overall global stiffness matrix and then imposes the specified boundary conditions. The modified stiffness matrix is used to compute the nodal displacements by solving the equations of static equilibrium for the various static loading conditions such as deadweight, thermal, anchor movements, settlement, wind and static seismic g-factors. The element forces and moments, stresses and support loads are computed using these displacements. Finally, it performs a code evaluation (based on the user-selected piping code) to determine if the computed results meet the code requirements.

CAEPIPE consists of three functional parts: Input, Analysis and Output. Input is used to create, modify, display or check a piping model. Input processes the piping geometry, section and material properties, supports and the specified loading conditions. The Analysis part uses this information in the model database to perform an "as-requested" analysis and generates the responses to the loading conditions. Output interactively displays and prints results. These results may include the appropriate code check. Refer CAEPIPE User's Manual, Technical Reference Manual and Code Compliance Manual [ref. 4] for details.

CAEPIPE can be used to perform dynamic analyses such as modal, seismic (Uniform Response Spectrum Method), time-history, harmonic and force spectrum analyses too. The procedures are described in the CAEPIPE Manuals [ref. 4].

The method used for the Uniform Response Spectrum analysis is described in the Technical Reference Manual. First the eigenvalues and eigenvectors are obtained using the Determinant Search method. Then the modal participation factors are calculated. Using the input response spectra specified by the user, the program calculates the modal displacements and modal element forces and moments. Finally, using the summation option specified by the user, CAEPIPE calculates the total displacements, element forces and moments and support loads. The differences in results, if any, for the dynamic verification problems presented here, may be due to the differences in mass modeling between CAEPIPE and the other programs used for comparison. Up to the current version, CAEPIPE has always used the "lumped mass" method, under which CAEPIPE lumps appropriate mass at each node of the piping system.

1 – Statics Verification Method

Several problems were created on CAEPIPE and analyzed for each of the features listed in this section. The same analysis models were also analyzed by other piping analysis programs. The results are tabulated in this manual.

Verification of Piping Codes

Code Compliance checks performed by CAEPIPE for various piping codes were verified by comparing CAEPIPE's results against the corresponding manual calculations performed using MS-Excel. These comparisons are reported in Chapter 6 of this Manual.

Verification of Stress Intensification Factors (SIFs)

Stress Intensification Factors (SIFs), as computed by CAEPIPE were compared against manual calculations performed using MS-Excel. These comparisons are reported in Chapter 6 of this Manual.

Note:

For Code Compliance checks, including validation of SIFs, Appendix D of various piping codes are applied, unless otherwise explicitly stated as "ASME B31J" is applied.

Verification of Other Features

The following features were verified using the following problems:

Model name	**Features verified**	**Results compared with**
P7	Hanger with limit stops and released restraints	DYNAFLEX
P8	Expansion bellows	DYNAFLEX
P9	Skewed Restraints	DYNAFLEX
P10	Milter Bend	DYNAFLEX
P11	Wind loads	PIPESTRESS
P12	Elastic Element	PIPESTRESS
P13	Displacements, Forces, and Moments	PIPESTRESS
P14	Friction and limit stops	Published results

Note on Load Cases

Three basic load cases are referred to in the following sections. They are

Dead weight case	In CAEPIPE, this would translate to Sustained load case (W+P) **without** the pressure(P=0) - Abbreviated as DW or W.
Thermal case	Abbreviated as T1. (T2, T3 etc. would refer to additional thermal cases).
Operating case	Combination of Dead weight, Pressure and Thermal load cases - Abbreviated as W+P1+T1.

Statics Verification Results

The tabulation of results from CAEPIPE and the other programs (and a few manual calculations using Excel) are given in this section. The table below lists the features verified, and the problems with which they were checked.

Table P0-1 List of CAEPIPE features verified (Statics)*

CAEPIPE Feature	Problem # or Model
ASME B31.1 code check	ASME_B311.mod
ASME B31.3 code check	Example1.mod, Example2.mod and Example3.mod Example1_SI.mod, Example2_SI.mod and Example3_SI.mod
ASME B31.4 code check	ASME_B314.mod
ASME B31.8 code check	ASME_B318.mod
ASME B31J code check	P6-B31J.mod
ASME B31.12 code check	ASMEB3112.mod
ASME Section III NC (2015) code check	P6.mod
ASME Section III NC (2017) code check	p6-ASME-NC-2017.mod
ASME Section III ND (2017) code check	p6-ASME-ND-2017.mod
IGEM	IGEM_2012.mod
EN 13480-3	EN13480-3.mod
Z662 (2019) code check	Z662_2019.mod
Loading conditions	
1) Pressure	4, 13
2) Temperature	1, 2, 3
4) Thermal Anchor movement	2, 3, 4
6) Static Seismic Acceleration	13
7) Wind	11
Use of Units	
1) English	1, 2, 3, 5, Example1, Example2 and Example3
2) Metric	4, 14, Example1_SI, Example2_SI and Example3_SI
Others	
Automatic hanger selection	3, 7
SIF calculation	6
Hangers and limit stops	7
Frictional Restraints	14
Bellows expansion joints	5, 8
Elastic elements	12
Miters	10
Skewed Restraints	9

The remainder of this section presents plots of models and tables comparing CAEPIPE's results for these models with other sources.

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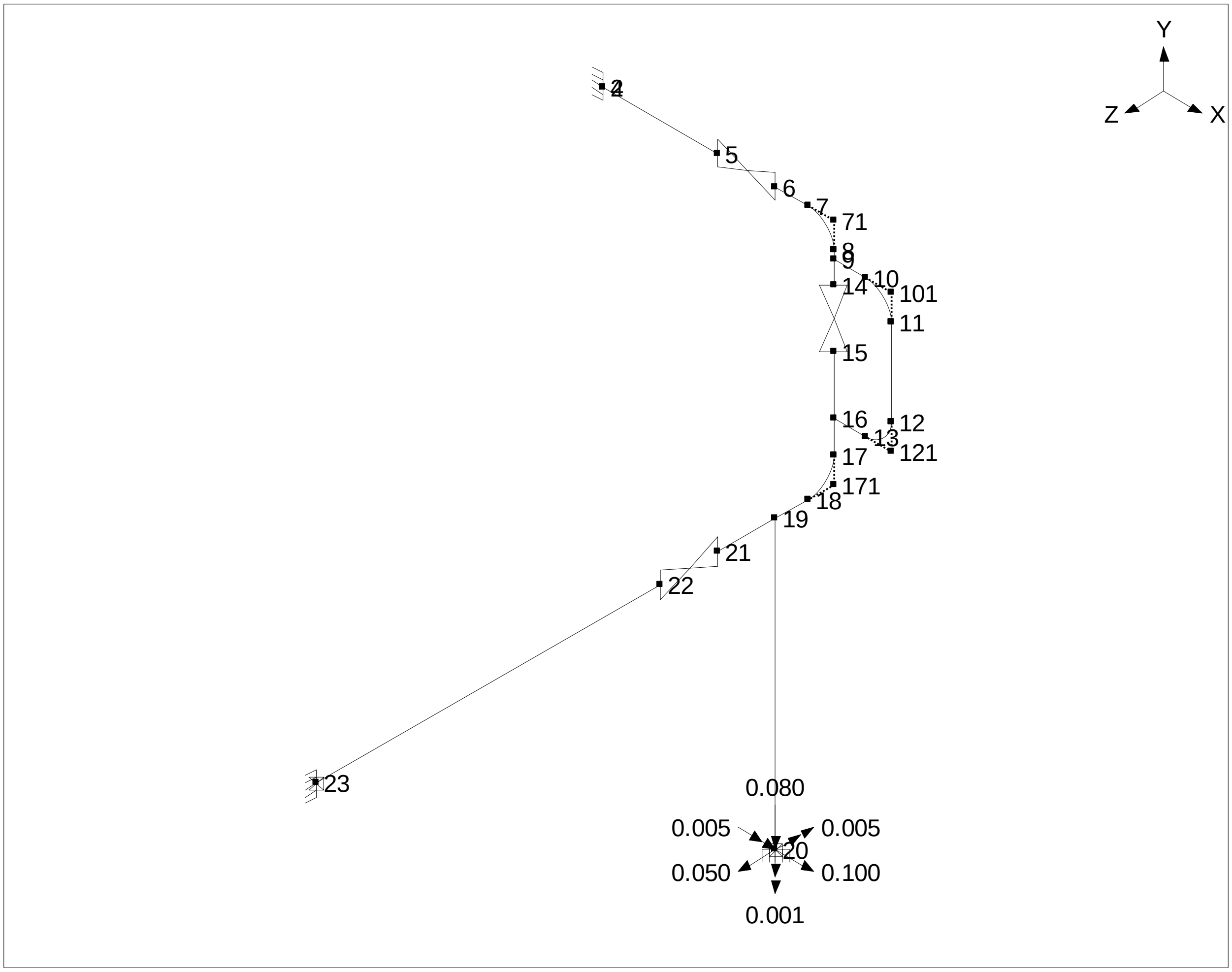
* See Table P0-2 for a list of Dynamics features verified.

Problem 1

VERIFICATION OF CAEPIPE, PROBLEM 1 p1



Problem SUMMARY	
What was compared	Displacements and Support loads
Load cases analyzed	Operating (W+P1+T1)
Filename	P1.mod
This problem uses piping code ASME, Section III, Class 2 (1986) Equation 9 Level B (upset) with loading conditions (T, P): (170˚F, 0 PSIG).	

The problem source [ref. 5] contains results from ANSYS and WESTDYN.

Table P1-1 Comparison of Nodal Displacements for Operating case with WESTDYN [WES] and ANSYS [ANS]

Node	Program	X (inch)	Y (inch)	Z (inch)	XX (rad)	YY (rad)	ZZ (rad)
4	CAE	0.049	-0.003	-0.143	-0.0010	0.0034	0.0020
	WES	0.050	-0.004	-0.145	-0.0010	0.0034	0.0020
	ANS	0.049	-0.003	-0.144	-0.0010	0.0033	0.0020
9	CAE	0.147	0.063	-0.258	-0.0016	0.0014	0.0017
	WES	0.147	0.063	-0.258	-0.0016	0.0013	0.0017
	ANS	0.147	0.063	-0.256	-0.0015	0.0013	0.0017
12	CAE	0.201	0.037	-0.232	-0.0020	0.0007	0.0017
	WES	0.201	0.037	-0.232	-0.0020	0.0007	0.0016
	ANS	0.201	0.037	-0.231	-0.0019	0.0007	0.0017
16	CAE	0.187	0.011	-0.218	-0.0020	0.0003	0.0016
	WES	0.187	0.011	-0.218	-0.0020	0.0004	0.0016
	ANS	0.186	0.011	-0.218	-0.0019	0.0003	0.0016
19	CAE	0.185	0.028	-0.172	-0.0045	-0.0020	0.0002
	WES	0.185	0.028	-0.172	-0.0044	-0.0020	0.0002
	ANS	0.185	0.028	-0.172	-0.0044	-0.0020	0.0002

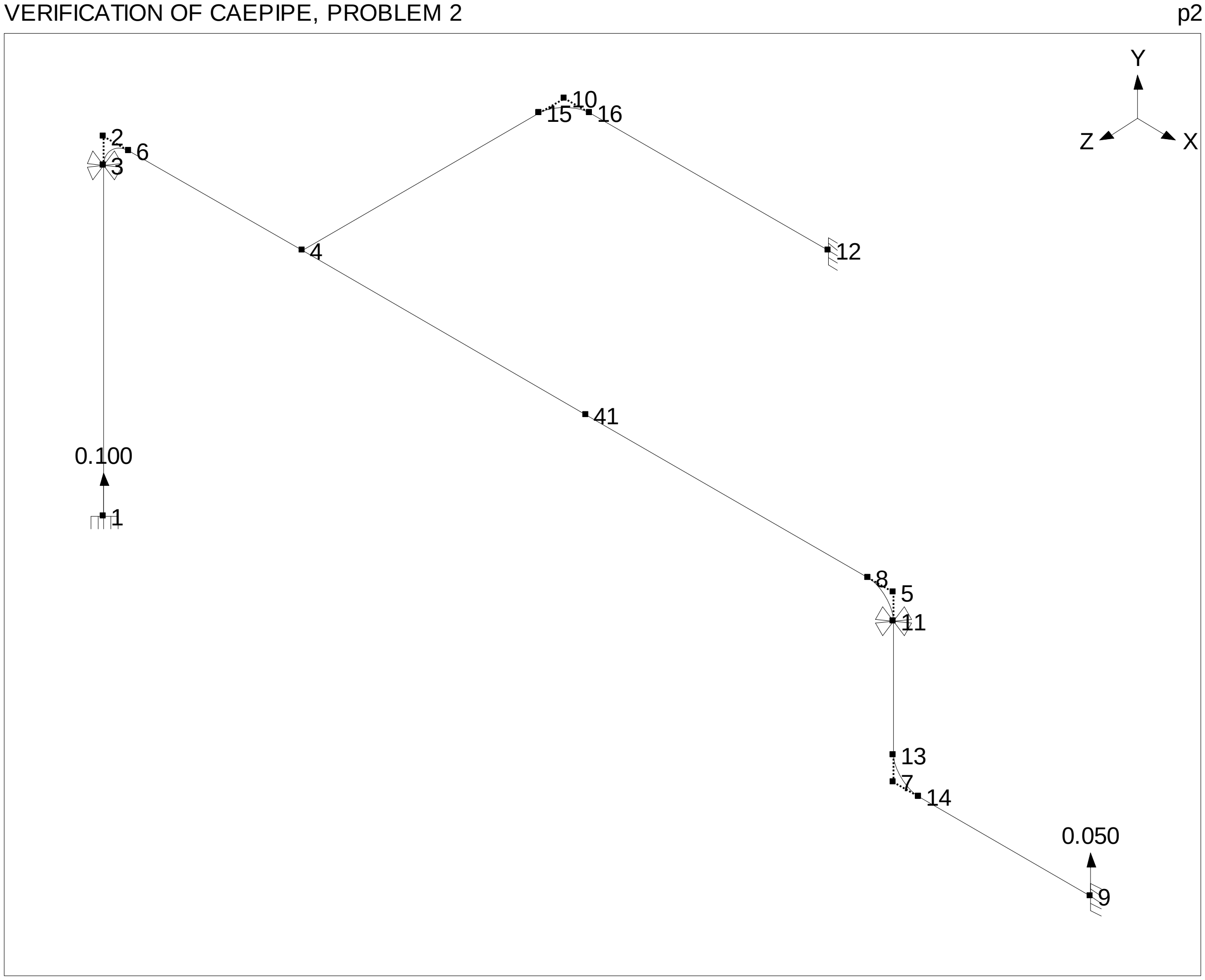
Table P1-2 Comparison of Support Loads for Operating case with WESTDYN [WES] and ANSYS [ANS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (in-lb)	MY (in-lb)	MZ (in-lb)
2	CAE	49	-3	-143	-10	34	20
	WES	49	-4	-144	-10	34	20
	ANS	49	-3	-144	-10	33	20
20	CAE	-286	-837	-1981	-66636	-1399	16609
	WES	-287	-837	-1981	-66516	-1407	16599
	ANS	-286	-713*	-1985	-66572	-1442	16591
23	CAE	237	469	2124	13342	-11406	210
	WES	238	469	2126	13173	-11382	210
	ANS	238	513*	2129	13678	-11357	221

The unit for material density in the ASME Benchmark problem is given in lb·m/in^3 in the problem description. To convert to CAEPIPE units of lb·f/in^3, the density given in the benchmark problem [ref. 5] must be multiplied by the factor g (386.1 in/sec^2). In addition, the modulus of elasticity used for the ASME results is 30 x 10^6 psi, a typical value for steel. The modulus has been incorrectly reported as 20 x 10^6 by the ASME in their problem description. With the above corrections, the ASME results and the CAEPIPE results are comparable.

* Mass at constraint node is not included in ANSYS analysis.

Problem 2



Problem SUMMARY	
What was compared	Displacements and loads
Load cases analyzed	Dead weight (DW), Thermal (T1)
Filename	P2.mod
This problem uses piping code ASME Class 2 with loading conditions (T, P): (180°F, 0 PSIG). This problem contains Specified Y displacements for the Thermal load case (T1).	

Table P2-1 Comparison of support loads for Dead Weight and Thermal cases with ADLPIPE [ADL], NUPIPE [NUP], and TPIPE [TPE]

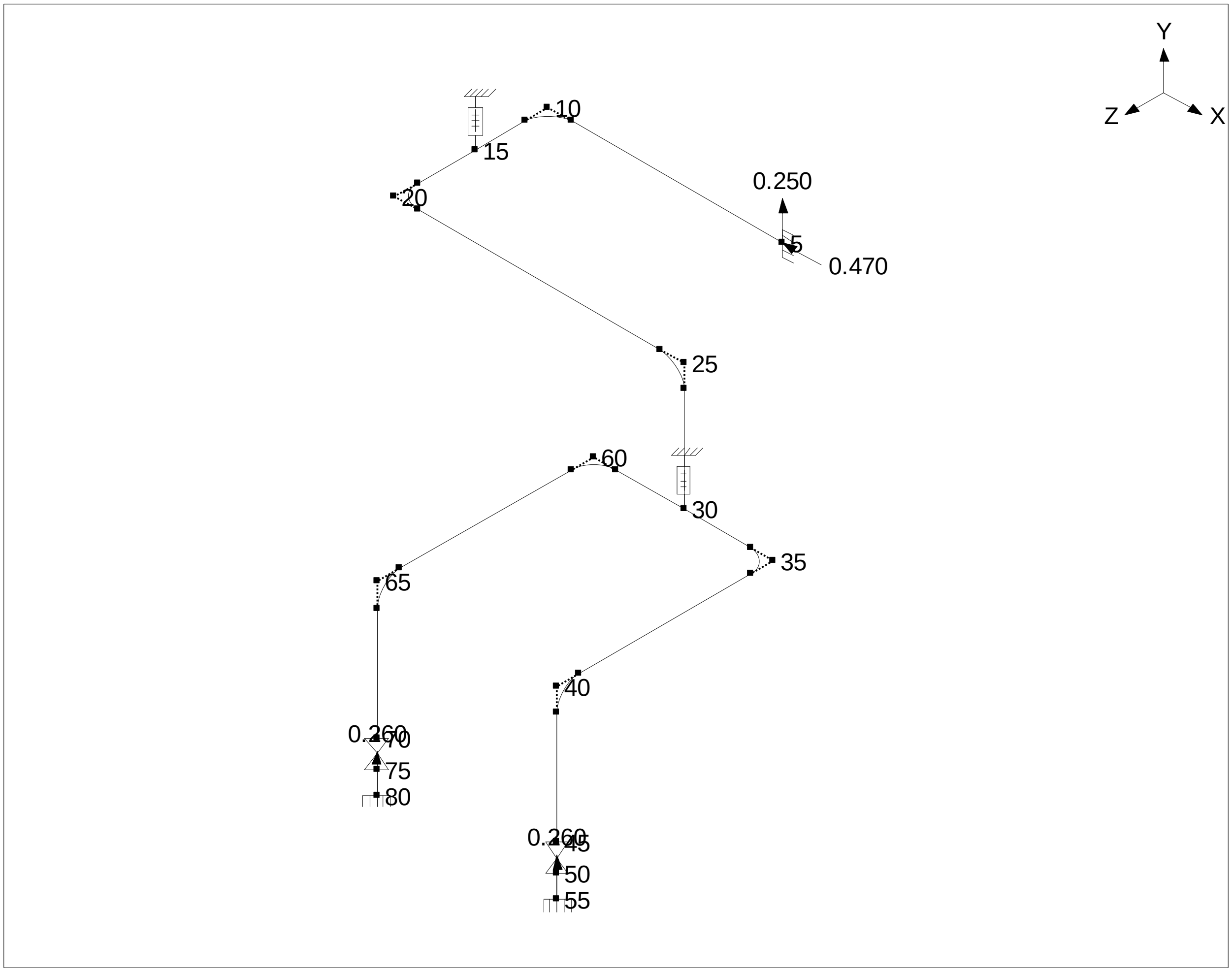
Load Case	Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
Dead Weight	1	CAE	-8	-134	-2	-3	0	12
		ADL	-8	-134	-2	-3	0	12
		NUP	-8	-134	-2	-3.3	0.4	11.9
		TPE	-7.8	-133.9	-2.1	-3.2	0.4	11.9
	9	CAE	44	-118	-1	1	-3	220
		ADL	44	-118	-1	1	-3	220
		NUP	44	-118	-1	0.5	-2.8	220
		TPE	43.9	-118.1	-1	0.5	-2.8	220.1
	12	CAE	1	-70	0	19	0	137
		ADL	1	-70	0	19	0	137
		NUP	1	-70	0	19.3	0.3	137.1
		TPE	1.1	-69.9	0.5	19.1	0.3	137.3
	3	CAE	-240		3			
		ADL	-240		3			
		NUP	-241		3			
		TPE	-241		2.6			
	11	CAE	203		1			
		ADL	203		1			
		NUP	204		1			
		TPE	203		0.9			
Thermal	1	CAE	1469	-307	181	275	-129	-2234
		ADL	1468	-307	181	275	-128	-2231
		NUP	1467	-307	181	275	-128.4	-2231
		TPE	1469	-306.8	181	275.3	-128.4	-2233.6
	9	CAE	-2475	-100	91	-54	270	462
		ADL	-2472	-100	90	-54	269	461
		NUP	-2472	-100	90	-53.8	269.2	461.4
		TPE	-2474.6	-100	90.4	-53.8	269.3	461.6
	12	CAE	179	407	-201	-743	-490	-1047
		ADL	178	406	-200	-743	-489	-1046
		NUP	178	406	-200	-742.5	-489	-1045.6
		TPE	178.6	406.5	-200.5	-742.9	-489	-1046.1
	3	CAE	-19321		14			
		ADL	-19297		14			
		NUP	-19297		14			
		TPE	-19313		13.7			
	11	CAE	20148		-85			
		ADL	20123		-85			
		NUP	20123		-85			
		TPE	20140		-84.6			

Table P2-2 Comparison of Nodal Displacements for Thermal case with ADLPIPE, NUPIPE, and TPIPE

Node	Program	X (inch)	Y (inch)	Z (inch)	XX (deg)	YY (deg)	ZZ (deg)
1	CAE	0.000	0.100	0.000	0.0000	0.0000	0.0000
	ADL	0	0.1	0	0	0	0
	NUP	0	0.1	0	0	0	0
	TPE	0	0.13	0	0	0	0
2A	CAE	0.000	0.158	0.000	-0.0605	-0.0705	0.4906
	ADL	0	0.158	0	-0.0	-0.07	0.49
	NUP	0	0.158	0	-0.06	-0.06	0.49
	TPE	0	0.198	0	-0.06	-0.12	0.48
2B	CAE	-0.054	0.219	-0.004	-0.1493	-0.0510	0.5746
	ADL	-0.054	0.219	-0.004	-0.15	-0.05	0.57
	NUP	-0.054	0.219	-0.004	-0.17	-0.06	0.57
	TPE	-0.067	0.274	-0.004	-0.17	-0.06	0.69
5A	CAE	0.053	0.108	-0.004	-0.0931	0.0199	-0.6470
	ADL	0.053	0.108	-0.004	-0.09	0.02	-0.65
	NUP	0.053	0.108	-0.004	-0.11	0.02	-0.63
	TPE	0.066	0.134	-0.005	-0.11	0.02	-0.80
5B	CAE	0.000	0.045	0.000	-0.0539	0.0343	-0.4280
	ADL	0.0	0.045	0.0	-0.05	0.03	-0.43
	NUP	0.0	0.045	0.0	-0.05	0.03	-0.46
	TPE	0.0	0.056	0.0	-0.06	0.04	-0.52

Problem 3

VERIFICATION OF CAEPIPE, PROBLEM 3 p3



Problem SUMMARY	
What was compared	Displacements, Support loads and Hanger selection
Load cases analyzed	Operating (W+P1+T1)
Filename	P3.mod
This problem uses piping code B31.3 with loading conditions (T, P): (875°F, 0 PSIG). This problem contains Specified X and Y displacements at Anchors for the Thermal load case (T1).	

Table P3-1 Comparison of Hanger Selection results with PIPELINE [PL]

Hanger Report									
Node	**Prog.**	**No. Reqd.**	**Fig No.**	**Size**	**Spring Rate (lb/inch)**	**Vertical Movement (inch)**	**Horizontal Movement (inch)**	**Hot Load (lb)**	**Cold Load (lb)**
15	CAE	1	82 Grinnell	11	680	0.331	1.319	1548	1773
	PL	1	82 Grinnell	11	680	0.331	1.319	1547	1772
30	CAE	1	B-268 Grinnell	13	600	0.837	0.817	2595	3097
	PL	1	B-268 Grinnell	13	600	0.837	0.817	2594	3096

Table P3-2 Comparison of Nodal displacements for Operating case with PIPELINE [PL]

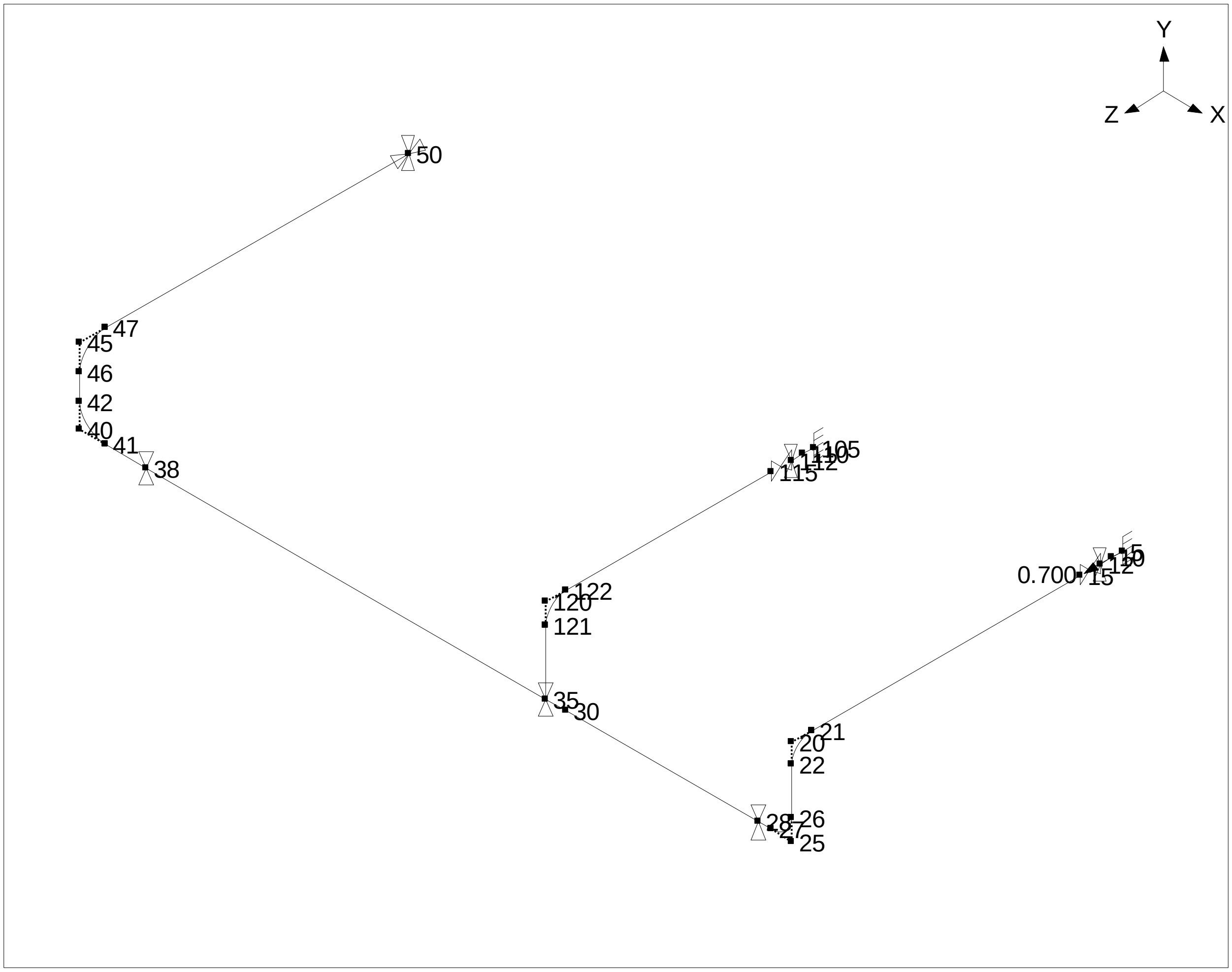
		Displacements		
Node	**Program**	**X (inches)**	**Y (inches)**	**Z (inches)**
5	CAE	-0.470	0.250	0.000
	PL	-0.470	0.250	0.000
15	CAE	-1.314	0.331	0.117
	PL	-1.314	0.331	0.117
30	CAE	0.051	0.837	-0.815
	PL	0.051	0.837	-0.815
45	CAE	0.013	0.447	-0.003
	PL	0.013	0.447	-0.003
70	CAE	-0.007	0.447	0.015
	PL	-0.007	0.447	0.015

Table P3-3 Comparison of Support Loads for Operating case with PIPELINE [PL]

Node	**Program**	**FX (lb)**	**FY (lb)**	**FZ (lb)**	**MX (ft-lb)**	**MY (ft-lb)**	**MZ (ft-lb)**
5	CAE	-411	234	-1099	-2644	-9661	-3137
	PL	-411	233	-1098	-2641	-9659	-3130
55	CAE	779	-2090	-47	-1503	-3946	-5806
	PL	778	-2090	-47	-1505	-3944	-5806
80	CAE	-367	-2513	1146	7069	2504	3366
	PL	-367	-2513	1145	7066	2504	3366
15	CAE		-1548				
	PL		-1547				
30	CAE		-2595				
	PL		-2594				

Problem 4

VERIFICATION OF CAEPIPE, PROBLEM 4 p4



Problem SUMMARY	
What was compared	Displacements and Support loads
Load cases analyzed	Thermal (T1)
Filename	P4.mod
This problem uses piping code B31.3 with loading conditions (T, P): (60°C, 1.46 BAR) and (153°C, 1.46 BAR). This problem contains Specified Z displacement for the Thermal load case (T1).	

Table P4-1 Comparison of Nodal Displacements for Thermal case with PIPELINE [PL]

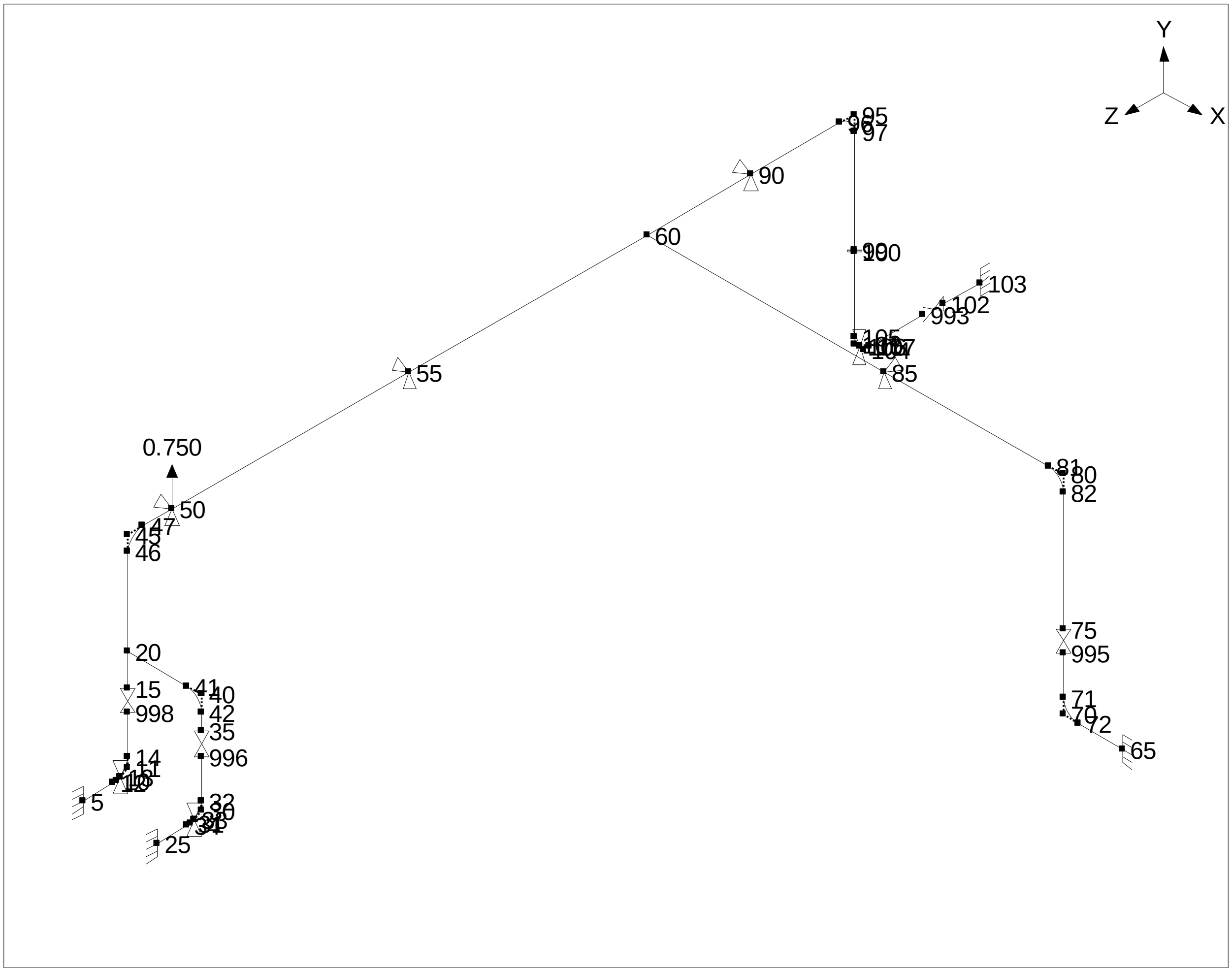
		Displacements		
Node	**Program**	**X (mm)**	**Y (mm)**	**Z (mm)**
5	CAE	0.000	0.000	0.700
	PL	0.000	0.000	0.700
10	CAE	0.005	0.000	0.772
	PL	0.005	0.000	0.772
12	CAE	0.017	0.000	0.850
	PL	0.017	0.000	0.850
15	CAE	0.040	0.000	0.978
	PL	0.040	0.000	0.978
20A	CAE	1.422	0.446	2.773
	PL	1.422	0.446	2.772
20B	CAE	1.650	0.457	3.086
	PL	1.650	0.457	3.086
25A	CAE	1.698	0.151	3.603
	PL	1.698	0.151	3.602
25B	CAE	1.581	0.005	4.107
	PL	1.581	0.005	4.106
28	CAE	1.496	0.000	4.306
	PL	1.496	0.000	4.305
30	CAE	0.210	0.000	6.523
	PL	0.210	-0.001	6.522
35	CAE	0.077	0.000	6.567
	PL	0.077	0.000	6.566
38	CAE	-2.588	0.000	3.388
	PL	-2.856	0.000	3.387
40A	CAE	-2.858	0.006	2.831
	PL	-2.856	0.006	2.830
40B	CAE	-3.019	0.178	2.378
	PL	-3.017	0.178	2.377
45A	CAE	-3.013	0.352	2.272
	PL	-3.011	0.351	2.271
45B	CAE	-2.649	0.445	2.019
	PL	-2.647	0.445	2.018
50	CAE	1.693	0.000	0.000
	PL	1.693	0.000	0.000
120A	CAE	0.080	1.531	6.493
	PL	0.080	1.531	6.492
120B	CAE	0.064	1.868	5.924
	PL	0.064	1.868	5.924
115	CAE	0.000	0.039	0.997
	PL	0.002	0.039	0.997
112	CAE	0.000	0.000	0.538
	PL	0.001	0.000	0.538

Table P4-2 Comparison of Support Loads for Thermal case with PIPELINE [PL]

Support Type	Node	Program	X-Tran (N)	Y-Tran (N)	Z-Tran (N)	X-Rot (N-m)	Y-Rot (N-m)	Z-Rot (N-m)
Anchor	5	CAE	18	-56	1180	0	765	-27
		PL	17	-54	1179	0	764	-26
	105	CAE	-18	-9387	-1693	-39	31	-17
		PL	-17	-9385	-1693	-39	31	-16
Restraint	12	CAE		-118				
		PL		-120				
	28	CAE		233				
		PL		233				
	35	CAE		-1294				
		PL		-1294				
	38	CAE		105				
		PL		104				
	112	CAE		10598				
		PL		10597				
	50	CAE		-81	513			
		PL		-81	513			

Problem 5

VERIFICATION OF CAEPIPE, PROBLEM 5 p5



Problem SUMMARY	
What was compared	Displacements and Support loads
Load cases analyzed	Operating (W+P1+T1)
Filename	P5.mod
This problem contains a Bellows Expansion joint at node 100. This problem uses piping code B31.3 with loading conditions (T, P): (550°F, 40 PSIG) and (70°F, 40 PSIG).	

Table P5-1 Comparison of Nodal Displacements for Operating case with DYNAFLEX [DYN]

Node	Program	X (inches)	Y (inches)	Z (inches)
5	CAE	0.000	0.000	0.000
	DYN	0	0	0
10A	CAE	-0.003	-0.010	-0.082
	DYN	-0.003	-0.010	-0.082
10B	CAE	-0.006	0.000	-0.101
	DYN	-0.006	0.000	-0.101
60	CAE	-0.141	-0.349	-0.187
	DYN	-0.141	-0.349	-0.187
85	CAE	0.516	0.012	-0.003
	DYN	0.516	0.012	-0.003
65	CAE	0.084	-0.180	0.000
	DYN	0.084	-0.180	0.000
90	CAE	-0.033	0.065	-0.474
	DYN	-0.033	0.065	-0.474
100	CAE	0.027	0.251	-0.185
	DYN	0.027	0.251	-0.183
993	CAE	0.000	-0.020	0.158
	DYN	0.000	-0.020	0.158

Table P5-2 Comparison of Support Loads for Operating case with DYNAFLEX [DYN]

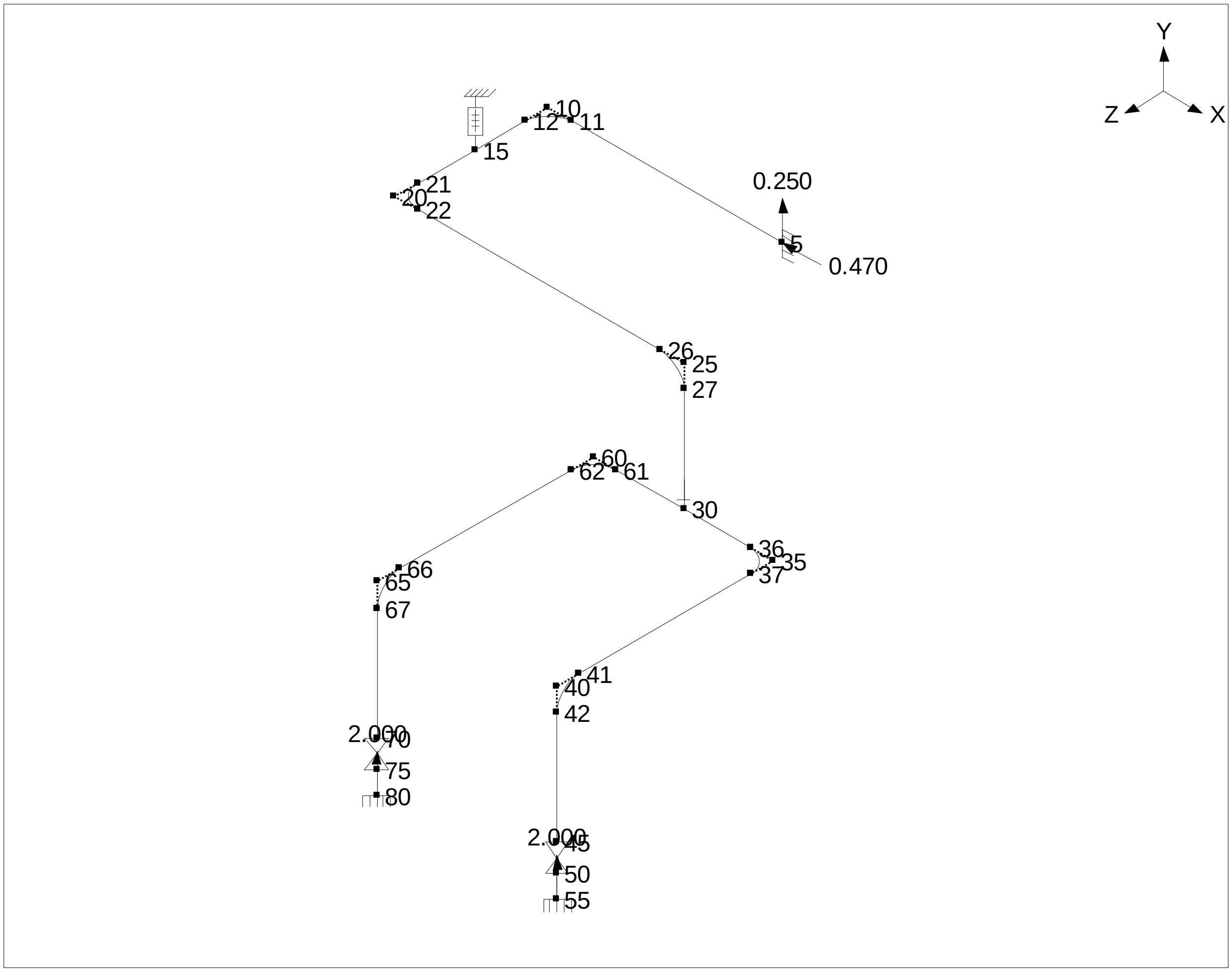
Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
5	CAE	-274	-5072	500	-6237	1605	253
	DYN	-274	-5068	502	-6230	1602	256
25	CAE	633	-4230	684	-5401	-514	-2614
	DYN	633	-4227	683	-5395	-518	-2614
103	CAE	55	-1510	-1127	4274	122	-348
	DYN	54	-1503	-1128	4261	122	-346
33	CAE	0	3103	0	0	0	0
	DYN	0	3104	0	0	0	0
13	CAE	0	6053	0	0	0	0
	DYN	0	6049	0	0	0	0
106	CAE	0	-1819	0	0	0	0
	DYN	0	-1826	0	0	0	0
50	CAE	-255	-2320	0	0	0	0
	DYN	-255	-2313	0	0	0	0
55	CAE	-420	-125	0	0	0	0
	DYN	-421	-125	0	0	0	0
65	CAE	838	-1624	0	443	-294	775
	DYN	838	-1621	0	442	-294	765
85	CAE	0	362	-57	0	0	0
	DYN	0	364	-57	0	0	0
90	CAE	-577	1952	0	0	0	0
	DYN	-577	1954	0	0	0	0

Problem 6

Comparison of Stress Intensification Factors (SIFs) for ASME B31.1, ASME B31.3, ASME B31J & ASME Section III NC – Class 2, ASME Section III ND – Class 3 and B1 & B2 Indices comparison for ASME Section III NC – Class 2 and ASME Section III ND – Class 3 are moved to the respective sub-sections within Chapter 6.

Problem 7

VERIFICATION OF CAEPIPE, PROBLEM 7 p7



Problem SUMMARY	
What was compared	Hanger selection, Support loads and loads on limit stops
Load cases analyzed	Operating (W+P1+T1)
Filename	P7.mod
This problem uses piping code B31.3 with loading conditions (T, P): (850°F, 300 PSIG).	

Table P7-1 Comparison of Support loads for Operating case with DYNAFLEX [DYN]

			Support Loads (N)					
Support Type	**Node**	**Program**	**FX (lb)**	**Fy (lb)**	**FZ (lb)**	**MX (ft-lb)**	**MY (ft-lb)**	**MZ (ft-lb)**
Anchor	5	CAE	-590	295	-1981	-6464	-15874	-7470
		DYN	-590	298	-1981	-6472	-15875	-7511
	55	CAE	953	-4198	-37	-19674	-3906	-7593
		DYN	952	-4198	-37	-19632	-3906	-7594
	80	CAE	-362	-4359	2018	-1927	3346	442
		DYN	-362	-4359	2019	-1921	3347	441

Table P7-2 Comparison of Hanger selection results with DYNAFLEX [DYN]

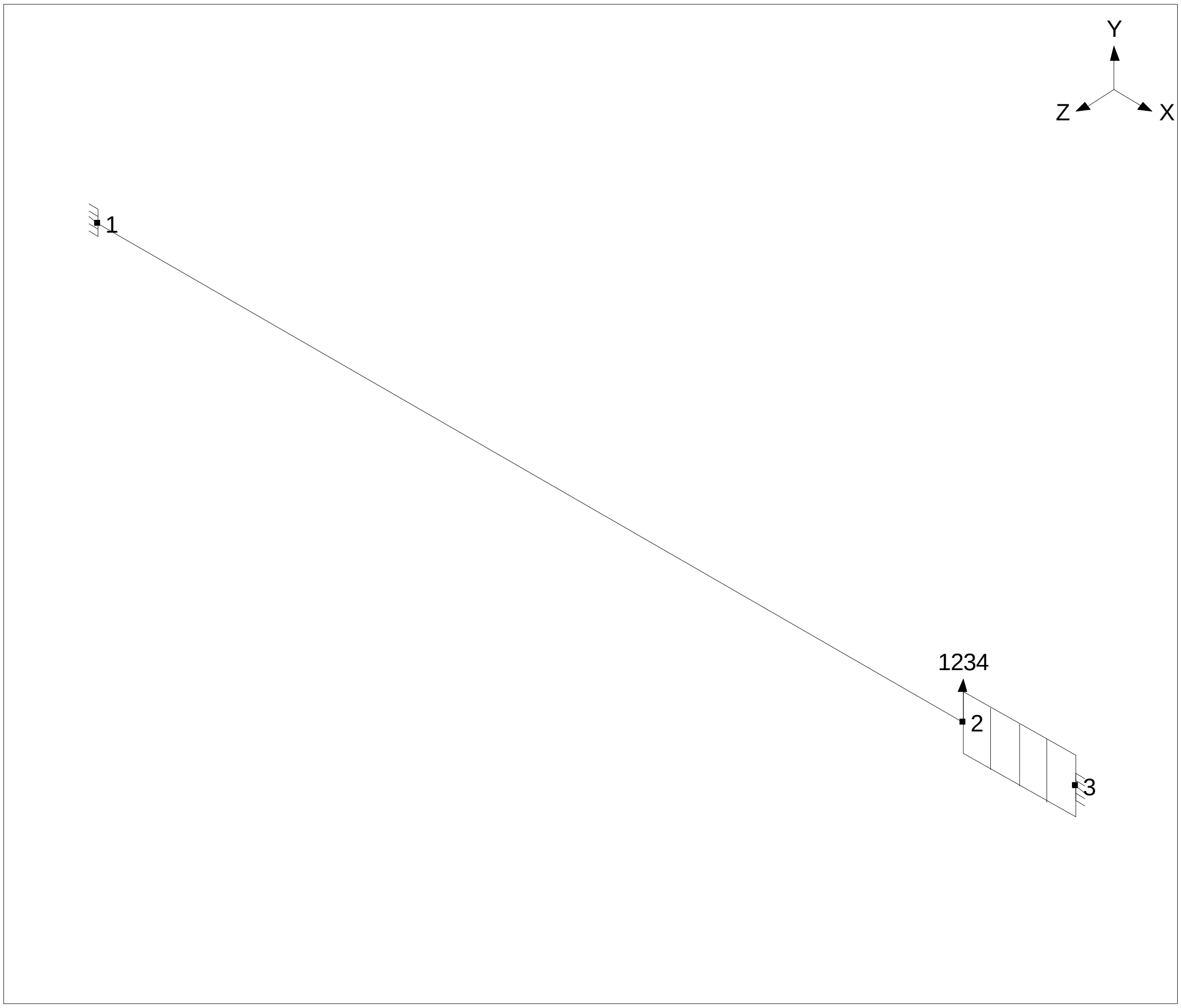
Hanger Report									
Node	**Prog.**	**No. Reqd.**	**Fig No.**	**Size**	**Spring Rate (lb/inch)**	**Vertical Movement (inch)**	**Horizontal Movement (inch)**	**Hot Load (lb)**	**Cold Load (lb)**
15	CAE	1	B-268 (= 82 Grinnell)	12	450	0.640	1.194	1973	2261
	DYN	1	82 Grinnell	12	450	0.641	1.194	1977	2265

Table P7-3 Comparison of Limit Stop loads for Operating case with DYNAFLEX [DYN]

Node	**Program**	**FY (lb)**
30	CAE	1869
	DYN	1860

Problem 8

VERIFICATION OF CAEPIPE, PROBLEM 8 p8



Problem SUMMARY	
What was compared	Displacements and Support loads
Load cases analyzed	Operating (W+P1+T1)
Filename	P8.mod
This problem uses piping code B31.3 with loading conditions (T, P): (500°F, 100 PSIG). This problem has a Bellows Expansion joint at node 2.	

Table P8-1 Comparison of Support loads for Operating case with DYNAFLEX [DYN]

Node	Program	FX (lb) [see Note]	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	CAE	~~-4404~~ -4440	829	0	0	0	10037
	DYN	-4404	829	0	0	0	10037
3	CAE	~~4404~~ 4440	198	0	0	0	-136
	DYN	4404	197	0	0	0	-136

Table P8-2 Comparison of Displacements for Operating case with DYNAFLEX [DYN]

Node	Program	X (inch)	Y (inch)	Z (inch)	XX (rad)	YY (rad)	ZZ (rad)
1	CAE	0.000	0.000	0.000	0.0000	0.0000	0.0000
	DYN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2	CAE	0.392	0.900	0.000	0.0000	0.0000	0.5891
	DYN	0.3917	0.9001	0.0000	0.0000	0.0000	0.5891
3	CAE	0.000	0.000	0.000	0.0000	0.0000	0.0000
	DYN	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Note:

Difference in Support load in FX direction between CAEPIPE and DYNAFLEX is due to fact that starting CAEPIPE Version 7.80, Linear Thermal Expansion of Bellows is included in the Analysis. On the other hand, DYNAFLEX does not include the Linear Thermal Expansion of Bellows in Analysis.

This can be verified as given below.

1. Alpha @ 500 deg. F = 7.02E-6 in/in/F
2. Delta T = 500 – 70 = 430 deg. F
3. Length of Bellow = 1’5” = 17”
4. Axial Stiffness of Bellows = 700 lb/inch

Thermal expansion of Bellows = Alpha x Delta T x L = 7.02E-6 x 430 x 17 = 0.05132”

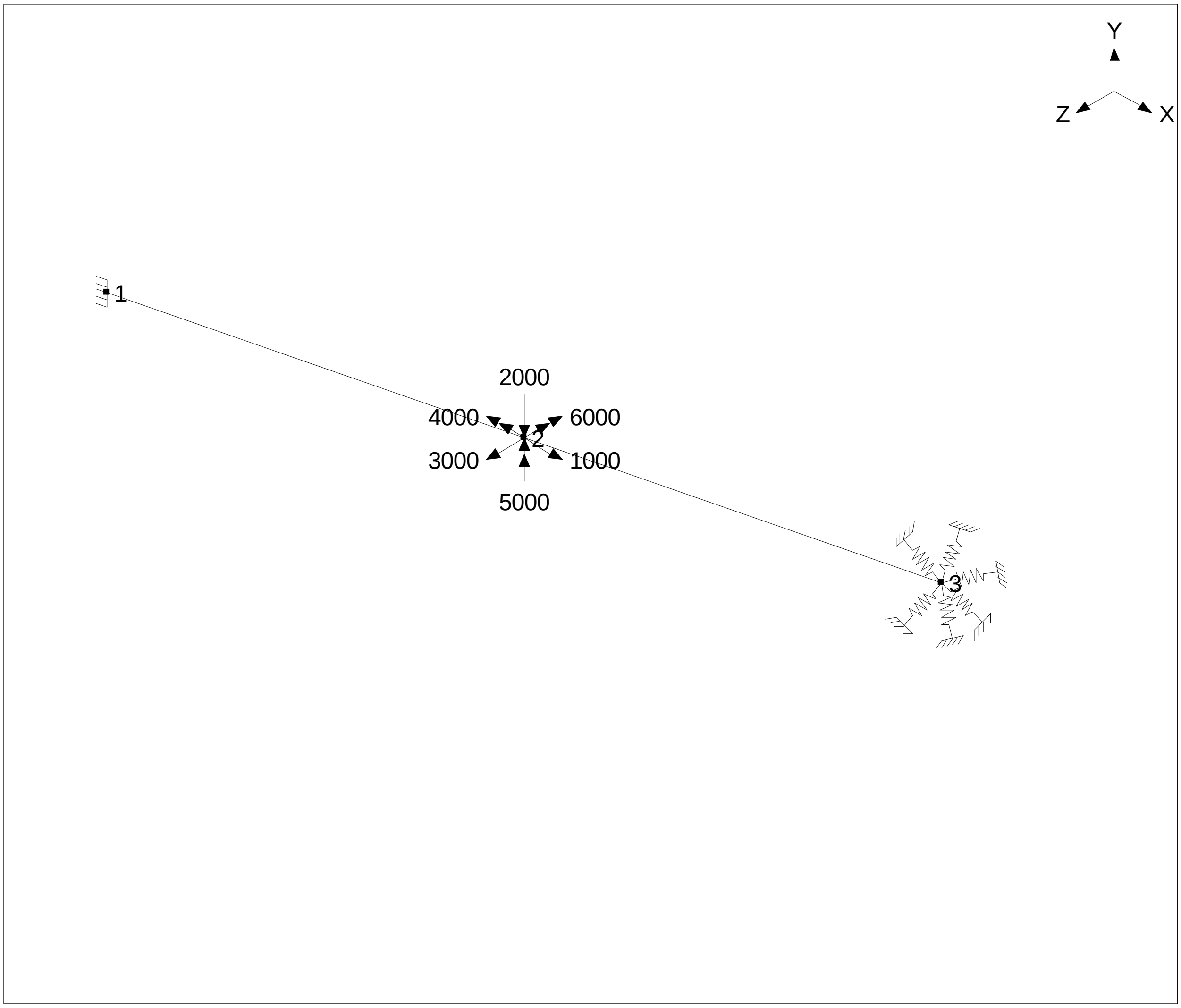
Additional Axial Force generated @ Nodes 1 and 3 due to

Thermal Expansion of Bellows = Thermal expansion x Axial Stiffness

= 0.05132 x 700 = 35.92 lb (= 4440 – 4404 = 36 lb from Table P8-1)

Problem 9

VERIFICATION OF CAEPIPE, PROBLEM 9 p9



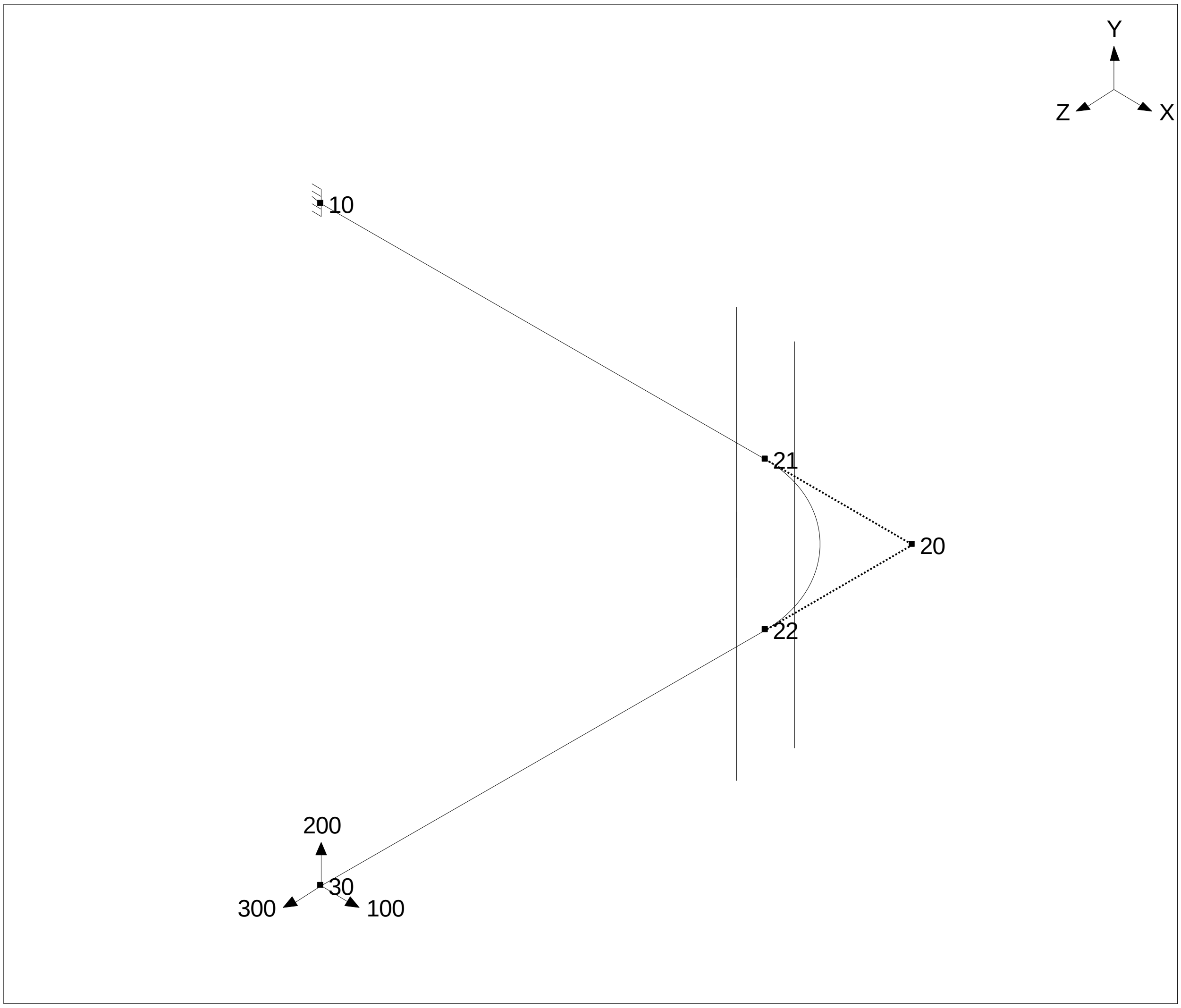
Problem SUMMARY	
What was compared	Loads on Skewed Restraints
Load cases analyzed	Sustained (W+P1)
Filename	P9.mod
This problem uses piping code B31.3 with loading conditions (T, P): (70°F, 0 PSIG).	

Table P9-1 Comparison of Skewed Restraints loads for Sustained case with DYNAFLEX [DYN]

Node	Program	X-comp	Y-comp	Z-comp	Type	Load (lb)/(ft-lb)
3	CAE	0.816	0.408	-0.408	Translational	-29
	DYN	0.82	0.41	-0.41	Translational	-29
	CAE	-0.408	0.816	0.408	Translational	-150
	DYN	-0.41	0.82	0.41	Translational	-150
	CAE		-0.447	0.894	Translational	168
	DYN		-0.43	0.90	Translational	168
	CAE	0.667	-0.667	-0.333	Rotational	4
	DYN	0.67	-0.67	-0.33	Rotational	3
	CAE		0.894	-0.447	Rotational	7
	DYN		0.90	-0.45	Rotational	7
	CAE	0.535	-0.802	0.267	Rotational	-9
	DYN	0.57	-0.79	0.23	Rotational	-9

Problem 10

VERIFICATION OF CAEPIPE, PROBLEM 10 p10



Problem SUMMARY	
What was compared	Element forces at the Miter bend
Load cases analyzed	Sustained (W+P)
Filename	P10.mod
This problem uses piping code B31.1 (1967) with loading conditions (T, P): (70°F, 500 PSIG).	

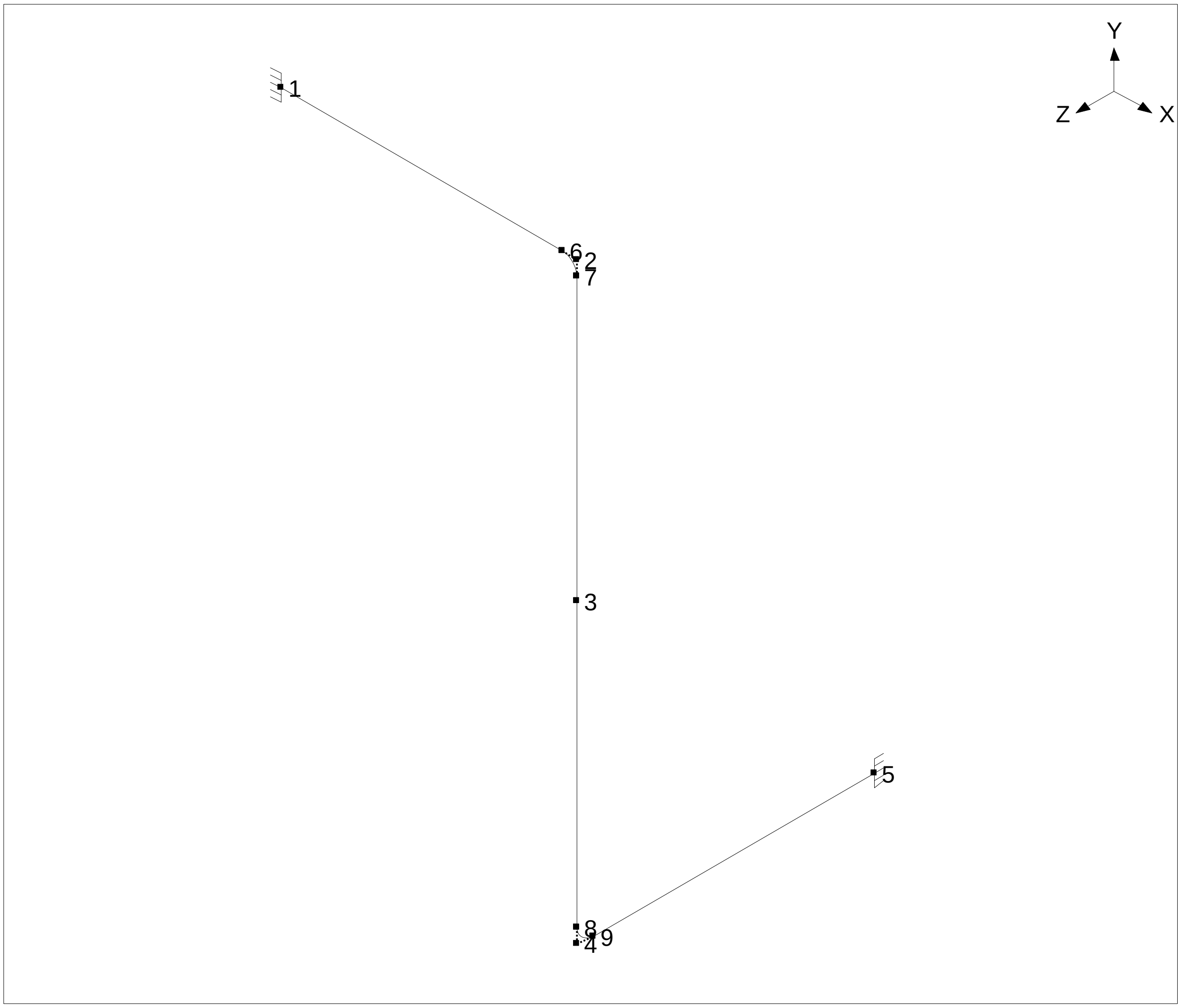
Table P10-1 Comparison of global element forces for Sustained case with DYNAFLEX [DYN]

								SIF		
Node	**Program**	**FX (lb)**	**FY (lb)**	**FZ (lb)**	**MX (ft-lb)**	**MY (ft-lb)**	**MZ (ft-lb)**	**In-plane**	**Out-of-plane**	**Stress (PSI)**
10*	CAE	-100	-95	-300	516	600	-368	1.00	1.00	3600
	DYN	-100	-94	-300	515	600	-368	1.00	1.00	3600
20B	CAE	100	158	300	-403	225	0	1.43	1.43	3573
	DYN	100	158	300	-403	225	0	1.43	1.43	3573
22*	CAE	-100	-158	-300	403	-225	0	1.00	1.00	3294
	DYN	-100	-158	-300	403	-225	0	1.00	1.00	3294
30*	CAE	100	200	300	0	0	0	1.00	1.00	2642
	DYN	100	200	300	0	0	0	1.00	1.00	2642

* A “blank” SIF in CAEPIPE results is the same as “1.00”.

Problem 11

VERIFICATION OF CAEPIPE, PROBLEM 11 p11



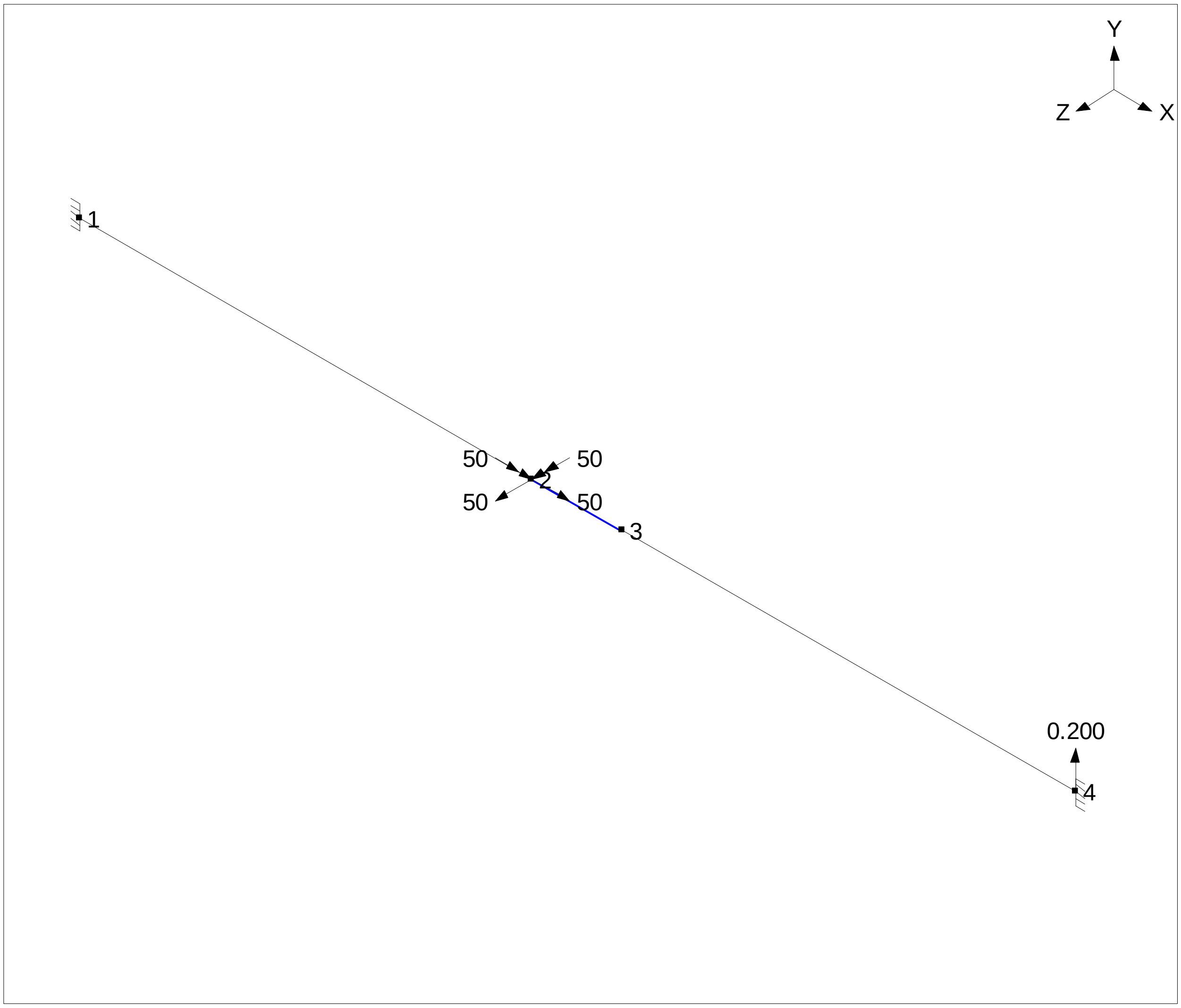
Problem SUMMARY	
What was compared	Restraint loads under Wind loading
Load cases analyzed	Wind (120 mph)
Filename	P11.mod
This problem uses piping code B31.3 with loading conditions (T, P): (70°F, 0 PSIG).	

Table P11-1 Comparison of Restraint loads for Wind case with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	CAE	1	-9	58	1	-189	-37
	PS	1	-9	58	1	-189	-37
5	CAE	-1	8	36	8	-24	-2
	PS	-1	8	36	8	-24	-2

Problem 12

VERIFICATION OF CAEPIPE, PROBLEM 12 p12



Problem SUMMARY	
What was compared	Elastic element (Restraint loads)
Load cases analyzed	Sustained (W+P1) and Thermal (T1)
Filename	P12.mod
This problem uses piping code B31.1 with loading conditions (T, P): (200°F, 200 PSIG).	

Table P12-1 Comparison of Support loads for the Thermal case with PIPESTRESS [PS]

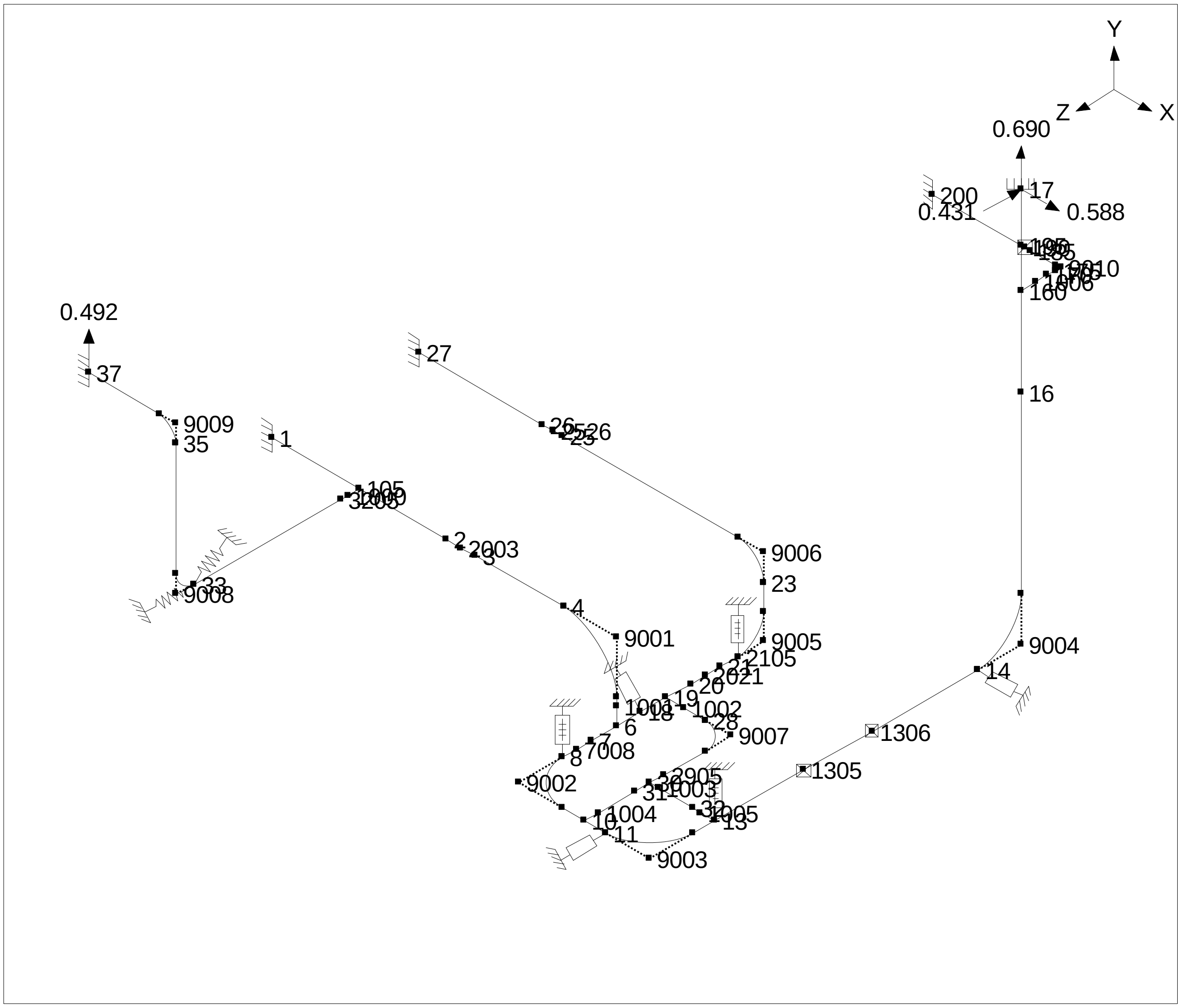
Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	CAE	-21020	21	0	0	0	114
	PS	-21020	21	0	0	0	114
4	CAE	21020	-21	0	0	0	114
	PS	21020	-21	0	0	0	114

Table P12-2 Comparison of Support loads for the Sustained case with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	CAE	30	-25	28	25	-69	-42
	PS	30	-25	28	25	-69	-43
4	CAE	20	-11	22	25	57	18
	PS	20	-11	22	25	57	18

Problem 13

VERIFICATION OF CAEPIPE, PROBLEM 13 p13



Problem SUMMARY	
What was compared	Displacements, Support loads and Member forces Load
Load cases analyzed	Sustained (W+P1), Thermal (T1) and Acceleration (g)
Filename	P13.mod
This problem uses piping code B31.3 with loading conditions (T, P): (665°F, 545 PSIG).	

Table P13-1 Comparison of Displacements for Thermal case with PIPESTRESS [PS]

Node	Program	X (inch)	Y (inch)	Z (inch)	XX (rad)	YY (rad)	ZZ (rad)
105	CAE	0.263	-0.025	0.031	-0.00022	-0.00095	-0.00074
	PS	0.263	-0.025	0.031	-0.0002	-0.0010	-0.0007
6	CAE	0.932	-0.497	0.273	-0.00070	-0.00005	-0.00195
	PS	0.932	-0.497	0.273	-0.0007	0.0000	-0.0019
9002B	CAE	1.061	-0.484	0.568	-0.00129	0.00028	-0.00097
	PS	1.060	-0.484	0.568	-0.0013	0.0003	-0.0010
13	CAE	1.302	-0.584	0.351	-0.00138	0.00090	-0.00016
	PS	1.301	-0.584	0.351	-0.0014	0.0009	-0.0002
160	CAE	0.619	0.337	-0.446	0.00045	0.00042	0.00095
	PS	0.619	0.337	-0.446	0.0004	0.0004	0.0009
30	CAE	1.106	-0.555	0.367	-0.00113	0.00004	-0.00111
	PS	1.106	-0.555	0.367	-0.0011	0.000	-0.0011

Table P13-2 Comparison of member global forces and moments for Thermal case with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
105	CAE	3632	491	-2963	10660	17001	14737
	PS	3632	492	-2962	10663	16992	14747
6	CAE	-1211	-110	-6972	3893	-2465	-12194
	PS	-1209	-112	-6975	3900	-2458	-12198
13	CAE	4056	1763	-2382	9413	-52705	-23562
	PS	4055	1764	-2382	9427	-52700	-23572
9002B	CAE	-1211	192	-6972	4033	-13131	-12674
	PS	-1209	190	-6975	4030	-13143	-12673
160	CAE	3525	1753	-2396	20377	19031	47446
	PS	3524	1754	-2396	20363	19025	47424
30	CAE	-10678	-1172	10352	4968	-21224	-2628
	PS	-10683	-1165	10369	4957	-21248	-2605

Table P13-3 Comparison of Support loads for Thermal case with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	CAE	-4028	-1998	1366	-4347	-27688	-23979
	PS	-4030	-1998	1366	-4355	-27691	-23990
17	CAE	3525	1753	-2396	32358	19031	65072
	PS	3524	1754	-2396	32342	19025	65042
27	CAE	-424	-705	-581	791	8798	-13908
	PS	-423	-706	-581	791	8799	-13918
37	CAE	-845	-645	1597	-6215	-7014	-4980
	PS	-845	-649	1596	-6214	-7012	-4998
200	CAE	531	10	14	0	0	43
	PS	532	10	14	0	0	43

Node	Program	Type	Load	Units			
33	CAE	Translational	2484	(lb)			
	PS	Translational	2488	(lb)			
33	CAE	Rotational	-6105	(ft-lb)			
	PS	Rotational	-6110	(ft-lb)			

Table P13-4 Comparison of Displacements for Sustained case with PIPESTRESS [PS]

Node	Program	X (inch)	Y (inch)	Z (inch)	XX (rad)	YY (rad)	ZZ (rad)
105	CAE	0.000	0.005	-0.001	-0.00006	0.00003	0.00022
	PS	0.000	0.005	-0.001	-0.0001	0.0000	0.0002
6	CAE	0.021	0.093	0.009	-0.00040	0.00000	0.00029
	PS	0.021	0.093	0.009	-0.0004	0.0000	0.0003
9002B	CAE	0.021	0.131	0.009	-0.00051	0.00001	0.00025
	PS	0.021	0.131	0.009	-0.0005	0.0000	0.0003
13	CAE	0.021	0.115	0.008	-0.00077	0.00002	0.00013
	PS	0.021	0.115	0.008	-0.0008	0.0000	0.0001
160	CAE	0.001	-0.000	0.000	-0.00001	0.0000	0.00003
	PS	0.001	0.000	0.000	0.0000	0.0000	0.0000
30	CAE	0.021	0.111	0.009	-0.00049	0.00000	0.00013
	PS	0.021	0.111	0.009	-0.0005	0.0000	0.0001

Table P13-5 Comparison of member global forces and moments for Sustained case with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
105	CAE	-5	108	7	2486	-419	-7367
	PS	-5	107	7	2493	-421	-7370
6	CAE	-57	-2322	-142	8801	-200	1970
	PS	-57	-2323	-142	8807	-200	1967
13	CAE	66	4913	20	7771	-935	347
	PS	66	4914	20	7780	933	349
9002B	CAE	-57	313	-142	2651	-238	636
	PS	-57	311	-142	2648	-237	637
160	CAE	63	-5516	19	-776	214	1517
	PS	63	-5516	19	-779	213	1517
30	CAE	-187	-514	234	1392	-395	-1617
	PS	-187	-514	234	1384	-394	-1627

Table P13-6 Comparison of Support loads for Sustained case with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	CAE	54	-990	-35	-1095	928	3545
	PS	54	-990	-35	-1101	930	3550
17	CAE	63	-6291	19	-873	214	1834
	PS	63	-6290	19	-875	213	1833
27	CAE	-71	-837	-13	-500	296	-1256
	PS	-70	-837	-13	-501	296	-1260
37	CAE	85	-444	28	-22	-96	-1254
	PS	85	-444	28	-22	-96	-1253
200	CAE	2	-23	0	-3	0	-38
	PS	2	-23	0	-3	0	-38
Node	**Program**	**Type**	**Load (lb)**				
8	CAE	User Hanger	-3722				
	PS	User Hanger	-3722				
2105	CAE	User Hanger	-2908				
	PS	User Hanger	-2908				

Table P13-7 Comparison of Displacements for Static seismic case with PIPESTRESS [PS]

Node	Program	X (inch)	Y (inch)	Z (inch)	XX (rad)	YY (rad)	ZZ (rad)
105	CAE	0.000	0.000	0.001	0.00005	0.00001	0.00001
	PS	0.000	0.000	0.001	0.0000	0.0000	0.0000
6	CAE	0.022	0.023	0.006	0.00015	0.00010	0.00041
	PS	0.022	0.023	0.006	0.0002	0.0001	0.0004
9002B	CAE	0.030	0.044	0.003	0.00014	0.00009	0.00029
	PS	0.030	0.044	0.003	0.0001	0.000	0.0003
13	CAE	0.026	0.049	0.002	0.00024	0.00009	0.00015
	PS	0.026	0.049	0.002	0.0002	0.0001	0.0001
160	CAE	0.000	0.000	0.001	0.00002	0.00002	0.00001
	PS	0.000	0.000	0.001	0.0000	0.0000	0.0000
30	CAE	0.026	0.041	0.001	0.00015	0.00010	0.00024
	PS	0.026	0.041	0.001	0.0001	0.0001	0.0002

Table P13-8 Comparison of member global forces and moments for Static seismic case with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
105	CAE	2490	255	154	1276	185	1149
	PS	2490	255	154	1277	184	1149
6	CAE	1133	81	131	440	4430	2214
	PS	1132	81	132	441	4428	2213
13	CAE	788	221	197	1310	941	1590
	PS	789	221	197	1314	938	1591
9002B	CAE	861	63	131	849	946	2056
	PS	860	63	132	849	944	2056

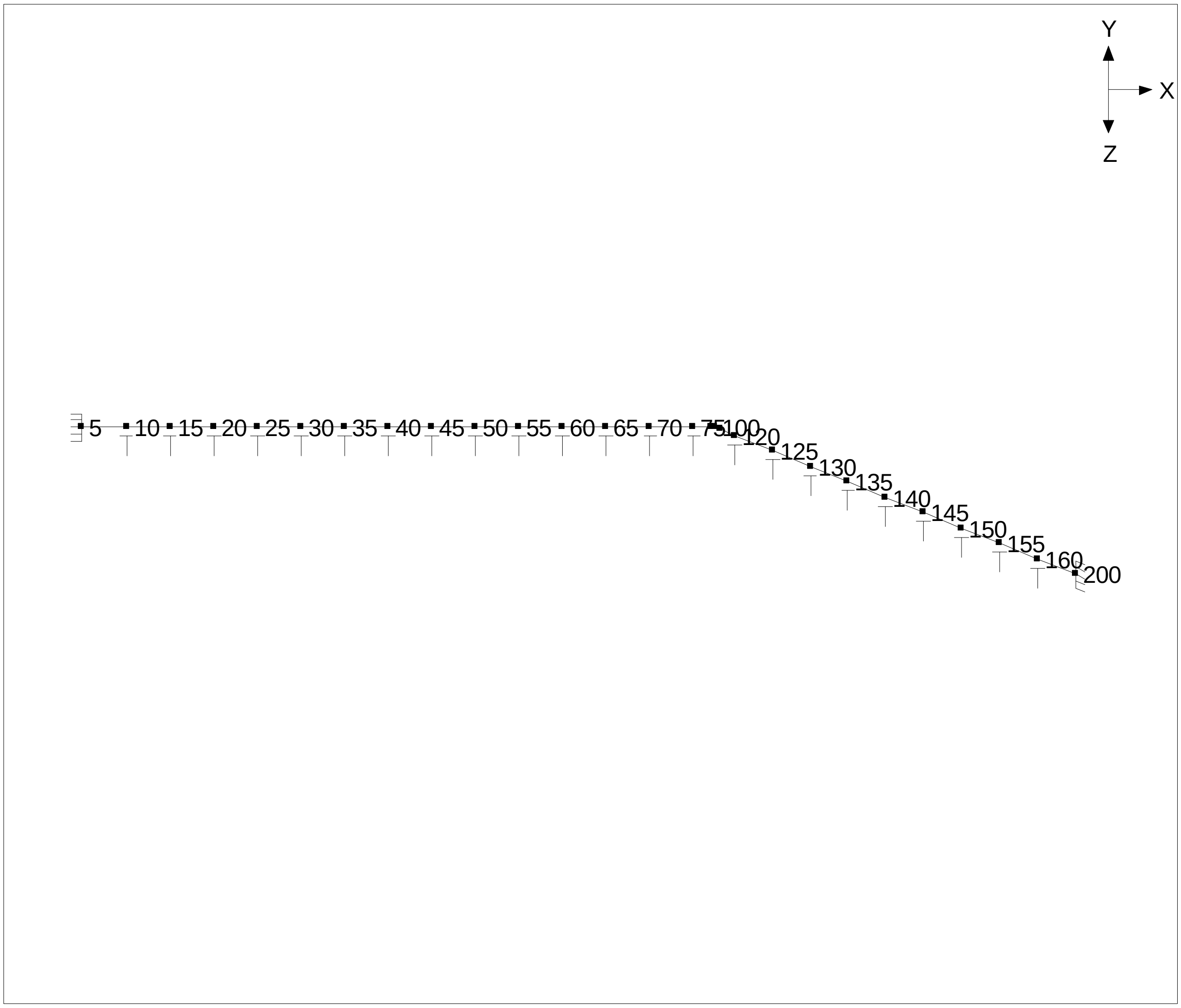
160	CAE	226	221	197	903	725	423
	PS	226	221	197	903	724	423
30	CAE	383	148	222	265	819	565
	PS	383	150	225	265	813	573

Table P13-9 Comparison of Support loads for Static seismic case with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
1	CAE	2699	302	149	933	659	377
	PS	2699	302	149	934	658	376
17	CAE	420	221	197	1887	725	1191
	PS	420	221	197	1887	724	1191
27	CAE	422	26	11	171	116	8
	PS	422	26	11	171	116	6
37	CAE	115	68	5	13	9	225
	PS	115	68	5	13	9	225
200	CAE	13	0	0	0	0	0
	PS	13	0	0	0	0	0
Node	**Program**	**Load (lb)**	**X comp**	**Y comp**	**Z comp**		
11	CAE	32			1.000		
	PS	32			1.000		
14	CAE	1585	1.000				
	PS	1585	1.000				
18	CAE	52	-1.000	1.000			
	PS	52	-1.000	1.000			

Problem 14

VERIFICATION OF CAEPIPE, PROBLEM 14 p14



Problem SUMMARY	
What was compared	Support loads (with and without Friction)
Load cases analyzed	Operating (W+P1+T1)
Filename	P14.mod, P14_1.mod
This problem uses the loading conditions (T, P): (-165°C, 0 BAR). This problem was analyzed for two cases: without Friction and with Friction at Limit stops (Friction coefficient of 0.3).	

Table P14-1 Comparison of Support loads for Operating case with published results* [PUB]

Node	Program	FX (N)	MY (N-m)	B.M. @ node 100A (N-m)	Type
5	CAE	223067	9971	-329088	With Friction
	PUB	222600	10001	328480	With Friction
	CAE	16752	-123990	-124504	Without Friction
	PUB	16746	-123942	124462	Without Friction

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* "Treatment of support friction in stress analysis" –Liang-Chuan Peng [ref 11].

2 – Dynamics Verification Method

The Dynamics features of CAEPIPE were verified by comparing their results to those obtained from other verified computer programs.

Following is a list of the verification problems presented in this section.

Model name	Results compared with
P15	DYNAFLEX [ref. 13]
P16	ANSYS [ref. 14]
P17	PISTAR [ref. 12]
P18	PIPELINE and Nuclear Regulatory Commission (NRC) program Benchmark problem #1 [ref. 15]
P19	PIPESTRESS [ref. 16]
P20	NRC program Benchmark problem #5 [ref. 17]
P21	PIPESTRESS [ref. 16]

It will be clear from the ensuing comparisons that the results obtained are comparable.

See the earlier section on "Program Description" for a brief description of the Uniform Response Spectrum analysis method.

Dynamics Verification Results

The tabulation of results from CAEPIPE and the other programs (and a few manual calculations) are given in this section. The table below lists the features tested and the problems with which they were tested.

Table P0-2 List of CAEPIPE features verified (Dynamics)*

CAEPIPE Feature	**Problem #**
Modal frequencies	15, 16, 17, 18, 19, 20, 21
Modal participation factors	15, 17, 18, 19, 20
Member forces and moments for Response Spectrum Analysis	18, 20, 21
Missing mass correction	21
Time History Analysis	22

The remainder of this section presents plots of models and tables comparing their results with other sources.

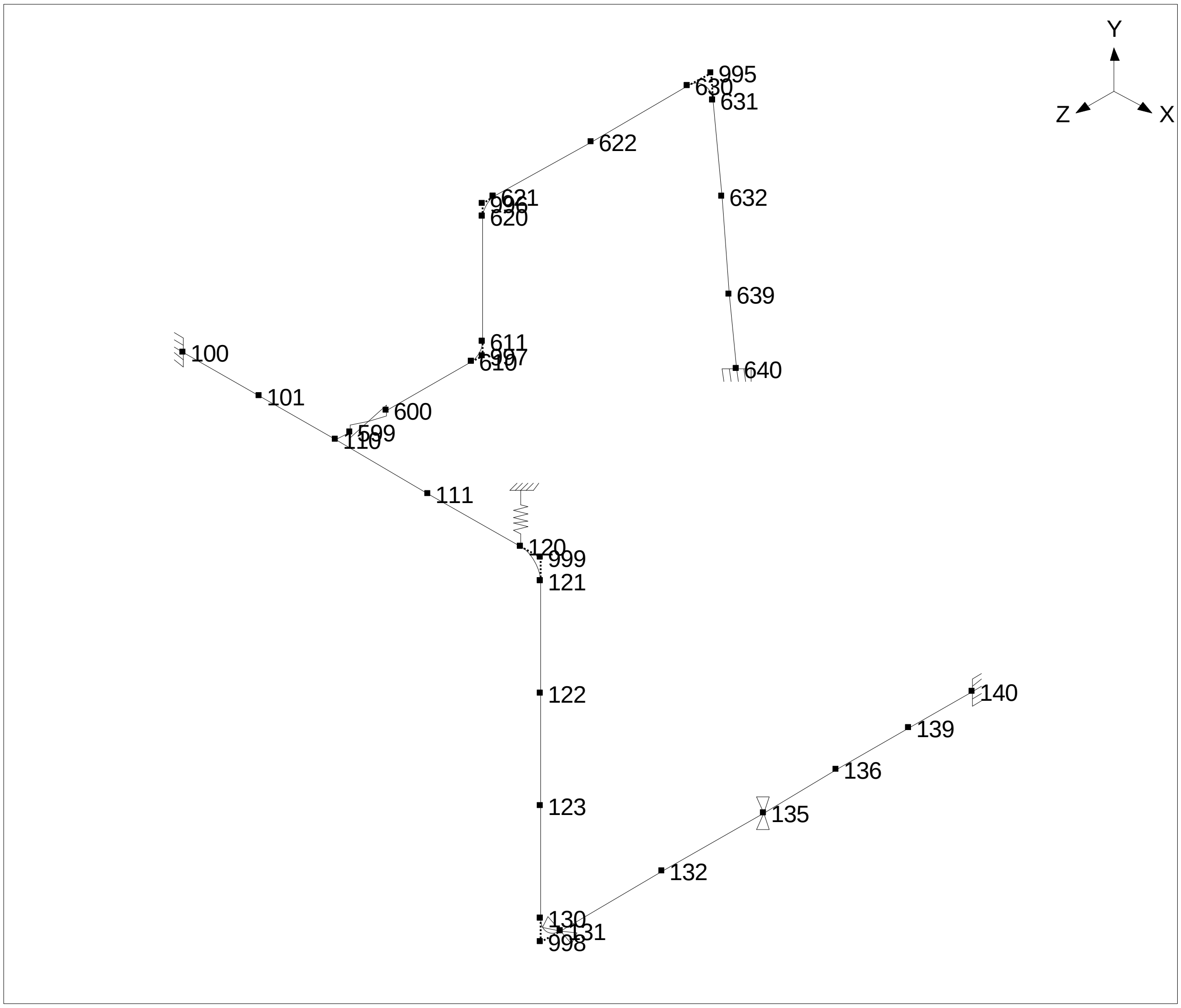
Note:

For the Dynamic problems listed in this Section, Flexibility Factors (FFs) given by ASME B31J are not used in calculating any of the results reported in this Section.

* See Table P0-1 for a list of Statics features verified.

Problem 15

VERIFICATION OF CAEPIPE, PROBLEM 15 p15



Problem SUMMARY	
What was compared	Modal frequencies and participation factors
Load cases analyzed	Modal analysis
Filename	P15.mod
This problem may be found in DYNAFLEX User's manual [ref. 13].	

Table P15-1 Comparison of modal frequencies with DYNAFLEX [DYN]

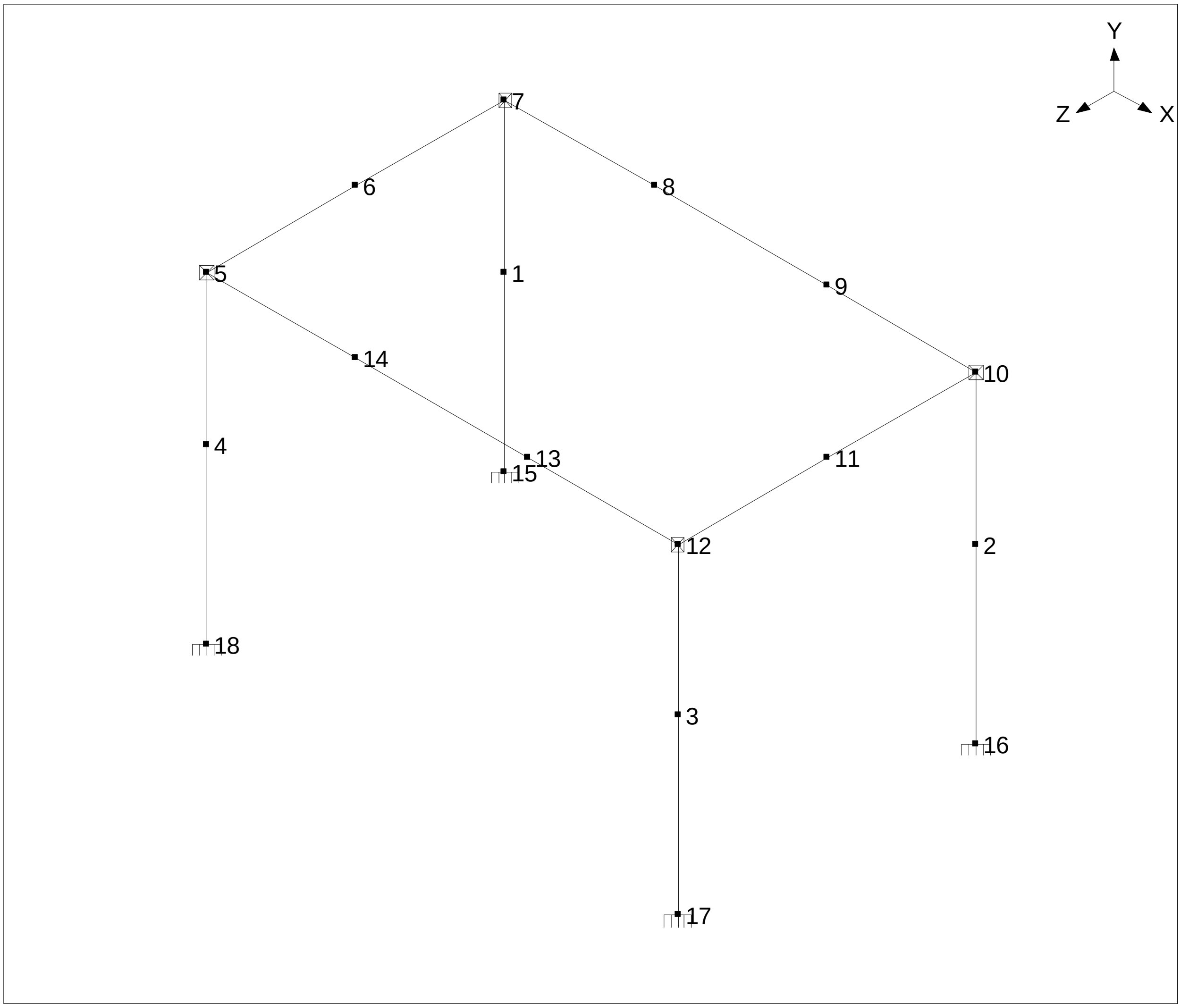
Mode No.	Program	Frequency (Hz)
1	CAE	3.304
	DYN	3.30
2	CAE	4.091
	DYN	4.09
3	CAE	5.026
	DYN	5.04
4	CAE	6.148
	DYN	6.12
5	CAE	7.553
	DYN	7.52
6	CAE	7.929
	DYN	7.82
7	CAE	13.939
	DYN	13.69
8	CAE	15.483
	DYN	15.16
9	CAE	16.010
	DYN	15.78
10	CAE	16.805
	DYN	16.55

Table P15-2 Comparison of Modal Participation Factors with DYNAFLEX [DYN]

Mode No.	Program	X	Y	Z
1	CAE	-1.2511	0.6047	-1.3243
	DYN	1.2508	0.5917	1.2921
2	CAE	0.6143	1.1366	-1.8502
	DYN	0.5929	1.1427	1.8662
3	CAE	-0.1634	-2.5551	-1.1770
	DYN	0.1683	2.5450	1.1779
4	CAE	-0.1277	0.0504	0.7491
	DYN	0.1262	0.0523	0.7412
5	CAE	0.1404	-0.7036	0.2702
	DYN	0.1385	0.6879	0.2611
6	CAE	0.0827	0.1399	-0.3224
	DYN	0.0417	0.1680	0.3121
7	CAE	-0.4039	0.1347	-0.3548
	DYN	0.4951	0.1337	0.2405
8	CAE	1.0775	0.0924	-0.8177
	DYN	0.9975	0.0931	0.8653
9	CAE	0.0751	0.3099	0.4654
	DYN	0.0384	0.3244	0.4369
10	CAE	-1.4752	0.6232	-0.0742
	DYN	1.5291	0.5906	0.0853

Problem 16

VERIFICATION OF CAEPIPE, PROBLEM 16 p16



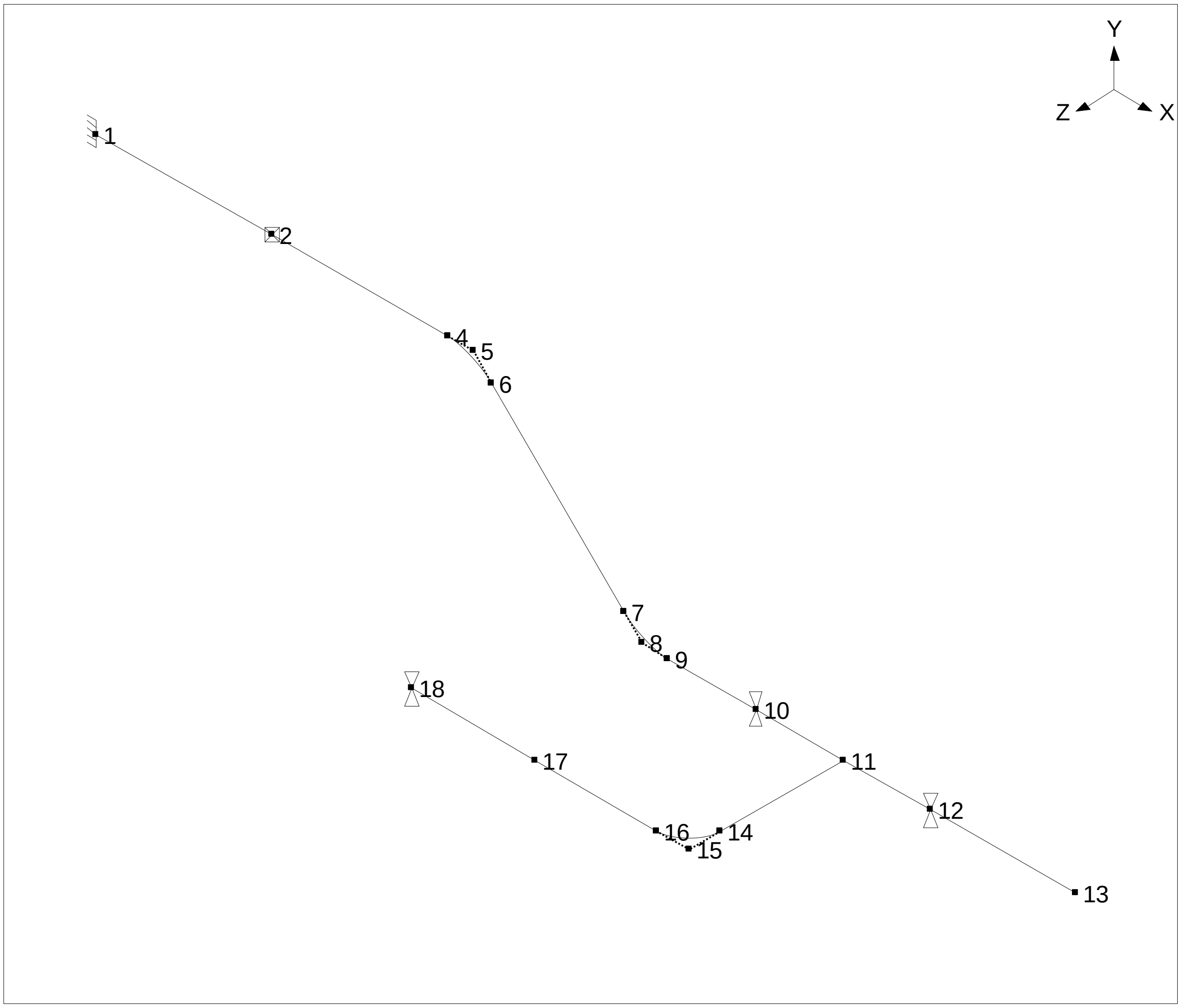
Problem SUMMARY	
What was compared	Modal frequencies
Load cases analyzed	Modal analysis
Filename	P16.mod
This problem may be found in [ref. 14]. The actual structure consists of lengths of two-inch steel pipe and steel cubes welded together.	

Table P16-1 Comparison of Frequencies with ANSYS [ANS]

Mode No.	Program	Frequency (Hz)
1	CAE	111.265
	ANS	111.5
2	CAE	115.832
	ANS	115.9
3	CAE	137.200
	ANS	137.6
4	CAE	215.852
	ANS	218.0
5	CAE	404.457
	ANS	404.2
6	CAE	422.836
	ANS	422.7
7	CAE	451.807
	ANS	451.7
8	CAE	549.236
	ANS	554.0
9	CAE	733.918
	ANS	735.7
10	CAE	758.899
	ANS	762.3

Problem 17

VERIFICATION OF CAEPIPE, PROBLEM 17 p17



Problem SUMMARY	
What was compared	Modal frequencies and participation factors
Load cases analyzed	Modal analysis
Filename	P17.mod
This model may be found in SAP IV User's Manual [ref. 18], but as it does not contain results, they were obtained from analyzing this model in PISTAR [ref. 12].	

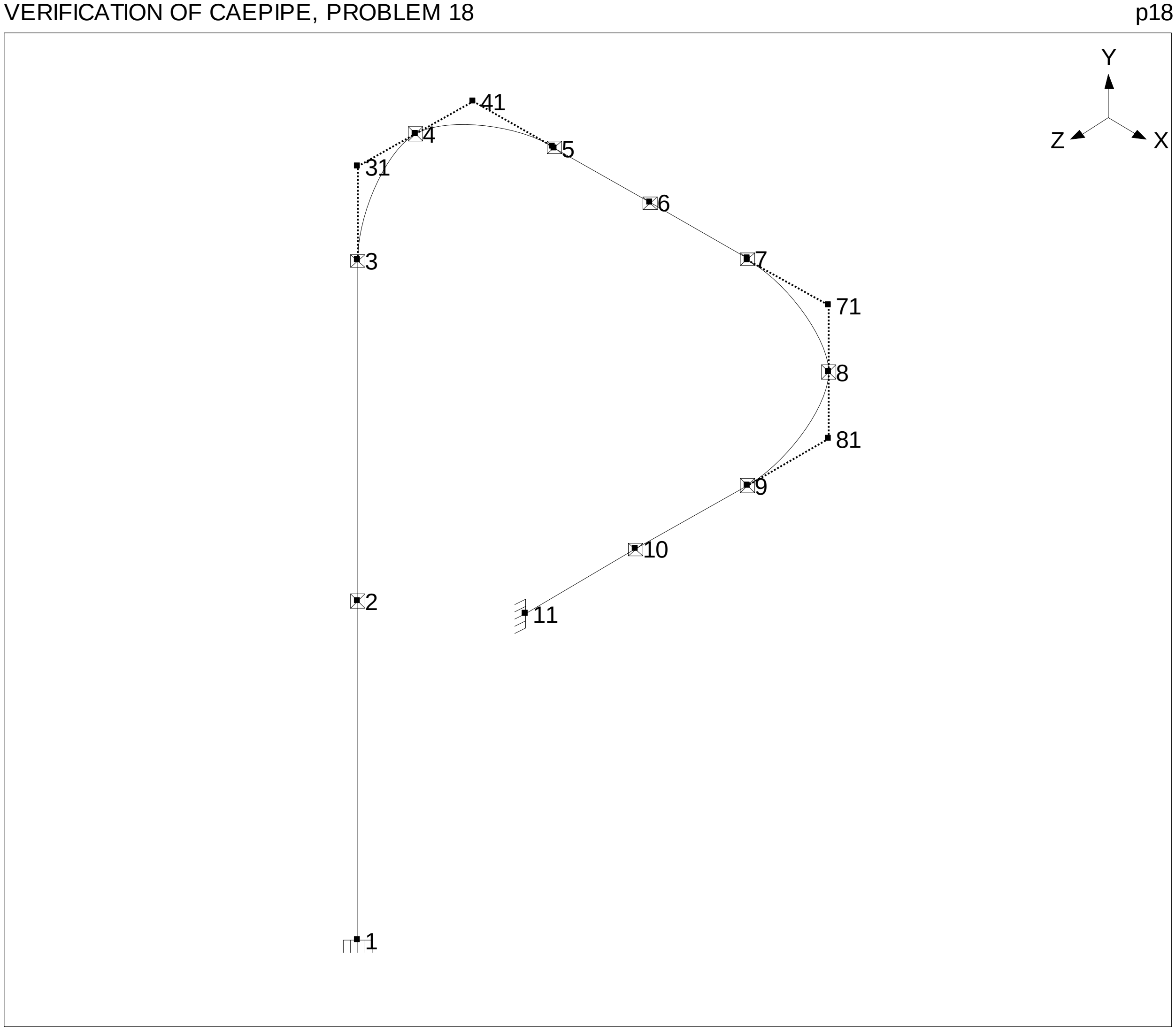
Table P17-1 Comparison of modal frequencies with PISTAR [PIS]

Mode No.	Program	Frequency (Hz)
1	CAE	1.454
	PIS	1.461
2	CAE	4.411
	PIS	4.412
3	CAE	7.999
	PIS	8.002
4	CAE	10.342
	PIS	10.370
5	CAE	11.855
	PIS	11.960

Table P17-2 Comparison of Modal Participation Factors with PISTAR [PIS]

Mode No.	Program	X	Y	Z
1	CAE	-0.2742	0.0543	5.5664
	PIS	0.2744	-0.0542	-5.5440
2	CAE	0.6549	-0.0186	1.3614
	PIS	0.6479	-0.0187	1.3580
3	CAE	-1.0609	0.3214	-3.6025
	PIS	-1.0480	0.3210	-3.6120
4	CAE	4.0733	-3.2782	-1.0967
	PIS	4.0510	-3.3070	-1.0780
5	CAE	0.5631	-2.1160	2.1569
	PIS	0.5340	-2.0930	2.1930

Problem 18



Problem SUMMARY	
What was compared	Modal frequencies, participation factors & member forces
Load cases analyzed	Modal analysis, Response Spectrum
Filename	P18.mod
This problem may be found in US NRC publication [ref. 15, Benchmark problem 1].	

Table P18-1 Comparison of modal frequencies with NRC [NRC]

Mode No.	Program	Frequency (Hz)
1	CAE	28.523
	NRC	28.53
2	CAE	55.727
	NRC	55.77
3	CAE	81.463
	NRC	81.50
4	CAE	141.661
	NRC	141.70
5	CAE	162.723
	NRC	162.80

Table P18-2 Comparison of Modal Participation Factors with NRC [NRC]

Mode No.	Program	X	Y	Z
1	CAE	0.1751	-0.0259	-0.3309
	NRC	0.1752	-0.0259	-0.3308
2	CAE	-0.3629	0.0021	-0.1476
	NRC	0.3628	-0.0020	0.1478
3	CAE	-0.0539	-0.2582	0.0279
	NRC	-0.0539	-0.2582	0.0279
4	CAE	-0.0836	0.0527	0.0117
	NRC	0.0836	-0.0526	-0.0117
5	CAE	0.0792	-0.0660	0.0111
	NRC	-0.0792	0.0660	-0.0111

Table P18-3 Comparison of Member Forces and Moments (in local coordinates) for Response Spectrum case with NRC* [NRC]

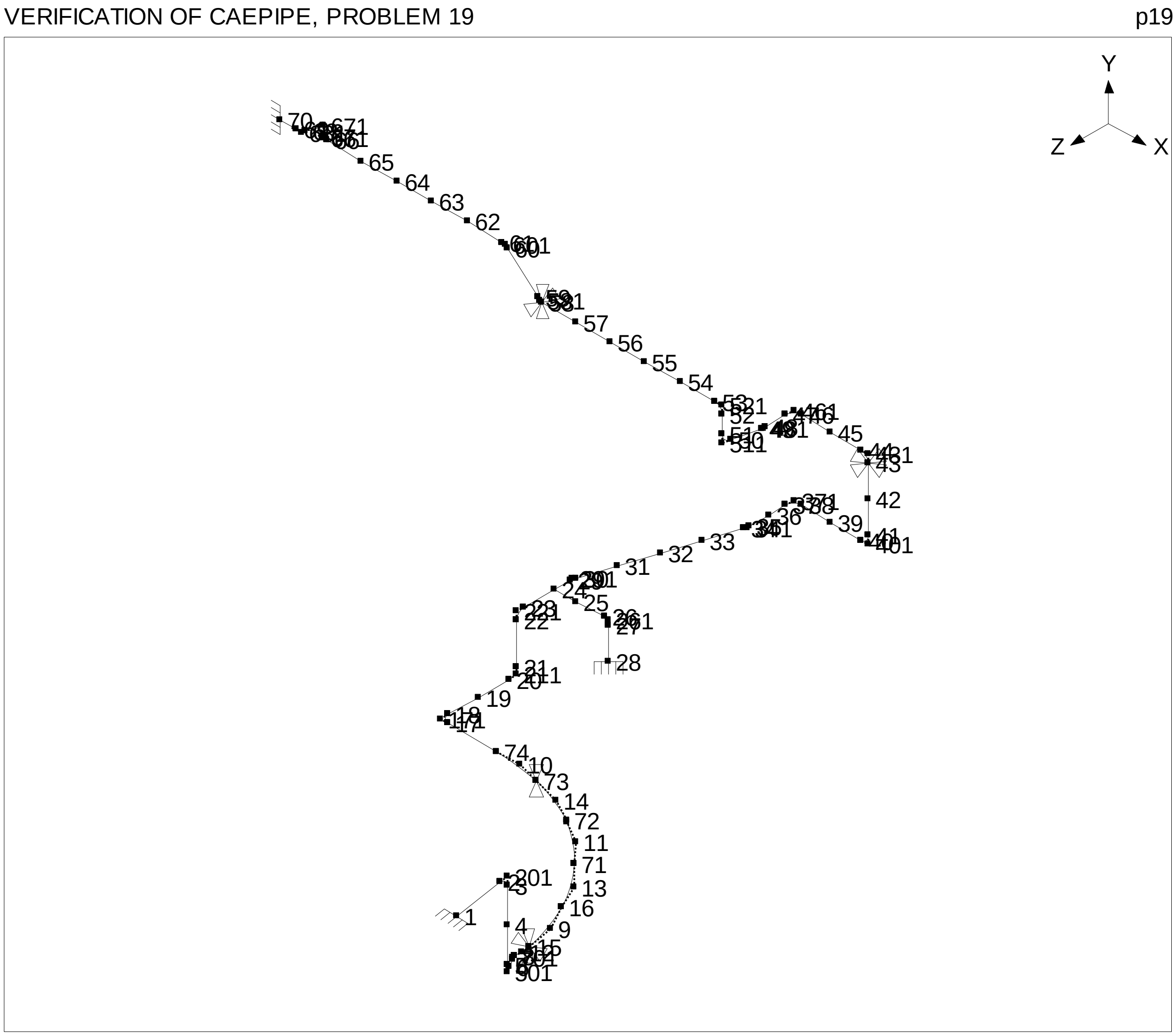
Node	Program	fx(lb)	fy (lb)	fz (lb)	mx (ft-lb)	my (ft-lb)	mz (ft-lb)
1	CAE	5	18	36	52	267	115
1 to 1I	NRC	5.0	17.9	36.4	52.5	268.9	116.2
6	CAE	18	3	17	35	35	22
6 to 5J	NRC	17.8	2.6	16.9	35.3	35.1	22.1
11	CAE	24	7	34	9	204	64
11 to 10J	NRC	24.0	7.5	34.8	9.4	206.4	64.5

* The designation "I" or "J" indicates the starting node or ending node of the member respectively and the number alongside indicates the element number (e.g., 1I means the starting node of the first element).

NRC's local coordinate system differs from that of CAEPIPE's, as provided below.

CAEPIPE	fx	fy	fz	mx	my	mz
NRC	axial	shear y	shear z	torsion	out-plane	in-plane

Problem 19



Problem SUMMARY	
What was compared	Modal frequencies & participation factors
Load cases analyzed	Modal analysis
Filename	P19.mod

Table P19-1 Comparison of modal frequencies with PIPESTRESS [PS]

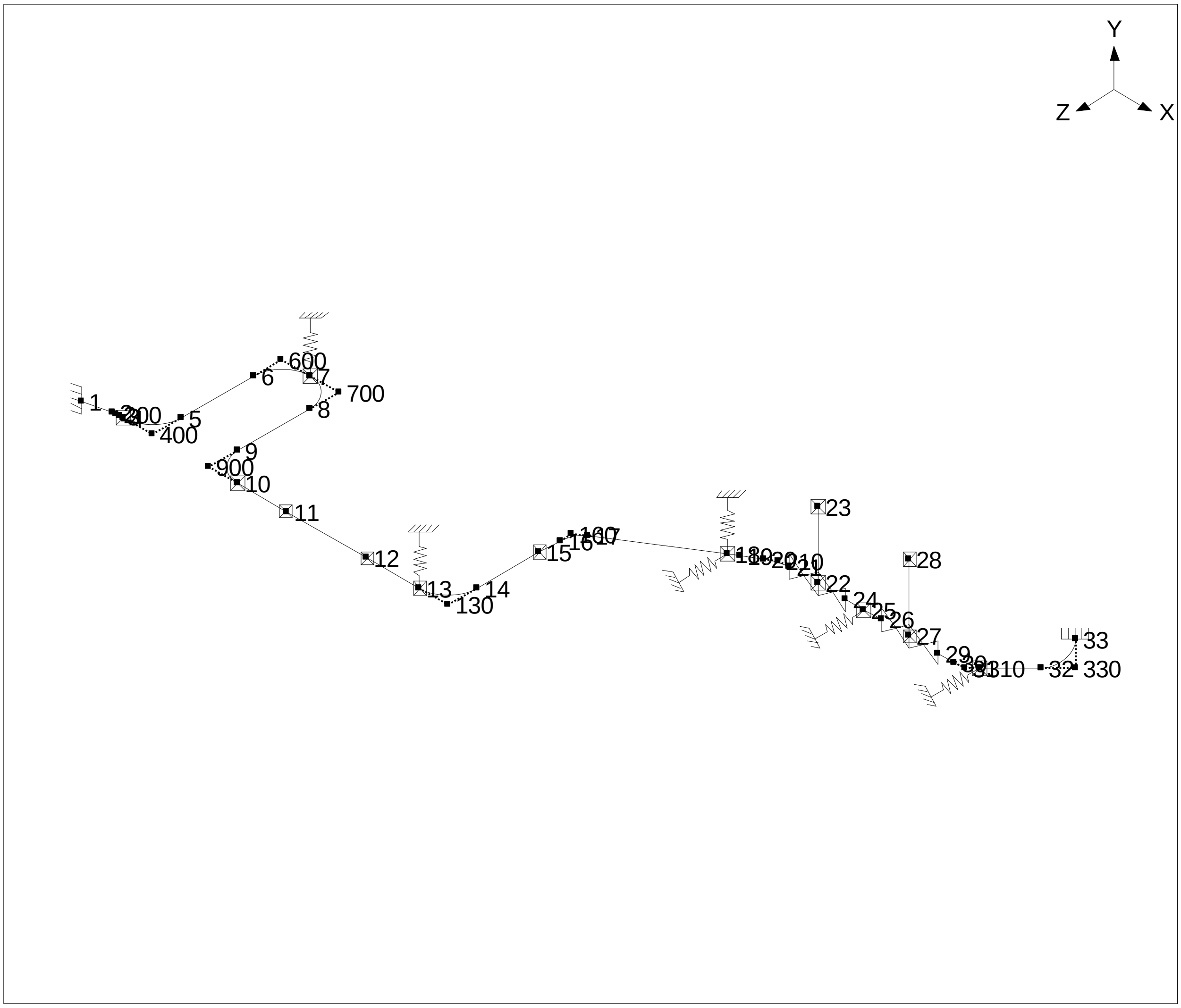
Mode No.	Program	Frequency (Hz)
1	CAE	3.249
	PS	3.253
2	CAE	5.697
	PS	5.702
3	CAE	6.793
	PS	6.795
4	CAE	7.865
	PS	7.866
5	CAE	8.529
	PS	8.526
6	CAE	10.864
	PS	10.864
7	CAE	11.453
	PS	11.485
8	CAE	13.592
	PS	13.589
9	CAE	14.707
	PS	14.700
10	CAE	15.378
	PS	15.383

Table P19-2 Comparison of Modal Participation Factors with PIPESTRESS [PS]

Mode No.	Program	X	Y	Z
1	CAE	-0.0214	-0.1925	-0.0098
	PS	0.0203	0.1840	0.0093
2	CAE	0.1140	-0.0292	-0.0685
	PS	0.1140	0.0292	0.0679
3	CAE	-0.1111	0.0557	0.0392
	PS	0.1100	0.0551	0.0388
4	CAE	-0.0529	-0.0872	-0.0496
	PS	0.0541	0.0890	0.0508
5	CAE	-0.0684	-0.0463	-0.0511
	PS	0.0681	0.0458	0.0508
6	CAE	-0.0389	0.0818	-0.1168
	PS	0.0401	0.0845	0.1210
7	CAE	-0.0017	-0.0143	0.2414
	PS	0.0021	0.0152	0.2570
8	CAE	-0.0201	0.0433	-0.1056
	PS	0.0196	0.0431	0.1040
9	CAE	0.0223	0.0368	-0.0886
	PS	0.0209	0.0350	0.0849
10	CAE	0.1038	0.0317	0.0917
	PS	0.1110	0.0338	0.0975

Problem 20

VERIFICATION OF CAEPIPE, PROBLEM 20 p20



Problem SUMMARY	
What was compared	Modal frequencies, participation factors and member forces & moments
Load cases analyzed	Modal analysis, Response Spectrum (Uniform)
Filename	P20.mod
This problem may be found in US NRC publication [ref. 17, Benchmark problem 5].	

Table P20-1 Comparison of modal frequencies with NRC [NRC]

Mode No.	Program	Frequency (Hz)
1	CAE	4.037
	NRC	4.036
2	CAE	4.258
	NRC	4.257
3	CAE	9.116
	NRC	9.116
4	CAE	11.189
	NRC	11.190
5	CAE	17.122
	NRC	17.110
6	CAE	18.193
	NRC	18.170
7	CAE	22.393
	NRC	22.380
8	CAE	27.197
	NRC	27.190
9	CAE	28.015
	NRC	28.010
10	CAE	37.988
	NRC	37.980
11	CAE	40.977
	NRC	40.970

Table P20-2 Comparison of Modal Participation Factors with NRC [NRC]

Mode No.	Program	X	Y	Z
1	CAE	-0.1605	2.8354	-0.2884
	NRC	0.1599	-2.8350	0.2883
2	CAE	3.3167	0.2293	1.2917
	NRC	3.3160	0.2289	1.2920
3	CAE	1.0367	-0.2524	-1.3934
	NRC	1.0360	-0.2527	-1.3940
4	CAE	0.2453	-0.6895	-0.0706
	NRC	0.2459	-0.6920	-0.0700
5	CAE	-2.3808	1.2343	-0.8154
	NRC	-2.3830	1.2520	-0.8249
6	CAE	-0.0315	3.5150	-0.0032
	NRC	-0.0157	3.5110	0.0040
7	CAE	-2.6645	-0.7057	-3.1012
	NRC	-2.6550	-0.7044	-3.1060
8	CAE	-1.1573	-0.5125	2.3949
	NRC	1.1580	0.5126	-2.3930
9	CAE	0.2594	-1.4393	-0.6791
	NRC	-0.2599	1.4380	0.6806

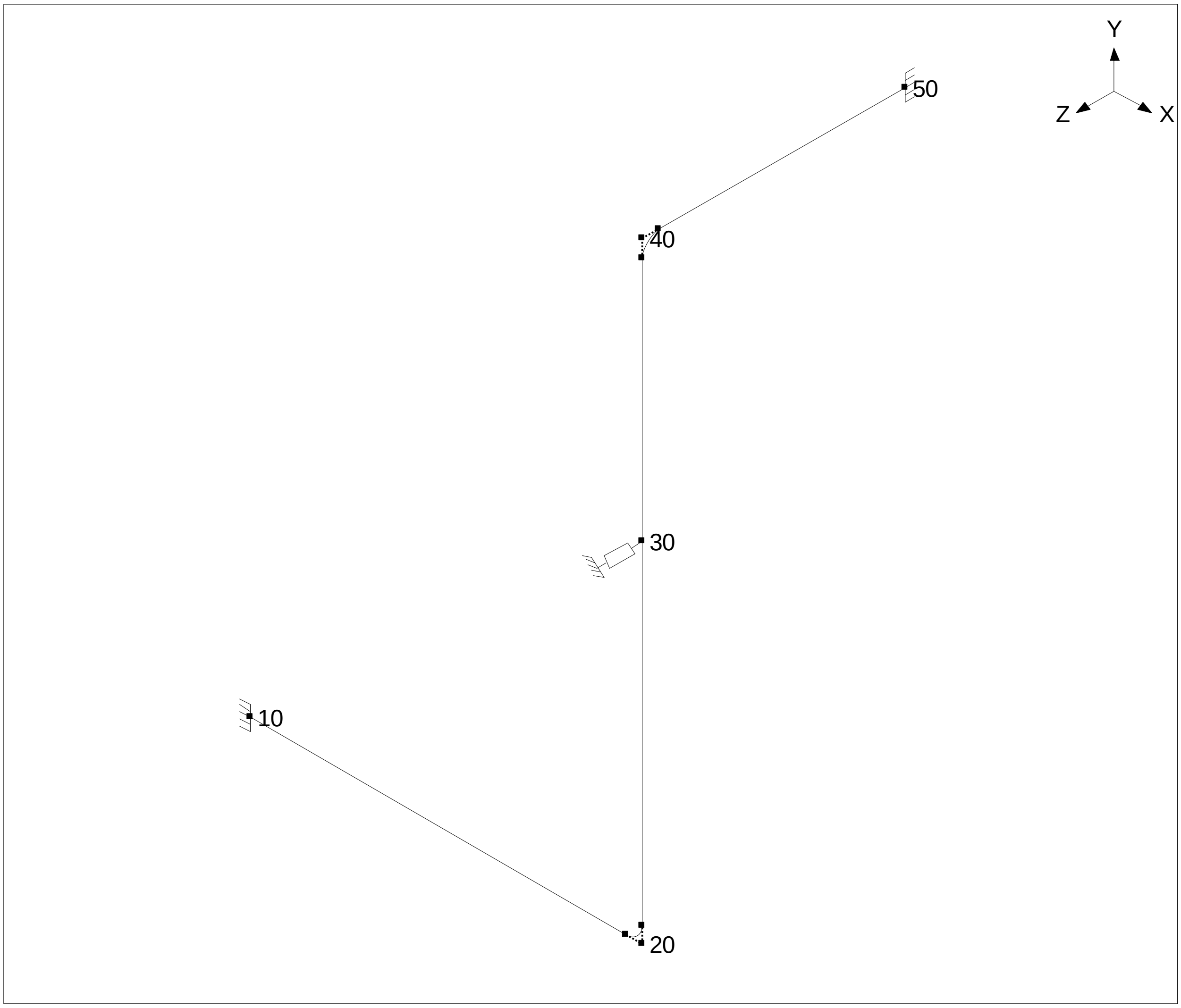
Mode No.	Program	X	Y	Z
10	CAE	-1.6526	1.1004	2.2768
	NRC	-1.6520	1.1000	2.2650
11	CAE	-1.3531	-1.3818	1.8182
	NRC	1.3610	1.3740	-1.8220

Table P20-3 Comparison of Member Forces and Moments (in local coordinates) for Response Spectrum (Uniform) case with NRC [NRC]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
400B	CAE	364	543	120	394	396	2007
5 to 4J	NRC	364	543	120	392	395	2005
900B	CAE	303	226	148	178	348	1116
10 to 9J	NRC	303	226	148	178	347	1116
15	CAE	175	97	233	531	688	484
15 to 14J	NRC	175	97	233	530	689	482
20	CAE	419	216	202	833	1918	1033
20 to 19J	NRC	418	216	202	830	1916	1029
25	CAE	409	80	284	1271	1218	772
25 to 24J	NRC	408	80	284	1266	1217	770
30	CAE	569	176	310	1306	1199	601
30 to 29J	NRC	568	176	309	1301	1197	599

Problem 21

VERIFICATION OF CAEPIPE, PROBLEM 21 p21-1



Problem SUMMARY	
What was compared	Effect of Missing mass correction on Support loads, etc.
Load cases analyzed	Modal analysis, Response Spectrum (Uniform)
Filename	P21-1.mod, P21-2.mod, P21-3.mod and P21-4.mod

This model has 7 mass points and 21 dynamic degrees of freedom (DDOF). Because nodes 10 and 50 are anchors, the active DOF are reduced to 15. Four runs are made to verify the “Missing mass correction” feature in CAEPIPE and these results are compared with corresponding results from PIPESTRESS runs. The details are as follows:

Run 1 (using P21-1.mod)	All 15 modes are extracted **without** missing mass correction (MMC) with cut-off frequency as 999Hz.
Run 2 (using P21-2.mod)	All 15 modes are extracted **with** MMC with cut-off frequency as 999Hz.
Run 3 (using P21-3.mod)	Only 6 modes are extracted **without** MMC with cut-off frequency as 150Hz.
Run 4 (using P21-4.mod)	Only 6 modes are extracted **with** MMC with cut-off frequency as 150Hz.

Run 1	All modes without MMC

Table P21-1 Comparison of frequencies (all modes, Run 1) with PIPESTRESS [PS]

Mode No.	Program	Frequency (Hz)
1	CAE	4.436
	PS	4.436
2	CAE	4.749
	PS	4.749
3	CAE	5.652
	PS	5.652
4	CAE	10.943
	PS	10.943
5	CAE	94.385
	PS	94.385
6	CAE	105.958
	PS	105.958
7	CAE	127.500
	PS	127.500
8	CAE	145.997
	PS	145.997
9	CAE	168.568
	PS	168.568
10	CAE	198.847
	PS	198.847
11	CAE	231.676
	PS	231.675
12	CAE	291.955
	PS	291.954
13	CAE	398.292
	PS	398.292
14	CAE	577.027
	PS	577.028
15	CAE	719.621
	PS	719.622

Table P21-2 Comparison of Support loads for the Response Spectrum (Uniform) case (Run 1) with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10	CAE	769	804	1270	4765	19460	10085
	PS	770	805	1271	4769	19477	10093
50	CAE	1690	2711	1602	23284	18392	1283
	PS	1691	2713	1603	23303	18408	1284
Node	**Program**	**Load (lb)**	**X comp**	**Y comp**	**Z comp**		
30	CAE	2786			1.000		
	PS	2789			1.000		

Table P21-3 Comparison of global element forces and moments for Response Spectrum (Unifrom) case (Run 1) with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10	CAE	769	804	1270	4765	19460	10085
	PS	770	805	1271	4769	19477	10093
20A	CAE	769	804	1270	4765	2987	4728
	PS	770	805	1271	4769	2990	4733
20A	CAE	684	352	153	4765	2987	4728
	PS	685	352	154	4769	2990	4733
20B	CAE	684	352	153	4707	3001	4525
	PS	685	352	154	4711	3004	4529
20B	CAE	639	764	1274	4707	3001	4525
	PS	640	764	1275	4711	3004	4529
30	CAE	639	764	1274	14750	3001	6845
	PS	640	764	1275	14763	3004	6851
30	CAE	627	1758	1568	14750	3001	6845
	PS	628	1759	1570	14763	3004	6851
40A	CAE	627	1758	1568	8364	3001	867
	PS	628	1759	1570	8371	3004	868
40A	CAE	1172	2248	1584	8364	3001	867
	PS	1173	2249	1585	8371	3004	868
40B	CAE	1172	2248	1584	7399	2592	1283
	PS	1173	2249	1585	7405	2595	1284
40B	CAE	1690	2711	1602	7399	2592	1283
	PS	1691	2713	1603	7405	2595	1284
50	CAE	1690	2711	1602	23284	18392	1283
	PS	1691	2713	1603	23303	18408	1284

Table P21-4 Comparison of Displacements for Response Spectrum (Uniform) case (Run 1) with PIPESTRESS [PS]

Node	Program	X (inch)	Y (inch)	Z (inch)	XX (rad)	YY (rad)	ZZ (rad)
10	CAE	0.000	0.000	0.000	0.00000	0.00000	0.00000
	PS	0.000	0.000	0.000	0.000	0.000	0.000
20A	CAE	0.001	1.769	3.786	0.01853	0.02572	0.01115
	PS	0.001	1.771	3.789	0.0185	0.0257	0.0112
20B	CAE	0.095	1.855	3.816	0.02310	0.02243	0.01076
	PS	0.095	1.856	3.819	0.0231	0.0224	0.0108
30	CAE	1.769	1.854	0.003	0.01017	0.01766	0.00487
	PS	1.770	1.856	0.003	0.0102	0.0177	0.0049
40A	CAE	1.781	1.853	0.086	0.00627	0.01753	0.00331
	PS	1.782	1.854	0.086	0.0063	0.0175	0.0033
40B	CAE	1.606	1.744	0.001	0.01584	0.01768	0.00326
	PS	1.608	1.745	0.001	0.0158	0.0177	0.0033
50	CAE	0.000	0.000	0.000	0.00000	0.00000	0.00000
	PS	0.000	0.000	0.000	0.000	0.000	0.000

Table P21-5 Comparison of Accelerations for Response Spectrum (Uniform) case (Run 1) with PIPESTRESS [PS]

Node.	Program	X (g)	Y (g)	Z (g)
10	CAE	0.000	0.000	0.000
	PS	0.000	0.000	0.000
20A	CAE	1.517	4.308	7.717
	PS	1.519	4.311	7.725
20B	CAE	1.073	4.450	7.774
	PS	1.074	4.456	7.781
30	CAE	4.919	4.398	1.805
	PS	4.923	4.402	1.807
40A	CAE	5.037	4.448	2.257
	PS	5.041	4.451	2.259
40B	CAE	4.572	4.454	1.234
	PS	4.576	4.458	1.235
50	CAE	0.000	0.000	0.000
	PS	0.000	0.000	0.000

Run 2	All modes with MMC

The frequencies, displacements, element forces and moments for this run are the same as for Run 1. The other results are tabulated below.

Table P21-6 Comparison of Support loads for Response Spectrum (Uniform) case (Run 2) with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10	CAE	787	843	1313	4765	19460	10085
	PS	788	843	1314	4769	19477	10093
50	CAE	1693	2716	1617	23284	18392	1283
	PS	1695	2718	1618	23303	18408	1284
Node	Program	Load (lb)	X comp	Y comp	Z comp		
30	CAE	2786			1.000		
	PS	2789			1.000		

Table P21-7 Comparison of Accelerations for Response Spectrum (Uniform) case (Run 2) with PIPESTRESS [PS]

Node.	Program	X (g)	Y (g)	Z (g)
10	CAE	1.035	1.553	2.070
	PS	1.036	1.554	2.072
20A	CAE	1.517	4.308	7.717
	PS	1.520	4.311	7.725
20B	CAE	1.073	4.450	7.774
	PS	1.114	4.453	7.780
30	CAE	4.919	4.398	1.805
	PS	4.923	4.402	1.807
40A	CAE	5.037	4.448	2.257
	PS	5.041	4.451	2.259
40B	CAE	4.572	4.454	1.234
	PS	4.576	4.458	1.235
50	CAE	1.035	1.553	2.070
	PS	1.036	1.554	2.072

Run 3	6 modes without MMC

Only six modes were extracted with a cut-off frequency of 150 Hz.

Table P21-8 Comparison of Frequencies (6 modes, Run 3) with PIPESTRESS [PS]

Mode No.	Program	Frequency (Hz)
1	CAE	4.436
	PS	4.436
2	CAE	4.749
	PS	4.749
3	CAE	5.652
	PS	5.652
4	CAE	10.943
	PS	10.943
5	CAE	94.385
	PS	94.385
6	CAE	105.958
	PS	105.958

Table P21-9 Comparison of Support loads for Response Spectrum (Uniform) case (Run 3) with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10	CAE	666	804	1270	4765	19460	10085
	PS	667	805	1271	4769	19477	10093
50	CAE	1690	2711	1565	23283	18392	1283
	PS	1691	2713	1566	23303	18408	1284
Node	**Program**	**Load (lb)**	**X comp**	**Y comp**	**Z comp**		
30	CAE	2750			1.000		
	PS	2752			1.000		

Table P21-10 Comparison of global forces and moments for Response Spectrum (Uniform) case (Run 3) with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10	CAE	666	804	1270	4765	19460	10085
	PS	667	805	1271	4769	19477	10093
20A	CAE	666	804	1270	4765	2987	4728
	PS	667	805	1271	4769	2990	4732
20A	CAE	665	292	150	4765	2987	4728
	PS	666	292	150	4769	2990	4732
20B	CAE	665	292	150	4707	3001	4525
	PS	666	292	150	4711	3004	4529
20B	CAE	639	704	1274	4707	3001	4525
	PS	640	705	1275	4711	3004	4529

30	CAE	639	704	1274	14750	3001	6845
	PS	640	705	1275	14763	3004	6851
30	CAE	627	1741	1568	14750	3001	6845
	PS	628	1742	1570	14763	3004	6851
40A	CAE	627	1741	1568	8363	3001	867
	PS	628	1742	1570	8370	3004	868
40A	CAE	1172	2239	1564	8363	3001	867
	PS	1173	2241	1566	8370	3004	868
40B	CAE	1172	2239	1564	7397	2592	1283
	PS	1173	2241	1566	7403	2595	1284
40B	CAE	1690	2711	1565	7397	2592	1283
	PS	1691	2713	1566	7403	2595	1284
50	CAE	1690	2711	1565	23283	18392	1283
	PS	1691	2713	1566	23303	18408	1284

Table P21-11 Comparison of Displacements for Response Spectrum (Uniform) case (Run 3) with PIPESTRESS [PS]

Node	Program	X (inch)	Y (inch)	Z (inch)	XX (rad)	YY (rad)	ZZ (rad)
10	CAE	0.000	0.000	0.000	0.00000	0.00000	0.00000
	PS	0.000	0.000	0.000	0.000	0.000	0.000
20A	CAE	0.001	1.769	3.786	0.01853	0.02572	0.01115
	PS	0.001	1.771	3.789	0.0185	0.0257	0.0112
20B	CAE	0.095	1.855	3.816	0.02310	0.02243	0.01076
	PS	0.095	1.856	3.819	0.0231	0.0224	0.0108
30	CAE	1.769	1.854	0.003	0.01017	0.01766	0.00487
	PS	1.770	1.856	0.003	0.0102	0.0177	0.0049
40A	CAE	1.781	1.853	0.086	0.00627	0.01753	0.00331
	PS	1.782	1.854	0.086	0.0063	0.0175	0.0033
40B	CAE	1.606	1.744	0.001	0.01584	0.01768	0.00326
	PS	1.608	1.745	0.001	0.0158	0.0177	0.0032
50	CAE	0.000	0.000	0.000	0.00000	0.00000	0.00000
	PS	0.000	0.000	0.000	0.000	0.000	0.000

Table P21-12 Comparison of Accelerations for Response Spectrum (Uniform) case (Run 3) with PIPESTRESS [PS]

Node.	Program	X (g)	Y (g)	Z (g)
10	CAE	0.000	0.000	0.000
	PS	0.000	0.000	0.000
20A	CAE	0.030	4.149	7.715
	PS	0.030	4.152	7.722
20B	CAE	0.274	4.330	7.770
	PS	0.274	4.333	7.777
30	CAE	4.919	4.328	0.006
	PS	4.923	4.332	0.006
40A	CAE	5.037	4.325	0.193
	PS	5.041	4.328	0.193
40B	CAE	4.572	4.075	0.003
	PS	4.576	4.079	0.004
50	CAE	0.000	0.000	0.000
	PS	0.000	0.000	0.000

Run 4	**6 modes with MMC**

The modal frequencies are the same here as in Run 3 (see Table P21-8). The support loads are different as shown in Table P21-13.

Table P21-13 Comparison of Support loads for Response Spectrum (Uniform) case Run 4) with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10	CAE	1005	952	1438	4765	19460	10085
	PS	1005	953	1440	4769	19477	10093
50	CAE	1704	2732	2095	23284	18392	1283
	PS	1706	2734	2097	23303	18408	1284
Node	Program	Load (lb)	X comp	Y comp	Z comp		
30	CAE	2950			1.000		
	PS	2952			1.000		

Table P21-14 Comparison of global element forces and moments for Response Spectrum (Uniform) case (Run 4) with PIPESTRESS [PS]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10	CAE	784	804	1270	4765	19460	10085
	PS	785	805	1271	4769	19477	10093
20A	CAE	784	804	1270	4765	2987	4728
	PS	785	805	1271	4769	2990	4733
20A	CAE	673	340	155	4765	2987	4728
	PS	674	340	155	4769	2990	4733
20B	CAE	673	340	155	4707	3001	4525
	PS	674	340	155	4711	3004	4529
20B	CAE	639	721	1274	4707	3001	4525
	PS	640	721	1275	4711	3004	4529
30	CAE	639	721	1274	14750	3001	6845
	PS	640	721	1275	14763	3004	6851
30	CAE	627	1743	1568	14750	3001	6845
	PS	628	1745	1570	14763	3004	6851
40A	CAE	627	1743	1568	8365	3001	867
	PS	628	1745	1570	8372	3004	868
40A	CAE	1172	2240	1631	8365	3001	867
	PS	1173	2242	1633	8372	3004	868
40B	CAE	1172	2240	1631	7399	2592	1283
	PS	1173	2242	1633	7405	2595	1284
40B	CAE	1690	2711	1831	7399	2592	1283
	PS	1691	2713	1832	7405	2595	1284
50	CAE	1690	2711	1831	23284	18392	1283
	PS	1691	2713	1832	23303	18408	1284

Table P21-15 Comparison of Displacements for Response Spectrum (Uniform) case (Run 4) with PIPESTRESS [PS]

Node	Program	X (inch)	Y (inch)	Z (inch)	XX (rad)	YY (rad)	ZZ (rad)
10	CAE	0.000	0.000	0.000	0.00000	0.00000	0.00000
	PS	0.000	0.000	0.000	0.000	0.000	0.000
20A	CAE	0.001	1.769	3.786	0.01853	0.02572	0.01115
	PS	0.001	1.771	3.789	0.0185	0.0257	0.0112
20B	CAE	0.095	1.855	3.816	0.02310	0.02243	0.01076
	PS	0.095	1.856	3.189	0.0231	0.0224	0.0108
30	CAE	1.769	1.854	0.003	0.01017	0.01766	0.00487
	PS	1.770	1.856	0.003	0.0102	0.0177	0.0049
40A	CAE	1.781	1.853	0.086	0.00627	0.01753	0.00331
	PS	1.782	1.854	0.086	0.0063	0.0175	0.0033
40B	CAE	1.606	1.744	0.002	0.01584	0.01768	0.00326
	PS	1.608	1.745	0.002	0.0158	0.0177	0.0032
50	CAE	0.000	0.000	0.000	0.00000	0.00000	0.00000
	PS	0.000	0.000	0.000	0.000	0.000	0.000

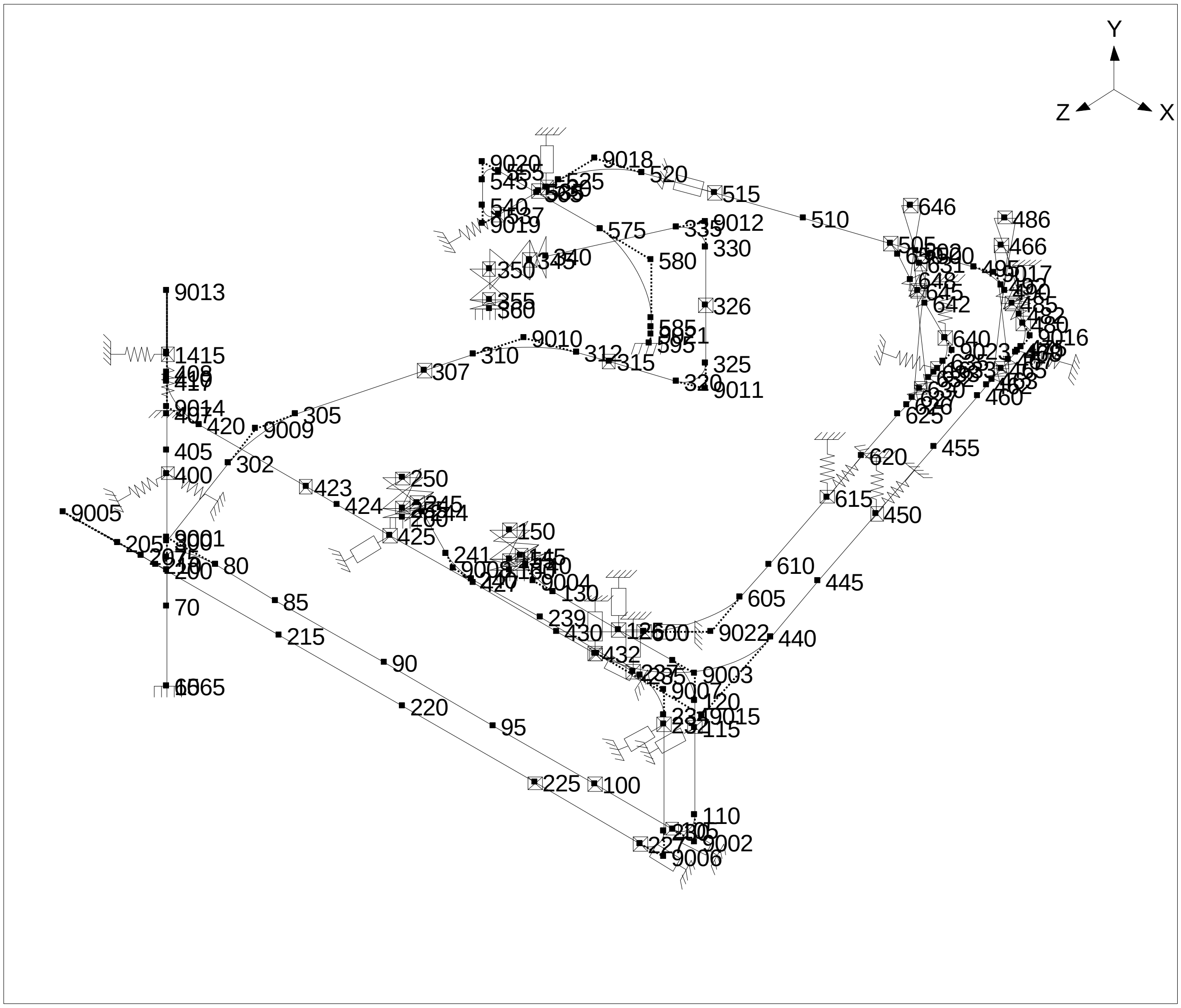
Table P21-16 Comparison of Accelerations for Response Spectrum (Uniform) case (Run 4) with PIPESTRESS [PS]

Node.	Program	X (g)	Y (g)	Z (g)
10	CAE	2.096	3.144	4.193
	PS	2.098	3.147	4.196
20A	CAE	1.809	4.274	7.718
	PS	1.811	4.278	7.726
20B	CAE	0.722	4.332	7.775
	PS	0.723	4.335	7.782
30	CAE	4.919	4.336	4.193
	PS	4.923	4.340	4.197
40A	CAE	5.037	4.337	4.160
	PS	5.041	4.341	4.164
40B	CAE	4.572	4.103	4.186
	PS	4.576	4.106	4.189
50	CAE	2.096	3.144	4.193
	PS	2.098	3.147	4.196

The support loads in Table P21-13 are higher than those in Table P21-2. This is because of the high acceleration found in the Spectrum table after the cut-off frequency of 150Hz. This high acceleration value is input in the spectrum to illustrate its role in the missing mass computations and is not representative of a real-world situation.

Problem 22

Force Time History Test - NUPIPE vs CAEPIPE p22



Problem SUMMARY	
What was compared	Time History Results at two time steps
Load cases analyzed	Modal analysis, Time History analysis
Filename	P22.mod

A NUPIPE time history model was created in CAEPIPE. There are 17 time functions with 526 time steps each. Since NUPIPE analysis included only 10 modes, the same was done in CAEPIPE. The results are comparable.

Table P22-1 Comparison of global element forces and moments for Time History case Time Step: 0.444s with NUPIPE [NUP]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
360	CAE	-7	-8	-6	-27	37	-20
	NUP	-7	-8	-6	-26.00	36.67	-19.75
595	CAE	0	2	-2	-12	-6	-12
	NUP	0	3	-2	-12.83	-6.58	-12.50
627	CAE	-22	40	-66	-137	0	33
	NUP	-21	39	-64	-134.00	-0.33	32.33
633	CAE	0	34	1	54	-1	-27
	NUP	0	31	1	53.75	-0.50	-27.42
1065*	CAE	3	6	-1	-4	-10	-5
	NUP	-3	-6	1	3.92	10.17	4.83

Table P22-2 Comparison of global element forces and moments for Time History case Time Step: 0.702s with NUPIPE [NUP]

Node	Program	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
360	CAE	7	7	6	24	-40	20
	NUP	7	7	6	25.25	-40.25	20.83
595	CAE	1	-1	1	1	0	0
	NUP	1	-2	1	3.25	1.58	2.42
627	CAE	17	-35	49	93	6	-52
	NUP	16	-33	47	89.00	5.58	-49.08
633	CAE	-11	-30	3	-35	-3	34
	NUP	-11	-29	2	-35.00	-2.50	34.50
1065*	CAE	-8	0	-4	-2	15	12
	NUP	7	1	4	1.25	-15.33	-11.83

* Different sign conventions are in effect at the elastic element (Node 1065) for CAE and NUP.

3 – API & NEMA Reports Verification Method

The rotating equipment reports from CAEPIPE were verified by comparing their results to those obtained from manual calculations.

Following is a list of the problems presented in this section.

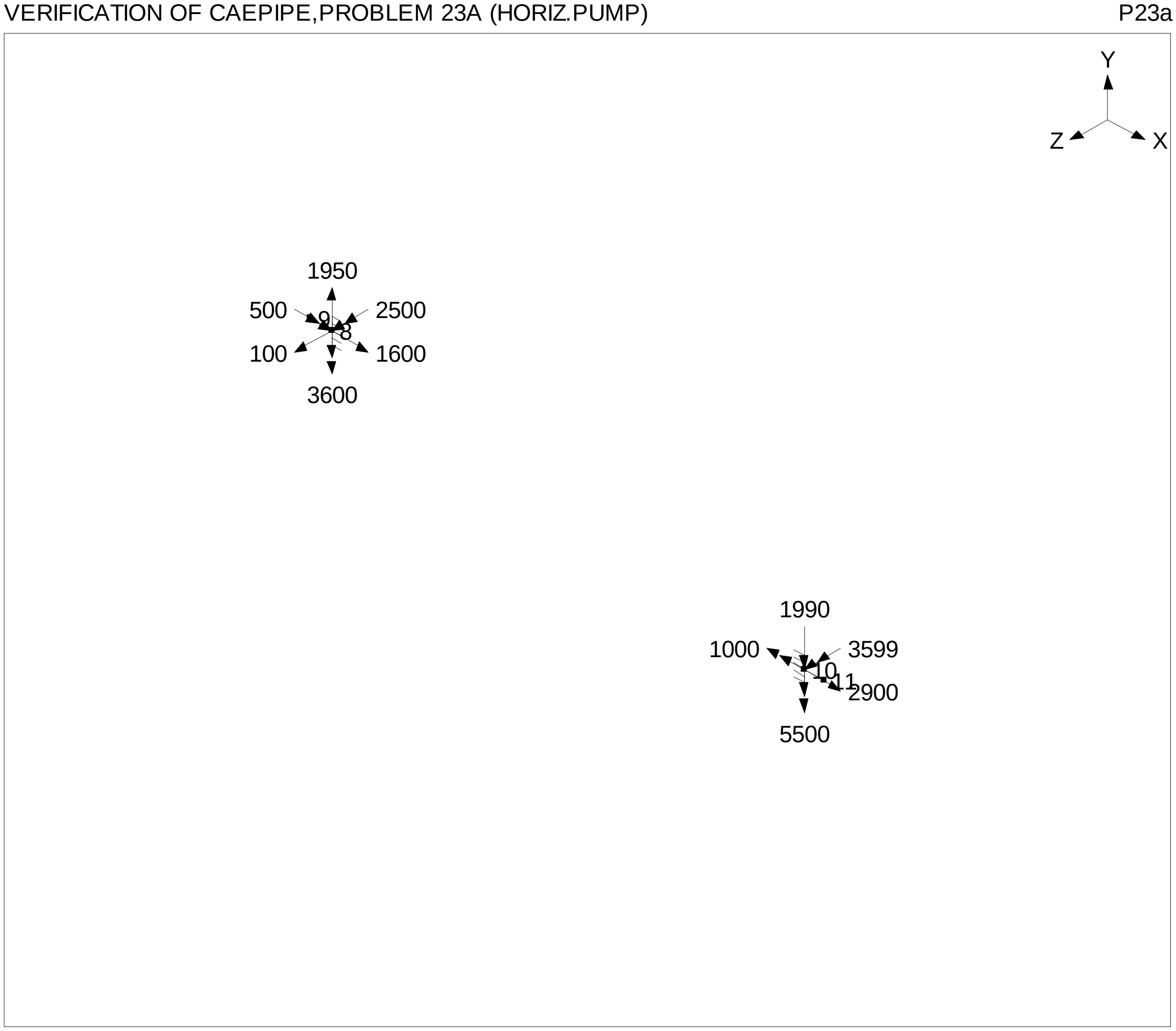
Model name	Results compared with
P23A (API 610 Horizontal Pump)	API 610 Publication example
P23B (API 610 Vertical Pump)	API 610 Publication example
P24 (NEMA SM-23, Turbine)	Manual calculations
P25 (API 617, Compressor)	Manual calculations

Results from CAEPIPE are identical to the compared results. Note that there is one round off error in API 610 Publication example (see the calculation of S in Table P23-5; CAEPIPE's result, however, is accurate).

This section tabulates results from two sources, CAEPIPE and the source to which it is compared.

Please see the above to select the problem of interest to you. The references are given in the next section.

Problem 23



Problem SUMMARY	
What was compared	API 610 reports for Horizontal and Vertical in-line pumps
Load cases analyzed	Operating case (W+P1+T1)
Filename	P23A.mod, P23B.mod

This set of problems deals with the API 610 reports [Ref. 19] in CAEPIPE. There are two models in this set. First one contains a Horizontal pump; Second problem contains a Vertical in-line pump. These problems are given as examples in [Ref. 19].

Results are compared with the results given in API 610. Tables P23-1 to P23-3 tabulate results for the horizontal pump.

Tables P23-4 and P23-5 tabulate results for the vertical in-line pump.

Horizontal Pump	**Problem 23a**

Table P23-1 Comparison of Applied forces and moments with API 610 [API] Allowables for the Suction node

Suction Node 10

Size 10 inches

Check of Condition F.1.1

			Ratio		
Forces (lb)	**Calculated**	**Allowed**	**CAE**	**API**	**Status**
FX	2900	1500	1.933	1.93	---
FY	0	1200	0.000	0.00	Ok
FZ	-1990	1000	1.990	1.99	---
FR	3517	2200	1.599		---
Moments (ft-lb)					
MX	-1000	3700	0.270	0.27	Ok
MY	-3599	1800	1.999	1.99	---
MZ	-5500	2800	1.964	1.96	---
MR	6649	5000	1.330		---

Check of Condition F.1.1

Equation F-1:

$$\left(\frac{FRS_{\mathrm{A}}}{1.5FRS_{\mathrm{T2}}}\right) + \left(\frac{MRS_{\mathrm{A}}}{1.5MRS_{\mathrm{T2}}}\right) \leq 2$$

API 610 Ratio = 1.95

CAEPIPE Ratio = 1.952

Status = ok

Table P23-2 Comparison of Applied forces and moments with API 610 [API] Allowables for the Discharge node

Discharge Node 8

Size 8 inches

Check of Condition F.1.1

			Ratio		
Forces (lb)	**Calculated**	**Allowed**	**CAE**	**API**	**Status**
FX	1600	850	1.882	1.88	---
FY	-100	700	0.143	0.14	Ok
FZ	1950	1100	1.773	1.77	---
FR	2524	1560	1.618		---
Moments (ft-lb)					
MX	500	2600	0.192	0.19	Ok
MY	-2500	1300	1.923	1.92	---
MZ	-3600	1900	1.895	1.89	---
MR	4411	3500	1.260		---

Check of Condition F.1.1

Equation F-2:

$$\left(\frac{F\mathrm{RD}_{\mathrm{A}}}{1.5F\mathrm{RD}_{\mathrm{T2}}}\right) + \left(\frac{M\mathrm{RD}_{\mathrm{A}}}{1.5M\mathrm{RD}_{\mathrm{T2}}}\right) \leq 2$$

$\text{Ratio}_{\text{API}}$ = 1.92

$\text{Ratio}_{\text{CAE}}$ = 1.919

Status = ok

Table P23-3 Comparison of Condition F.1.2.c with API 610 [API] Allowables

Check of Condition F.1.2.c

			Ratio		
Forces (lb)	**Calculated**	**Allowed**	**CAE**	**API**	**Status**
FRC (Eqn. F-3)	4501	5640	0.798	0.798	Ok
MYC (Eqn. F-4)	-2358	6200	0.380	0.380	Ok
MRC (Eqn. F-5)	8180	12750	0.642	0.642	Ok

Table P23-4 Comparison of Applied forces and moments with API 610 [API] Allowables

Suction Node 4

Size 4 inches

Check of Condition F.1.1

			Ratio	
Forces (lb)	**Calculated**	**Allowed***	**CAE**	**Status†**
FX	500	640	0.781	Ok
FY	1200	800	1.500	---
FZ	300	520	0.577	Ok
FR	1334	1140	1.170	---
Moments (ft-lb)				
MX	100	1960	0.051	Ok
MY	1500	1000	1.500	---
MZ	1000	1480	0.676	Ok
MR	1806	2660	0.679	Ok

Check of Condition F.2

Equation F-6:

$$S = \sqrt{(\frac{\sigma}{2}) + (\frac{\sigma^2}{4} + \tau^2)} < 5950$$

S_{API} = 5105 psi

S_{CAE} = 5105 psi

Allowed = 5950 psi

Status = ok

* As this column contains twice the API 610 Table 2 values, the Ratio should now be less than or equal to 1.0 for the Status to be ok.

† '-' under Status denotes indeterminacy at this stage. The final test (Eqn. F-6) determines whether Status is ok or failed.

Table P23-5 Comparison of Applied forces and moments with API 610 [API] Allowables

Discharge Node 3

Size 3 inches

Check of Condition F.1.1

			Ratio	
Forces (lb)	**Calculated**	**Allowed[*]**	**CAE**	**Status[†]**
FX	-300	480	0.625	Ok
FY	500	600	0.833	Ok
FZ	100	400	0.250	Ok
FR	592	860	0.688	Ok
Moments (ft-lb)				
MX	-2000	1400	1.429	---
MY	-200	700	0.286	Ok
MZ	100	1060	0.094	Ok
MR	2012	1900	1.059	---

Check of Condition F.2

Equation F-6:

$$S = \sqrt{(\frac{\sigma}{2}) + (\frac{\sigma^2}{4} + \tau^2)} < 5950$$

S_{API} = 14181 psi

S_{CAE} = 14212 psi

Allowed = 5950 psi

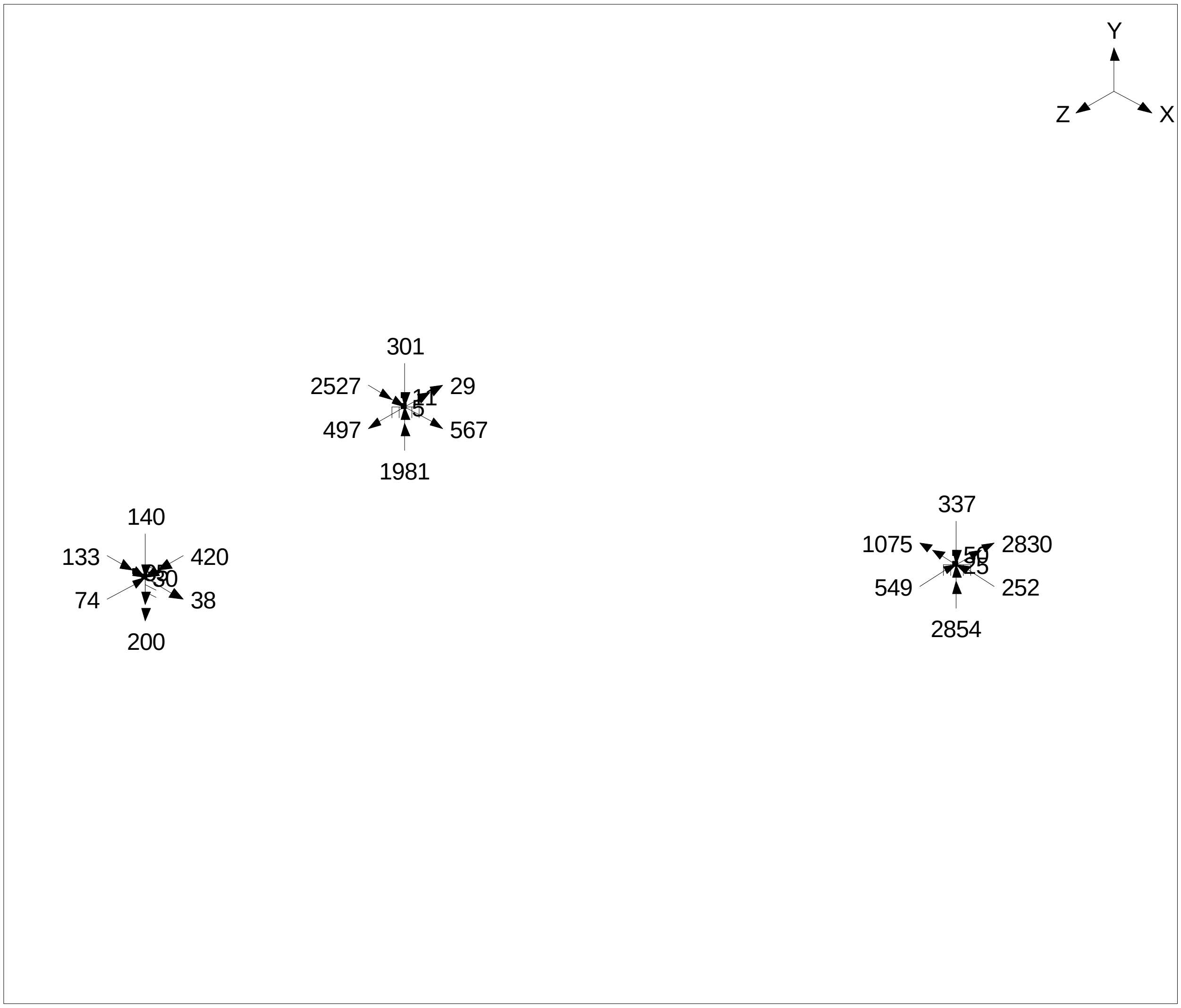
Status = failed

[*] As this column contains twice the API 610 Table 2 values, the Ratio should now be less than or equal to 1.0 for the Status to be ok.

[†] '-' under Status denotes indeterminacy at this stage. The final test (Eqn. F-6) determines whether Status is ok or failed.

Problem 24

VERIFICATION OF CAEPIPE, PROBLEM 24 (NEMA SM-23) p24



Problem SUMMARY	
What was compared	NEMA SM-23 Turbine report with manual calculations
Load cases analyzed	Operating case (W+P1+T1)
Filename	P24.mod
This problem uses piping code ASME, Section III, Class 2 (1986) Equation 9 Level B (upset) with loading conditions (T, P) : (170°F, 0 PSIG).	

This problem contains a turbine with an 8" inlet (node 5), 12" exhaust (node 25) and a 4" extraction nozzle (node 30). A NEMA SM-23 report (see [Ref. 20]) is generated by CAEPIPE.

Table P24-1 Table of Applied forces and moments in the turbine

Node	Type	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
5	Inlet	567	-301	497	2527	1981	-29
25	Exhaust	-252	-337	-549	-1075	2854	-2830
30	Extraction 1	38	-140	-74	133	-200	420

Table P24-2 Resultants at each connection (nozzle)

				Resultants	
Node	**Type**	**F (lb)**	**M (ft-lb)**	**3F+M**	**Allowable**
5	Inlet	812	3211	5647	4000
25	Exhaust	692	4161	6236	4667
30	Extraction 1	163	484	972	2000

Table P24-3 Combined resultant components at exhaust connection (node 25)

	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
Calculated	353	-778	-126	1789	6848	330
Allowable	549	1374	1099	2747	1374	1374

Table P24-4 Combined resultants at exhaust connection (node 25)

			Resultants	
	F (lb)	**M (ft-lb)**	**2F+M**	**Allowable**
Combined	864	7086	8813	2747

The offsets dx5 etc. are calculated as the difference in the coordinates:

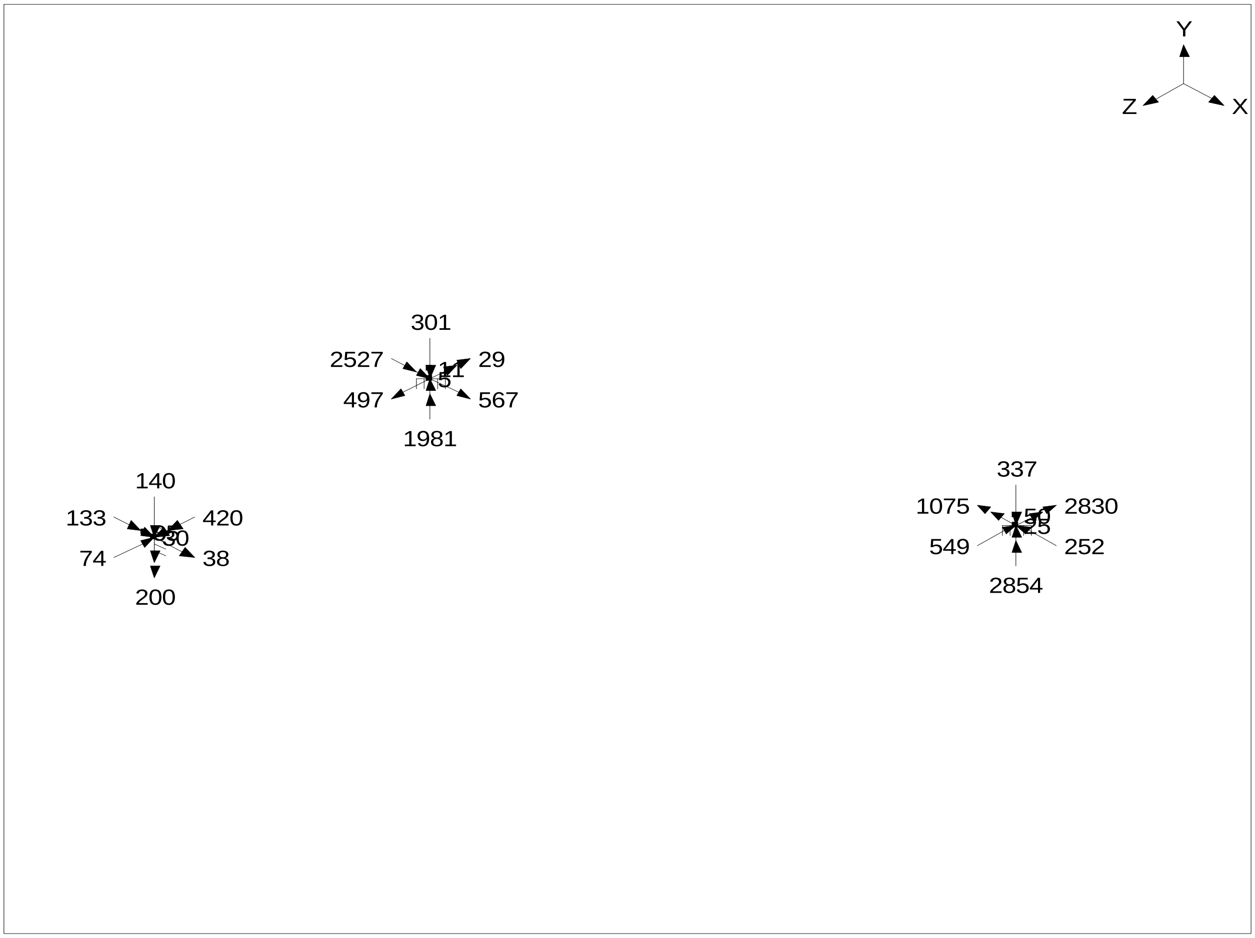
Example: dx5 = (X5 – X25) * [T], where X5 and X25 are the X coordinates at nodes 5 and 25, and [T] is the transformation matrix to convert from the global coordinate system to the turbine coordinate system.

Node.	X (ft)	Y (ft)	Z (ft)
5	0.0000	0.0000	0.0000
25	4.6042	0.71875	-0.59375
30	-1.6667	-1.84380	0.78125

Distances					
dx_5 (ft)	**dx_{30} (ft)**	**dy_5 (ft)**	**dy_{30} (ft)**	**dz_5 (ft)**	**dz_{30} (in)**
-4.6042	-6.271	-0.719	-2.5625	0.594	1.375

Problem 25

VERIFICATION OF CAEPIPE, PROBLEM 25 (API-617) p25



Problem SUMMARY	
What was compared	API 617 Centrifugal Compressor report with manual calculations
Load cases analyzed	Operating case (W+P1+T1)
Filename	P25.mod
This problem uses piping code ASME, Section III, Class 2 (1986) Equation 9 Level B (upset) with loading conditions (T, P) : (170°F, 0 PSIG).	

This problem is identical to Problem 24 except the compressor here which replaces the turbine. This compressor, too, has an 8" inlet (node 5), 12" exhaust (node 25) and a 4" extraction nozzle (node 30). An API 617 report (see [Ref. 21]) is generated by CAEPIPE. The computed results are compared with manual calculations.

Table P25-1 Table of Applied forces and moments on the compressor

Node	Type	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
5	Inlet	567	-301	497	2527	1981	-29
25	Exhaust	-252	-337	-549	-1075	2854	-2830
30	Extraction 1	38	-140	-74	133	-200	420

Table P25-2 Resultants at each connection (nozzle)

				Resultants	
Node	**Type**	**F (lb)**	**M (ft-lb)**	**3F+M**	**Allowable**
5	Inlet	812	3211	5647	7400
25	Exhaust	692	4161	6236	8633
30	Extraction 1	163	484	972	3700

Table P25-3 Combined resultant components at exhaust connection (node 25)

	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
Calculated	353	-778	-126	1789	6848	330
Allowable	1016	2541	2033	5082	2541	2541

Table P25-4 Combined resultants at exhaust connection (node 25)

			Resultants	
	F (lb)	**M (ft-lb)**	**2F+M**	**Allowable**
Combined	864	7086	8813	5082

The offsets dx5 etc. are calculated as the difference in the coordinates:

Example: dx5 = (X5 – X25) * [T], where X5 and X25 are the X coordinates at nodes 5 and 25, and [T] is the transformation matrix to convert from the global coordinate system to the turbine coordinate system.

Node.	X (ft)	Y (ft)	Z (ft)
5	0.0000	0.0000	0.00000
25	4.6042	0.71875	-0.59375
30	-1.6667	-1.84380	0.78125

Distances					
dx_5 (ft)	**dx_{30} (ft)**	**dy_5 (ft)**	**dy_{30} (ft)**	**dz_5 (ft)**	**dz_{30} (in)**
-4.6042	-6.271	-0.719	-2.5625	0.594	1.375

4 - Verification for Export of Local Element Forces & Moments

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

CAEPIPE includes a feature 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 (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 RespSpectrumABSS_NoMissMass_NoSeisDisp _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 with 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 are 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 10.50      Verification of Modal Forces and Moments       Dec 21,2021
--------------------------------------------------------------------------------
                                      Options
--------------------------------------------------------------------------------
  Piping code = B31.1 (2020)
  Do not use liberal allowable stresses
  Include axial force in stress calculations
  Use B31J for SIFs and Flexibility Factors
  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
 3 Spectrum = SpectrumXYZ
 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    CS Level
  Node  KX/kx    KY/ky    KZ/kz    KXX/kxx  KYY/kyy  KZZ/kzz  X Y Z XXYYZZ    Tag
--------------------------------------------------------------------------------
  10    Rigid    Rigid    Rigid    Rigid    Rigid    Rigid                 GCS LVL-0
  90     Rigid     Rigid     Rigid     Rigid     Rigid     Rigid                 GCS LVL-0
```

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)	Soil
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

Pipe Loads

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

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

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

Spectrum Levels

Level	Spectrum X	Spectrum Y	Spectrum Z	Factor X	Factor Y	Factor Z	Sum Modal	Sum Direction	Sum Level
LVL-0	SpecXYZ	SpecXYZ	SpecXYZ	1	1	1	SRSS	SRSS	SRSS

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

```
Caepipe            RespSpectrumSRSS_NoMissMass_NoSeisDisp        Page 1
Version 10.50     Verification of Modal Forces and Moments      Dec 21,2021
```

Pipe element forces in local coordinates: Response spectrum (Uniform)

Node	Axial (lb)	y shear (lb)	z shear (lb)	Torque (ft-lb)	...In plane... Bend.Moment (ft-lb)	SIF	.Out of plane.. Bend.Moment (ft-lb)	SIF	SL+SO (psi)
10	39153	65201	36207	158859	493301		273116		18272
20A	39153	65201	36207	158859	229101		129233		11328
20A	38957	62931	34542	158859	229101	3.31	129233	2.76	19780
20B	62931	38957	34542	139680	169876	3.31	126821	2.76	15941
20B	45042	14930	24342	139680	126821		169876		10006
30	45042	14930	24342	139680	123498		367995		11535
30	33037	13589	20162	139680	123498		367995		11348
40A	33037	13589	20162	139680	103656		291622		9927
40A	25357	55799	26790	139680	291622	3.31	103656	2.76	16231
40B	55799	25357	26790	117501	249924	3.31	100429	2.76	15056
40B	56897	8965	20867	117501	249924		100429		9528
50	56897	8965	20867	117501	235518		118001		9394
60	57946	39621	28915	117501	202524		139344		9251
70	57946	39621	28915	117501	128460		253383		10227
80	58894	63171	40310	117501	200221		308558		11795
90	58894	63171	40310	117501	741756		632830		23146

Other forces in local coordinates: Response spectrum (Uniform)

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 (Uniform)

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 (Uniform)

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 (Uniform)

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 (Axial)	fy (y shear)	fz (z shear)	mx (Torsion)	my (Outplane moment)	mz (Inplane moment)
		(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

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Caepipe           RespSpectrumSRSS_WithMissMass_NoSeisDisp       Page 1
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Pipe element forces in local coordinates: Response spectrum (Uniform)

Node	Axial (lb)	y shear (lb)	z shear (lb)	Torque (ft-lb)	...In plane... Bend.Moment (ft-lb)	SIF	.Out of plane.. Bend.Moment (ft-lb)	SIF	SL+SO (psi)
10	132689	118937	70303	159112	683223		363212		22701
20A	132689	118937	70303	159112	240453		130305		12939
20A	78282	83746	34672	159112	240453	3.31	130305	2.76	20794
20B	83746	78282	34672	139726	230779	3.31	127325	2.76	18284
20B	49613	15034	27879	139726	127325		230779		10859
30	49613	15034	27879	139726	124085		379204		11706
30	38742	13590	24973	139726	124085		379204		11590
40A	38742	13590	24973	139726	104373		298847		10114
40A	46612	64462	26889	139726	298847	3.31	104373	2.76	16815
40B	64462	46612	26889	117549	267522	3.31	102242	2.76	15800
40B	101966	25798	25878	117549	267522		102242		10471
50	101966	25798	25878	117549	270115		118984		10543
60	157621	43752	34345	117549	257247		148840		11536
70	157621	43752	34345	117549	234097		301564		13292
80	250547	78402	52625	117549	265998		348739		15869
90	250547	78402	52625	117549	783679		648558		26801

Other forces in local coordinates: Response spectrum (Uniform)

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 (Uniform)

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 (Uniform)

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 (Uniform)

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 (Axial)	fy (y shear)	fz (z shear)	mx (Torsion)	my (Outplane moment)	mz (Inplane moment)
		(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

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--------------------------------------------------------------------------------
        Pipe element forces in local coordinates: Response spectrum (Uniform)
--------------------------------------...In plane... .Out of plane..------
         Axial  y shear z shear Torque  Bend.Moment    Bend.Moment   SL+SO
  Node    (lb)    (lb)    (lb)  (ft-lb) (ft-lb)  SIF   (ft-lb)  SIF  (psi)
--------------------------------------------------------------------------------
  10     148402  179646   76537  258926 1137906         436164        29569
  20A    148402  179646   76537  258926  437125         176764        16289

  20A     93996  144455   40906  258926  437125  3.31   176764  2.76  28257
  20B    144455   93996   40906  144108  337825  3.31   185063  2.76  23373

  20B    110322   21268   43592  144108  185063         337825        13520
  30     110322   21268   43592  144108  148942         480361        14184

  30      99451   19823   40686  144108  148942         480361        14014
  40A     99451   19823   40686  144108  154165         462859        13479

  40A    107321   80175   33123  144108  462859  3.31   154165  2.76  23744
  40B     80175  107321   33123  209418  407228  3.31   139937  2.76  21237

  40B    117679   86507   32112  209418  407228         139937        12991
  50     117679   86507   32112  209418  546415         170705        14917

  60     173335  104461   40578  209418  654964         213028        17515
  70     173335  104461   40578  209418  996067         403154        23776

  80     266261  139110   58859  209418 1149385         462796        27993
  90     266261  139110   58859  209418 2213445         818717        46808

--------------------------------------------------------------------------------
           Other forces in local coordinates: Response spectrum (Uniform)
--------------------------------------------------------------------------------
                    fx      fy      fz        mx       my        mz
  Node       Type   (lb)    (lb)    (lb)     (ft-lb)  (ft-lb)   (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 (Uniform)
--------------------------------------------------------------------------------
 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 (Uniform)

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 (Uniform)

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 (Axial)	fy (y shear)	fz (z shear)	mx (Torsion)	my (Outplane moment)	mz (Inplane moment)
		(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

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Pipe element forces in local coordinates: Response spectrum (Uniform)

					...In plane...		.Out of plane..		
Node	Axial (lb)	y shear (lb)	z shear (lb)	Torque (ft-lb)	Bend.Moment (ft-lb)	SIF	Bend.Moment (ft-lb)	SIF	SL+SO (psi)
10	39153	65201	36207	158859	493301		273116		18272
20A	39153	65201	36207	158859	229101		129233		11328
20A	38957	62931	34542	158859	229101	3.31	129233	2.76	19780
20B	62931	38957	34542	139680	169876	3.31	126821	2.76	15941
20B	45042	14930	24342	139680	126821		169876		10006
30	45042	14930	24342	139680	123498		367995		11535
30	33037	13589	20162	139680	123498		367995		11348
40A	33037	13589	20162	139680	103656		291622		9927
40A	25357	55799	26790	139680	291622	3.31	103656	2.76	16231
40B	55799	25357	26790	117501	249924	3.31	100429	2.76	15056
40B	56897	8965	20867	117501	249924		100429		9528
50	56897	8965	20867	117501	235518		118001		9394
60	57946	39621	28915	117501	202524		139344		9251
70	57946	39621	28915	117501	128460		253383		10227
80	58894	63171	40310	117501	200221		308558		11795
90	58894	63171	40310	117501	741756		632830		23146

Other forces in local coordinates: Response spectrum (Uniform)

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 (Uniform)

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 (Axial)	fy (y shear)	fz (z shear)	mx (Torsion)	my (Outplane moment)	mz (Inplane moment)
		(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

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Pipe element forces in local coordinates: Response spectrum (Uniform)

Node	Axial (lb)	y shear (lb)	z shear (lb)	Torque (ft-lb)	...In plane... Bend.Moment (ft-lb)	SIF	.Out of plane.. Bend.Moment (ft-lb)	SIF	SL+SO (psi)
10	148402	179646	76537	258926	1137906		436164		29569
20A	148402	179646	76537	258926	437125		176764		16289
20A	93996	144455	40906	258926	437125	3.31	176764	2.76	28257
20B	144455	93996	40906	144108	337825	3.31	185063	2.76	23373
20B	110322	21268	43592	144108	185063		337825		13520
30	110322	21268	43592	144108	148942		480361		14184
30	99451	19823	40686	144108	148942		480361		14014
40A	99451	19823	40686	144108	154165		462859		13479
40A	107321	80175	33123	144108	462859	3.31	154165	2.76	23744
40B	80175	107321	33123	209418	407228	3.31	139937	2.76	21237
40B	117679	86507	32112	209418	407228		139937		12991
50	117679	86507	32112	209418	546415		170705		14917
60	173335	104461	40578	209418	654964		213028		17515
70	173335	104461	40578	209418	996067		403154		23776
80	266261	139110	58859	209418	1149385		462796		27993
90	266261	139110	58859	209418	2213445		818717		46808

Other forces in local coordinates: Response spectrum (Uniform)

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 (Uniform)

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 (Uniform)

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 (Uniform)

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 (Axial)	fy (y shear)	fz (z shear)	mx (Torsion)	my (Outplane moment)	mz (Inplane moment)
		(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
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Pipe element forces in local coordinates: Response spectrum

					...In plane...		.Out of plane..		
Node	Axial (lb)	y shear (lb)	z shear (lb)	Torque (ft-lb)	Bend.Moment (ft-lb)	SIF	Bend.Moment (ft-lb)	SIF	SL+SO (psi)
10	49390	92203	51726	269107	684511		314542		21421
20A	49390	92203	51726	269107	292648		159374		12845
20A	49171	88997	49619	269107	292648	3.31	159374	2.76	22552
20B	88997	49171	49619	240224	194992	3.31	174239	2.76	17959
20B	62757	25748	27470	240224	174239		194992		11264
30	62757	25748	27470	240224	170459		469922		13670
30	42907	20903	28175	240224	170459		469922		13366
40A	42907	20903	28175	240224	173847		357222		11645
40A	25932	70579	41446	240224	357222	3.31	173847	2.76	19300
40B	70579	25932	41446	192914	286371	3.31	139943	2.76	17035
40B	71814	12432	28189	192914	286371		139943		10679
50	71814	12432	28189	192914	280764		190020		10909
60	72992	48114	39027	192914	256395		228410		11066
70	72992	48114	39027	192914	161039		308782		11569
80	74056	74517	57544	192914	283076		356969		13528
90	74056	74517	57544	192914	953728		874864		27875

Other forces in local coordinates: Response spectrum (Uniform)

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 (Uniform)

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 (Uniform)

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 (Uniform)

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 (Axial)	fy (y shear)	fz (z shear)	mx (Torsion)	my (Outplane moment)	mz (Inplane moment)
		(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

5 - Verification of NRL Method

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

CAEPIPE includes a new feature 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.

```
Caepipe                       RespSpectrumNRL                  Page 1
Version 10.50        Verification of NRL Modal Summation         Dec 21,2021
-----------------------------------------------------------------------------------
                                      Options
-----------------------------------------------------------------------------------
  Piping code = B31.1 (2020)
  Do not use liberal allowable stresses
  Include axial force in stress calculations
  Use B31J for SIFs and Flexibility Factors
  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
-----------------------------------------------------------------------------------
```

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)	Soil
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

Pipe Loads

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

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

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

Spectrum Levels

Level	Spectrum			Factor			Sum		
	X	Y	Z	X	Y	Z	Modal	Direction	Level
LVL-0	Test	Test	Test	1	1	1	NRL	SRSS	SRSS

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

Caepipe   RespSpectrumNRL   Page 1
Version 10.50   Verification of NRL Modal Summation   Dec 21,2021

Pipe element forces in local coordinates: Response spectrum (Uniform)

Node	Axial (lb)	y shear (lb)	z shear (lb)	Torque (ft-lb)	...In plane... Bend.Moment (ft-lb)	SIF	.Out of plane.. Bend.Moment (ft-lb)	SIF	SL+SO (psi)
10	2886158	2646215	1436041	3069679	14183467		6915296		282583
20A	2886158	2646215	1436041	3069679	3943230		1670215		121232
20A	1738090	1702378	551336	3069679	3943230	3.31	1670215	2.76	189833
20B	1702378	1738090	551336	2779195	4525448	3.31	1657014	2.76	205728
20B	888282	299416	614246	2779195	1657014		4525448		97061
30	888282	299416	614246	2779195	2974994		6719519		130145
30	594051	278063	535978	2779195	2974994		6719519		125717
40A	594051	278063	535978	2779195	2255935		5136839		102289
40A	840381	1389294	665007	2779195	5136839	3.31	2255935	2.76	216237
40B	1389294	840381	665007	2733141	3971821	3.31	2250683	2.76	187355
40B	2248750	982361	687818	2733141	3971821		2250683		112611
50	2248750	982361	687818	2733141	3483326		2740630		111069
62	3632871	1645451	1202054	2733141	4631168		3960584		155049
65	3632871	1645451	1202054	2733141	16749208		13732266		376384

Other forces in local coordinates: Response spectrum (Uniform)

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 (Uniform)

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	1670215	3069679
20A	551336	1702378	1738090	3943230	1670215	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 (Uniform)

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	2250683	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 (Uniform)

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 (Axial)	fy (y shear)	fz (z shear)	mx (Torsion)	my (Outplane)	mz (Inplane)
		(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 10.50                                                    Dec 21,2021
-----------------------------------------------------------------------------------
                                       Options
-----------------------------------------------------------------------------------
  Piping code = B31.3 (2018)
  Do not use liberal allowable stresses
  Include axial force in stress calculations
  Do not use B31J for SIFs and Flexibility Factors
  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
-----------------------------------------------------------------------------------
                (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   Radius   Thickness  Bend  Flex.   Int.  Angle  Int.  Angle
  Node   (inch)    (inch)    Matl  Factor  Node  (deg)  Node  (deg)
-----------------------------------------------------------------------------------
  20     81     L
  40     81     L
-----------------------------------------------------------------------------------
                                       Valves
-----------------------------------------------------------------------------------
               Weight  Length  Thick Insul Add Wght   DX      DY      DZ
  From    To    (lb)   (inch)    X   Wgt X  (lb)    (inch)  (inch)  (inch)
-----------------------------------------------------------------------------------
  50     60    0               3.00  1.75
```

Valves

From	To	Weight (lb)	Length (inch)	Thick X	Insul Wgt X	Add Wght (lb)	DX (inch)	DY (inch)	DZ (inch)
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)	Soil
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

Pipe Loads

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

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

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

Spectrum Levels

Level	Spectrum			Factor			Sum		
	X	Y	Z	X	Y	Z	Modal	Direction	Level
LVL-0	Test	Test	Test	1	1	1	NRL	SRSS	SRSS

Displacements: Response spectrum (Uniform)

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

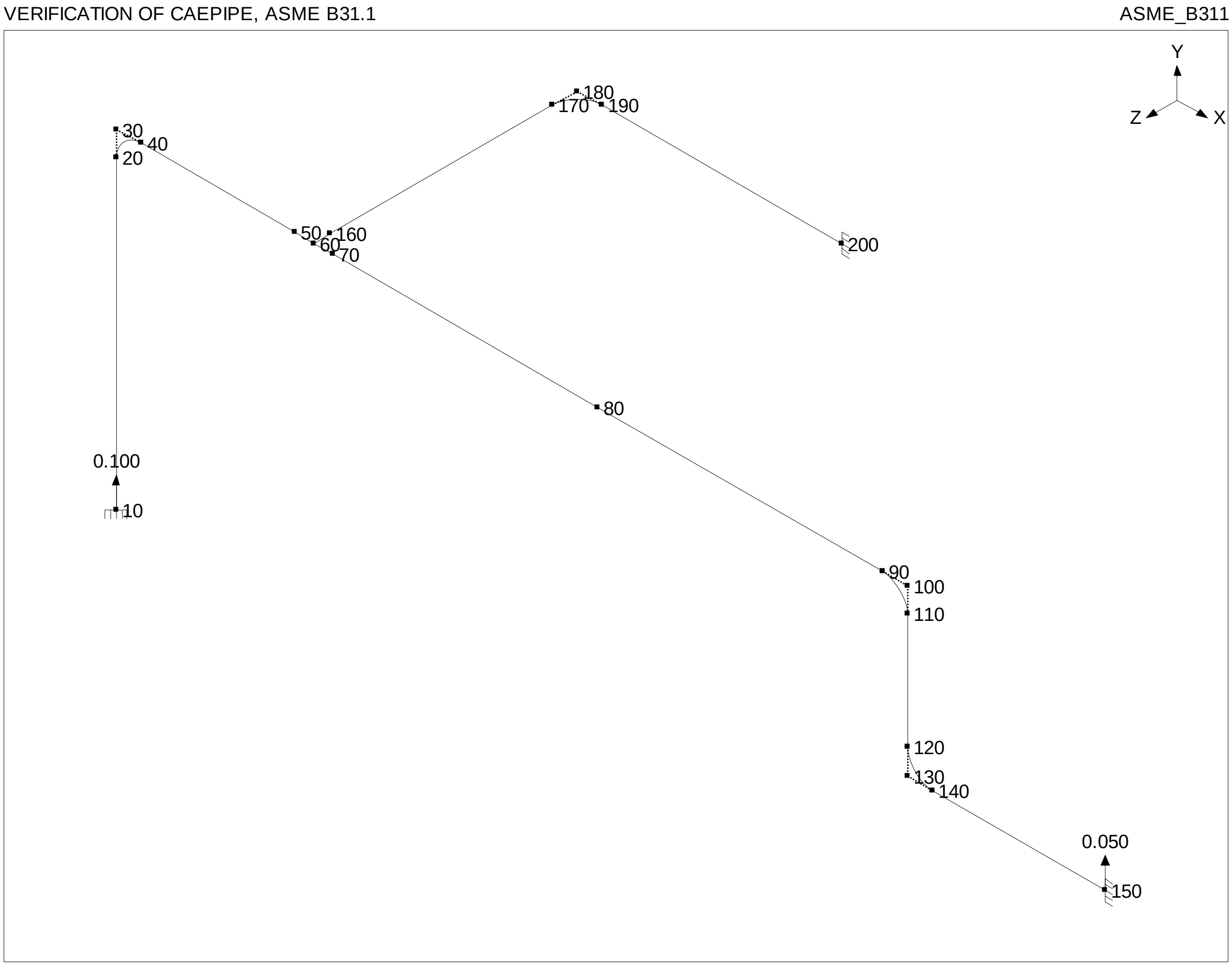
Node	X (g's)	Y (g's)	Z (g's)
10	0.000	0.000	0.000
20A	3.290	6.853	0.458
20B	33.414	33.650	19.805
30	45.930	34.728	72.447
40A	50.400	34.833	74.225
40B	81.290	71.012	2.534
50	67.308	57.609	2.076
60	54.988	46.344	1.941
62	48.766	40.716	1.873
65	0.000	0.000	0.000

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

6 - Verification of Code Compliance

ASME B31.1 (2020)



Problem SUMMARY	
What was compared	ASME B31.1 Code Compliance results (SL, SE and SO)
Load cases analyzed	Dead weight (DW), Thermal (T1), Seismic and Wind
Filename	ASME_B311.mod
This problem uses piping code ASME B31.1 with loading conditions (T, P): (180°F, 50 PSIG). This problem contains Specified Y displacements for the Thermal load case (T1).	

Values shown in Tables below under CAEPIPE for SL and SE respectively are rounded off when displayed on screen.

Options

Piping code = B31.1 (2020)
Do not use liberal allowable stresses
Include axial force in stress calculations
Use B31J for SIFs and Flexibility Factors
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
Do not use pressure correction for bends
Pressure stress = PD / 4t
Peak pressure factor = 1.00
Cut off frequency = 33 Hz
Number of modes = 6
Include missing mass correction
Do not 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 CAEPIPE, ASME B31.1								
2	10	From							Anchor
3	20			4'7-1/2"		1	1	1	
4	30	Bend		0'4-1/2"		1	1	1	
5	40		0'4-1/2"			1	1	1	
6	50		2'4"			1	1	1	
7	60		0'3-1/2"			1	1	1	Welding tee
8	70		0'3-1/2"			1	1	1	
9	80		4.0213			1	1	1	
10	90		4.3120			1	1	1	
11	100	Bend	0'4-1/2"			1	1	1	
12	110			-0'4-1/2"		1	1	1	
13	120			-1'9"		1	1	1	
14	130	Bend		-0'4-1/2"		1	1	1	
15	140		0'4-1/2"			1	1	1	
16	150		2'7-1/2"			1	1	1	Anchor
17	60	From							
18	160				-0'2-7/8"	1	2	1	
19	170				-3'4-5/8"	1	2	1	
20	180	Bend			-0'4-1/2"	1	2	1	
21	190		0'4-1/2"			1	2	1	
22	200		3'7-1/2"			1	2	1	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
150	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
200	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)
30	4.5	U						
100	4.5	U						
130	4.5	U						
180	4.5	U						

Branch SIFs

Node	Type
60	Welding tee ,No. of flanges = 0

Specified Displacements

Node	Type	Load	X(inch)	Y(inch)	Z(inch)	XX(deg)	YY(deg)	ZZ(deg)	Disp. in
10	Anchor	T1		0.100					GCS
150	Anchor	T1		0.050					GCS

Pipe material 1: Steel-Thermal loading case

Density = 0.403 (lb/in3), Nu = 0.300, Joint factor = 1.00

Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
180	30.0E+6	9.61E-6	15000

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)	Soil
1	3"	STD	3.5	0.216	0	12.5					
2	2-1/2"	STD	2.875	0.203	0	12.5					

Loads

Static seismic load: X = 0.30, Y = 0.20, Z = 0.30 (g's)
Acceleration load combination = Square Root of Sum of Squares

Wind Load 1

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

Elevation (feet)	Velocity (mph)
0	80
10	80

Wind Load 2

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

Elevation (feet)	Velocity (mph)
0	80
10	80

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	DT (F)	DP (psi)	Sp. gravity	Add.Wgt (lb/ft)	Wind Load	1 2 3 4
1	180	50.0					180	50.0			Y	

Table S101-1 Comparison of Sustained Stress (SL) [ASME B31.1] with Manual calculations using MS-Excel

Node	CAEPIPE SL (psi)	Excel Calculated SL (psi)
60 (Run Element 50 – 60)	763	763
60 (Run Element 60 – 70)	453	453
60 (Branch Element 60 – 160)	683	684
80 (Pipe Element 80 – 90)	858	859
100A (Bend Element 100A – 100B)	576	576
180A (Bend Element 180A – 180 B)	570	570

See Excel file ASME-B311-2020-SL.xlsx from the folder "CodeComplaince" for manual calculations.

Table S101-2 Comparison of Thermal Expansion Stress (SE), [ASME B31.1] with Manual calculations using MS-Excel

Element (From Node – To Node)	CAEPIPE SE (psi)	Excel Calculated SE (psi)
10	**6313**	**6313**
20	**2378**	**2378**
30A	**3954**	**3959**
30B	**4541**	**4548**
40	**2871**	**2871**
50	**1983**	**1983**
50	**1983**	**1983**
60	**2428**	**2422**
60	**1751**	**1747**
70	**1094**	**1094**
70	**1094**	**1094**
80	**1200**	**1200**
80	**1200**	**1200**
90	**1860**	**1860**
100A	**3129**	**3135**
100B	**2140**	**2143**
110	**1247**	**1247**
120	**1794**	**1795**
130A	**3157**	**3163**

130B	**4214**	**4221**
140	**2429**	**2429**
150	**2023**	**2023**
60	**4985**	**4964**
160	**3176**	**3176**
160	**3176**	**3176**
170	**1869**	**1868**
180A	**2150**	**2149**
180B	**2001**	**2001**
190	**1897**	**1897**
200	**4900**	**4900**

See Excel file ASME-B311-2020-SE_SL_SO.xlsx from the folder "CodeComplaince" for manual calculations.

Table S101-3 Comparison of Occasional Stress (SL+SO), [ASME B31.1] with Manual calculations using MS-Excel for Seismic Load

Element (From Node – To Node)	CAEPIPE SL+SO (psi)	Excel Calculated SL+SO (psi)
10	**1458**	**1458**
20	**1074**	**1074**
30A	**1370**	**1372**
30B	**1257**	**1259**
40	**996**	**996**
50	**824**	**824**
50	**824**	**824**
60	**966**	**966**
60	**631**	**631**
70	**664**	**664**
70	**664**	**664**
80	**1048**	**1049**
80	**1048**	**1049**

90	**726**	**727**
100A	**902**	**904**
100B	**850**	**851**
110	**683**	**683**
120	**701**	**701**
130A	**861**	**862**
130B	**848**	**849**
140	**703**	**703**
150	**2242**	**2242**
60	**1077**	**1077**
160	**1047**	**1047**
160	**1047**	**1047**
170	**919**	**919**
180A	**940**	**941**
180B	**892**	**893**
190	**873**	**874**
200	**1967**	**1968**

See Excel file ASME-B311-2020-SE_SL_SO.xlsx from the folder "CodeComplaince" for manual calculations.

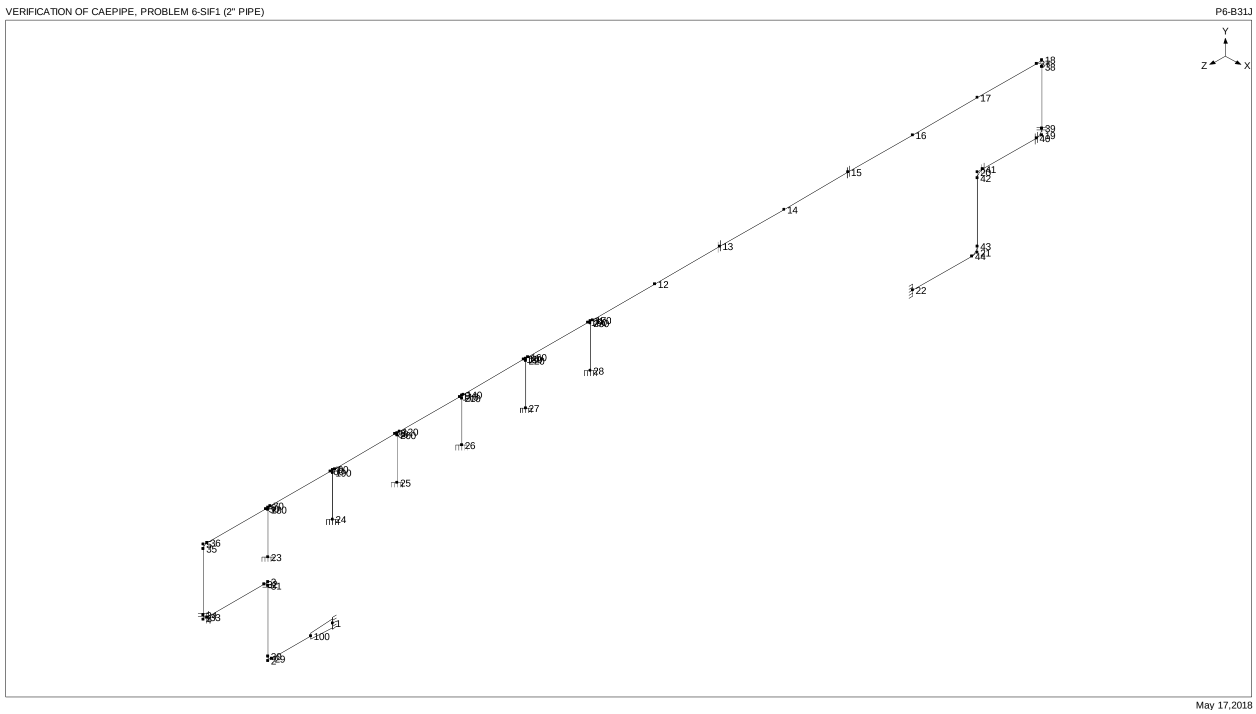
Table S101-4 Comparison of Occasional Stress (SO), [ASME B31.1] with Manual calculations using MS-Excel for Wind Load

Element (From Node – To Node)	CAEPIPE SO (psi)	Excel Calculated SO (psi)
10	**667**	**667**
20	**801**	**801**
30A	**1009**	**1011**
30B	**908**	**910**
40	**729**	**730**
50	**672**	**672**
50	**672**	**672**
60	**775**	**775**

60	**479**	**478**
70	**543**	**543**
70	**543**	**543**
80	**835**	**835**
80	**835**	**835**
90	**554**	**554**
100A	**677**	**678**
100B	**681**	**682**
110	**556**	**556**
120	**530**	**530**
130A	**649**	**650**
130B	**585**	**586**
140	**483**	**484**
150	**1718**	**1717**
60	**602**	**601**
160	**591**	**591**
160	**591**	**591**
170	**544**	**544**
180A	**545**	**546**
180B	**582**	**582**
190	**581**	**581**
200	**1321**	**1320**

See Excel file ASME-B311-2020-SE_SL_SO.xlsx from the folder "CodeComplaince" for manual calculations.

ASME B31.1 (2020) – Stress Intensification Factors (SIFs)



Problem SUMMARY	
What was compared	Stress Intensification Factors (SIFs) for ASME B31.1 (2020) as per ASME B31J
Load cases analyzed	Not applicable
Filename	P6-B311.mod

SUB-Problem	P6-B311
Pipe Section: 2”	(T, P) – (170° F, 1000 PSIG)
	Pressure Correction ON

Table S102.1 Comparison of Elbow SIFs as per ASME B31.1 (2020) with manual calculations

Elbow @ Node	ASME B31.1 (2020) and ASME B31J					
	In-plane		Out-of-plane		Torsion	
	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc
2	2.22	2.22	1.85	1.85	1.00	1.00
3	1.76	1.76	1.47	1.47	1.00	1.00
4	1.40	1.40	1.16	1.16	1.00	1.00
19	1.21	1.21	1.01	1.01	1.00	1.00
20	1.43	1.43	1.19	1.19	1.00	1.00
21	1.68	1.68	1.40	1.40	1.00	1.00

Table S102.2 Comparison of Nodal SIFs as per ASME B31.1 (2020) with manual calculations

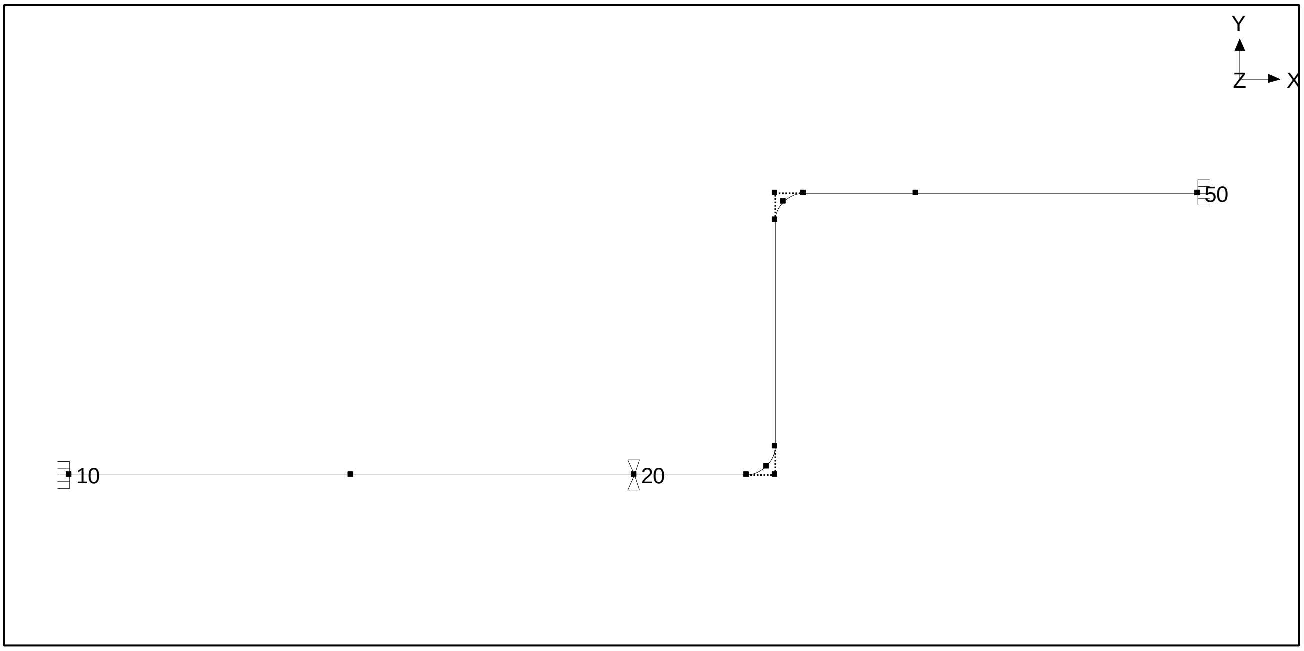
Node	ASME B31.1 (2020) and ASME B31J						Remarks
	In-plane		Out-of-plane		Torsion		
	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc	
6 (Run)	1.96	1.96	1.08	1.08	1.27	1.27	Welding TEE
6 (Branch)	1.23	1.23	1.57	1.57	1.57	1.57	
7 (Run)	1.89	1.89	1.33	1.33	1.00	1.00	Reinforced Fabricated TEE
7 (Branch)	1.14	1.14	1.35	1.35	1.00	1.00	
8 (Run)	2.64	2.64	2.15	2.15	2.98	2.98	Unreinforced Fabricated TEE
8 (Branch)	1.96	1.96	3.51	3.51	2.18	2.18	
9 (Run)	2.26	2.26	1.69	1.69	1.60	1.60	Extruded Outlet
9 (Branch)	1.63	1.63	2.48	2.48	2.07	2.07	
10 (Run)	2.00	2.00	1.28	1.28	1.34	1.34	Sweepolet (Welded-in contour)
10 (Branch)	1.31	1.31	1.79	1.79	1.64	1.64	
11 (Run)	2.34	2.34	2.15	2.15	2.98	2.98	Weldolet (Branch Welded on fittings)
11 (Branch)	1.94	1.94	2.38	2.38	2.18	2.18	
100	1.68	1.68	1.68	1.68	1.00	1.00	Reducer

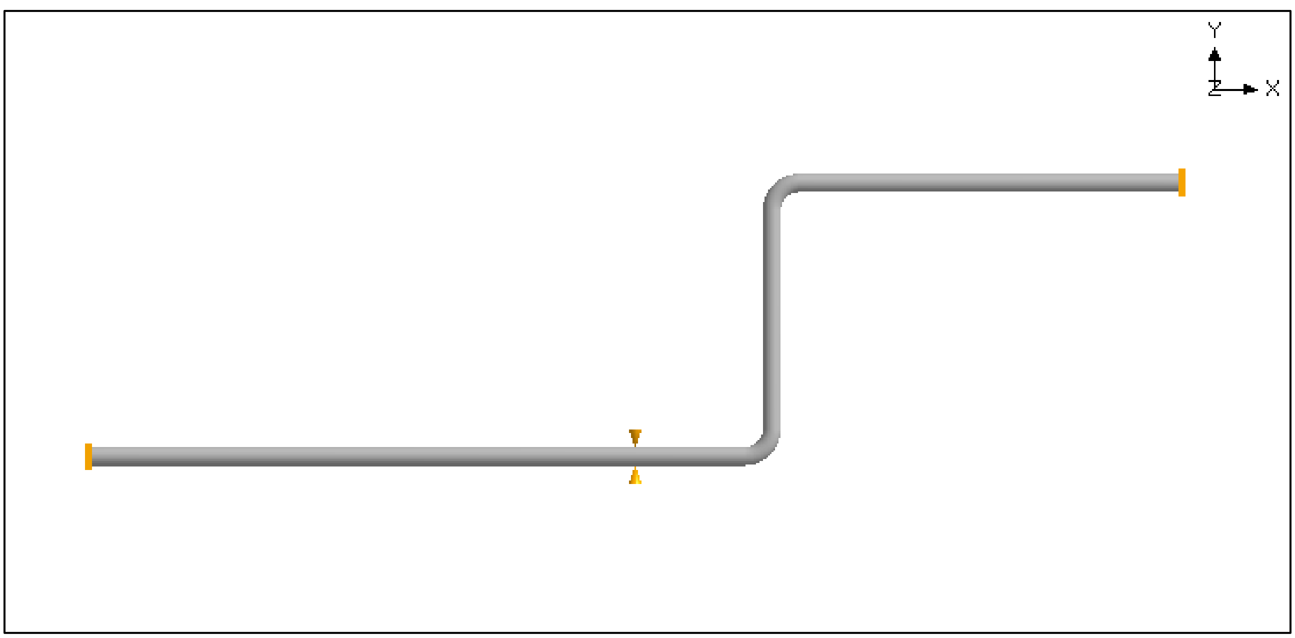
Refer to P6-B311-SIF.xls available under the folder “SIF” for manual calculations.

ASME B31.3 (2018) – B31 Code Case 209 (English Units)

Three Example problems given in ASME B31 Code Case 209 (2020) titled "Piping System Stress Analysis Examples" have been developed in both English and SI units. Models thus developed were then analyzed using CAEPIPE. The results thus obtained (such as Stresses, Element forces and moments, Support loads and Displacements) are compared against the results shown in ASME B31 Code Case 209 results and tabulated below for reference.

Example 1: Code Complaint Piping System – English Units





Options

```
  Piping code = B31.3 (2018)
  Do not use liberal allowable stresses
  Include axial force in stress calculations
  Do not use B31J for SIFs and Flexibility Factors
  Reference temperature = 30 (F)
  Number of thermal cycles = 7000
  Number of thermal loads = 1
  Thermal = Operating - Sustained
  Use modulus at reference temperature
  Include hanger stiffness
  Do not include Bourdon effect
  Use pressure correction for bends
  Pressure stress = Pd^2 / (D^2 - d^2)
  Peak pressure factor = 1.00
  Cut off frequency = 33 Hz
  Number of modes = 20
  Do not include missing mass correction
  Do not 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 = Example 1 from Code Case 209 of B31.3 - 2018
 2    10 From                                                         Anchor
 3    15          20'0"                            A106  400   L1
 4    20          20'0"                            A106  400   L1     Y restraint
 5    30 Bend     10'0"                            A106  400   L1
 6    40 Bend                20'0"                 A106  400   L1
 7    45          10'0"                            A106  400   L1
 8    50          20'0"                            A106  400   L1     Anchor
```

Anchors **(See Notes 1 & 2)**

```
                 (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
  50    Rigid     Rigid    Rigid     Rigid    Rigid    Rigid                  GCS
```

Bends

```
  Bend   Radius   Thickness  Bend  Flex.   Int.  Angle  Int.  Angle
  Node   (inch)    (inch)    Matl  Factor  Node  (deg)  Node  (deg)

  30     24     L                          31    45
  40     24     L                          41    45
```

Restraints **(See Note 3)**

```
  Node     X     Y     Z

  20           Yes
```

Pipe material A106: A106 GRADE B **(See Note 4)**

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)
-20	29.9E+6	6.25E-6	20000
70	29.4E+6	6.40E-6	20000
100	29.3E+6	6.47E-6	20000
200	28.8E+6	6.70E-6	20000
300	28.3E+6	6.90E-6	20000
400	27.4E+6	7.10E-6	19900
500	27.3E+6	7.30E-6	19000
600	26.5E+6	7.40E-6	17900
650	26.0E+6	7.50E-6	17300
700	25.5E+6	7.60E-6	16700
750	24.9E+6	7.70E-6	13900
800	24.2E+6	7.80E-6	11400
850	23.4E+6	7.85E-6	8700
900	22.5E+6	7.90E-6	5900
950	21.5E+6	8.00E-6	4000
1000	20.4E+6	8.10E-6	2500
1050	19.2E+6	8.15E-6	1600
1100	18.0E+6	8.20E-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)	Soil
400	16"	STD	16	0.375	0.063	12.5	11	5			

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	DT (F)	DP (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
L1	500	500					550	550	1.000		

Notes:

1. **When Translational Stiffnesses KX, KY and KZ are input as "Rigid", CAEPIPE internally sets their value as 1E+12 lb/in.**
2. **When Rotational Stiffnesses KXX, KYY and KZZ are input as "Rigid", CAEPIPE internally sets their value as 1E+12 lb-in/rad.**
3. **For Restraint, CAEPIPE internally sets the Translational Stiffness value as 1E+12 lb/in.**
4. **Material properties for ASTM A106 Grade B Seamless Pipe are taken from Table A-1, Table C-1 and Table C-6 of ASME B31.3 (2018).**

   Alpha values are taken from Row A corresponding to "Mean Coefficient of Thermal Expansion" for Group 1 Carbon and Low Alloy Steel going from 70 deg F to the indicated temperature.
5. **Pressure stress option used for Example 1 is NOT stated explicitly, i.e., it is not clear whether the Code Case 209 is using Thin shell formula (PD/4T) or Thick sheel formula [Pd^2/(D^2-d^2)]. From the Sustained Stresses results tabulated in Code Case**

209, it is observed that the CAEPIPE Sustained stresses compare well with Code Case 209 results when Pd^2/(D^2-d^2) is chosen in CAEPIPE.

6. Nominal section properties are used for Stifnesses, forces, moments and displacements calculations in CAEPIPE.
7. Nominal less allowance are used for Sustained Stress (SL) calculations in CAEPIPE.
8. Nominal section properties are used for Thermal Expansion Stress (SE) calculations in CAEPIPE.
9. Code Case 209 does not explicitly state whether Appendix D or B31J (2017) is used for Flexibility Factor (FF) calculations. In CAEPIPE, Appendix D is selected for calculating FFs. The results computed by CAEPIPE compare well with the results reported in Code Case 209.
10. Para. S301.7 refers to both Appendix D and ASME B31J (2017) for calculating SIFs. Fortunately, SIF calculations for Bends and Pipes are the same as per Appendix D and ASME B31J (2017) for this Example 1.

Table S301.5.1 Operating Load Case Results: Internal Loads and Deflections

Node Number	Axial Force (Unsigned) (lb)	Bending Moment (Unsigned) (ft-lb)	Horizontal Deflection (in)	Vertical Deflection (in)	Forces and Moments @ Node # for Element and Deflections at that Node
10	6691	16307	0.0	0.0	CAEPIPE (@ 10 for Element 10-15)
	6670	16300	0.0	0.0	CODE CASE 209
15	6691	8118	0.8	-0.1	CAEPIPE (@ 15 for Element 15-20)
	6670	8110	0.8	-0.1	CODE CASE 209
20	6691	34183	1.6	0.0	CAEPIPE (@20 for Element 20-30A)
	6670	34200	1.6	0.0	CODE CASE 209
30 near	6691	47841	2.0	-0.1	CAEPIPE (@ 30A for Element 30A-31)
	6670	47700	1.9	-0.1	CODE CASE 209)
30 mid	11324	57302	2.0	-0.1	CAEPIPE (@ 31 for Element 31-30B)
	11400	57100	2.0	-0.1	CODE CASE 209
30 far	9062	53249	1.8	0.1	CAEPIPE (@ 30B for Element 30B-40A)
	9040	53100	1.8	0.1	CODE CASE 209
40 near	6393	53804	-1.0	0.7	CAEPIPE (@40A for Element 40A-41)
	6380	53600	-1.0	0.7	CODE CASE 209
40 mid	9066	59623	-1.2	0.8	CAEPIPE (@ 41 for Element 41-40B)
	9050	59400	-1.2	0.8	CODE CASE 209
40 far	6691	55068	-1.2	0.9	CAEPIPE (@ 40B for Element 40B-45)
	6670	54900	-1.1	0.9	CODE CASE 209
45	6691	13448	-0.8	0.6	CAEPIPE (@45 for Element 45-50)
	6670	13400	-0.8	0.6	CODE CASE 209
50	6691	43858	0.0	0.0	CAEPIPE (@50 for Element 45-50)
	6670	43600	0.0	0.0	CODE CASE 209

Table S301.5.2 Operating Load Case Results: Reaction Loads on Supports and Anchors

Node Number	FX (Signed) (lb)	FY (Signed) (lb)	MZ (Signed) (ft-lb)	Remarks
10 Anchor	-6691	-2889	-16307	Support Load from CAEPIPE
	-6670	-2890	-16300	Support Load from CODE CASE 209
20 Support	---	-14703	---	Support Load from CAEPIPE
	---	-14700	---	Support Load from CODE CASE 209
50 Anchor	6691	1198	-43858	Support Load from CAEPIPE
	6670	1180	-43600	Support Load from CODE CASE 209

Table S301.6 Sustained Forces, Moments and Stresses

Node Number	Axial Force (Unsigned) (lb)	Bending Moment (Unsigned) (ft-lb)	Sustained Stress (S_L) (psi)	Forces and Moments @ Node # for Element and Highest Stress at that Node
10	735	12725	8571	CAEPIPE (@ 10 for Element 10-15)
	735	12700	8600	CODE CASE 209
20	735	41393	14387	CAEPIPE (@ 20 for Element 20-30A)
	735	41400	14400	CODE CASE 209
30 near	735	3892	7543	CAEPIPE (@ 30A for Element 30A-31)
	735	3900	7500	CODE CASE 209
30 mid	3865	10348	9915	CAEPIPE (@ 31 for Element 31-30B)
	3860	10300	9900	CODE CASE 209
30 far	4469	12028	10546	CAEPIPE (@ 30B for Element 30B-40A)
	4480	12000	10500	CODE CASE 209
40 near	1800	270	6028	CAEPIPE (@40A for Element 40A-41)
	1800	270	6000	CODE CASE 209
40 mid	1607	184	6007	CAEPIPE (@ 41 for Element 41-40B)
	1610	185	6000	CODE CASE 209
40 far	735	1733	6682	CAEPIPE (@ 40B for Element 40B-45)
	735	1720	6700	CODE CASE 209
50	735	27927	11655	CAEPIPE (@ 50 for Element 45-50)
	735	27900	11600	CODE CASE 209

Table S301.7 Displacement Stress Range

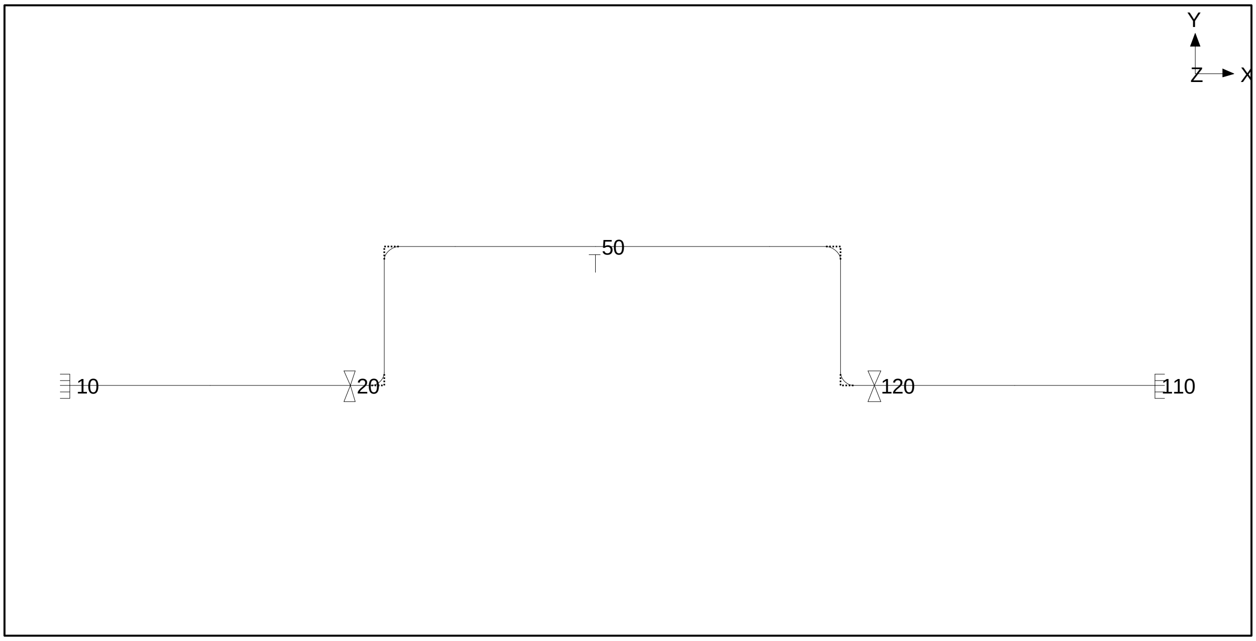
Node Number	Axial Force (Unsigned) (lb)	Bending Moment (Unsigned) (ft-lb)	Displacement Stress Range (S_E) (psi)	Forces and Moments @ Node # for Element and Highest Stress at that Node
10	5956	3582	935	CAEPIPE (@ 10 for Element 10-15)
	5940	3570	930	CODE CASE 209
20	5956	7210	1555	CAEPIPE (@ 20 for Element 20-30A)
	5940	7190	1550	CODE CASE 209
30 near	5956	43949	20007	CAEPIPE (@ 30A for Element 30A-31)
	5940	43800	19900	CODE CASE 209
30 mid	7459	46955	21435	CAEPIPE (@ 31 for Element 31-30B)
	7200*	46800	21300	CODE CASE 209
30 far	4592	41222	18711	CAEPIPE (@ 30B for Element 30B-40A)
	4580	41100	18600	CODE CASE 209
40 near	4592	54074	24468	CAEPIPE (@40A for Element 40A-41)
	4580	53900	24400	CODE CASE 209
40 mid	7459	59807	27191	CAEPIPE (@ 41 for Element 41-40B)
	7420	59600	27100	CODE CASE 209
40 far	5956	56801	25763	CAEPIPE (@ 40B for Element 41-40B)
	5940	56600	25700	CODE CASE 209
50	5956	71785	12584	CAEPIPE (@ 50 for Element 45-50)
	5940	71500	12400	CODE CASE 209

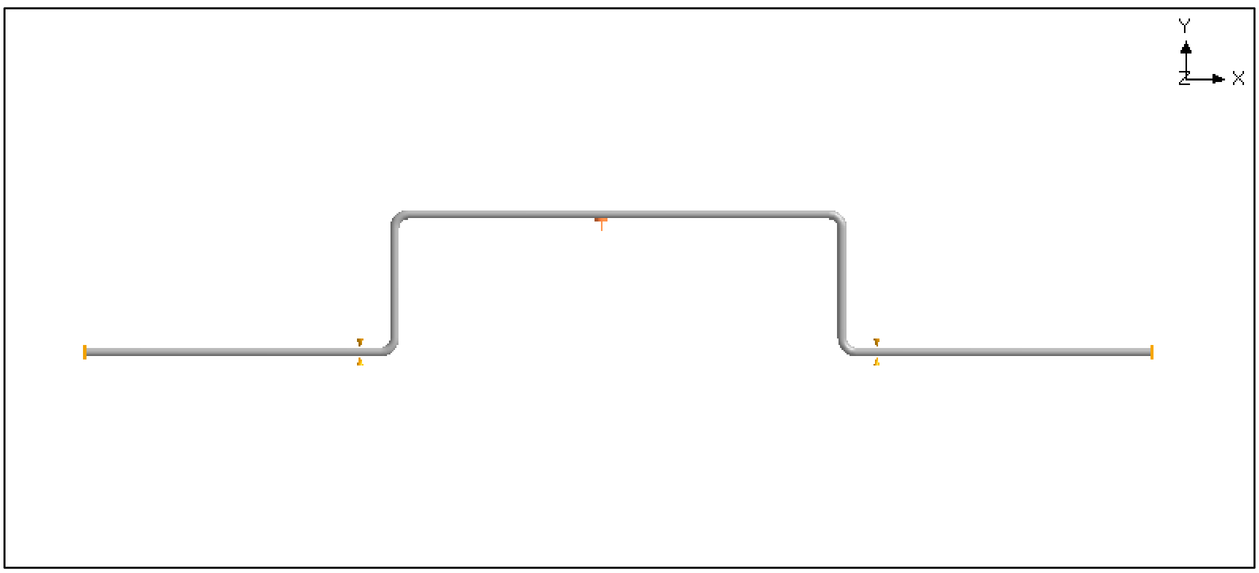
* May be a typographical error in B31 Code Case 209. From Operating – Sustained for 30 mid = 11400 – 3860 = 7540 lb.

Other Comparisons

Description	CAEPIPE	CODE CASE 209
Allowable S_h in psi for Sustained Stress	19, 000 psi	19,000 psi
Allowable S_A in psi for Displacement Stress Range	29, 750 psi	29, 750 psi

Example 2: Anticipated Sustained Conditions Considering Pipe Lift-Off – English Units





Options

Piping code = B31.3 (2018)
Do not use liberal allowable stresses
Include axial force in stress calculations
Do not use B31J for SIFs and Flexibility Factors
Reference temperature = 30 (F)
Number of thermal cycles = 7000
Number of thermal loads = 1
Thermal = Operating - Sustained
Use modulus at reference temperature
Include hanger stiffness
Do not include Bourdon effect
Use pressure correction for bends
Pressure stress = Pd^2 / (D^2 - d^2)
Peak pressure factor = 1.00
Cut off frequency = 33 Hz
Number of modes = 20
Do not include missing mass correction
Do not 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 = Example 2 - ASME B31.3 (2018) - Code Case 209								
2	10	From							Anchor
3	15		20'0"			A106	400	L1	
4	20		20'0"			A106	400	L1	Y restraint
5	30	Bend	5'0"			A106	400	L1	
6	40	Bend		20'0"		A106	400	L1	
7	45		10'0"			A106	400	L1	
8	50		20'0"			A106	400	L1	Limit stop
9	110	From	150'0"						Anchor
10	115		-20'0"			A106	400	L1	
11	120		-20'0"			A106	400	L1	Y restraint
12	130	Bend	-5'0"			A106	400	L1	
13	140	Bend		20'0"		A106	400	L1	
14	145		-10'0"			A106	400	L1	
15	50					A106	400	L1	

Anchors **(See Notes 1 & 2)**

Node	KX/kx	(lb/inch) KY/ky	KZ/kz	KXX/kxx	(in-lb/deg) KYY/kyy	KZZ/kzz	Releases X Y Z XXYYZZ	Anchor In Pipe
10	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
110	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)
30	24 L				31	45		
40	24 L				41	45		
130	24 L				131	45		

Bends

Bend Node	Radius (inch)	Thickness (inch)	Bend Matl	Flex. Factor	Int. Node	Angle (deg)	Int. Node	Angle (deg)
140	24	L			141	45		

Limit stops **(See Note 3)**

Node	Cnect Node	Lower Lmt (inch)	Upper Lmt (inch)	Direction X comp	Direction Y comp	Direction Z comp	Friction Coeff.	Stiffness (lb/inch)
50		0.000	None		1.000			Rigid

Restraints **(See Note 4)**

Node	X	Y	Z
20		Yes	
120		Yes	

Pipe material A106: A106 GRADE B **(See Note 5)**

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)
-20	29.9E+6	6.25E-6	20000
70	29.4E+6	6.40E-6	20000
100	29.3E+6	6.47E-6	20000
200	28.8E+6	6.70E-6	20000
300	28.3E+6	6.90E-6	20000
400	27.7E+6	7.10E-6	19900
500	27.3E+6	7.30E-6	19000
600	26.7E+6	7.40E-6	17900
650	26.1E+6	7.50E-6	17300
700	25.5E+6	7.60E-6	16700
750	24.9E+6	7.70E-6	13900
800	24.2E+6	7.80E-6	11400
850	23.3E+6	7.85E-6	8700
900	22.4E+6	7.90E-6	5900
950	21.4E+6	8.00E-6	4000
1000	20.4E+6	8.10E-6	2500
1050	19.2E+6	8.15E-6	1600
1100	18.0E+6	8.20E-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)	Soil
400	16"	STD	16	0.375	0.125	12.5	11	5			

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	DT (F)	DP (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
L1	550	440					575	465	1.000		

Notes:

1. **When Translational Stiffnesses KX, KY and KZ are input as "Rigid", CAEPIPE internally sets their value as 1E+12 lb/in.**
2. **When Rotational Stiffnesses KXX, KYY and KZZ are input as "Rigid", CAEPIPE internally sets their value as 1E+12 lb-in/rad.**
3. **For Limit Stops, when the Stiffness is input as "Rigid", CAEPIPE internally sets its value as 1E+12 lb/in**
4. **For Restraint, CAEPIPE internally sets the Translational Stiffness value as 1E+12 lb/in**
5. **Material properties for ASTM A106 Grade B Seamless Pipe are taken from Table A-1, Table C-1 and Table C-6 of ASME B31.3 (2018).**
6. **Alpha values are taken from Row A corresponding to "Mean Coefficient of Thermal Expansion" for Group 1 Carbon and Low Alloy Steel going from 70 deg F to the indicated temperature.**
7. **Pressure stress option used for Example 1 is NOT stated explicitly, i.e., it is not clear whether the Code Case 209 is using Thin shell formula (PD/4T) or Thick sheel formula [Pd^2/(D^2-d^2)]. From the Sustained Stresses results tabulated in Code Case 209, it is observed that the CAEPIPE Sustained stresses compare well with Code Case 209 results when Pd^2/(D^2-d^2) is chosen in CAEPIPE.**
8. **Nominal section properties are used for Stifnesses, forces, moments and displacements calculations in CAEPIPE.**
9. **Nominal less allowance are used for Sustained Stress (SL) calculations in CAEPIPE.**
10. **Nominal section properties are used for Thermal Expansion Stress (SE) calculations in CAEPIPE.**
11. **Code Case 209 does not explicitly state whether Appendix D or B31J (2017) is used for Flexibility Factor (FF) calculations. In CAEPIPE, Appendix D is selected for calculating FFs. The results computed by CAEPIPE compare well with the results reported in Code Case 209.**
12. **Para. S302.6.3 refers to both Appendix D and ASME B31J (2017) for calculating SIFs. Fortunately, SIF calculations for Bends and Pipes are the same as per Appendix D and ASME B31J (2017) for this Example 2.**

Table S302.5 Results for Operating Case 1: Reactions on Supports and Anchors

Global Axis Forces and Moments

Node Number	FX (Signed) (lb)	FY (Signed) (lb)	MZ (Signed) (ft-lb)	Remarks
10 Anchor	-5481	-4536	-38176	Anchor Load from CAEPIPE
	-5500	-4500	-38100	Anchor Load from CODE CASE 209
20 Support	---	-11025	---	Restraint Load from CAEPIPE
	---	-11000	---	Restraint Load from CODE CASE 209
50 Y+	---	0	---	Limit Stop Load from CAEPIPE
	---	0	---	Limit Stop Load from CODE CASE 209

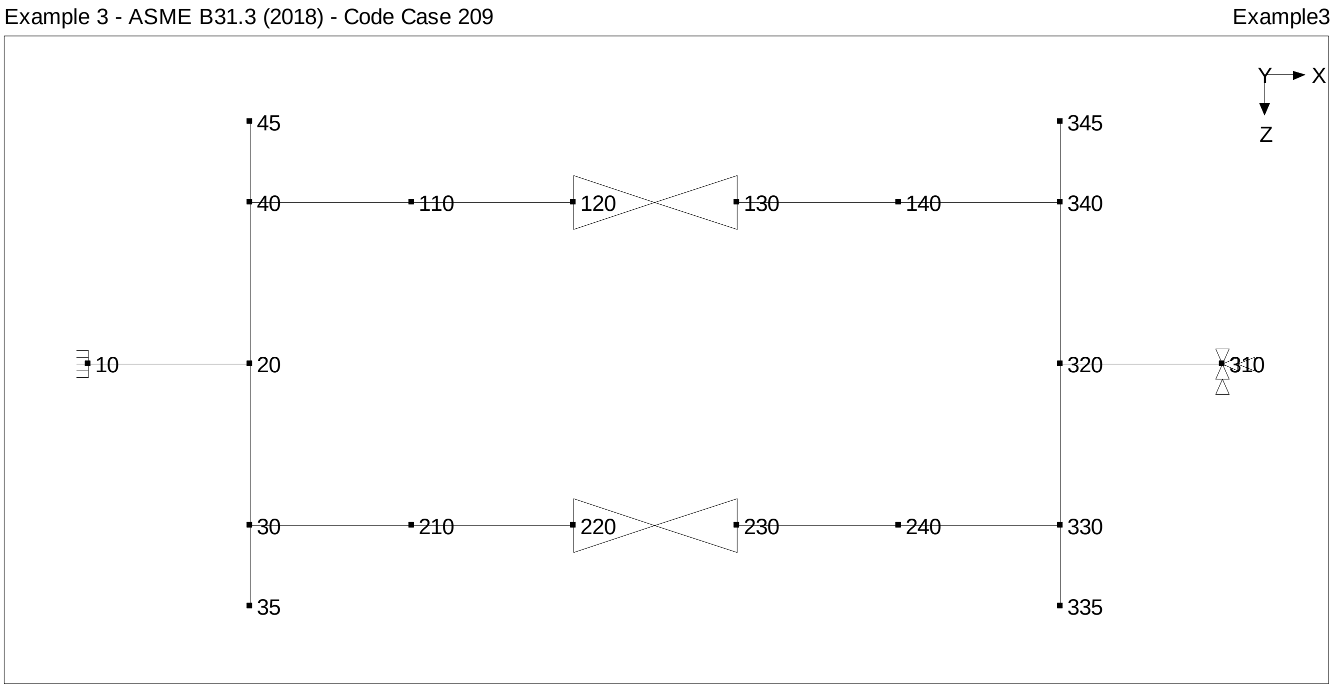
Table S302.6.3 Sustained Forces, Moments and Stresses for Sustained Condition with Node 50 Support Removed

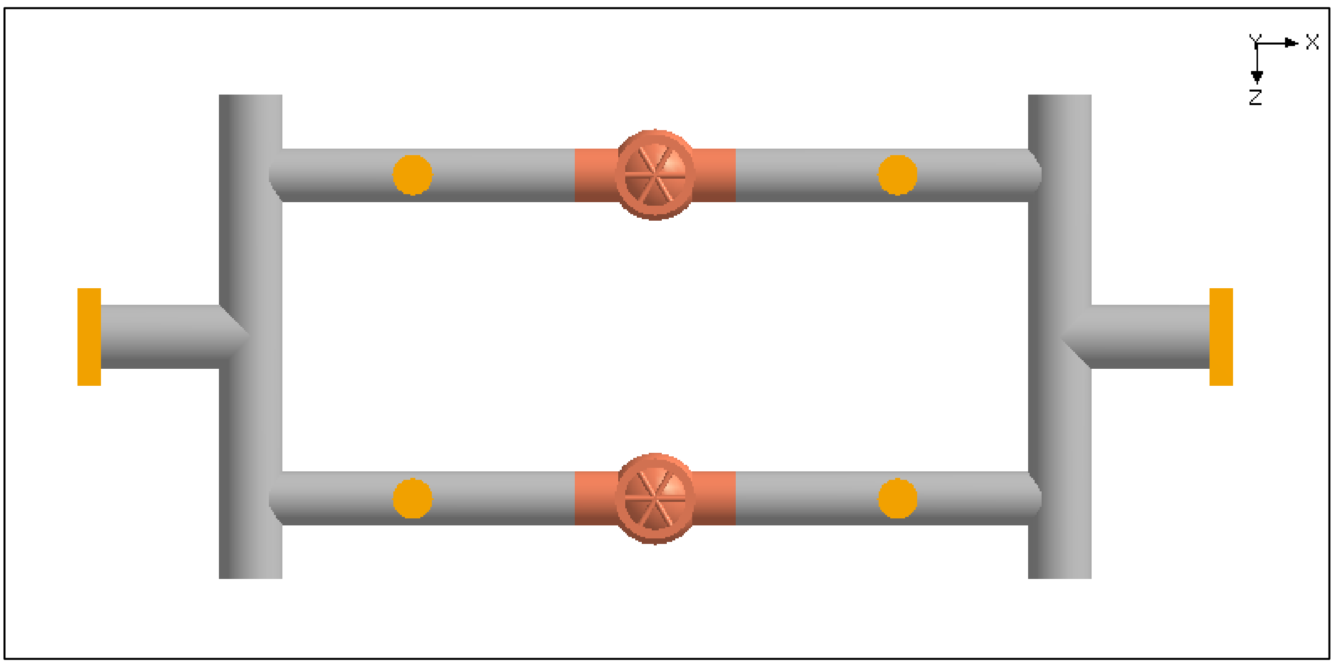
Node Number	Forces and Moments		Sustained Stress (S_L) (psi)	Local Forces and Moments @ Node # for Element and Highest Stress at that Node
	Axial (Unsigned) (lb)	MZ (Unsigned) (ft-lb)		
10 Anchor	2012	18756	11242	CAEPIPE (@10 for Element 10-15)
	2000	18800	11300	CODE CASE 209
20 Support	2012	29253	13869	CAEPIPE (@20 for Element 20-30A)
	2000	29200	13900	CODE CASE 209
30 near	2012	3339	8230	CAEPIPE (@30A for Element 30A - 31)
	2000	3300	8140	CODE CASE 209
30 mid	7168	7170	9742	CAEPIPE (@31 for Element 31 - 30B)
	7200	7150	9770	CODE CASE 209
30 far	7864	9033	10623	CAEPIPE (@30B for Element 30B-40A)
	7850	9000	10600	CODE CASE 209
40 near	5195	23152	17921	CAEPIPE (@41 for Element 40A - 41)
	5200	23200	18000	CODE CASE 209
40 mid	4910	23055	17921	CAEPIPE (@30B for Element 41 – 40B)
	5050	23000	17900	CODE CASE 209
40 far	2012	17453	15335	CAEPIPE (@41 for Element 40B - 45)
	2000	17500	15300	CODE CASE 209
50 Y+	2012	47939	18544	CAEPIPE (@50 for Element 45-50)
	2000	47800	18600	CODE CASE 209

Results shown in the table above are referred from "Local Element forces" of Model Example2_S50R.mod for CAEPIPE.

Unsigned Axial Forces are listed from CAEPIPE and Code Case 209 in the Table listed above, as the sign convention used in CAEPIPE may be different from the sign convention used in Code Case 209 for Local forces and moments.

Example 3: Moment Reversal – English Units





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Caepipe                              Example3                          Page 1
Version 10.50   Example 3 - ASME B31.3 (2018) - Code Case 209      Dec 21,2021
```

Options

Piping code = B31.3 (2018)
Use liberal allowable stresses
Include axial force in stress calculations
Do not use B31J for SIFs and Flexibility Factors
Reference temperature = 40 (F)
Number of thermal cycles = 3900
Number of thermal loads = 2
Solve thermal case
Use modulus at reference temperature
Include hanger stiffness
Do not include Bourdon effect
Do not use pressure correction for bends
Pressure stress = Pd^2 / (D^2 - d^2)
Peak pressure factor = 1.00
Cut off frequency = 33 Hz
Number of modes = 20
Include missing mass correction
Do not 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 = Example 3 - ASME B31.3 (2018) - Code Case 209								
2	10	From							Anchor
3	20		5'0"			A53B	24	H	Welding tee
4	30				5'0"	A53B	24	H	Welding tee
5	35				2'6"	A53B	24	H	
6	20	From							
7	40				-5'0"	A53B	24	H	Welding tee
8	45				-2'6"	A53B	24	H	
9	40	From							
10	110		5'0"			A53B	20	EB	Y restraint
11	120		5'0"			A53B	20	EB	
12	130	Valve	5'0"			A53B	20	EB	
13	140		5'0"			A53B	20	EB	Y restraint
14	340		5'0"			A53B	20	EB	
15	30	From							
16	210		5'0"			A53B	20	WB	Y restraint
17	220		5'0"			A53B	20	WB	
18	230	Valve	5'0"			A53B	20	WB	
19	240		5'0"			A53B	20	WB	Y restraint
20	330		5'0"			A53B	20	WB	
21	310	From	35'0"						Anchor
22	320		-5'0"			A53B	24	H	Welding tee
23	330					A53B	24	H	Welding tee
24	335				2'6"	A53B	24	H	
25	320	From							
26	340					A53B	24	H	Welding tee
27	345				-2'6"	A53B	24	H	

Anchors **(See Notes 1 & 2)**

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

Branch SIFs

Node	Type
20	Welding tee
30	Welding tee
40	Welding tee
320	Welding tee
330	Welding tee
340	Welding tee

Restraints **(See Note 3)**

Node	X	Y	Z
110		Yes	
140		Yes	
210		Yes	
240		Yes	

Valves **(See Note 4)**

From	To	Weight (lb)	Length (inch)	Thick X	Insul Wgt X	Add Wght (lb)	DX (inch)	DY (inch)	DZ (inch)
120	130	2000		10.00	3.00				
220	230	2000		10.00	3.00				

Pipe material A53B: A53 GRADE B **(See Note 5)**

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)
-20	29.9E+6	6.25E-6	20000
70	29.4E+6	6.40E-6	20000
100	29.3E+6	6.47E-6	20000
200	28.8E+6	6.70E-6	20000
300	28.3E+6	6.90E-6	20000
400	27.4E+6	7.10E-6	19900
500	27.3E+6	7.30E-6	19000
600	26.5E+6	7.40E-6	17900
650	26.0E+6	7.50E-6	17300
700	25.5E+6	7.60E-6	16700
750	24.9E+6	7.70E-6	13900
800	24.2E+6	7.80E-6	11400
850	23.4E+6	7.85E-6	8700
900	22.5E+6	7.90E-6	5900
950	21.5E+6	8.00E-6	4000
1000	20.4E+6	8.10E-6	2500
1050	19.2E+6	8.15E-6	1600
1100	18.0E+6	8.20E-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)	Soil
24	24"	STD	24	0.375	0	12.5					
20	20"	STD	20	0.375	0	12.5					

Notes:

1. **When Translational Stiffnesses KX, KY and KZ are input as "Rigid", CAEPIPE internally sets their value as 1E+12 lb/in.**
2. **When Rotational Stiffnesses KXX, KYY and KZZ are input as "Rigid", CAEPIPE internally sets their value as 1E+12 lb-in/rad.**
3. **For Restraint, CAEPIPE internally sets the Translational Stiffness value as 1E+12 lb/in.**
4. **By Default CAEPIPE uses Thickness Factor (Thickness X) as 3.0 and Insulation Weight Factor (Insl Wgt X) as 1.75 for Valves. Other programs may use 10.0 and 3.0 respectively. So, it is changed as 10.0 and 3.0 for this Example 3 problem.**
5. **Material properties for ASTM A53 Grade B Seamless Pipe are taken from Table A-1, Table C-1 and Table C-6 of ASME B31.3 (2018).**

   Alpha values are taken from Row A corresponding to "Mean Coefficient of Thermal Expansion" for Group 1 Carbon and Low Alloy Steel going from 70 deg F to the indicated temperature.
6. **Pressure stress option used for Example 1 is NOT stated explicitly, i.e., it is not clear whether the Code Case 209 is using Thin shell formula (PD/4T) or Thick sheel formula [Pd^2/(D^2-d^2)]. From the Sustained Stresses results tabulated in Code Case 209, it is observed that the CAEPIPE Sustained stresses compare well with Code Case 209 results when Pd^2/(D^2-d^2) is chosen in CAEPIPE.**

7. **Nominal section properties are used for Stifnesses, forces, moments and displacements calculations in CAEPIPE.**
8. **Nominal section properties are used for Thermal Expansion Stress (SE) calculations in CAEPIPE.**
9. **Code Case 209 does not explicitly state whether Appendix D or B31J (2017) is used for Flexibility Factor (FF) calculations. So, in CAEPIPE, Appendix D is selected for calculating FFs. The results computed by CAEPIPE compare well with the results reported in Code Case 209.**
10. **Para. S303.1 refers to Appendix D for calculating SIFs. Hence, In CAEPIPE, Appendix D is selected for calculating SIFs for this Example 3.**
11. **As per para. 302.3.5 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at Metal temperatures ≤ 371°C (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence f ≤ 1.0 for all materials including Ferrous materials.**

    In view of the above, f is always <= 1.00 in CAEPIPE at this time.

Table S303.7.1 Case 1 (Expansion T1-T_{ref}): Displacement Stress Range

Node Number	Global Axis Forces and Moments		Eq. (17) Stress (S_E) (psi) [see Note 1]	Global Forces and Moments @ Node # for Element and Highest Stress at that Node
	FX (Signed) (lb)	MY (Signed) (ft-lb)		
10 Anchor	0	115168	8538	CAEPIPE (@10 for Element 10-20)
	0	114000	8440	CODE CASE 209
20 tee	0	-115168	**29173**	CAEPIPE (@20 for Element 10-20)
	0	-114000	28800	CODE CASE 209
30 tee	-18646	35647	**16290**	CAEPIPE (@30 for Element 20-30)
	-18500	35500	16100	CODE CASE 209
40 tee	18646	35647	**16290**	CAEPIPE (@40 for Element 20-40)
	18500	35500	16100	CODE CASE 209
110 Y	18646	35647	4648	CAEPIPE (@110 for Element 40-110)
	18500	35500	4600	CODE CASE 209
120	18646	35647	4648	CAEPIPE (@120 for Element 110-120)
	18500	35500	4600	CODE CASE 209
130 meter	18646	35647	4648	CAEPIPE (@130 for Valve 120-130)
	18500	35500	4600	CODE CASE 209
140 Y	18646	35647	4648	CAEPIPE (@140 for Element 130-140)
	18500	35500	4600	CODE CASE 209
310 Anchor	0	-115168	8538	CAEPIPE (@310 for Element 310-320)
	0	-114000	8440	CODE CASE 209
320 tee	0	115168	**29173**	CAEPIPE (@320 for Element 310-320)
	0	114000	28800	CODE CASE 209
330 tee	-18646	35647	**16290**	CAEPIPE (@330 for Element 240-330)
	-18500	35500	16100	CODE CASE 209
340 tee	18646	35647	**16290**	CAEPIPE (@340 for Element 140-340)
	18500	35500	16100	CODE CASE 209
210 Y	-18646	35647	4648	CAEPIPE (@210 for Element 30-210)
	-18500	35500	4600	CODE CASE 209
220	-18646	35647	4648	CAEPIPE (@220 for Element 210-220)
	-18500	35500	4600	CODE CASE 209
230 meter	-18646	35647	4648	CAEPIPE (@230 for Valve 220-230)
	-18500	35500	4600	CODE CASE 209
240 Y	-18646	35647	4648	CAEPIPE (@240 for Element 230-240)
	-18500	35500	4600	CODE CASE 209

Note 1: For Tee elements, Stress reported is the maximum of stresses for the three elements meeting at Tee Intersection Node.

Table S303.7.2 Case 2 (Expansion T2-T_{ref}): Displacement Stress Range

Node Number	Global Axis Forces and Moments FX (Signed) (lb)	Global Axis Forces and Moments MY (Signed) (ft-lb)	Eq. (17) Stress (S_E) (psi) [see Note 1]	Global Forces and Moments @ Node # for Element and Highest Stress at that Node
10 Anchor	0	-115168	8538	CAEPIPE (@10 for Element 10-20)
	0	-114000	8440	CODE CASE 209
20 tee	0	115168	**29173**	CAEPIPE (@20 for Element 10-20)
	0	114000	28800	CODE CASE 209
30 tee	18646	-35647	**16290**	CAEPIPE (@30 for Element 20-30)
	18500	-35500	16100	CODE CASE 209
40 tee	-18646	-35647	**16290**	CAEPIPE (@40 for Element 20-40)
	-18500	-35500	16100	CODE CASE 209
110 Y	-18646	-35647	4648	CAEPIPE (@110 for Element 40-110)
	-18500	-35500	4600	CODE CASE 209
120	-18646	-35647	4648	CAEPIPE (@120 for Element 110-120)
	-18500	-35500	4600	CODE CASE 209
130 meter	-18646	-35647	4648	CAEPIPE (@130 for Valve 120-130)
	-18500	-35500	4600	CODE CASE 209
140 Y	-18646	-35647	4648	CAEPIPE (@140 for Element 130-140)
	-18500	-35500	4600	CODE CASE 209
310 Anchor	0	115168	8538	CAEPIPE (@310 for Element 310-320)
	0	114000	8440	CODE CASE 209
320 tee	0	-115168	**29173**	CAEPIPE (@320 for Element 310-320)
	0	-114000	28800	CODE CASE 209
330 tee	18646	-35647	**16290**	CAEPIPE (@330 for Element 240-330)
	18500	-35500	16100	CODE CASE 209
340 tee	-18646	-35647	**16290**	CAEPIPE (@340 for Element 140-340)
	-18500	-35500	16100	CODE CASE 209
210 Y	18646	-35647	4648	CAEPIPE (@210 for Element 30-210)
	18500	-35500	4600	CODE CASE 209
220	18646	-35647	4648	CAEPIPE (@220 for Element 210-220)
	18500	-35500	4600	CODE CASE 209
230 meter	18646	-35647	4648	CAEPIPE (@230 for Valve 220-230)
	18500	-35500	4600	CODE CASE 209
240 Y	18646	-35647	4648	CAEPIPE (@240 for Element 230-240)
	18500	-35500	4600	CODE CASE 209

Note 1: For Tee elements, Stress reported is the maximum of stresses for the three elements meeting at Tee Intersection Node.

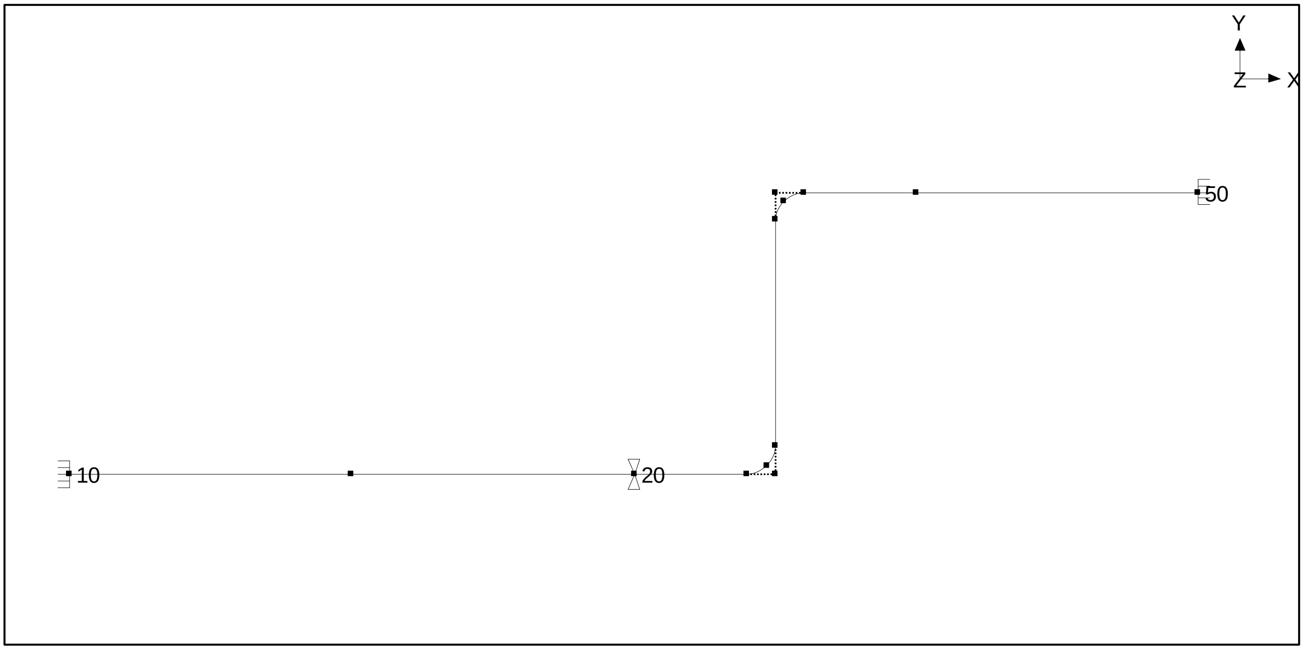
Table S303.7.3 Case 3: Moment Reversal - (Expansion T1-T2): Displacement Stress Range

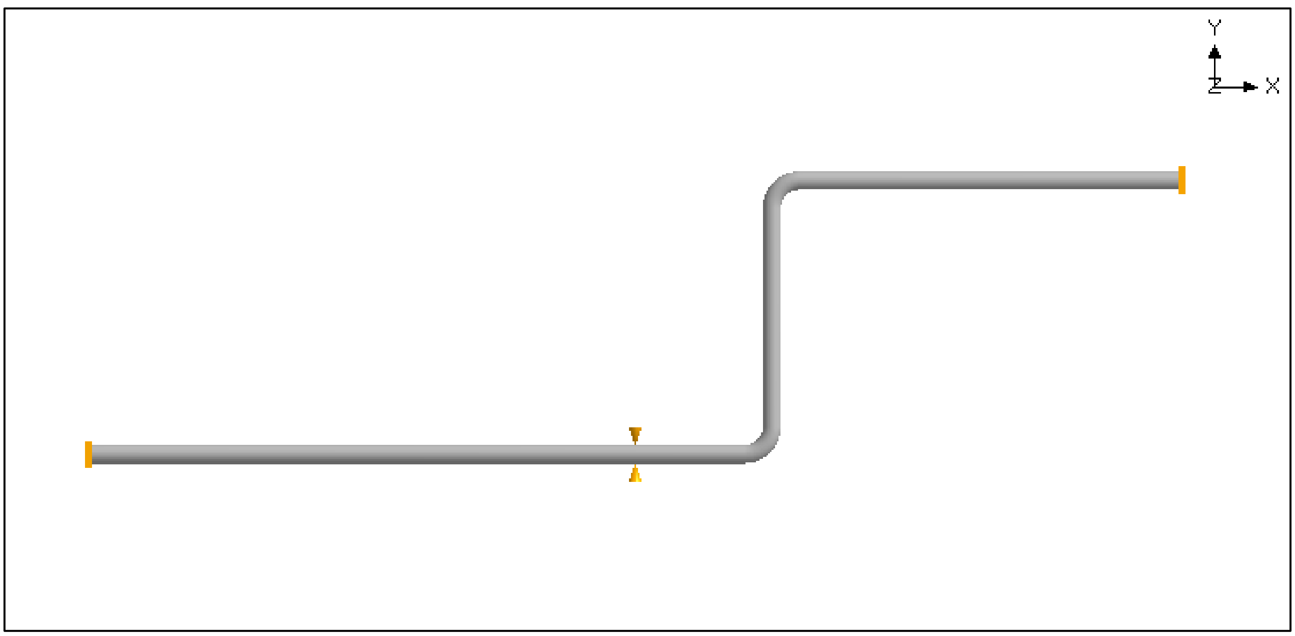
Node Number	Global Axis Forces and Moments		Eq. (17) Stress (S_E) (psi) [see Note 1]	Global Forces and Moments @ Node # for Element and Highest Stress at that Node
	FX (Unsigned) (lb)	MY (Unsigned) (ft-lb)		
10 Anchor	0	230336	17077	CAEPIPE (@10 for Element 10-20)
	0	229000	16900	CODE CASE 209
20 tee	0	230336	**58346**	CAEPIPE (@20 for Element 10-20)
	0	229000	57700	CODE CASE 209
30 tee	37293	71295	**32580**	CAEPIPE (@30 for Element 20-30)
	37000	70900	32200	CODE CASE 209
40 tee	37293	71295	**32580**	CAEPIPE (@40 for Element 20-40)
	37000	70900	32200	CODE CASE 209
110 Y	37293	71295	9297	CAEPIPE (@110 for Element 40-110)
	37000	70900	9230	CODE CASE 209
120	37293	71295	9297	CAEPIPE (@120 for Element 110-120)
	37000	70900	9230	CODE CASE 209
130 meter	37293	71295	9297	CAEPIPE (@130 for Valve 120-130)
	37000	70900	9230	CODE CASE 209
140 Y	37293	71295	9297	CAEPIPE (@140 for Element 130-140)
	37000	70900	9230	CODE CASE 209
310 Anchor	0	230336	17077	CAEPIPE (@310 for Element 310-320)
	0	229000	16900	CODE CASE 209
320 tee	0	230336	**58346**	CAEPIPE (@320 for Element 310-320)
	0	229000	57700	CODE CASE 209
330 tee	37293	71295	**32580**	CAEPIPE (@330 for Element 240-330)
	37000	70900	32200	CODE CASE 209
340 tee	37293	71295	**32580**	CAEPIPE (@340 for Element 140-340)
	37000	70900	32200	CODE CASE 209
210 Y	37293	71295	9297	CAEPIPE (@210 for Element 30-210)
	37000	70900	9230	CODE CASE 209
220	37293	71295	9297	CAEPIPE (@220 for Element 210-220)
	37000	70900	9230	CODE CASE 209
230 meter	37293	71295	9297	CAEPIPE (@230 for Valve 220-230)
	37000	70900	9230	CODE CASE 209
240 Y	37293	71295	9297	CAEPIPE (@240 for Element 230-240)
	37000	70900	9230	CODE CASE 209

Note 1: For Tee elements, Stress reported is the maximum of stresses for the three elements meeting at Tee Intersection Node.

ASME B31.3 (2018) – B31 Code Case 209 (SI Units)

Example 1: Code Complaint Piping System – SI Units





Options

- Piping code = B31.3 (2018)
- Do not use liberal allowable stresses
- Include axial force in stress calculations
- Do not use B31J for SIFs and Flexibility Factors
- Reference temperature = -1 (C)
- Number of thermal cycles = 7000
- Number of thermal loads = 1
- Thermal = Operating - Sustained
- Use modulus at reference temperature
- Include hanger stiffness
- Do not include Bourdon effect
- Use pressure correction for bends
- Pressure stress = Pd^2 / (D^2 - d^2)
- Peak pressure factor = 1.00
- Cut off frequency = 33 Hz
- Number of modes = 20
- Do not include missing mass correction
- Do not use friction in dynamic analysis
- Vertical direction = Y

#	Node	Type	DX (mm)	DY (mm)	DZ (mm)	Mat	Sec	Load	Data
1	Title = Example 1 from Code Case 209 of B31.3 - 2018								
2	10	From							Anchor
3	15		6100			A106	400	L1	
4	20		6100			A106	400	L1	Y restraint
5	30	Bend	3050			A106	400	L1	
6	40	Bend			6100	A106	400	L1	
7	45		3050			A106	400	L1	
8	50		6100			A106	400	L1	Anchor

Anchors **(See Notes 1 & 2)**

Node	KX/kx (N/mm)	KY/ky	KZ/kz	KXX/kxx (Nm/deg)	KYY/kyy	KZZ/kzz	Releases X Y Z XXYYZZ	Anchor In Pipe
10	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
50	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS

Bends

Bend Node	Radius (mm)	Thickness (mm)	Bend Matl	Flex. Factor	Int. Node	Angle (deg)	Int. Node	Angle (deg)
30	609.6	L			31	45		
40	609.6	L			41	45		

Restraints **(See Note 3)**

Node	X	Y	Z
20		Yes	

Pipe material A106: A106 GRADE B **(See Note 4)**

Density = 7833 (kg/m3), Nu = 0.300, Joint factor = 1.00, Type = CS
Yield strength = 241.0 (MPa)

Temp (C)	E (MPa)	Alpha (mm/mm/C)	Allowable (MPa)
-29	205780	11.22E-6	138.0
20	202350	11.50E-6	138.0
50	200670	11.80E-6	138.0
75	199330	11.90E-6	138.0
100	198000	12.10E-6	138.0
125	196500	12.30E-6	138.0
150	195000	12.40E-6	138.0
175	193500	12.60E-6	138.0
200	192000	12.70E-6	138.0
225	190500	12.90E-6	135.0
250	189000	13.00E-6	132.0
275	187000	13.20E-6	129.0
300	185000	13.30E-6	126.0

Pipe Sections

Name	Nominal Dia.	Sch	O.D. (mm)	Thk (mm)	Cor.Al (mm)	M.Tol (%)	Ins.Dens (Kg/m3)	Ins.Th (mm)	Lin.Dens (Kg/m3)	Lin.Th (mm)	Soil
400	16"	STD	406.4	9.53	1.600	12.5	176	127			

Pipe Loads

Load Name	T1 (C)	P1 (kPa)	T2 (C)	P2 (kPa)	T3 (C)	P3 (kPa)	DT (C)	DP (kPa)	Specific gravity	Add.Wgt (kg/m)	Wind Load
L1	260	3450					288	3800	1.000		

Notes:

1. **When Translational Stiffnesses KX, KY and KZ are input as "Rigid", CAEPIPE internally sets their value as 1.7513E+11 N/mm.**
2. **When Rotational Stiffnesses KXX, KYY and KZZ are input as "Rigid", CAEPIPE internally sets their value as 1.13E+11 Nm/rad.**
3. **For Restraint, CAEPIPE internally sets the Translational Stiffness value as 1.8513E+11 N/mm.**
4. **Material properties for ASTM A106 Grade B Seamless Pipe are taken from Table A-1, Table C-1 and Table C-6 of ASME B31.3 (2018).**

   Alpha values are taken from Row A corresponding to "Mean Coefficient of Thermal Expansion" for Group 1 Carbon and Low Alloy Steel going from 20 deg C to the indicated temperature.
5. **Pressure stress option used for Example 1 is NOT stated explicitly, i.e., it is not clear whether the Code Case 209 is using Thin shell formula (PD/4T) or Thick sheel formula [Pd^2/(D^2-d^2)]. From the Sustained Stresses results tabulated in Code Case 209, it is observed that the CAEPIPE Sustained stresses compare well with Code Case 209 results when Pd^2/(D^2-d^2) is chosen in CAEPIPE.**

6. **Nominal section properties are used for Stifnesses, forces, moments and displacements calculations in CAEPIPE.**
7. **Nominal less allowance are used for Sustained Stress (SL) calculations in CAEPIPE.**
8. **Nominal section properties are used for Thermal Expansion Stress (SE) calculations in CAEPIPE.**
9. **Code Case 209 does not explicitly state whether Appendix D or B31J (2017) is used for Flexibility Factor (FF) calculations. In CAEPIPE, Appendix D is selected for calculating FFs. The results computed by CAEPIPE compare well with the results reported in Code Case 209.**
10. **Para. S301.7 refers to both Appendix D and ASME B31J (2017) for calculating SIFs. Fortunately, SIF calculations for Bends and Pipes are the same as per Appendix D and ASME B31J (2017) for this Example 1.**

Table S301.5.1 Operating Load Case Results: Internal Loads and Deflections

Node Number	Axial Force (Unsigned) (N)	Bending Moment (Unsigned) (N-m)	Horizontal Deflection (mm)	Vertical Deflection (mm)	Forces and Moments @ Node # for Element and Deflections at that Node
10	29 582	22 109	0	0	CAEPIPE (@ 10 for Element 10-15)
	29 700	22 100	0	0	CODE CASE 209
15	29 582	11 007	21	-1	CAEPIPE (@ 15 for Element 15-20)
	29 700	11 000	21	-1	CODE CASE 209
20	29 582	46 464	42	0	CAEPIPE (@20 for Element 20-30A)
	29 700	46 400	42	0	CODE CASE 209
30 near	29 582	64 520	50	-3	CAEPIPE (@ 30A for Element 30A-31)
	29 700	64 700	50	-3	CODE CASE 209)
30 mid	50 150	77 324	51	-2	CAEPIPE (@ 31 for Element 31-30B)
	50 700	77 500	51	-2	CODE CASE 209
30 far	40 176	71 883	47	1	CAEPIPE (@ 30B for Element 30B-40A)
	40 200	72 000	47	2	CODE CASE 209
40 near	28 294	**72 499**	-26	18	CAEPIPE (@40A for Element 40A-41)
	28 400	72 600	-26	18	CODE CASE 209
40 mid	40 100	80 336	-30	21	CAEPIPE (@ 41 for Element 41-40B)
	40 100	80 400	-30	21	CODE CASE 209
40 far	29 582	74 189	-29	23	CAEPIPE (@ 40B for Element 40B-45)
	29 700	74 300	-29	23	CODE CASE 209
45	29 582	18 079	-21	16	CAEPIPE (@45 for Element 45-50)
	29 700	18 100	-21	16	CODE CASE 209
50	29 582	58 761	0	0	CAEPIPE (@50 for Element 45-50)
	29 700	59 000	0	0	CODE CASE 209

Table S301.5.2 Operating Load Case Results: Reaction Loads on Supports and Anchors

Node Number	FX (Signed) (N)	FY (Signed) (N)	MZ (Signed) (N-m)	Remarks
10 Anchor	-29 582	-12 854	-22 109	Support Load from CAEPIPE
	-29 700	-12 900	-22 100	Support Load from CODE CASE 209
20 Support	---	-65 295	---	Support Load from CAEPIPE
	---	-65 300	---	Support Load from CODE CASE 209
50 Anchor	29 582	5 171	-58 761	Support Load from CAEPIPE
	29 700	5 300	-59 000	Support Load from CODE CASE 209

Table S301.6 Sustained Forces, Moments and Stresses

Node Number	Axial Force (Unsigned) (N)	Bending Moment (Unsigned) (N-m)	Sustained Stress (S_L) (MPa)	Forces and Moments @ Node # for Element and Highest Stress at that Node
10	3 272	17 277	59.0	CAEPIPE (@ 10 for Element 10-15)
	3 270	17 300	59.0	CODE CASE 209
20	3 272	56 189	99.1	CAEPIPE (@ 20 for Element 20-30A)
	3 270	56 100	98.9	CODE CASE 209
30 near	3 272	5 300	52.0	CAEPIPE (@ 30A for Element 30A-31)
	3 270	5 280	52.7	CODE CASE 209
30 mid	17 206	14 059	68.3	CAEPIPE (@ 31 for Element 31-30B)
	17 200	14 000	69.1	CODE CASE 209
30 far	19 895	16 338	72.6	CAEPIPE (@ 30B for Element 30B-40A)
	19 900	16 300	73.3	CODE CASE 209
40 near	8 013	366	41.5	CAEPIPE (@40A for Element 40A-41)
	8 000	370	42.0	CODE CASE 209
40 mid	7 155	249	41.4	CAEPIPE (@ 41 for Element 41-40B)
	7 170	250	42.1	CODE CASE 209
40 far	3 272	2 351	46.0	CAEPIPE (@ 40B for Element 40B-45)
	3 270	2 350	46.0	CODE CASE 209
50	3 272	37 910	80.3	CAEPIPE (@ 50 for Element 45-50)
	3 270	37 800	79.5	CODE CASE 209

Table S301.7 Displacement Stress Range

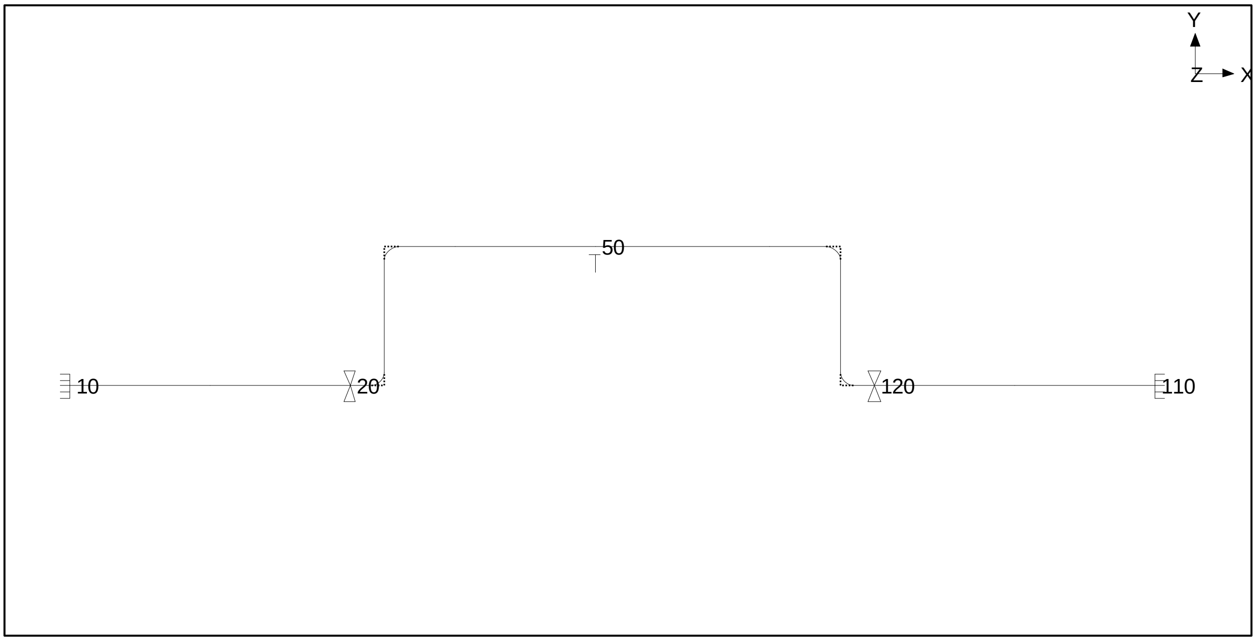
Node Number	Axial Force (Unsigned) (N)	Bending Moment (Unsigned) (N-m)	Displacement Stress Range (S_E) (MPa)	Forces and Moments @ Node # for Element and Highest Stress at that Node
10	26 309	4 832	6.41	CAEPIPE (@ 10 for Element 10-15)
	26 400	4 480	6.43	CODE CASE 209
20	26 309	9 725	10.7	CAEPIPE (@ 20 for Element 20-30A)
	26 400	9 740	10.7	CODE CASE 209
30 near	26 309	59 220	136.9	CAEPIPE (@ 30A for Element 30A-31)
	26 400	59 400	137	CODE CASE 209
30 mid	32 945	63 265	146.7	CAEPIPE (@ 31 for Element 31-30B)
	32 200*	63 400	147	CODE CASE 209
30 far	20 281	55 545	128.1	CAEPIPE (@ 30B for Element 30B-40A)
	20 400	55 700	128	CODE CASE 209
40 near	20 281	72 865	167.5	CAEPIPE (@40A for Element 40A-41)
	20 400	72 900	168	CODE CASE 209
40 mid	32 945	80 585	186.1	CAEPIPE (@ 41 for Element 41-40B)
	33 200	80 800	187	CODE CASE 209
40 far	26 309	76 540	176.3	CAEPIPE (@ 40B for Element 41-40B)
	26 400	76 700	177	CODE CASE 209
50	26 309	96 671	86.1	CAEPIPE (@ 50 for Element 45-50)
	26 400	97 000	86.4	CODE CASE 209

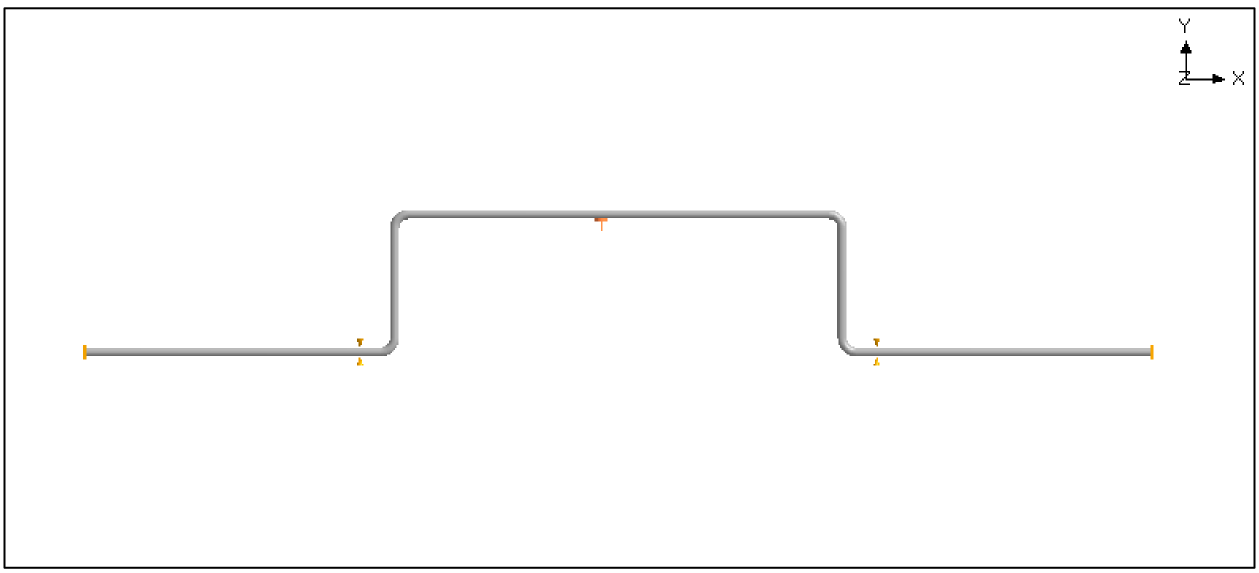
* May be a typographical error in Code Case 209. From Operating – Sustained for 30 mid = 50700 – 17200 = 33 500 N.

Other Comparisons

Description	CAEPIPE	CODE CASE 209
Allowable S_h in MPa for Sustained Stress	130.8 MPa	130.8 MPa
Allowable S_A in MPa for Displacement Stress Range	205.2 MPa	205.2 MPa

Example 2: Anticipated Sustained Conditions Considering Pipe Lift-Off – SI Units





Options

Piping code = B31.3 (2018)
Do not use liberal allowable stresses
Include axial force in stress calculations
Do not use B31J for SIFs and Flexibility Factors
Reference temperature = -1 (C)
Number of thermal cycles = 7000
Number of thermal loads = 1
Thermal = Operating - Sustained
Use modulus at reference temperature
Include hanger stiffness
Do not include Bourdon effect
Use pressure correction for bends
Pressure stress = Pd^2 / (D^2 - d^2)
Peak pressure factor = 1.00
Cut off frequency = 33 Hz
Number of modes = 20
Do not include missing mass correction
Do not use friction in dynamic analysis
Vertical direction = Y

#	Node	Type	DX(mm)	DY(mm)	DZ(mm)	Mat	Sec	Load	Data
1	Title = Example 2 - ASME B31.3 (2018) - Code Case 209								
2	10	From							Anchor
3	15		6100			A106	400	L1	
4	20		6100			A106	400	L1	Y restraint
5	30	Bend	1520			A106	400	L1	
6	40	Bend		6100		A106	400	L1	
7	45		3050			A106	400	L1	
8	50		6100			A106	400	L1	Limit stop
9	110	From	45750						Anchor
10	115		-6100			A106	400	L1	
11	120		-6100			A106	400	L1	Y restraint
12	130	Bend	-1520			A106	400	L1	
13	140	Bend		6100		A106	400	L1	
14	145		-3050			A106	400	L1	
15	50					A106	400	L1	

Anchors **(See Notes 1 & 2)**

	(N/mm)			(Nm/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
110	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS

Bends

Bend Node	Radius (mm)	Thickness (mm)	Bend Matl	Flex. Factor	Int. Node	Angle (deg)	Int. Node	Angle (deg)
30	609.6	L			31	45		
40	609.6	L			41	45		
130	609.6	L			131	45		

Bends

Bend Node	Radius (mm)	Thickness (mm)	Bend Matl	Flex. Factor	Int. Node	Angle (deg)	Int. Node	Angle (deg)
140	609.6	L			141	45		

Limit stops **(See Note 3)**

Node	Cnect Node	Lower Lmt (mm)	Upper Lmt (mm)	Direction X comp	Direction Y comp	Direction Z comp	Friction Coeff.	Stiffness (N/mm)
50		0.000	None		1.000			Rigid

Restraints **(See Note 4)**

Node	X	Y	Z
20		Yes	
120		Yes	

Pipe material A106: A106 GRADE B **(See Note 5)**

Density = 7833 (kg/m3), Nu = 0.300, Joint factor = 1.00, Type = CS
Yield strength = 241.0 (MPa)

Temp (C)	E (MPa)	Alpha (mm/mm/C)	Allowable (MPa)
-29	205780	11.22E-6	138.0
20	202350	11.50E-6	138.0
50	200670	11.80E-6	138.0
75	199330	11.90E-6	138.0
100	198000	12.10E-6	138.0
125	196500	12.30E-6	138.0
150	195000	12.40E-6	138.0
175	193500	12.60E-6	138.0
200	192000	12.70E-6	138.0
225	190500	12.90E-6	135.0
250	189000	13.00E-6	132.0
275	187000	13.20E-6	129.0
300	185000	13.30E-6	126.0
325	182000	13.40E-6	122.0
350	179000	13.60E-6	118.0

Pipe Sections

Name	Nominal Dia.	Sch	O.D. (mm)	Thk (mm)	Cor.Al (mm)	M.Tol (%)	Ins.Dens (Kg/m3)	Ins.Th (mm)	Lin.Dens (Kg/m3)	Lin.Th (mm)	Soil
400	16"	STD	406.4	9.53	3.18	12.5	176	127			

Pipe Loads

Load Name	T1 (C)	P1 (kPa)	T2 (C)	P2 (kPa)	T3 (C)	P3 (kPa)	DT (C)	DP (kPa)	Specific gravity	Add.Wgt (kg/m)	Wind Load
L1	288	3040					302	3230	1.000		

Notes:

1. **When Translational Stiffnesses KX, KY and KZ are input as "Rigid", CAEPIPE internally sets their value as 1.7513E+11 N/mm.**
2. **When Rotational Stiffnesses KXX, KYY and KZZ are input as "Rigid", CAEPIPE internally sets their value as 1.13E+11 Nm/rad.**
3. **For Limit Stops, when the Stiffness is input as "Rigid", CAEPIPE internally sets its value as 1.7513E+11 N/mm.**
4. **For Restraint, CAEPIPE internally sets the Translational Stiffness value as 1.7513E+11 N/mm.**
5. **Material properties for ASTM A106 Grade B Seamless Pipe are taken from Table A-1, Table C-1 and Table C-6 of ASME B31.3 (2018).**
6. **Alpha values are taken from Row A corresponding to "Mean Coefficient of Thermal Expansion" for Group 1 Carbon and Low Allo[p/;ly Steel going from 20 deg C to the indicated temperature.**
7. **Pressure stress option used for Example 1 is NOT stated explicitly, i.e., it is not clear whether the Code Case 209 is using Thin shell formula (PD/4T) or Thick sheel formula [Pd^2/(D^2-d^2)]. From the Sustained Stresses results tabulated in Code Case 209, it is observed that the CAEPIPE Sustained stresses compare well with Code Case 209 results when Pd^2/(D^2-d^2) is chosen in CAEPIPE.**
8. **Nominal section properties are used for Stifnesses, forces, moments and displacements calculations in CAEPIPE.**
9. **Nominal less allowance are used for Sustained Stress (SL) calculations in CAEPIPE.**
10. **Nominal section properties are used for Thermal Expansion Stress (SE) calculations in CAEPIPE.**
11. **Code Case 209 does not explicitly state whether Appendix D or B31J (2017) is used for Flexibility Factor (FF) calculations. In CAEPIPE, Appendix D is selected for calculating FFs. The results computed by CAEPIPE compare well with the results reported in Code Case 209.**
12. **Para. S302.6.3 refers to both Appendix D and ASME B31J (2017) for calculating SIFs. Fortunately, SIF calculations for Bends and Pipes are the same as per Appendix D and ASME B31J (2017) for this Example 2.**

Table S302.5 Results for Operating Case 1: Reactions on Supports and Anchors

Global Axis Forces and Moments

Node Number	FX (Signed) (N)	FY (Signed) (N)	MZ (Signed) (N-m)	Remarks
10 Anchor	-24 389	-20 207	-51 888	Anchor Load from CAEPIPE
	-24 400	-20 200	-51 700	Anchor Load from CODE CASE 209
20 Support	---	-49 057	---	Restraint Load from CAEPIPE
	---	-49 000	---	Restraint Load from CODE CASE 209
50 Y+	---	0	---	Limit Stop Load from CAEPIPE
	---	0	---	Limit Stop Load from CODE CASE 209

Table S302.6.3 Sustained Forces, Moments and Stresses for Sustained Condition with Node 50 Support Removed

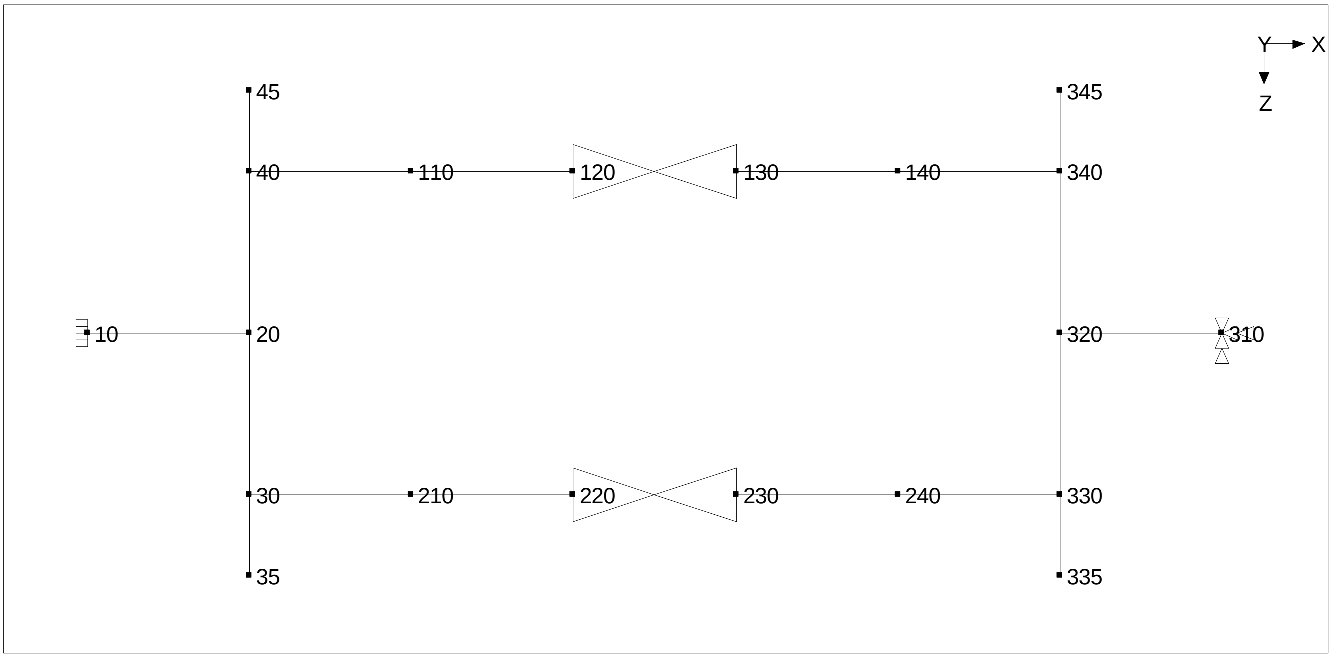
Node Number	Forces and Moments		Sustained Stress (S_L) (MPa)	Local Forces and Moments @ Node # for Element and Highest Stress at that Node
	Axial (Unsigned) (N)	MZ (Unsigned) (N-m)		
10 Anchor	8 957	25 531	77.7	CAEPIPE (@10 for Element 10-15)
	9 000	25 400	77.5	CODE CASE 209
20 Support	8 957	39 578	95.6	CAEPIPE (@20 for Element 20-30A)
	9 000	39 600	95.6	CODE CASE 209
30 near	8 957	4 567	56.9	CAEPIPE (@30A for Element 30A - 31)
	9 000	4 500	55.9	CODE CASE 209
30 mid	31 918	9 695	67.2	CAEPIPE (@31 for Element 31 - 30B)
	32 200	9 700	67.1	CODE CASE 209
30 far	35 017	12 224	73.3	CAEPIPE (@30B for Element 30B-40A)
	35 000	12 200	73.2	CODE CASE 209
40 near	23 135	31 494	124	CAEPIPE (@41 for Element 40A - 41)
	23 100	31 400	124	CODE CASE 209
40 mid	21 868	31 361	123.8	CAEPIPE (@30B for Element 41 – 40B)
	22 500	31 200	123	CODE CASE 209
40 far	8 957	23 756	106	CAEPIPE (@41 for Element 40B - 45)
	9 000	23 600	106	CODE CASE 209
50 Y+	8 957	65 131	128.1	CAEPIPE (@50 for Element 45-50)
	9 000	64 900	128	CODE CASE 209

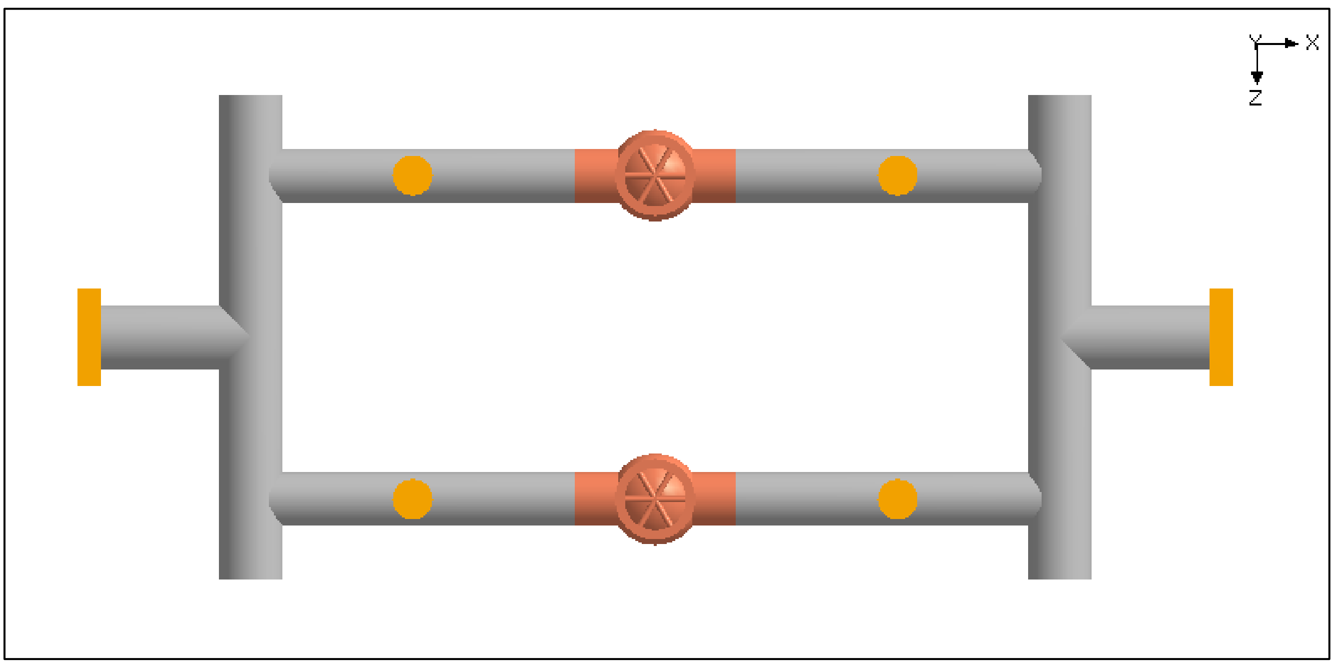
Results shown in the table above are referred from "Local Element forces" of Model Example2_S50R.mod for CAEPIPE.

Unsigned Axial Forces are listed from CAEPIPE and Code Case 209 in the Table listed above, as the sign convention used in CAEPIPE may be different from the sign convention used in Code Case 209 for Local forces and moments.

Example 3: Moment Reversal – SI Units

Example 3 - ASME B31.3 (2018) - Code Case 209 Example3





Options

Piping code = B31.3 (2018)
Use liberal allowable stresses
Include axial force in stress calculations
Do not use B31J for SIFs and Flexibility Factors
Reference temperature = 4 (C)
Number of thermal cycles = 3900
Number of thermal loads = 2
Solve thermal case
Use modulus at reference temperature
Include hanger stiffness
Do not include Bourdon effect
Do not use pressure correction for bends
Pressure stress = Pd^2 / (D^2 - d^2)
Peak pressure factor = 1.00
Cut off frequency = 33 Hz
Number of modes = 20
Include missing mass correction
Do not use friction in dynamic analysis
Vertical direction = Y

#	Node	Type	DX(mm)	DY(mm)	DZ(mm)	Mat	Sec	Load	Data
1	Title = Example 3 - ASME B31.3 (2018) - Code Case 209								
2	10	From							Anchor
3	20		1520			A53B	24	H	Welding tee
4	30				1520	A53B	24	H	Welding tee
5	35				760	A53B	24	H	
6	20	From							
7	40				-1520	A53B	24	H	Welding tee
8	45				-760	A53B	24	H	
9	40	From							
10	110		1520			A53B	20	EB	Y restraint
11	120		1520			A53B	20	EB	
12	130	Valve	1520			A53B	20	EB	
13	140		1520			A53B	20	EB	Y restraint
14	340		1520			A53B	20	EB	
15	30	From							
16	210		1520			A53B	20	WB	Y restraint
17	220		1520			A53B	20	WB	
18	230	Valve	1520			A53B	20	WB	
19	240		1520			A53B	20	WB	Y restraint
20	330		1520			A53B	20	WB	
21	310	From	10640						Anchor
22	320		-1520			A53B	24	H	Welding tee
23	330					A53B	24	H	Welding tee
24	335				760	A53B	24	H	
25	320	From							
26	340					A53B	24	H	Welding tee
27	345				-760	A53B	24	H	

Anchors **(See Notes 1 & 2)**

Node	KX/kx (N/mm)	KY/ky (N/mm)	KZ/kz (N/mm)	KXX/kxx (Nm/deg)	KYY/kyy (Nm/deg)	KZZ/kzz (Nm/deg)	Releases X Y Z XXYYZZ	Anchor In Pipe
10	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
310		Rigid	Rigid	Rigid	Rigid	Rigid		GCS

Branch SIFs

Node	Type
20	Welding tee
30	Welding tee
40	Welding tee
320	Welding tee
330	Welding tee
340	Welding tee

Restraints **(See Note 3)**

Node	X	Y	Z
110		Yes	
140		Yes	
210		Yes	
240		Yes	

Valves **(See Note 4)**

From	To	Weight (kg)	Length (mm)	Thick X	Insul Wgt X	Add Wght (Kg)	DX (mm)	DY (mm)	DZ (mm)
120	130	907.18		10.00	3.00				
220	230	907.18		10.00	3.00				

Pipe material A53B: A53 GRADE B **(See Note 5)**

Density = 7833 (kg/m3), Nu = 0.300, Joint factor = 1.00, Type = CS
Yield strength = 241.0 (MPa)

Temp (C)	E (MPa)	Alpha (mm/mm/C)	Allowable (MPa)
-29	205780	11.22E-6	138.0
20	202350	11.50E-6	138.0
50	200670	11.80E-6	138.0
75	199330	11.90E-6	138.0
100	198000	12.10E-6	138.0
125	196500	12.30E-6	138.0
150	195000	12.40E-6	138.0
175	193500	12.60E-6	138.0
200	192000	12.70E-6	138.0
225	190500	12.90E-6	135.0
250	189000	13.00E-6	132.0
275	187000	13.20E-6	129.0
300	185000	13.30E-6	126.0
325	182000	13.40E-6	122.0
350	179000	13.60E-6	118.0

Pipe Sections

Name	Nominal Dia.	Sch	O.D. (mm)	Thk (mm)	Cor.Al (mm)	M.Tol (%)	Ins.Dens (Kg/m3)	Ins.Th (mm)	Lin.Dens (Kg/m3)	Lin.Th (mm)	Soil
24	24"	STD	609.6	9.53	0	12.5					
20	20"	STD	508	9.53	0	12.5					

Notes:

1. **When Translational Stiffnesses KX, KY and KZ are input as "Rigid", CAEPIPE internally sets their value as 1.7513E+11 N/mm.**
2. **When Rotational Stiffnesses KXX, KYY and KZZ are input as "Rigid", CAEPIPE internally sets their value as 1.13E+11 Nm/rad.**
3. **For Restraint, CAEPIPE internally sets the Translational Stiffness value as 1.7513E+11 N/mm.**
4. **By Default CAEPIPE uses Thickness Factor (Thickness X) as 3.0 and Insulation Weight Factor (Insl Wgt X) as 1.75 for Valves. Other programs may use 10.0 and 3.0 respectively. So, it is changed as 10.0 and 3.0 for this Example 3 problem.**
5. **Material properties for ASTM A53 Grade B Seamless Pipe are taken from Table A-1, Table C-1 and Table C-6 of ASME B31.3 (2018).**

   Alpha values are taken from Row A corresponding to "Mean Coefficient of Thermal Expansion" for Group 1 Carbon and Low Alloy Steel going from 20 deg F to the indicated temperature.
6. **Pressure stress option used for Example 1 is NOT stated explicitly, i.e., it is not clear whether the Code Case 209 is using Thin shell formula (PD/4T) or Thick sheel formula [Pd^2/(D^2-d^2)]. From the Sustained Stresses results tabulated in Code Case 209, it is observed that the CAEPIPE Sustained stresses compare well with Code Case 209 results when Pd^2/(D^2-d^2) is chosen in CAEPIPE.**
7. **Nominal section properties are used for Stifnesses, forces, moments and displacements calculations in CAEPIPE.**

8. **Nominal section properties are used for Thermal Expansion Stress (SE) calculations in CAEPIPE.**

9. **Code Case 209 does not explicitly state whether Appendix D or B31J (2017) is used for Flexibility Factor (FF) calculations. So, in CAEPIPE, Appendix D is selected for calculating FFs. The results computed by CAEPIPE compare well with the results reported in Code Case 209.**

10. **Para. S303.1 refers to Appendix D for calculating SIFs. Hence, In CAEPIPE, Appendix D is selected for calculating SIFs for this Example 3.**

11. **As per para. 302.3.5 (d), f = maximum value of stress range factor; 1.2 for ferrous materials with specified minimum tensile strengths ≤ 517 MPa (75 ksi) and at Metal temperatures ≤ 371°C (700°F). This criterion is not implemented in CAEPIPE as the provision for entering the minimum tensile strength in material property is not available at this time. Hence f ≤ 1.0 for all materials including Ferrous materials.**

    In view of the above, f is always <= 1.00 in CAEPIPE at this time.

Table S303.7.1 Case 1 (Expansion T1-T_{ref}): Displacement Stress Range

Node Number	Global Axis Forces and Moments		Eq. (17) Stress (S_E) (MPa) [see Note 1]	Global Forces and Moments @ Node # for Element and Highest Stress at that Node
	FX (Signed) (N)	MY (Signed) (N-m)		
10 Anchor	0	157 065	59.2	CAEPIPE (@10 for Element 10-20)
	0	154 000	58.2	CODE CASE 209
20 tee	0	-157 065	**202.2**	CAEPIPE (@20 for Element 10-20)
	0	-154 000	199	CODE CASE 209
30 tee	-83 650	48 616	**112.9**	CAEPIPE (@30 for Element 20-30)
	-81 600	47 600	110	CODE CASE 209
40 tee	83 650	48 616	**112.9**	CAEPIPE (@40 for Element 20-40)
	81 600	47 600	110	CODE CASE 209
110 Y	83 650	48 616	32.2	CAEPIPE (@110 for Element 40-110)
	81 600	47 600	31.8	CODE CASE 209
120	83 650	48 616	32.2	CAEPIPE (@120 for Element 110-120)
	81 600	47 600	31.8	CODE CASE 209
130 meter	83 650	48 616	32.2	CAEPIPE (@130 for Valve 120-130)
	81 600	47 600	31.8	CODE CASE 209
140 Y	83 650	48 616	32.2	CAEPIPE (@140 for Element 130-140)
	81 600	47 600	31.8	CODE CASE 209
310 Anchor	0	-157 065	59.2	CAEPIPE (@310 for Element 310-320)
	0	-154 000	58.2	CODE CASE 209
320 tee	0	157 065	**202.2**	CAEPIPE (@320 for Element 310-320)
	0	154 000	199	CODE CASE 209
330 tee	-83 650	48 616	**112.9**	CAEPIPE (@330 for Element 240-330)
	-81 600	47 600	110	CODE CASE 209
340 tee	83 650	48 616	**112.9**	CAEPIPE (@340 for Element 140-340)
	81 600	47 600	110	CODE CASE 209
210 Y	-83 650	48 616	32.2	CAEPIPE (@210 for Element 30-210)
	-81 600	47 600	31.8	CODE CASE 209
220	-83 650	48 616	32.2	CAEPIPE (@220 for Element 210-220)
	-81 600	47 600	31.8	CODE CASE 209
230 meter	-83 650	48 616	32.2	CAEPIPE (@230 for Valve 220-230)
	-81 600	47 600	31.8	CODE CASE 209
240 Y	-83 650	48 616	32.2	CAEPIPE (@240 for Element 230-240)
	-81 600	47 600	31.8	CODE CASE 209

Note 1: For Tee elements, Stress reported is the maximum of stresses for the three elements meeting at Tee Intersection Node.

Table S303.7.2 Case 2 (Expansion T2-T_{ref}): Displacement Stress Range

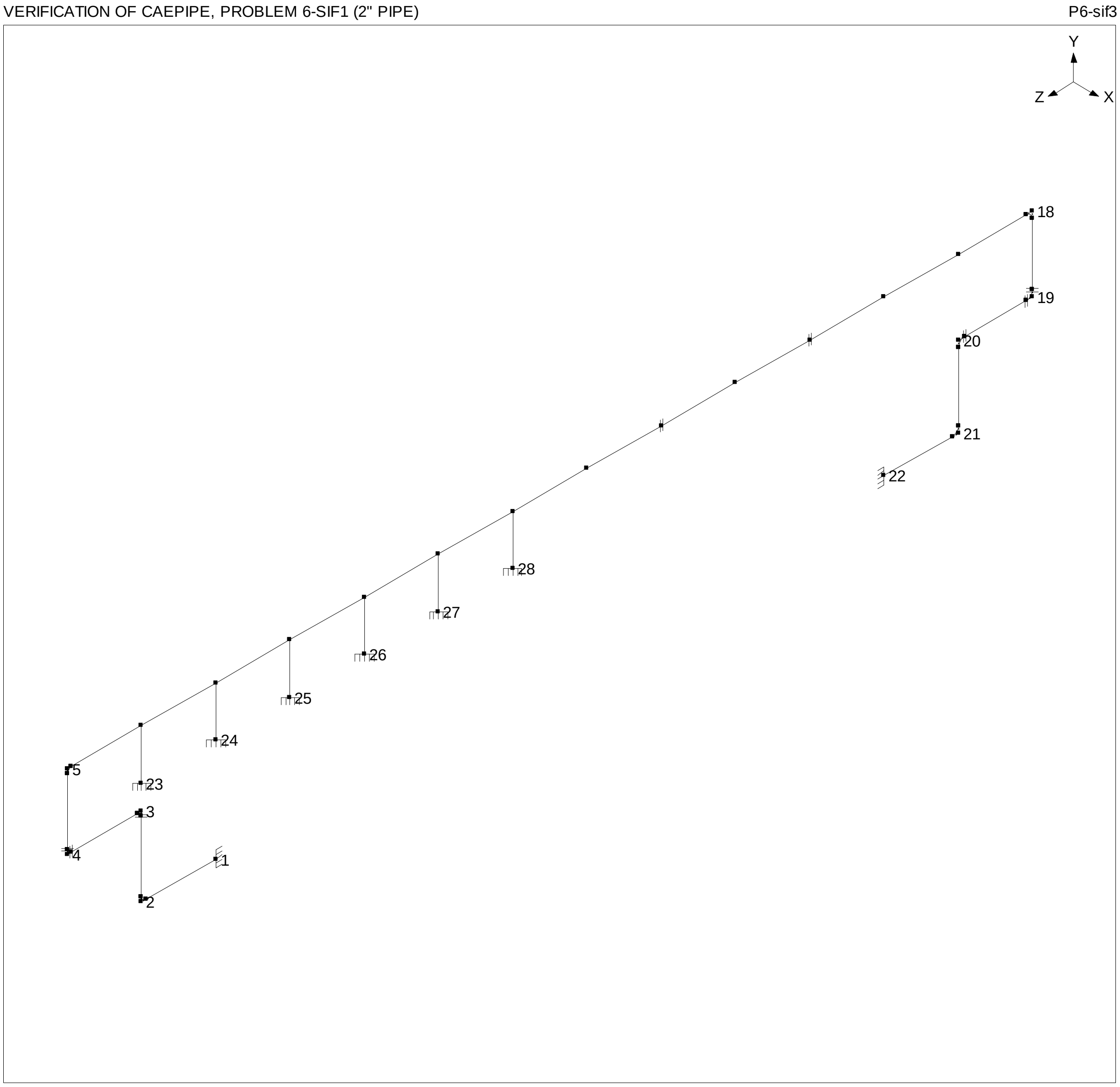
Node Number	Global Axis Forces and Moments		Eq. (17) Stress (S_E) (MPa) [see Note 1]	Global Forces and Moments @ Node # for Element and Highest Stress at that Node
	FX (Signed) (N)	MY (Signed) (N-m)		
10 Anchor	0	-157 065	59.2	CAEPIPE (@10 for Element 10-20)
	0	-154 000	58.2	CODE CASE 209
20 tee	0	157 065	**202.2**	CAEPIPE (@20 for Element 10-20)
	0	154 000	199	CODE CASE 209
30 tee	83 650	-48 616	**112.9**	CAEPIPE (@30 for Element 20-30)
	81 600	-47 600	110	CODE CASE 209
40 tee	-83 650	-48 616	**112.9**	CAEPIPE (@40 for Element 20-40)
	-81 600	-47 600	110	CODE CASE 209
110 Y	-83 650	-48 616	32.2	CAEPIPE (@110 for Element 40-110)
	-81 600	-47 600	31.8	CODE CASE 209
120	-83 650	-48 616	32.2	CAEPIPE (@120 for Element 110-120)
	-81 600	-47 600	31.8	CODE CASE 209
130 meter	-83 650	-48 616	32.2	CAEPIPE (@130 for Valve 120-130)
	-81 600	-47 600	31.8	CODE CASE 209
140 Y	-83 650	-48 616	32.2	CAEPIPE (@140 for Element 130-140)
	-81 600	-47 600	31.8	CODE CASE 209
310 Anchor	0	157 065	59.2	CAEPIPE (@310 for Element 310-320)
	0	154 000	58.2	CODE CASE 209
320 tee	0	-157 065	**202.2**	CAEPIPE (@320 for Element 310-320)
	0	-154 000	199	CODE CASE 209
330 tee	83 650	-48 616	**112.9**	CAEPIPE (@330 for Element 240-330)
	81 600	-47 600	110	CODE CASE 209
340 tee	-83 650	-48 616	**112.9**	CAEPIPE (@340 for Element 140-340)
	-81 600	-47 600	110	CODE CASE 209
210 Y	83 650	-48 616	32.2	CAEPIPE (@210 for Element 30-210)
	81 600	-47 600	31.8	CODE CASE 209
220	83 650	-48 616	32.2	CAEPIPE (@220 for Element 210-220)
	81 600	-47 600	31.8	CODE CASE 209
230 meter	83 650	-48 616	32.2	CAEPIPE (@230 for Valve 220-230)
	81 600	-47 600	31.8	CODE CASE 209
240 Y	83 650	-48 616	32.2	CAEPIPE (@240 for Element 230-240)
	81 600	-47 600	31.8	CODE CASE 209

Note 1: For Tee elements, Stress reported is the maximum of stresses for the three elements meeting at Tee Intersection Node.

Table S303.7.3 Case 3: Moment Reversal - (Expansion T1-T2): Displacement Stress Range

Node Number	Global Axis Forces and Moments		Eq. (17) Stress (S_E) (MPa) [see Note 1]	Global Forces and Moments @ Node # for Element and Highest Stress at that Node
	FX (Unsigned) (N)	MY (Unsigned) (N-m)		
10 Anchor	0	314 130	118.4	CAEPIPE (@10 for Element 10-20)
	0	307 000	118	CODE CASE 209
20 tee	0	314 130	**404.3**	CAEPIPE (@20 for Element 10-20)
	0	307 000	398	CODE CASE 209
30 tee	167 300	97 231	**225.9**	CAEPIPE (@30 for Element 20-30)
	163 000	95 200	221	CODE CASE 209
40 tee	167 300	97 231	**225.9**	CAEPIPE (@40 for Element 20-40)
	163 000	95 200	221	CODE CASE 209
110 Y	167 300	97 231	64.5	CAEPIPE (@110 for Element 40-110)
	163 000	95 200	63.7	CODE CASE 209
120	167 300	97 231	64.5	CAEPIPE (@120 for Element 110-120)
	163 000	95 200	63.7	CODE CASE 209
130 meter	167 300	97 231	64.5	CAEPIPE (@130 for Valve 120-130)
	163 000	95 200	63.7	CODE CASE 209
140 Y	167 300	97 231	64.5	CAEPIPE (@140 for Element 130-140)
	163 000	95 200	63.7	CODE CASE 209
310 Anchor	0	314 130	118.4	CAEPIPE (@310 for Element 310-320)
	0	307 000	118	CODE CASE 209
320 tee	0	314 130	**404.3**	CAEPIPE (@320 for Element 310-320)
	0	307 000	398	CODE CASE 209
330 tee	167 300	97 231	**225.9**	CAEPIPE (@330 for Element 240-330)
	163 000	95 200	221	CODE CASE 209
340 tee	167 300	97 231	**225.9**	CAEPIPE (@340 for Element 140-340)
	163 000	95 200	221	CODE CASE 209
210 Y	167 300	97 231	64.5	CAEPIPE (@210 for Element 30-210)
	163 000	95 200	63.7	CODE CASE 209
220	167 300	97 231	64.5	CAEPIPE (@220 for Element 210-220)
	163 000	95 200	63.7	CODE CASE 209
230 meter	167 300	97 231	64.5	CAEPIPE (@230 for Valve 220-230)
	163 000	95 200	63.7	CODE CASE 209
240 Y	167 300	97 231	64.5	CAEPIPE (@240 for Element 230-240)
	163 000	95 200	63.7	CODE CASE 209

Note 1: For Tee elements, Stress reported is the maximum of stresses for the three elements meeting at Tee Intersection Node.



Problem SUMMARY	
What was compared	Stress Intensification Factors (SIFs)
Load cases analyzed	Not applicable
Filename	P6-SIFx.mod (x = 3, 4)
This problem is split into two sub-problems; P6-SIF3.MOD, P6-SIF4.MOD. Each model has the same geometry but has a variation in pipe size and/or loading conditions (T, P).	

SUB-Problem 3 Pipe Section: 2”	P6-SIF3 (T, P) – (170° F, 1000 PSIG) Pressure Correction ON

Table S304.1 Comparison of Elbow SIFs for ASME B31.3 with manual calculations

Elbow @ Node	ASME B31.3 SIF			
	In-plane		Out-of-plane	
	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc
2	2.22	2.22	1.85	1.85
3	1.76	1.76	1.47	1.47
4	1.40	1.40	1.16	1.16
19	1.21	1.21	1.01	1.01
20	1.43	1.43	1.19	1.19
21	1.68	1.68	1.40	1.40

Table S304.2 Comparison of Nodal SIFs for ASME B31.3 with manual calculations

Node	ASME B31.3 SIF			
	In-plane		Out-of-plane	
	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc
6	1.44	1.44	1.58	1.58
7	1.24	1.24	1.32	1.32
8	2.77	2.77	3.36	3.36
9	2.22	2.22	2.62	2.62
10	1.44	1.44	1.58	1.58
11	1.52	1.52	1.52	1.52

SUB-Problem 4 Pipe Section: 24”	P6-SIF4 (T, P) – (70° F, 1000 PSIG)

OD	Thickness (t)	Pad thickness (t_e)	Crotch radius (r_x)	Mean radius (r_m)
24”	0.375”	0.5”	0.5”	11.8125”

Table S305.1 Comparison of Elbow SIFs for ASME B31.3 with manual calculations

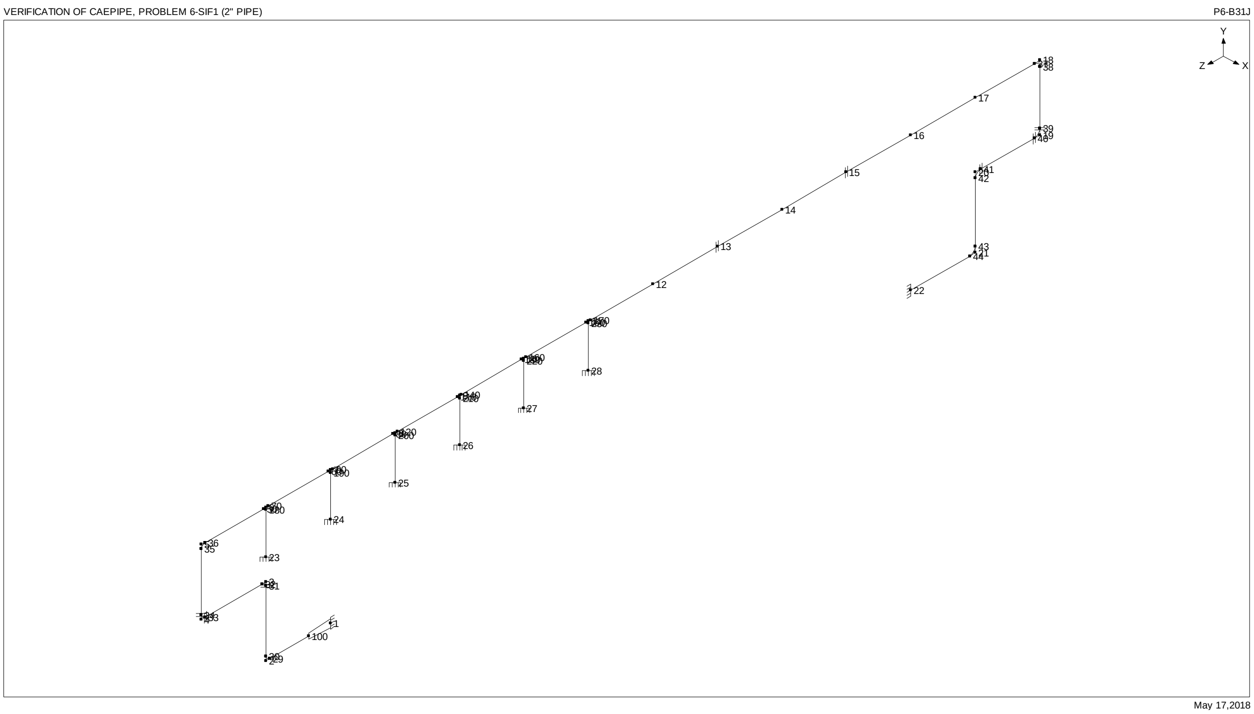
Elbow @ Node	ASME B31.3 SIF			
	In-plane		Out-of-plane	
	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc
2	2.74	2.74	2.29	2.29
3	1.74	1.74	1.45	1.45
4	1.10	1.10	1.00	1.00
19	1.00	1.00	1.00	1.00
20	1.22	1.22	1.02	1.02
21	1.81	1.81	1.51	1.51

Table S305.2 Comparison of Nodal SIFs for ASME B31.3 with manual calculations

	ASME B31.3 SIF			
	In-plane		Out-of-plane	
Node	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc
6	3.42	3.42	4.22	4.22
7	3.12	3.12	3.83	3.83
8	6.98	6.98	8.98	8.98
9	6.80	6.80	8.73	8.73
10	3.42	3.42	4.22	4.22
11	4.05	4.05	4.05	4.05

Refer to P6-B313-2018-SIF.xls available under the folder "SIF" for manual calculations.

ASME B31J (2017) – Stress Intensification Factors (SIFs)



Problem SUMMARY	
What was compared	Stress Intensification Factors (SIFs) for B31J
Load cases analyzed	Not applicable
Filename	P6-B31J.mod

SUB-Problem	P6-B31J
Pipe Section: 2"	(T, P) – (170° F, 1000 PSIG)
	Pressure Correction ON

Table S304.1 Comparison of Elbow SIFs as per ASME B31J with manual calculations

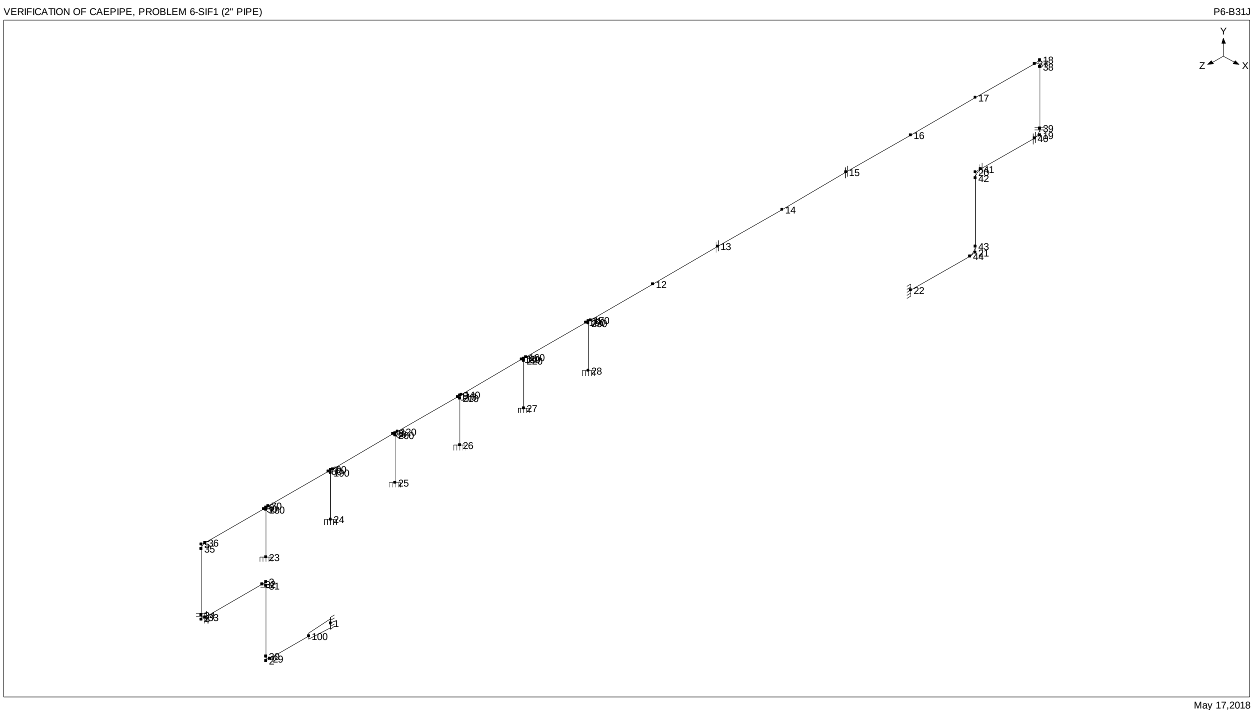
Elbow @ Node	ASME B31J					
	In-plane		Out-of-plane		Torsion	
	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc
2	2.22	2.22	1.85	1.85	1.00	1.00
3	1.76	1.76	1.47	1.47	1.00	1.00
4	1.40	1.40	1.16	1.16	1.00	1.00
19	1.21	1.21	1.01	1.01	1.00	1.00
20	1.43	1.43	1.19	1.19	1.00	1.00
21	1.68	1.68	1.40	1.40	1.00	1.00

Table S304.2 Comparison of Nodal SIFs as per ASME B31J with manual calculations

Node	ASME B31J						Remarks
	In-plane		Out-of-plane		Torsion		
	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc	CAEPIPE	Manual Calc	
6 (Run)	1.96	1.96	1.08	1.08	1.27	1.27	Welding TEE
6 (Branch)	1.23	1.23	1.57	1.57	1.57	1.57	
7 (Run)	1.89	1.89	1.33	1.33	1.00	1.00	Reinforced Fabricated TEE
7 (Branch)	1.14	1.14	1.35	1.35	1.00	1.00	
8 (Run)	2.64	2.64	2.15	2.15	2.98	2.98	Unreinforced Fabricated TEE
8 (Branch)	1.96	1.96	3.51	3.51	2.18	2.18	
9 (Run)	2.26	2.26	1.69	1.69	1.60	1.60	Extruded Outlet
9 (Branch)	1.63	1.63	2.48	2.48	2.07	2.07	
10 (Run)	2.00	2.00	1.28	1.28	1.34	1.34	Sweepolet (Welded-in contour)
10 (Branch)	1.31	1.31	1.79	1.79	1.64	1.64	
11 (Run)	2.34	2.34	2.15	2.15	2.98	2.98	Weldolet (Branch Welded on fittings)
11 (Branch)	1.94	1.94	2.38	2.38	2.18	2.18	
100	1.68	1.68	1.68	1.68	1.00	1.00	Reducer

Refer to P6-B31J-SIF.xls available under the folder "SIF" for manual calculations.

IGEM (2012) – Stress Concentration Factors (SCFs)



Problem SUMMARY	
What was compared	Stress Concentration Factors (SCFs) for IGEM
Load cases analyzed	Sustained, Expansion and Operating
Filename	IGEM_SCF.mod

SUB-Problem Pipe Section: 2”	IGEM_SIF.mod (T, P) – (170° F, 1000 PSIG) Pressure Correction ON

Table IG.1 Comparison of Sustained SCFs for Elbows & Miters as per IGEM with Manual Calculations

Node	SCFs computed	Pressure Ip	Bending Ib	Thrust It	Torsion Iq	Shear Is
Elbow @ 2	CAEPIPE	1.00	3.20	1.00	1.00	1.00
	Manual	1.00	3.20	1.00	1.00	1.00
Elbow @ 3	CAEPIPE	1.00	2.54	1.00	1.00	1.00
	Manual	1.00	2.54	1.00	1.00	1.00
Elbow @ 4	CAEPIPE	1.00	2.02	1.00	1.00	1.00
	Manual	1.00	2.02	1.00	1.00	1.00
Miter @ 18	CAEPIPE	1.00	3.46	1.00	1.00	1.00
	Manual	1.00	3.46	1.00	1.00	1.00
Elbow @ 19	CAEPIPE	1.00	1.75	1.00	1.00	1.00
	Manual	1.00	1.75	1.00	1.00	1.00
Elbow @ 20	CAEPIPE	1.00	2.06	1.00	1.00	1.00
	Manual	1.00	2.06	1.00	1.00	1.00
Elbow @ 21	CAEPIPE	1.00	2.43	1.00	1.00	1.00
	Manual	1.00	2.43	1.00	1.00	1.00

Refer to IGEM-SCF.xls available under the folder “SIF” for manual calculations.

Table IG.2 Comparison of Cyclic SCFs for Elbows & Miters as per IGEM with Manual Calculations

Node	SCFs computed	Pressure Ip	Bending Ib	Thrust It	Torsion Iq	Shear Is
Elbow @ 2	CAEPIPE	2.00	4.80	1.30	1.00	2.00
	Manual	2.00	4.80	1.30	1.00	2.00
Elbow @ 3	CAEPIPE	2.00	3.81	1.30	1.00	2.00
	Manual	2.00	3.81	1.30	1.00	2.00
Elbow @ 4	CAEPIPE	2.00	3.02	1.30	1.00	2.00
	Manual	2.00	3.02	1.30	1.00	2.00
Miter @ 18	CAEPIPE	2.00	3.46	1.30	1.00	2.00
	Manual	2.00	3.46	1.30	1.00	2.00
Elbow @ 19	CAEPIPE	2.00	2.62	1.30	1.00	2.00
	Manual	2.00	2.62	1.30	1.00	2.00
Elbow @ 20	CAEPIPE	2.00	3.09	1.30	1.00	2.00
	Manual	2.00	3.09	1.30	1.00	2.00
Elbow @ 21	CAEPIPE	2.00	3.64	1.30	1.00	2.00
	Manual	2.00	3.64	1.30	1.00	2.00

Refer to IGEM-SCF.xls available under the folder “SIF” for manual calculations.

Table IG.3 Comparison of Nodal Sustained SCFs as per IGEM with manual calculations

Node	Type	SCFs computed	Pressure Ip	Bending Ib	Thrust It	Torsion Iq	Shear Is
Welding Tee @ Node 6	Run 50-6 Run 6-70	CAEPIPE	1.00	1.87	1.00	1.00	1.00
		Manual	1.00	1.87	1.00	1.00	1.00
	Branch 6-180	CAEPIPE	1.00	1.49	1.00	1.00	1.00
		Manual	1.00	1.49	1.00	1.00	1.00
Reinforced Fabricated Tee @ Node 7	Run 60-7 Run 7-90	CAEPIPE	1.00	1.35	1.00	1.00	1.00
		Manual	1.00	1.35	1.00	1.00	1.00
	Branch 7-190	CAEPIPE	1.00	1.35	1.00	1.00	1.00
		Manual	1.00	1.35	1.00	1.00	1.00
Unreinforced Fabricated Tee @ Node 8	Run 80-8 Run 8-120	CAEPIPE	1.00	6.72	1.00	1.00	1.00
		Manual	1.00	6.72	1.00	1.00	1.00
	Branch 8-200	CAEPIPE	1.00	6.72	1.00	1.00	1.00
		Manual	1.00	6.72	1.00	1.00	1.00
Extruded Tee @ Node 9	Run 110-9 Run 9-140	CAEPIPE	1.00	6.16	1.00	1.00	1.00
		Manual	1.00	6.16	1.00	1.00	1.00
	Branch 9-210	CAEPIPE	1.00	6.16	1.00	1.00	1.00
		Manual	1.00	6.16	1.00	1.00	1.00
Sweepolet @ Node 10	Run 130-10 Run 10-160	CAEPIPE	1.00	2.50	1.00	1.00	1.00
		Manual	1.00	2.50	1.00	1.00	1.00
	Branch 10-220	CAEPIPE	1.00	2.50	1.00	1.00	1.00
		Manual	1.00	2.50	1.00	1.00	1.00
Weldolet @ Node 10	Run 150-11 Run 11-170	CAEPIPE	1.00	3.03	1.00	1.00	1.00
		Manual	1.00	3.03	1.00	1.00	1.00
	Branch 11-230	CAEPIPE	1.00	3.03	1.00	1.00	1.00
		Manual	1.00	3.03	1.00	1.00	1.00
Reducer @ Node 100	-	CAEPIPE	2.00	2.00	2.00	2.00	2.00
		Manual	2.00	2.00	2.00	2.00	2.00

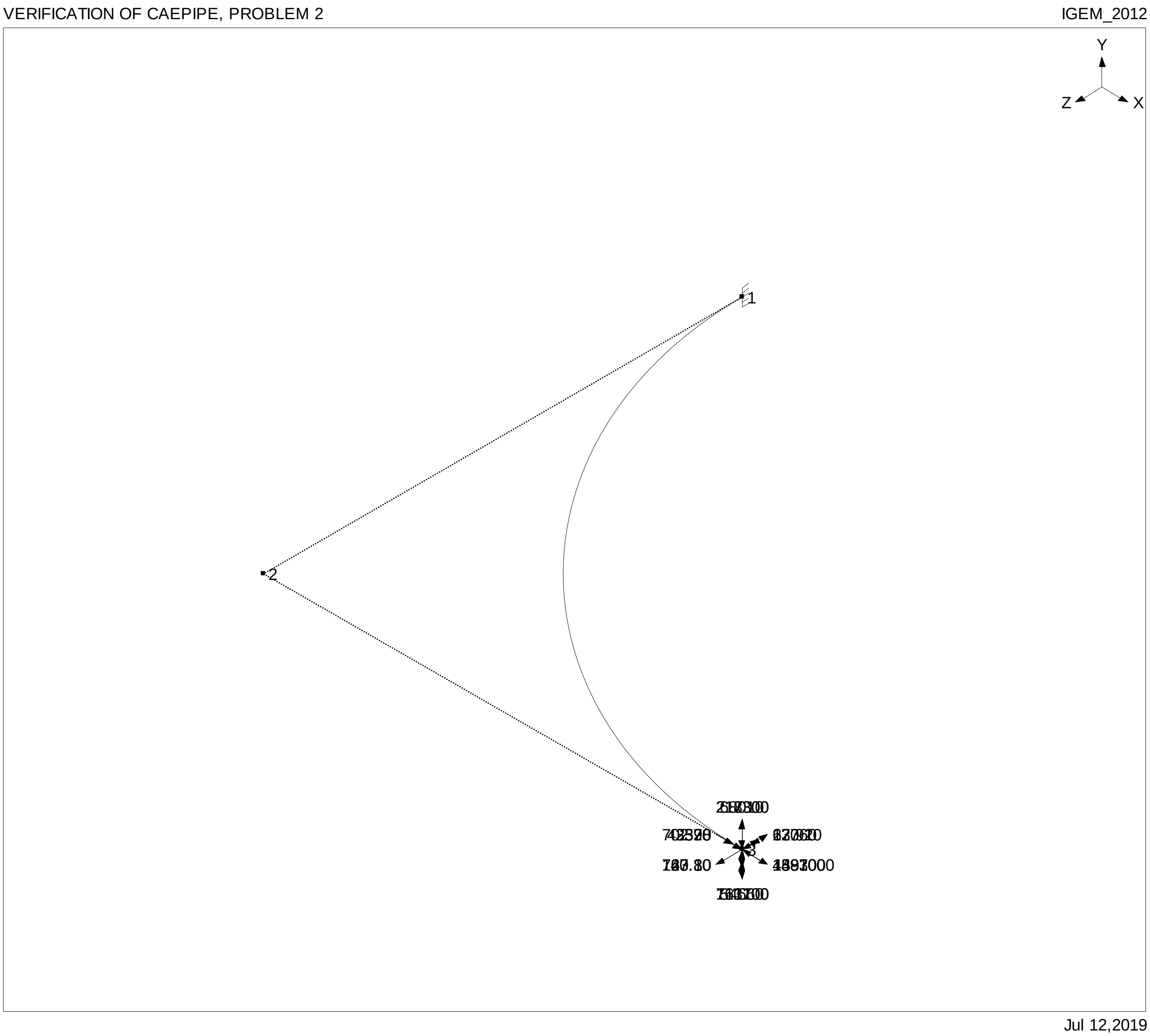
Refer to IGEM-SCF.xls available under the folder "SIF" for manual calculations.

Table IG.4 Comparison of Nodal Cyclic SCFs as per IGEM with manual calculations

Node	Type	SCFs computed	Pressure Ip	Bending Ib	Thrust It	Torsion Iq	Shear Is
Welding Tee @ Node 6	Run 50-6 Run 6-70	CAEPIPE	4.09	2.50	2.83	1.00	2.00
		Manual	4.09	2.50	2.83	1.00	2.00
	Branch 6-180	CAEPIPE	4.09	2.50	5.84	1.00	2.00
		Manual	4.09	2.50	5.83	1.00	2.00
Reinforced Fabricated Tee @ Node 7	Run 60-7 Run 7-90	CAEPIPE	4.09	1.50	2.83	1.00	2.00
		Manual	4.09	1.50	2.83	1.00	2.00
	Branch 7-190	CAEPIPE	4.09	1.50	5.84	1.00	2.00
		Manual	4.09	1.50	5.83	1.00	2.00
Unreinforced Fabricated Tee @ Node 8	Run 80-8 Run 8-120	CAEPIPE	4.09	6.72	2.83	1.00	2.00
		Manual	4.09	6.72	2.83	1.00	2.00
	Branch 8-200	CAEPIPE	4.09	6.72	5.83	1.00	2.00
		Manual	4.09	6.72	5.84	1.00	2.00
Extruded Tee @ Node 9	Run 110-9 Run 9-140	CAEPIPE	4.09	6.16	2.83	1.00	2.00
		Manual	4.09	6.16	2.83	1.00	2.00
	Branch 9-210	CAEPIPE	4.09	6.16	5.84	1.00	2.00
		Manual	4.09	6.16	5.83	1.00	2.00
Sweepolet @ Node 10	Run 130-10 Run 10-160	CAEPIPE	4.09	2.50	2.83	1.00	2.00
		Manual	4.09	2.50	2.83	1.00	2.00
	Branch 10-220	CAEPIPE	4.09	2.50	5.84	1.00	2.00
		Manual	4.09	2.50	5.83	1.00	2.00
Weldolet @ Node 10	Run 150-11 Run 11-170	CAEPIPE	4.09	3.03	2.83	1.00	2.00
		Manual	4.09	3.03	2.83	1.00	2.00
	Branch 11-230	CAEPIPE	4.09	3.03	5.84	1.00	2.00
		Manual	4.09	3.03	5.83	1.00	2.00
Reducer @ Node 100	-	CAEPIPE	1.70	2.71	1.00	1.00	2.00
		Manual	1.70	2.71	1.00	1.00	2.00

Refer to IGEM-SCF.xls available under the folder "SIF" for manual calculations.

IGEM (2012)



Problem SUMMARY	
What was compared	IGEM (2012) Code Compliance results (SL and SE)
Load cases analyzed	Dead weight (DW) and Thermal
Filename	IGEM_2012.mod
Compared against	Appendix 8: Worked Example from IGEM (2012)

APPENDIX 8 : WORKED EXAMPLE

A8.1 INTRODUCTION

This worked example illustrates how the proposed IGE/TD/12 Edition 2 stress equations, SCFs and allowable stresses are used, for example for a bend.

A8.2 ASSESSMENT OF A BEND

A 36" x 45° seam welded bend, analysed as part of a flexibility analysis, is required to be assessed for normal sustained, shakedown and fatigue loading.

The geometry and material properties are as follows:

- pipe outside diameter (D_o) = 914.4 mm
- wall thickness of bend (T) = 13.97 mm
- bend radius (R) =2743.0 mm
- bend angle (alpha) = 45°.

No flanges are present at the ends of the bend.

Pipe material is grade X60 with a SMYS = 413 N/mm^2 UTS = 517 N/mm^2 and Young's Modulus (E) = 210 x 10^3 N/mm^2.

A8.2.1 Calculation of bend SCFs

From Appendix 4, three criteria are specified to determine if pressure-stiffening effects are to be considered. If all the criteria are satisfied, the bending SCF (i_b) can be divided by an empirical factor.

1. No flanges at either end ? – this criterion is satisfied.

2. $R/r_m < 1.7$? – where r_m is the matching pipe mean radius:

   $r_m = (D_o - T) \times 0.5$
   $= 450.2$ mm
   $R/r_m = 2743/450.2$.

3. R x alpha > 2 r_m ? – where alpha is the arc angle of the bend in radians:

   $R \times \alpha = 2743.0 \times (\pi \times 45 / 180) = 2154.0$
   $2 \times r_m = 2 \times 450.2 = 900.4$.

Criterion 2 above is not satisfied, therefore the empirical factor to reduce the bending SCF is not applicable.

For sustained bending loads:

$i_b = 1.3 / h^{2/3}$ where $h = T R / r_m^2 = 13.97 \times 2743 / 450.2^2 = 0.189$

$i_b = 1.3 / 0.189^{2/3}$

$i_b = 3.947$.

For cyclic bending loads:

$i_b = 1.95 / h^{2/3}$

$i_b = 1.95 / 0.189^{2/3}$

$i_b = 5.92$.

Hence, the seam welded pipe bend SCFs can be summarised as follows:

	Pressure i_p	**Bending** i_b	**Thrust** i_t	**Torsion** i_q	**Shear** i_s
Sustained	1.0	3.95	1.0	1.0	1.0
Cyclic	2.0	5.92	1.3	1.0	2.0

Table IG.S1 Sustained SCF from CAEPIPE:

Caepipe : Pipe forces in local coordinates: Sustained (W+P) - [IGEM_2012.res (D:\KPDevelopment\Verifi...

File Results View Options Window Help

#	Node	Axial (N)	y Shear (N)	z Shear (N)	Torsion(Nm) Moment	SCF	Inplane(Nm) Moment	SCF	Outplane(Nm) Moment	SCF	Flex. Factors FFi	FFo	FFt	SCFs Ip	It	Is	SL (MPa)
1	2A	163	139700	54931	173543	1.00	493850	3.95	-163009	3.95	8.73	8.73		1.00	1.00	1.00	491.4
	2B	139700	-163	68010	703	1.00	111100	3.95	-28	3.95	8.73	8.73		1.00	1.00	1.00	300.4

Table IG.S2 Cyclic SCF from CAEPIPE:

Caepipe : Pipe forces in local coordinates: Expansion (T1) - [IGEM_2012.res (D:\KPDevelopment\Verifica...

File Results View Options Window Help

#	Node	Axial (N)	y Shear (N)	z Shear (N)	Torsion(Nm) Moment	SCF	Inplane(Nm) Moment	SCF	Outplane(Nm) Moment	SCF	Flex. Factors FFi	FFo	FFt	SCFs Ip	It	Is	SE (MPa)
1	2A	728	-1591000	-217300	-608115	1.00	-5129818	5.92	639625	5.92	8.73	8.73		2.00	1.30	2.00	4399
	2B	-1591000	-728	-217300	43570	1.00	-763700	5.92	12060	5.92	8.73	8.73		2.00	1.30	2.00	1093

A8.2.2 Sustained loading assessment of bend

The worst case loading for sustained conditions is summarised.

Internal pressure, including an overpressure allowance, P = 90 bar

- axial force, F = 1.397e5 N
- in-plane shear force, V_i = 6.801e4 N
- out-plane shear force, V_o = 163.1 N
- in-plane bending moment, M_i = 1.111e8 N mm
- out-plane bending moment, M_o = 2.792e4 N mm
- torsional moment, M_q = 7.029e5 N mm.

Note that the value of F excludes the axial force generated in the pipe wall by internal pressure.

Now calculate the resultant bending moment, M_b, and resultant shear force, V_T.

$$M_b = \sqrt{M_i^2 + M_o^2} = \sqrt{(1.111e8)^2 + (2.792e4)^2}$$

$$M_b = 1.111e8 \text{ N mm}$$

$$V_T = \sqrt{V_i^2 + V_o^2} = \sqrt{(6.801\ e4)^2 + (163.1)^2}$$

$$= 6.801\ e4 \text{ N}$$

$$S_h = i_p \frac{PD_o}{2T} \pm i_b \frac{32\ M_b\ D_o}{\pi\,[D_o^4 - D_i^4]}$$

$$S_h = 1.0\ \frac{9.0 \times 914.4}{2 \times 13.97} \pm 3.95\ \frac{32 \times 1.111e8 \times 914.4}{\pi\,[914.4^4 - 886.46^4]}$$

$$S_h = 344.6 \text{ N/mm}^2 \text{ or } 244.5 \text{ N/mm}^2$$

$$S_a = i_t \left[\left(\frac{PD_o}{4T} + \frac{4F}{\pi[D_o^2 - D_i^2]}\right) \pm \frac{32\ M_b\ D_o}{\pi\,[D_o^4 - D_i^4]}\right]$$

$$S_a = 1.0 \left[\left(\frac{9.0\text{x}914.4}{4\text{x}13.97} + \frac{4\text{x}1.397e5}{\pi[914.4^2 - 886.46^2]}\right) \pm \frac{32 \times 1.111e8 \times 914.4}{\pi\,[914.4^4 - 886.46^4]}\right]$$

$$S_a = 163.5 \text{ N/mm}^2 \text{ or } 138.1 \text{ N/mm}^2$$

$$S_q = i_q \frac{16 D_o M_q}{\pi[D_o^4 - D_i^4]} + i_s \frac{4 V_T}{\pi[D_o^2 - D_i^2]}$$

$$S_q = 1.0\ \frac{16 \times 914.4 \times 7.029e5}{\pi\,[914.4^4 - 886.46^4]} + 1.0\ \frac{4 \times 6.801e4}{\pi\,[914.4^2 - 886.46^2]}$$

S_q = **1.75 N/mm2**

Now calculate the maximum value of von Mises stress from the above individual stress components using both values of axial stress and hoop stress in turn.

$$S_{VM} = \sqrt{[S_h - S_a]^2 + S_h\, S_a + 3\, S_q^2}$$

$$S_{VM} = \sqrt{[244.5 - 163.5]^2 + 244.5 \times 163.5 + 3 \times 1.75^2} \text{ or}$$

$$S_{VM} = \sqrt{[244.5 - 138.1]^2 + 244.5 \times 138.1 + 3 \times 1.75^2} \text{ or}$$

$$S_{VM} = \sqrt{[344.6 - 163.5]^2 + 344.6 \times 163.5 + 3 \times 1.75^2} \text{ or}$$

$$S_{VM} = \sqrt{[344.6 - 138.1]^2 + 344.6 \times 138.1 + 3 \times 1.75^2}$$

S_{VM} = 298.6 N/mm^2 or 300.4 N/mm^2 or 215.8 N/mm^2 or 212.4 N/mm^2.

The allowable sustained stress is derived from clause 8.5.3 using the design factors for the area type according to Table 2.

Assuming an Area Type "R", the maximum design factor f = 0.67 and the loading is due to normal sustained conditions.

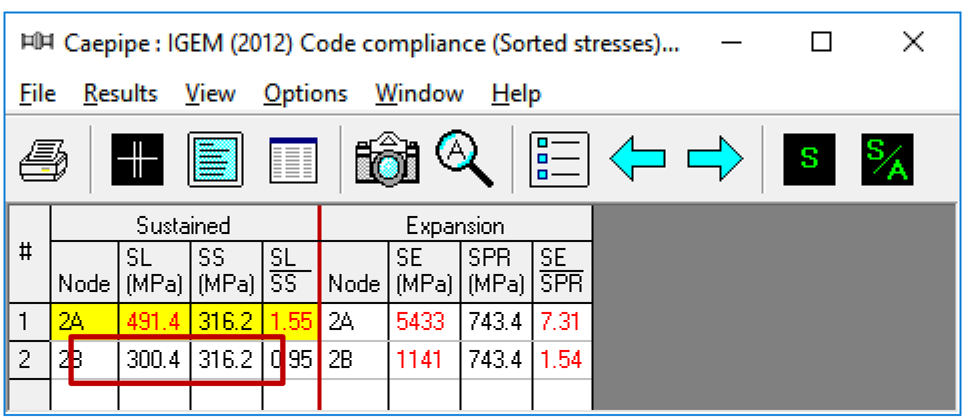
Ratio of SMYS/UTS is 413/517 = 0.80.

Therefore, the maximum permitted normal sustained stress, S_s, is derived as follows:

S_s = 0.34 x (SMYS + UTS) = 0.34 (413 + 517) = 316.2 N/mm^2.

The calculated sustained stress S_{VM} = 300.4 N/mm^2 and is less than the allowable sustained stress of S_s = 316.2 N/mm^2.

Table IG.S3 Sustained Stress from CAEPIPE at Node 2B:



#	Sustained				Expansion			
	Node	SL (MPa)	SS (MPa)	SL / SS	Node	SE (MPa)	SPR (MPa)	SE / SPR
1	2A	491.4	316.2	1.55	2A	5433	743.4	7.31
2	2B	300.4	316.2	0.95	2B	1141	743.4	1.54

A8.2.3 **Shakedown loading assessment of bend**

The two load cases identified for shakedown assessment are summarised below:

	Case 'N'	Case 'M'	Range 'N – M'
Pressure, P (N/mm^2)	9.0	0.0	9.0
Axial Force, F (N)	-1.591e6	4.483e5	-2.039e6
In-Plane Shear Force, V_i (N)	-2.173e5	2.183e5	-4.356e5
Out-Plane Shear Force, V_o (N)	727.8	40.3	687.5
In-Plane Bending Moment, M_i (N mm)	-7.637e8	5.466e7	-8.184e8
Out-Plane Bending Moment, M_o (N mm)	-1.206e7	-6.371e5	-1.142e7
Torsional Moment, M_q (N mm)	4.357e7	2.328e6	4.124e7

$$M_b = \sqrt{(M_{iN} - M_{iM})^2 + (M_{oN} - M_{oM})^2}$$

$$M_b = \sqrt{(-8.184e8)^2 + (-1.142e7)^2}$$

$$M_b = 8.184e8 \text{ N mm.}$$

$$V_T = \sqrt{(V_{iN} - V_{iM})^2 + (V_{oN} - V_{oM})^2}$$

$$V_T = \sqrt{(-4.356e5)^2 + (687.5)^2}$$

$$V_T = 4.356e5 \text{ N.}$$

Now calculate the individual stress components. From A.3.3:

$$S_h = i_p \frac{PD_o}{2T} \pm i_b \frac{32\ M_b\ D_o}{\pi\,[D_o^4 - D_i^4]}$$

$$S_h = 2.0 \frac{9.0 \times 914.4}{2 \times 13.97} \pm 5.92 \frac{32 \times 8.184e8 \times 914.4}{\pi\,[914.4^4 - 886.46^4]}$$

$$S_h = 1142.0 \text{ N/mm}^2 \text{ or } 36.1 \text{ N/mm}^2.$$

$$S_a = i_t \left[\left(\frac{PD_o}{4T} + \frac{4F}{\pi[D_o^2 - D_i^2]}\right) \pm \frac{32\ M_b\ D_o}{\pi\,[D_o^4 - D_i^4]}\right]$$

$$S_a = 1.3 \left[\left(\frac{9.0 \text{x} 914.4}{4 \text{x} 13.97} + \frac{4 \times -2.039e6}{\pi[914.4^2 - 886.46^2]}\right) \pm \frac{32 \times 8.184e8 \times 914.4}{\pi\,[914.4^4 - 886.46^4]}\right]$$

$$S_a = 245.8 \text{ N/mm}^2 \text{ or } 3.0 \text{ N/mm}^2.$$

$$S_q = i_q \frac{16 D_o M_q}{\pi[D_o^4 - D_i^4]} + i_s \frac{4V_T}{\pi[D_o^2 - D_i^2]}$$

$$S_q = 1.0 \frac{16 \times 914.4 \times 4.124e7}{\pi\,[914.4^4 - 886.46^4} + 2.0 \frac{4 \times 4.35e5}{\pi\,[9.14.4^2 - 886.46^2]}$$

$$S_q = 24.4 \text{ N/mm}^2.$$

Now calculate the maximum value of von Mises stress from the above individual stress components using both values of axial stress and hoop stress in turn.

$$S_{VM} = \sqrt{[S_h - S_a]^2 + S_h\ S_a + 3\ S_q^{\ 2}}$$

$$S_{VM} = \sqrt{[36.1 - 245.8]^2 + 36.1 \times 245.8 + 3 \times 24.4^2} \text{ or}$$

$$S_{VM} = \sqrt{[36.1 - 3.0]^2 + 36.1 \times 3.0. + 3 \times 24.4^2} \text{ or}$$

$$S_{VM} = \sqrt{[1142.0 - 245.8]^2 + 1142.0 \times 245.8 + 3 \times 24.4^2} \text{ or}$$

$$S_{VM} = \sqrt{[1142.0 - 3.0]^2 + 1142.0 \times 3.0 + 3 \times 24.4^2}$$

S_{VM} = 1042.0 N/mm^2 or 1141.3 N/mm^2 or 233.7 N/mm^2 or 54.7 N/mm^2.

The allowable shakedown stress range is derived from clause 8.5.5 by using the shakedown factor of 1.8 from Table 4 for carbon steel.

Therefore, the maximum permitted shakedown stress, where S_{YT} = S_Y = 413 N/mm^2 is:

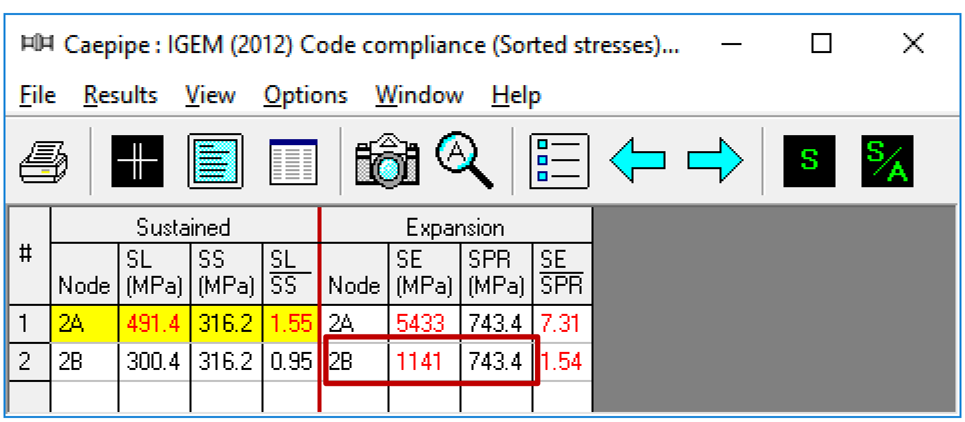
$$S_{PR} = \frac{K_{SD}\ [S_Y + S_{YT}]}{2}$$

$$S_{PR} = \frac{1.8\ [413 + 413]}{2}$$

$$S_{PR} = 743.4 \text{ N/mm}^2$$

The calculated shakedown stress range, S_{VM} = 1141.3 N/mm^2, is greater than the allowable elastic shakedown stress range of S_{PR} = 743.4 N/mm^2.

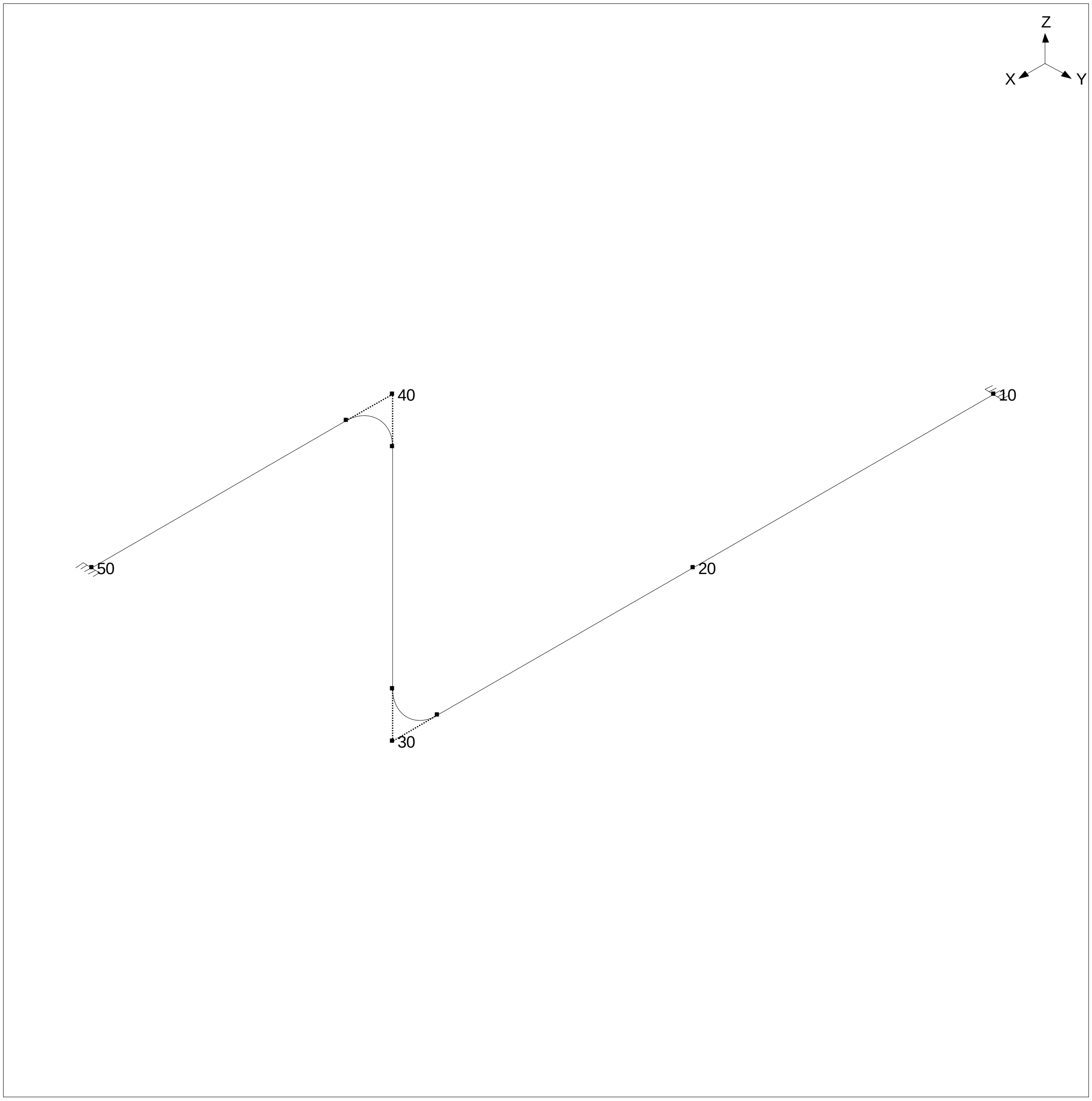
Table IG.S4 Expansion Stress from CAEPIPE at Node 2B:



#	Sustained				Expansion			
	Node	SL (MPa)	SS (MPa)	SL / SS	Node	SE (MPa)	SPR (MPa)	SE / SPR
1	2A	491.4	316.2	1.55	2A	5433	743.4	7.31
2	2B	300.4	316.2	0.95	2B	1141	743.4	1.54

ASME B31.4 (2019)

Verification of Stresses for ASME B31.4 ASME_B314



Dec 8,2017

Problem SUMMARY	
What was compared	B31.4 (2019) Code Compliance results (SL and SE)
Load cases analyzed	Dead weight (DW), Thermal (T1), Seismic & Wind
Filename	ASME_B314.mod
Manual Calculation using Excel	See ASME-B314-2019-Restrained_MaxShear.xls from folder CodeCompliance for details

Options

Piping code = B31.4 (2019)
Include axial force in stress calculations
Do not use B31J for SIFs and Flexibility Factors
Reference temperature = 32 (F)
Number of thermal cycles = 7000
Number of thermal loads = 3
Solve thermal case
Use modulus at reference temperature
Include hanger stiffness
Do not include Bourdon effect
Do not 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
Do not use friction in dynamic analysis
Vertical direction = Z

#	Node	Type	DX(ft'in")	DY(ft'in")	DZ(ft'in")	Mat	Sec	Load	Data
1	Title = Verification of Stresses for ASME B31.4								
2	10	From							Anchor
3	20		3.2808			A16	4IN	L1	
4	30	Bend	3.2808			A16	4IN	L1	
5	40	Bend			3.2808	A16	4IN	LW	
6	50		3.2808			A16	4IN	LW	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
50	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)
30	6	L						
40	6	L						

Coordinates

Node	X (ft'in")	Y (ft'in")	Z (ft'in")
10	0	0	0
20	3.2808	0	0
30A	6.0617	0	0
30	6.5617	0	0
30B	6.5617	0	0'6"
40A	6.5617	0	2.7808

Coordinates

Node	X (ft'in")	Y (ft'in")	Z (ft'in")
40	6.5617	0	3.2808
40B	7.0617	0	3.2808
50	9.8425	0	3.2808

Pipe material A16: A106 Grade C

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

Temp (F)	E (psi)	Alpha (in/in/F)	Yield (psi)
-20	29.5E+6	6.50E-6	40000
70	29.5E+6	6.50E-6	40000
100	29.3E+6	6.50E-6	40000
150	29.1E+6	6.50E-6	40000
200	28.8E+6	6.50E-6	40000
250	28.6E+6	6.50E-6	40000

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)
4IN	4"	5S	4.5	0.083	0	0.0				

Soils

Name	Type	Density (lb/ft3)	Strength (psi)	Delta (deg)	Ks	Ground Level (ft'in")	Include Ins. Thk
S1	Cohesionless	62.428		30	0.30	2.4606	No

Buried Sections

Section	Soil
4IN	S1

Loads

Static seismic load: X = 0.30, Y = 0.30, Z = 0.20 (g's)
Acceleration load combination = Square Root of Sum of Squares

Wind Load 1

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

Elevation (feet)	Velocity (mph)
0	50

10	50

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	DT (F)	DP (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
L1	250	43.5	200	29.0	-186	21.8	250	43.5	0.600		
LW	250	43.5	200	29.0	-186	21.8	250	43.5	0.600		Y

Values shown in Tables below under CAEPIPE are rounded off when displayed on screen.

Table S401.1 Sustained Stress (SL) – Manual Calculation:

Sustained Stress (SL) as per ASME B31.4 (2019)			
Node Number	20		
Max.Pressure (Psi)	43.5	Poission's Ratio	0.3
Outer Diameter (OD) (in)	4.5	Wall Thickness (Thk) (in)	0.083
T1 (Deg F)	250	Fittings	FALSE
Inplane SIF	1.00	Outplane SIF	1.00
Axial force (fx) (lbs)	-2	Torque (in-lb)	0
Inplane Moment (in-lb)	0	Outplane Moment (in-lb)	102
Area of Cross Section (in2)	1.151742424	Section Modulus (in3)	1.248794512
rSH	353.7650602	Fa/A	-1.736499375
M/Z	81.679	Mt/Z	0.000
Hoop (SH)	1179.22		
SLp	433.71	SLn	270.35
Seq1	745.51	Seq2	908.87
SL	908.87		

Table S401.2 Sustained Stress (SL) - CAEPIPE:

Pipe forces in local coordinates: Sustained (W+P)										
Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (in-lb)	Inplane(in-lb)		Outplane(in-lb)		SL (psi)
					Moment	SIF	Moment	SIF	
10 20	-2 -2	0 0	-13 13	0 0	0 0		109 102		915 909
20 30A	-2 -2	0 0	-11 11	0 0	0 0		102 93		909 903
30A 30B	-2 -24	-31 2	0 0	0 0	-93 63	4.12 4.12	0 0	3.43 3.43	1059 1003
30B 40A	-25 -7	0 0	2 2	0 0	0 0		-63 -12		619 593
40A 40B	-7 -2	-2 1	0 0	0 0	-12 -20	4.12 4.12	0 0	3.43 3.43	613 637
40B 50	-2 -2	0 0	-1 21	0 0	0 0		-20 312		604 838

Table S401.3 Sustained + Occasional Stress (SL+SO) due to Wind – Manual Calculation:

Sustained + Occasional Stress (SL+SO) due to Wind as per ASME B31.4 (2019)			
Node Number	20		
Max.Pressure (Psi)	43.5	Peak Pressure Factor	1
Outer Diameter (OD) (in)	4.5	Wall Thickness (Thk) (in)	0.083
T1 (Deg F)	250	Fittings	FALSE
Inplane SIF	1.00	Outplane SIF	1.00
Axial force (fx) (lbs)	2	Torque (in-lb)	0
Inplane Moment (in-lb)	0	Outplane Moment (in-lb)	1
Area of Cross Section (in2)	1.151742424	Section Modulus (in3)	1.248794512
rSH	353.7650602	Fa/A	0
M/Z	82.480	Mt/Z	0.000
Hoop (SH)	1179.22		
SLp	436.24	SLn	271.29
Seq1	742.97	Seq2	907.93
SL+SO	907.93		

Table S401.4 Sustained + Occasional Stress (SL+SO) due to Wind – CAEPIPE:

Pipe forces in local coordinates: Wind									
Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (in-lb)	Inplane(in-lb) Moment	Inplane SIF	Outplane(in-lb) Moment	Outplane SIF	SL+SO (psi)
10 20	2 2	0 0	0 0	0 0	0 0		-1 1		914 908
20 30A	2 2	0 0	0 0	0 0	0 0		1 7		908 906
30A 30B	2 -1	-1 -2	0 0	0 0	-7 9	4.12 4.12	0 0	3.43 3.43	1074 1026
30B 40A	-1 -1	0 0	0 0	0 0	0 0		-9 -8		627 600
40A 40B	0 -2	-2 0	0 0	0 0	-8 4	4.12 4.12	0 0	3.43 3.43	633 649
40B 50	-3 -3	0 0	0 0	0 0	0 0		4 3		609 843

Table S401.5 Sustained + Occasional Stress (SL+SO) due to Seismic – Manual Calculation:

Sustained + Occasional Stress (SL+SO) due to Seismic as per ASME B31.4 (2019)			
Node Number	20		
Max.Pressure (Psi)	43.5	Peak Pressure Factor	1
Outer Diameter (OD) (in)	4.5	Wall Thickness (Thk) (in)	0.083
T1 (Deg F)	250	Fittings	FALSE
Inplane SIF	1.00	Outplane SIF	1.00
Axial force (fx) (lbs)	11	Torque (in-lb)	15
Inplane Moment (in-lb)	26	Outplane Moment (in-lb)	20
Area of Cross Section (in2)	1.151742424	Section Modulus (in3)	1.248794512
rSH	353.7650602	Fa/A	7.814247187
M/Z	107.946	Mt/Z	12.012
Hoop (SH)	1179.22		
SLp	469.53	SLn	253.63
Seq1	710.20	Seq2	925.90
SL+SO	925.90		

Table S401.6 Sustained + Occasional Stress (SL+SO) due to Seismic – CAEPIPE:

Pipe forces in local coordinates: Seismic (g)									
Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (in-lb)	Inplane(in-lb)		Outplane(in-lb)		SL+SO (psi)
					Moment	SIF	Moment	SIF	
10 20	18 11	6 2	3 3	15 15	100 26		22 20		981 927
20 30A	11 4	4 2	2 2	15 15	26 13		20 21		927 919
30A 30B	4 5	6 3	4 3	15 36	21 17	4.12 4.12	13 4	3.43 3.43	1114 1043
30B 40A	5 1	3 3	3 3	36 36	4 2		17 10		655 624
40A 40B	1 4	3 0	3 5	36 18	10 9	4.12 4.12	2 12	3.43 3.43	652 678
40B 50	4 11	5 11	0 4	18 18	12 247		9 62		627 1052

Table S401.7 Displacement Stress (SE) for T1-T3 – Manual Calculation:

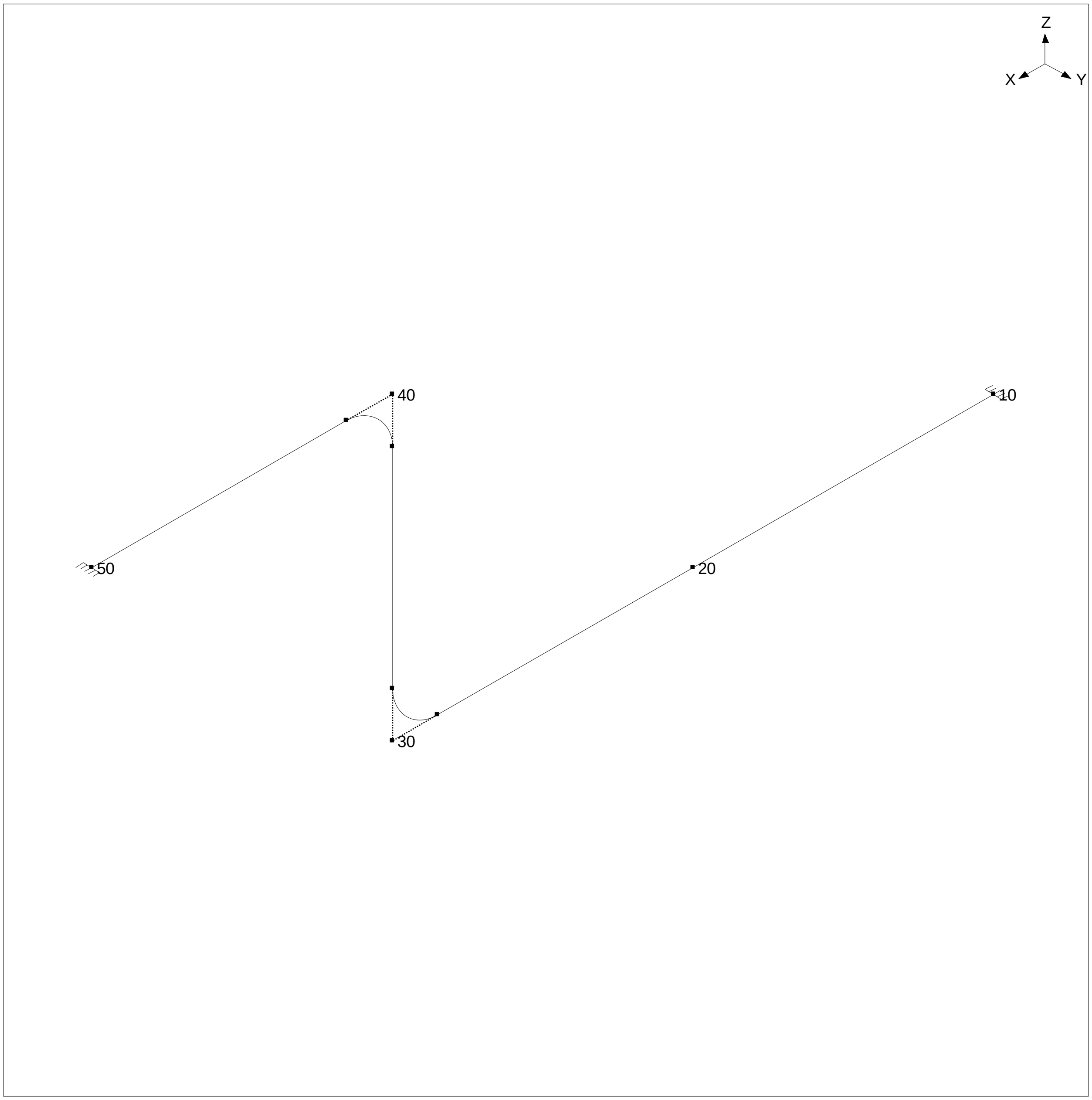
Restrained Stress (Seq) as per ASME B31.4 (2019) based on Max. Shear Stress Theory			
Node Number	20		
Max.Pressure (Psi)	43.5	Peak Pressure Factor	1
Outer Diameter (OD) (in)	4.5	Wall Thickness (Thk) (in)	0.083
T1 (Deg F)	250	Tref (Deg F)	32
T2 (Deg F)	-186	Alpha at T1	6.50E-06
Young's Modulus at Tref	2.95E+07	Alpha at T2	6.50E-06
ExAlphaxDeltaT1	-41801.5	ExAlphaxDeltaT2	41801.5
SE (T1-T2)	-83603		
rSH	353.7650602	Fa/A	7.814
M/Z	107.946	Mt/Z	12.012
SLp	-83133.47	SLn	-83349.37
Hoop (SH)	1179.22		
Seq1	84312.69	Seq2	84528.59
SE	84528.59		

Table S401.8 Displacement Stress (SE) for T1-T3 - CAEPIPE:

Pipe forces in local coordinates: Expansion (T1-T3)									
Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (in-lb)	Inplane(in-lb)		Outplane(in-lb)		SE (psi)
					Moment	SIF	Moment	SIF	
10 20	-850 -850	0 0	68 68	0 0	0 0		-625 2070		84580 84526
20 30A	-792 -792	0 0	-161 -161	0 0	0 0		2070 -3303		84526 84518
30A 30B	-742 -962	-962 742	0 0	0 0	3303 4620	4.12 4.12	0 0	3.43 3.43	84713 84641
30B 40A	-961 -961	0 0	436 436	0 0	0 0		-4620 7311		3700 5854
40A 40B	-954 -580	-580 954	0 0	0 0	7311 5063	4.12 4.12	0 0	3.43 3.43	24120 16703
40B 50	-580 -580	0 0	-954 -954	0 0	0 0		5063 -26779		4054 21444

ASME B31.8 (2018)

Verification of Stresses for ASME B31.8 ASME_B318



Dec 8,2017

Problem SUMMARY	
What was compared	B31.8 (2018) Code Compliance results (SL and SE)
Load cases analyzed	Dead weight (DW), Thermal (T1), Seismic & Wind
Filename	ASME_B318.mod
Manual Calculation using Excel	See ASME-B318-2018-Restrained_MaxShear.xls from folder CodeCompliance for details

```
--------------------------------------------------------------------------------
                                   Options
--------------------------------------------------------------------------------
  Piping code = B31.8 (2018)
  Use liberal allowable stresses
  Include axial force in stress calculations
  Do not use B31J for SIFs and Flexibility Factors
  Design factor F = 0.80
  Reference temperature = 32 (F)
  Number of thermal cycles = 7000
  Number of thermal loads = 3
  Solve thermal case
  Use modulus at reference temperature
  Include hanger stiffness
  Do not include Bourdon effect
  Do not 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
  Do not use friction in dynamic analysis
  Vertical direction = Z
--------------------------------------------------------------------------------
 #  Node  Type   DX(ft'in") DY(ft'in") DZ(ft'in")  Mat   Sec   Load   Data
--------------------------------------------------------------------------------
 1 Title = Verification of Stresses for ASME B31.8
 2    10 From                                                       Anchor
 3    20          3.2808                           A16   4IN   L1
 4    30 Bend     3.2808                           A16   4IN   L1
 5    40 Bend                         3.2808       A16   4IN   LW
 6    50          3.2808                           A16   4IN   LW     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
  50    Rigid    Rigid    Rigid    Rigid    Rigid    Rigid                   GCS
--------------------------------------------------------------------------------
                                    Bends
--------------------------------------------------------------------------------
  Bend   Radius   Thickness  Bend  Flex.   Int.  Angle  Int.  Angle
  Node   (inch)    (inch)    Matl  Factor  Node  (deg)  Node  (deg)
--------------------------------------------------------------------------------
  30     6      L
  40     6      L
--------------------------------------------------------------------------------
                                 Coordinates
--------------------------------------------------------------------------------
  Node     X (ft'in")   Y (ft'in")   Z (ft'in")
--------------------------------------------------------------------------------
  10       0            0            0
  20       3.2808       0            0
  30A      6.0617       0            0
  30       6.5617       0            0
```

Coordinates

Node	X (ft'in")	Y (ft'in")	Z (ft'in")
30B	6.5617	0	0'6"
40A	6.5617	0	2.7808
40	6.5617	0	3.2808
40B	7.0617	0	3.2808
50	9.8425	0	3.2808

Pipe material A16: A106 Grade C

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

Temp (F)	E (psi)	Alpha (in/in/F)	Yield (psi)
-20	29.5E+6	6.50E-6	40000
70	29.5E+6	6.50E-6	40000
100	29.3E+6	6.50E-6	40000
150	29.1E+6	6.50E-6	40000
200	28.8E+6	6.50E-6	40000
250	28.6E+6	6.50E-6	40000

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)
4IN	4"	5S	4.5	0.083	0	0.0				

Soils

Name	Type	Density (lb/ft3)	Strength (psi)	Delta (deg)	Ks	Ground Level (ft'in")	Include Ins. Thk
S1	Cohesionless	62.428		30	0.30	2.4606	No

Buried Sections

Section	Soil
4IN	S1

Loads

Static seismic load: X = 0.30, Y = 0.30, Z = 0.20 (g's)
Acceleration load combination = Square Root of Sum of Squares

Wind Load 1

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

(feet)	(mph)
0	50
10	50

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	DT (F)	DP (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
L1	250	43.5	200	29.0	-186	21.8	250	43.5	0.600		
LW	250	43.5	200	29.0	-186	21.8	250	43.5	0.600		Y

Values shown in Tables below under CAEPIPE are rounded off when displayed on screen.

Table S801.1 Sustained Stress (SL) – Manual Calculation:

Sustained Stress (SL) as per ASME B31.8 (2018)			
Node Number	20		
Max.Pressure (Psi)	43.5	Poission's Ratio	0.3
Outer Diameter (OD) (in)	4.5	Wall Thickness (Thk) (in)	0.083
T1 (Deg F)	250	Fittings	FALSE
Inplane SIF	1.00	Outplane SIF	1.00
Axial force (fx) (lbs)	-2	Torque (in-lb)	0
Inplane Moment (in-lb)	0	Outplane Moment (in-lb)	102
Area of Cross Section (in2)	1.151742424	Section Modulus (in3)	1.248794512
rSH	353.7650602	Fa/A	-1.736499375
M/Z	81.679		
Hoop (SH)	1179.22		
SLp	433.71	SLn	270.35
Seq1	1179.22	Seq2	1179.22
SL	1179		

Table S801.2 Sustained Stress (SL) - CAEPIPE:

Pipe forces in local coordinates: Sustained (W+P)									
Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (in-lb)	Inplane(in-lb) Moment	Inplane SIF	Outplane(in-lb) Moment	Outplane SIF	SL (psi)
10 20	-2 -2	0 0	-13 13	0 0	0 0		109 102		1179 1179
20 30A	-2 -2	0 0	-11 11	0 0	0 0		102 93		1179 1179
30A 30B	-2 -24	-31 2	0 0	0 0	-93 63	4.12 4.12	0 0	3.43 3.43	1179 1179
30B 40A	-25 -7	0 0	2 2	0 0	0 0		-63 -12		619 593
40A 40B	-7 -2	-2 1	0 0	0 0	-12 -20	4.12 4.12	0 0	3.43 3.43	593 604
40B 50	-2 -2	0 0	-1 21	0 0	0 0		-20 312		604 838

Table S801.3 Sustained + Occasional Stress (SL+SO) due to Wind – Manual Calculation:

Sustained + Occasional Stress (SL+SO) due to Wind as per ASME B31.8 (2018)			
Node Number	20		
Max.Pressure (Psi)	43.5	Peak Pressure Factor	1
Outer Diameter (OD) (in)	4.5	Wall Thickness (Thk) (in)	0.083
T1 (Deg F)	250	Fittings	FALSE
Inplane SIF	1.00	Outplane SIF	1.00
Axial force (fx) (lbs)	2	Torque (in-lb)	0
Inplane Moment (in-lb)	0	Outplane Moment (in-lb)	1
Area of Cross Section (in2)	1.151742424	Section Modulus (in3)	1.248794512
rSH	353.7650602	Fa/A	0
M/Z	82.480		
Hoop (SH)	1179.22		
SLp	436.24	SLn	271.29
Seq1	1179.22	Seq2	1179.22
SL + SO	1179		

Table S801.4 Sustained + Occasional Stress (SL+SO) due to Wind – CAEPIPE:

Pipe forces in local coordinates: Wind									
Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (in-lb)	Inplane(in-lb) Moment	Inplane(in-lb) SIF	Outplane(in-lb) Moment	Outplane(in-lb) SIF	SL+SO (psi)
10 20	2 2	0 0	0 0	0 0	0 0		-1 1		1179 1179
20 30A	2 2	0 0	0 0	0 0	0 0		1 7		1179 1179
30A 30B	2 -1	-1 -2	0 0	0 0	-7 9	4.12 4.12	0 0	3.43 3.43	1179 1179
30B 40A	-1 -1	0 0	0 0	0 0	0 0		-9 -8		627 600
40A 40B	0 -2	-2 0	0 0	0 0	-8 4	4.12 4.12	0 0	3.43 3.43	600 609
40B 50	-3 -3	0 0	0 0	0 0	0 0		4 3		609 843

Table S401.5 Sustained + Occasional Stress (SL+SO) due to Seismic – Manual Calculation:

Sustained + Occasional Stress (SL+SO) due to Seismic as per ASME B31.8 (2018)			
Node Number	20		
Max.Pressure (Psi)	43.5	Peak Pressure Factor	1
Outer Diameter (OD) (in)	4.5	Wall Thickness (Thk) (in)	0.083
T1 (Deg F)	250	Fittings	FALSE
Inplane SIF	1.00	Outplane SIF	1.00
Axial force (fx) (lbs)	11	Torque (in-lb)	15
Inplane Moment (in-lb)	26	Outplane Moment (in-lb)	20
Area of Cross Section (in2)	1.151742424	Section Modulus (in3)	1.248794512
rSH	353.7650602	Fa/A	7.814247187
M/Z	110.562		
Hoop (SH)	1179.22		
SLp	472.14	SLn	251.02
Seq1	1179.22	Seq2	1179.22
SL + SO	1179		

Table S401.6 Sustained + Occasional Stress (SL+SO) due to Seismic – CAEPIPE:

Pipe forces in local coordinates: Seismic (g)									
Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (in-lb)	Inplane(in-lb) Moment	Inplane SIF	Outplane(in-lb) Moment	Outplane SIF	SL+SO (psi)
10 20	18 11	6 2	3 3	15 15	100 26		22 20		1179 1179
20 30A	11 4	4 2	2 2	15 15	26 13		20 21		1179 1179
30A 30B	4 5	6 3	4 3	15 36	21 17	4.12 4.12	13 4	3.43 3.43	1179 1179
30B 40A	5 1	3 3	3 3	36 36	4 2		17 10		655 624
40A 40B	1 4	3 0	3 5	36 18	10 9	4.12 4.12	2 12	3.43 3.43	624 627
40B 50	4 11	5 11	0 4	18 18	12 247		9 62		627 1052

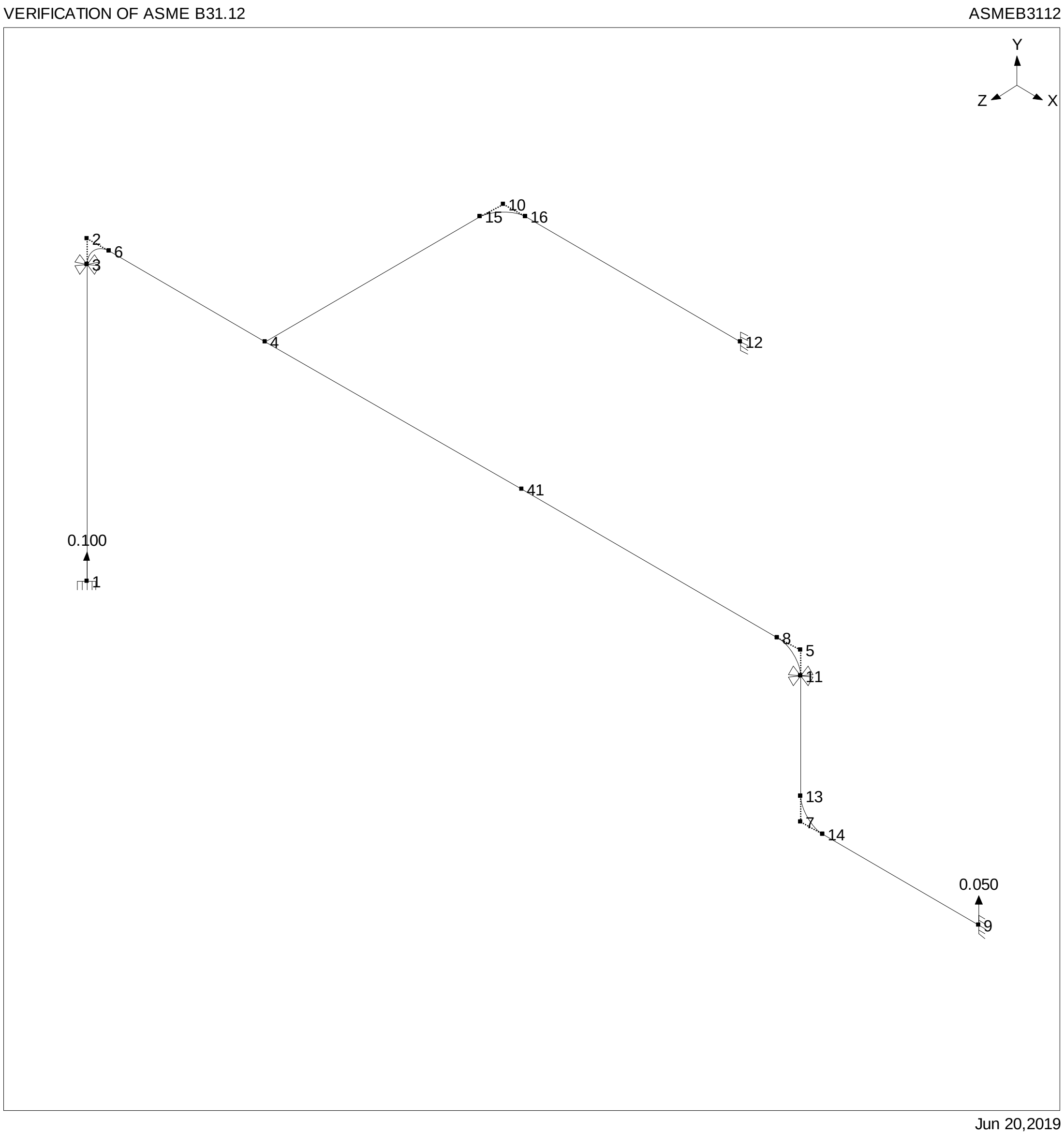
Table S401.7 Displacement Stress (SE) for T1-T3 – Manual Calculation:

Restrained Stress (Seq) as per ASME B31.8 (2018) based on Max. Shear Stress Theory			
Node Number	20		
Max.Pressure (Psi)	43.5	Peak Pressure Factor	1
Outer Diameter (OD) (in)	4.5	Wall Thickness (Thk) (in)	0.083
T1 (Deg F)	250	Tref (Deg F)	32
T2 (Deg F)	-186	Alpha at T1	6.50E-06
Young's Modulus at Tref	2.95E+07	Alpha at T2	6.50E-06
ExAlphaxDeltaT1	-41801.5	ExAlphaxDeltaT2	41801.5
SE (T1-T2)	-83603		
rSH	353.7650602	Fa/A	7.814
M/Z	110.562		
SLp	-83130.86	SLn	-83351.98
Hoop (SH)	1179.22		
Seq1	84310.08	Seq2	84531.20
SE	84531		

Table S401.8 Displacement Stress (SE) for T1-T3 - CAEPIPE:

Pipe forces in local coordinates: Expansion (T1-T3)									
Node	Axial (lb)	y Shear (lb)	z Shear (lb)	Torque (in-lb)	Inplane(in-lb)		Outplane(in-lb)		SE (psi)
					Moment	SIF	Moment	SIF	
10 20	-850 -850	0 0	68 68	0 0	0 0		-625 2070		84240 84528
20 30A	-792 -792	0 0	-161 -161	0 0	0 0		2070 -3303		84306 84521
30A 30B	-742 -962	-962 742	0 0	0 0	3303 4620	4.12 4.12	0 0	3.43 3.43	84325 84524
30B 40A	-961 -961	0 0	436 436	0 0	0 0		-4620 7311		3700 5854
40A 40B	-954 -580	-580 954	0 0	0 0	7311 5063	4.12 4.12	0 0	3.43 3.43	24120 16703
40B 50	-580 -580	0 0	-954 -954	0 0	0 0		5063 -26779		4054 21444

ASME B31.12 (2019)



Problem SUMMARY	
What was compared	ASME B31.12 Code Compliance results (SL and SE)
Load cases analyzed	Dead weight (DW), Thermal (T1)
Filename	P2.mod
This problem uses piping code ASME B31.12 with loading conditions (T, P): (180°F, 100 PSIG). This problem contains Specified Y displacements for the Thermal load case (T1).	

Values shown in Tables below under CAEPIPE for SL and SE respectively are rounded off when displayed on screen.

```
--------------------------------------------------------------------------------
                                   Options
--------------------------------------------------------------------------------
  Piping code = B31.12 (2019)
  Do not use liberal allowable stresses
  Include axial force in stress calculations
  Do not use B31J for SIFs and Flexibility Factors
  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
  Do not use pressure correction for bends
  Pressure stress = Pd^2 / (D^2 - d^2)
  Peak pressure factor = 1.00
  Cut off frequency = 33 Hz
  Number of modes = 6
  Include missing mass correction
  Do not 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 ASME B31.12
 2     1 From                                                         Anchor
 3     3                  4'7-1/2"             1     1     1      XZ restraint
 4     2 Bend             0'4-1/2"             1     1     1
 5     6         0'4-1/2"                      1     1     1
 6     4         2'7-1/2"                      1     1     1      Welding tee
 7    41         4.3130                        1     1     1
 8     8         4.3120                        1     1     1
 9     5 Bend    0'4-1/2"                      1     1     1
10    11                  -0'4-1/2"            1     1     1      XZ restraint
11    13                  -1'9"                1     1     1
12     7 Bend             -0'4-1/2"            1     1     1
13    14         0'4-1/2"                      1     1     1
14     9         2'7-1/2"                      1     1     1      Anchor
15     4 From
16    15                             -3'7-1/2" 1     2     1
17    10 Bend                        -0'4-1/2" 1     2     1
18    16         0'4-1/2"                      1     2     1
19    12         3'7-1/2"                      1     2     1      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
--------------------------------------------------------------------------------
  1     Rigid    Rigid    Rigid    Rigid    Rigid    Rigid                 GCS
  9     Rigid    Rigid    Rigid    Rigid    Rigid    Rigid                 GCS
  12    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)
2	4.5	U						
5	4.5	U						
7	4.5	U						
10	4.5	U						

Branch SIFs

Node	Type
4	Welding tee

Restraints

Node	X	Y	Z
3	Yes		Yes
11	Yes		Yes

Specified Displacements

Node	Type	Load	X(inch)	Y(inch)	Z(inch)	XX(deg)	YY(deg)	ZZ(deg)	Disp. in
1	Anchor	T1		0.100					GCS
9	Anchor	T1		0.050					GCS

Pipe material 1: Steel-Thermal loading case

Density = 0.403 (lb/in3), Nu = 0.300, Joint factor = 1.00, Type = CS
Yield strength = 30000 (psi)

Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
180	30.0E+6	9.61E-6	15000

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)	Soil
1	3"	STD	3.5	0.216	0	0.0					
2	Non Std		3.49	0.216	0	0.0					

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	DT (F)	DP (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
1	180	100					180	100			Y

Table S1201-1 Comparison of Sustained Stress (SL) [ASME B31.12] with Manual calculations using MS-Excel

Node	CAEPIPE SL (psi)	Excel Calculated SL (psi)
2A	525	526
2B	1031	1033
4 (Element 6 – 4)	899	900
41 (Element 41 – 8)	731	730
10A	559	558
10B	692	690

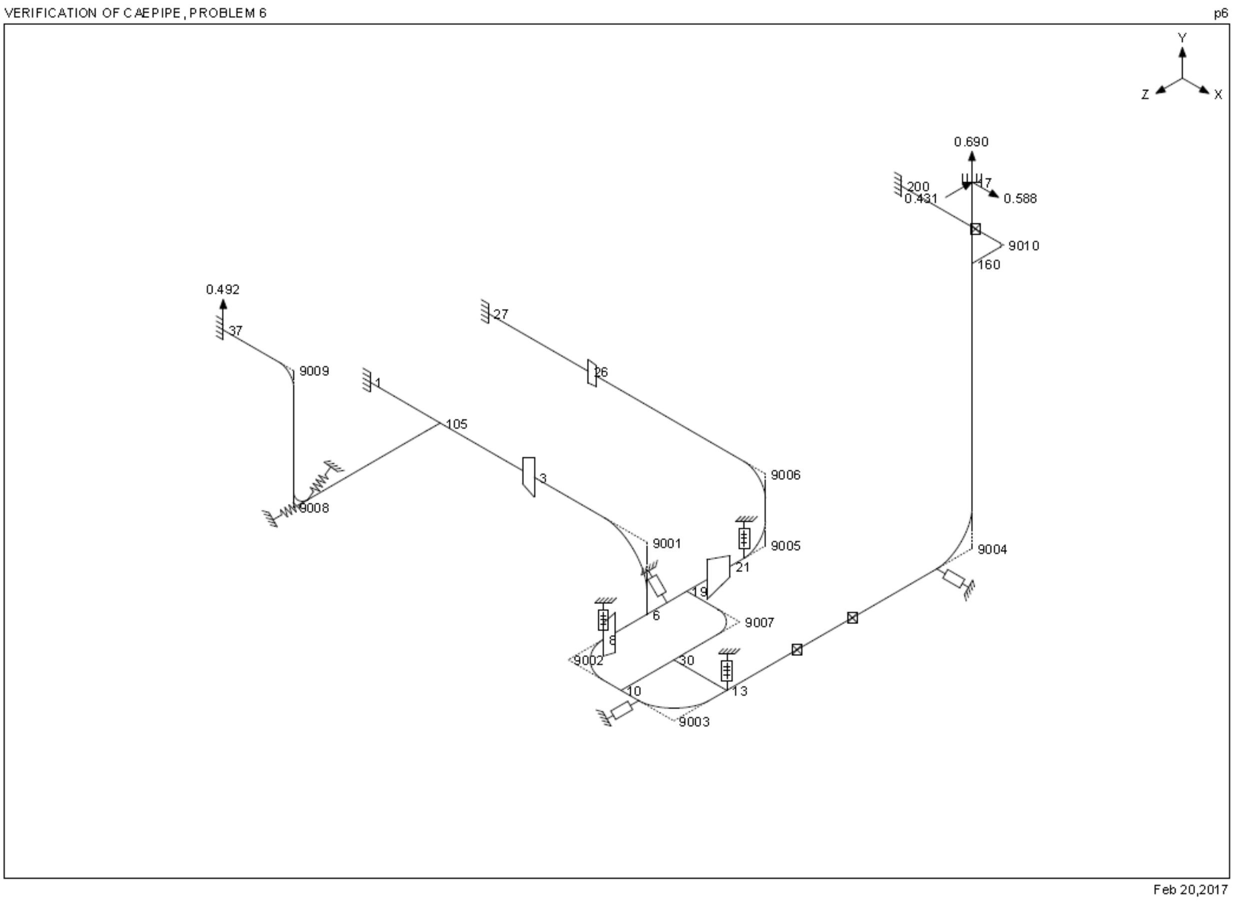
Table S1201-2 Comparison of Thermal Expansion Stress (SE), [ASME B31.12] with Manual calculations using MS-Excel

Node	CAEPIPE SE (psi)	Excel Calculated SE (psi)
2A	57118	57118
2B	33374	33374
4 (Element 6 – 4)	28165	28167
41 (Element 41 – 8)	15501	15501
10A	7994	7995
10B	7478	7480

Values from CAEPIPE and Manual calculations differ slightly and are therefore acceptable.

See Excel files ASME-B3112-2019-SL.xlsx and ASME-B3112-2019-SE.xlsx from the folder “CodeComplaince” for manual calculations.

ASME Section III Subsection NC - Class 2 (2015)



Problem SUMMARY	
What was compared	B1 and B2 Indices, Stress Intensification Factors (SIFs) and Stresses for ASME Section III Subsection NC – Class 2 (2015)
Load cases analyzed	Not applicable
Filename	P6.mod

This problem compares the manually calculated B1 Indices, B2 Indices, SIFs and Stresses to those obtained from CAEPIPE. The manual calculations for B1 & B2 Indices and SIFs are given in Excel files as listed below.

Node Numbers	Description
9001, 9002, 9005, 9008 & 9010	Welding elbow
1,2,3,4 & 1001	Girth Buttweld
13,19,105 & 160	Reinforced Fabricated Tee
6,10 & 30	Welding Tee
1305, 1306, 32 & 1005	Tapered Transition
3, 8, 21 & 26	Reducer

Table S320.1 Comparison of Nodal B1, B2 and SIFs for ASME Section III Subsection NC – Class 2 (2015) with manual calculations using MS-Excel

Element / Node	Type	Results from CAEPIPE			Values from Manual Calculation		
		B1	B2	SIF	B1	B2	SIF
9001A 9001B	Welding elbow	0.00 0.00	4.05 4.05	2.80 2.80	0.00 0.00	4.05 4.05	2.80 2.80
9002A 9002B	Welding elbow	0.00 0.00	3.95 3.95	2.73 2.73	0.00 0.00	3.95 3.95	2.73 2.73
9005A 9005B	Welding elbow	0.00 0.00	3.91 3.91	2.71 2.71	0.00 0.00	3.91 3.91	2.71 2.71
9008A 9008B	Welding elbow	0.02 0.02	2.98 2.98	2.06 2.06	0.02 0.02	2.98 2.98	2.06 2.06
9010A 9010B	Welding elbow	0.50 0.50	1.00 1.00	1.00 1.00	0.50 0.50	1.00 1.00	1.00 1.00
1,2,3,4 & 1001	Butt Weld	0.50	1.00	1.00	0.50	1.00	1.00
Run 9003B –13	Reinforced fabricated tee @ Node 13	0.50	4.34	5.79	0.50	4.34	5.79
Run 18 –19	Reinforced fabricated tee @ Node 19	0.50	2.66	3.54	0.50	2.66	3.54
Run 1 – 105	Reinforced fabricated tee @ Node 105	0.50	2.13	2.85	0.50	2.13	2.85
Run 16 – 160	Reinforced fabricated tee @ Node 160	0.50	2.42	3.23	0.50	2.42	3.23
1305	Tapered Transition	0.50	1.00	1.42	0.50	1.00	1.42
32	Tapered Transition	0.50	1.00	1.40	0.50	1.00	1.40
1005	Tapered Transition	0.50	1.00	1.34	0.50	1.00	1.34
2003 - 3 @ 3	Reducer	1.00	1.00	2.00	1.00	1.00	2.00
7008 – 8 @ 8	Reducer	1.00	1.00	2.00	1.00	1.00	2.00
20 – 21 @ 21	Reducer	1.00	1.00	2.00	1.00	1.00	2.00
2526 – 26 @ 26	Reducer	1.00	1.00	2.00	1.00	1.00	2.00

Refer to P6-ASME-Class2-2015-B1-B2-SIF.xlsx available under the folder “SIF” for manual calculations.

Table S320.2 Comparison of Sustained (SL) and Sustained + Occasional Stresses for ASME Section III Subsection NC – Class 2 (2015) with MS-Excel calculations

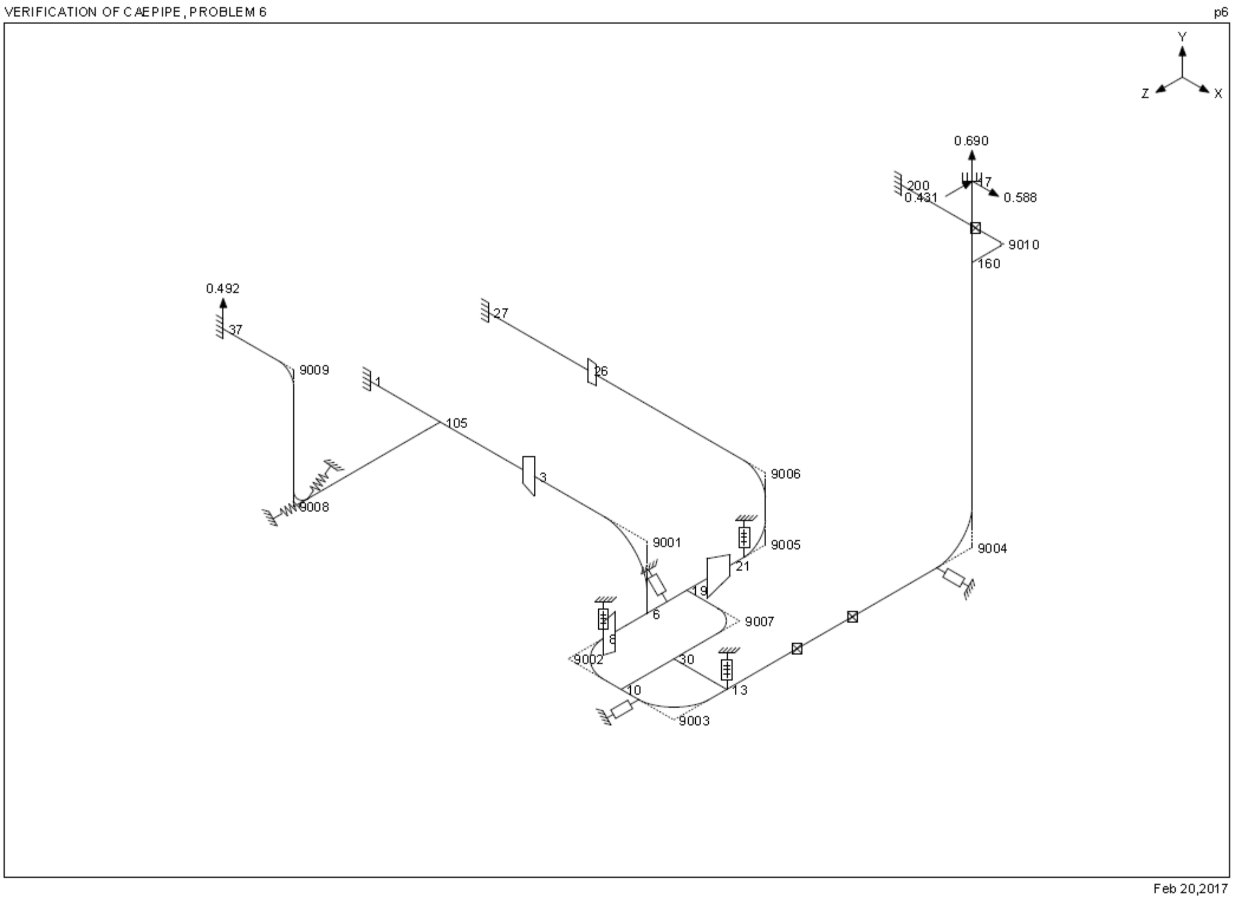
Element From To	Sustained(8)		Sustained (8) Excel Calculated		Occasional (9)		Occasional (9) Excel Calculated	
	SL	1.5SH	SL	1.5SH	SL+SO	1.8SH	SL+SO	1.8SH
	(psi)	(psi)			(psi)	(psi)	(psi)	(psi)
105	4942	25410			5426	30492		
2	4964	25410	4964	25410	5399	30492	5399	30492
9001A	391	25410	391	25410	1367	30492	1367	30492
9001B	529	25410			932	30492		
7008	9626	25410			9753	30492		
8	9254	25410	9254	25410	9430	30492	9430	30492
9002A	252	25410	252	25410	944	30492	944	30492
9002B	458	25410				30492		
9002B	4711	25410			4868	30492		
10	4970	25410	4970	25410	5433	30492	5433	30492
9003B	4846	25410			4969	30492		
13	6126	25410	6126	25410	6680	30492	6680	30492
1305	1998	25410	1998	25410	2117	30492	2117	30492
1306	2090	25410			2198	30492		

Table S320.3 Comparison of Expansion (10) and Expansion (11) Stresses for ASME Section III Subsection NC – Class 2 (2015) with MS-Excel calculations

Element From To	Expansion (10)		Expansion (10) Excel Calculated		Expansion (11)		Expansion (11) Excel Calculated	
	SE	SA	SE	SA	SL+SE	SH+SA	SL+SE	SH+SA
	(psi)	(psi)			(psi)	(psi)	(psi)	(psi)
2003	4504	29235			9804	46175		
3	1478	29235	1478	29235	6544	46175	6544	46175
9005A	2922	29235			7753	46175		
9005B	2137	29235	2137	29235	6599	46175	6599	46175
3	739	29235			5703	46175		
4	1098	29235	1098	29235	5955	46175	5955	46175
18	951	29235			6011	46175		
19	2374	29235	2375	29235	7845	46175	7845	46175
30	11875	29235	11875	29235	16604	46175	16604	46175
31	3654	29235			8197	46175		
20	550	29235			5553	46175		
21	2565	29235	2565	29235	7201	46175	7201	46175

Refer to P6-ASME-Class2-2015.xls available under the folder "CodeComplaince" for manual calculations.

ASME Section III Subsection NC - Class 2 (2017)



Problem SUMMARY	
What was compared	B1 and B2 Indices, Stress Intensification Factors (SIFs) and Stresses for ASME Section III Subsection NC – Class 2 (2017)
Load cases analyzed	Not applicable
Filename	p6-ASME-NC-2017.mod

This problem compares the manually calculated B1 Indices, B2 Indices, SIFs and Stresses to those obtained from CAEPIPE. The manual calculations for B1 & B2 Indices and SIFs are given in Excel files as listed below.

Node Numbers	**Description**
9001, 9002, 9005, 9008 & 9010	Welding elbow
1,2,3,4 & 1001	Girth Buttweld
13,19,105 & 160	Reinforced Fabricated Tee
6,10 & 30	Welding Tee
1305, 1306, 32 & 1005	Tapered Transition
3, 8, 21 & 26	Reducer

Table NC-17.320.1 Comparison of Nodal B1, B2 and SIFs for ASME Section III Subsection NC – Class 2 (2017) with manual calculations performed using MS-Excel

Element / Node	Type	Results from CAEPIPE			Values from Manual Calculation		
		B1	B2	SIF	B1	B2	SIF
9001A 9001B	Welding elbow	0.00 0.00	4.05 4.05	2.80 2.80	0.00 0.00	4.05 4.05	2.80 2.80
9002A 9002B	Welding elbow	0.00 0.00	3.95 3.95	2.73 2.73	0.00 0.00	3.95 3.95	2.73 2.73
9005A 9005B	Welding elbow	0.00 0.00	3.91 3.91	2.71 2.71	0.00 0.00	3.91 3.91	2.71 2.71
9008A 9008B	Welding elbow	0.02 0.02	2.98 2.98	2.06 2.06	0.02 0.02	2.98 2.98	2.06 2.06
9010A 9010B	Welding elbow	0.50 0.50	1.00 1.00	1.00 1.00	0.50 0.50	1.00 1.00	1.00 1.00
1,2,3,4 & 1001	Butt Weld	0.50	1.00	1.00	0.50	1.00	1.00
Run 9003B –13	Reinforced fabricated tee @ Node 13	0.50	4.34	5.79	0.50	4.34	5.79
Run 18 –19	Reinforced fabricated tee @ Node 19	0.50	2.66	3.54	0.50	2.66	3.54
Run 1 – 105	Reinforced fabricated tee @ Node 105	0.50	2.13	2.85	0.50	2.13	2.85
Run 16 – 160	Reinforced fabricated tee @ Node 160	0.50	2.42	3.23	0.50	2.42	3.23
1305	Tapered Transition	0.50	1.00	1.42	0.50	1.00	1.42
32	Tapered Transition	0.50	1.00	1.40	0.50	1.00	1.40
1005	Tapered Transition	0.50	1.00	1.34	0.50	1.00	1.34
2003 - 3 @ 3	Reducer	1.00	1.00	2.00	1.00	1.00	2.00
7008 – 8 @ 8	Reducer	1.00	1.00	2.00	1.00	1.00	2.00
20 – 21 @ 21	Reducer	1.00	1.00	2.00	1.00	1.00	2.00
2526 – 26 @ 26	Reducer	1.00	1.00	2.00	1.00	1.00	2.00

Refer to P6-ASME-Class2-2017-B1-B2-SIF.xlsx available under the folder “SIF” for manual calculations.

Table NC-17.320.2 Comparison of Sustained (SL) and Sustained + Occasional Stresses for ASME Section III Subsection NC – Class 2 (2017) with MS-Excel calculations

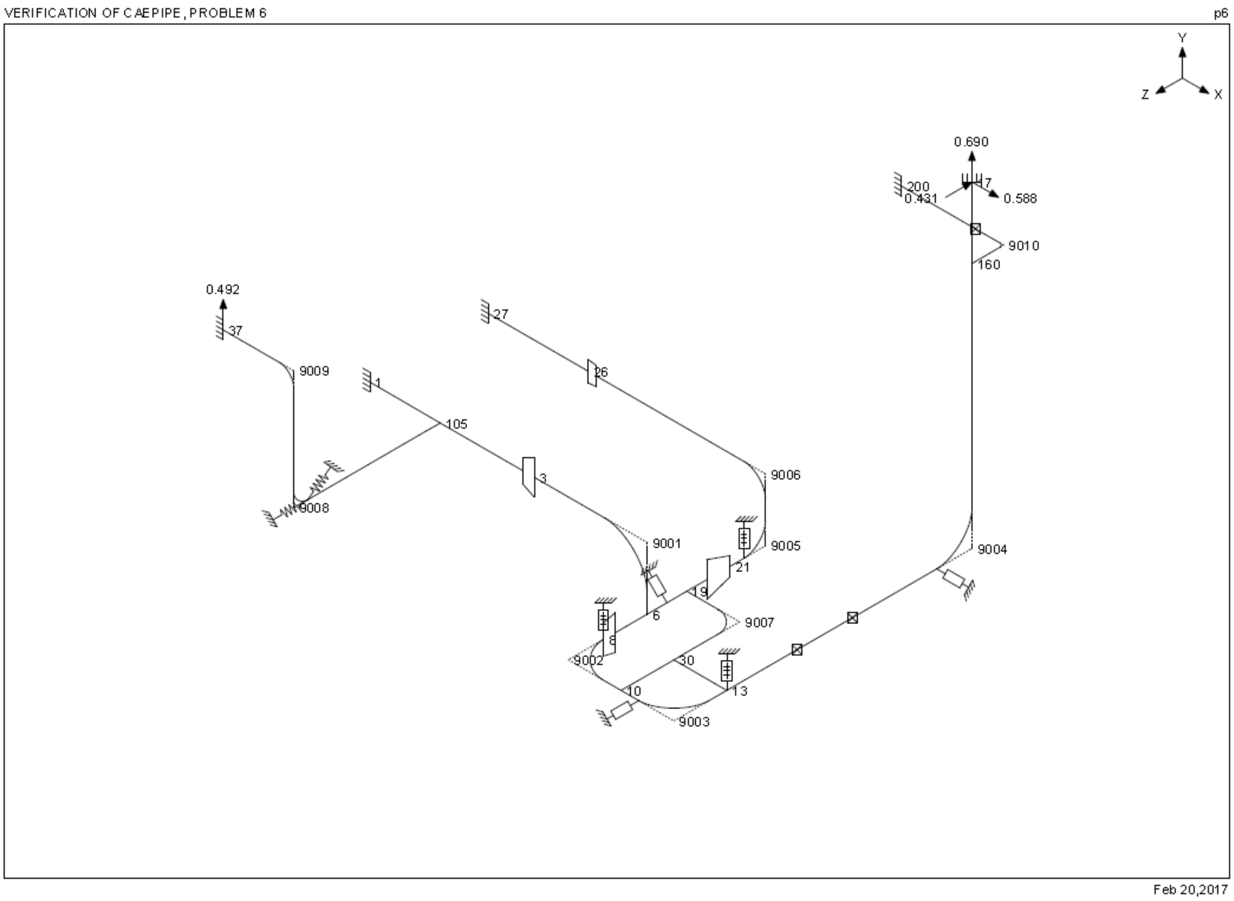
Element From To	Sustained(8)		Sustained (8) Excel Calculated		Occasional (9)		Occasional (9) Excel Calculated	
	SL	1.5SH	SL	1.5SH	SL+SO	1.8SH	SL+SO	1.8SH
	(psi)	(psi)			(psi)	(psi)	(psi)	(psi)
105	4942	25410			5426	30492		
2	4964	25410	4964	25410	5399	30492	5399	30492
9001A	391	25410	391	25410	1367	30492	1367	30492
9001B	529	25410			932	30492		
7008	9626	25410			9753	30492		
8	9254	25410	9254	25410	9430	30492	9430	30492
9002A	252	25410	252	25410	944	30492	944	30492
9002B	458	25410				30492		
9002B	4711	25410			4868	30492		
10	4970	25410	4970	25410	5433	30492	5433	30492
9003B	4846	25410			4969	30492		
13	6126	25410	6126	25410	6680	30492	6680	30492
1305	1998	25410	1998	25410	2117	30492	2117	30492
1306	2090	25410			2198	30492		

Table NC-17.320.3 Comparison of Expansion (10) and Expansion (11) Stresses for ASME Section III Subsection NC – Class 2 (2017) with MS-Excel calculations

Element From To	Expansion (10)		Expansion (10) Excel Calculated		Expansion (11)		Expansion (11) Excel Calculated	
	SE	SA	SE	SA	SL+SE	SH+SA	SL+SE	SH+SA
	(psi)	(psi)			(psi)	(psi)	(psi)	(psi)
2003	4504	29235			9804	46175		
3	1478	29235	1478	29235	6544	46175	6544	46175
9005A	2922	29235			7753	46175		
9005B	2137	29235	2137	29235	6599	46175	6599	46175
3	739	29235			5703	46175		
4	1098	29235	1098	29235	5955	46175	5955	46175
18	951	29235			6011	46175		
19	2374	29235	2375	29235	7845	46175	7845	46175
30	11875	29235	11875	29235	16604	46175	16604	46175
31	3654	29235			8197	46175		
20	550	29235			5553	46175		
21	2565	29235	2565	29235	7201	46175	7201	46175

Refer to P6-ASME-Class2-2017.xls available under the folder “CodeComplaince” for manual calculations.

ASME Section III Subsection ND - Class 3 (2017)



Problem SUMMARY	
What was compared	B1 and B2 Indices, Stress Intensification Factors (SIFs) and Stresses for ASME Section III Subsection ND – Class 3 (2017)
Load cases analyzed	Not applicable
Filename	p6-ASME-ND-2017.mod

This problem compares the manually calculated B1 Indices, B2 Indices, SIFs and Stresses to those obtained from CAEPIPE. The manual calculations for B1 & B2 Indices and SIFs are given in Excel files as listed below.

Node Numbers	Description
9001, 9002, 9005, 9008 & 9010	Welding elbow
1,2,3,4 & 1001	Girth Buttweld
13,19,105 & 160	Reinforced Fabricated Tee
6,10 & 30	Welding Tee
1305, 1306, 32 & 1005	Tapered Transition
3, 8, 21 & 26	Reducer

Table ND-17.320.1 Comparison of Nodal B1, B2 and SIFs for ASME Section III Subsection ND – Class 3 (2017) with manual calculations performed using MS-Excel

Element / Node	Type	Results from CAEPIPE			Values from Manual Calculation		
		B1	B2	SIF	B1	B2	SIF
9001A 9001B	Welding elbow	0.00 0.00	4.05 4.05	2.80 2.80	0.00 0.00	4.05 4.05	2.80 2.80
9002A 9002B	Welding elbow	0.00 0.00	3.95 3.95	2.73 2.73	0.00 0.00	3.95 3.95	2.73 2.73
9005A 9005B	Welding elbow	0.00 0.00	3.91 3.91	2.71 2.71	0.00 0.00	3.91 3.91	2.71 2.71
9008A 9008B	Welding elbow	0.02 0.02	2.98 2.98	2.06 2.06	0.02 0.02	2.98 2.98	2.06 2.06
9010A 9010B	Welding elbow	0.50 0.50	1.00 1.00	1.00 1.00	0.50 0.50	1.00 1.00	1.00 1.00
1,2,3,4 & 1001	Butt Weld	0.50	1.00	1.00	0.50	1.00	1.00
Run 9003B –13	Reinforced fabricated tee @ Node 13	0.50	4.34	5.79	0.50	4.34	5.79
Run 18 –19	Reinforced fabricated tee @ Node 19	0.50	2.66	3.54	0.50	2.66	3.54
Run 1 – 105	Reinforced fabricated tee @ Node 105	0.50	2.13	2.85	0.50	2.13	2.85
Run 16 – 160	Reinforced fabricated tee @ Node 160	0.50	2.42	3.23	0.50	2.42	3.23
1305	Tapered Transition	0.50	1.00	1.42	0.50	1.00	1.42
32	Tapered Transition	0.50	1.00	1.40	0.50	1.00	1.40
1005	Tapered Transition	0.50	1.00	1.34	0.50	1.00	1.34
2003 - 3 @ 3	Reducer	1.00	1.00	2.00	1.00	1.00	2.00
7008 – 8 @ 8	Reducer	1.00	1.00	2.00	1.00	1.00	2.00
20 – 21 @ 21	Reducer	1.00	1.00	2.00	1.00	1.00	2.00
2526 – 26 @ 26	Reducer	1.00	1.00	2.00	1.00	1.00	2.00

Refer to P6-ASME-Class3-2017-B1-B2-SIF.xlsx available under the folder “SIF” for manual calculations.

Table ND-17.320.2 Comparison of Sustained (SL) and Sustained + Occasional Stresses for ASME Section III Subsection ND – Class 3 (2017) with MS-Excel calculations

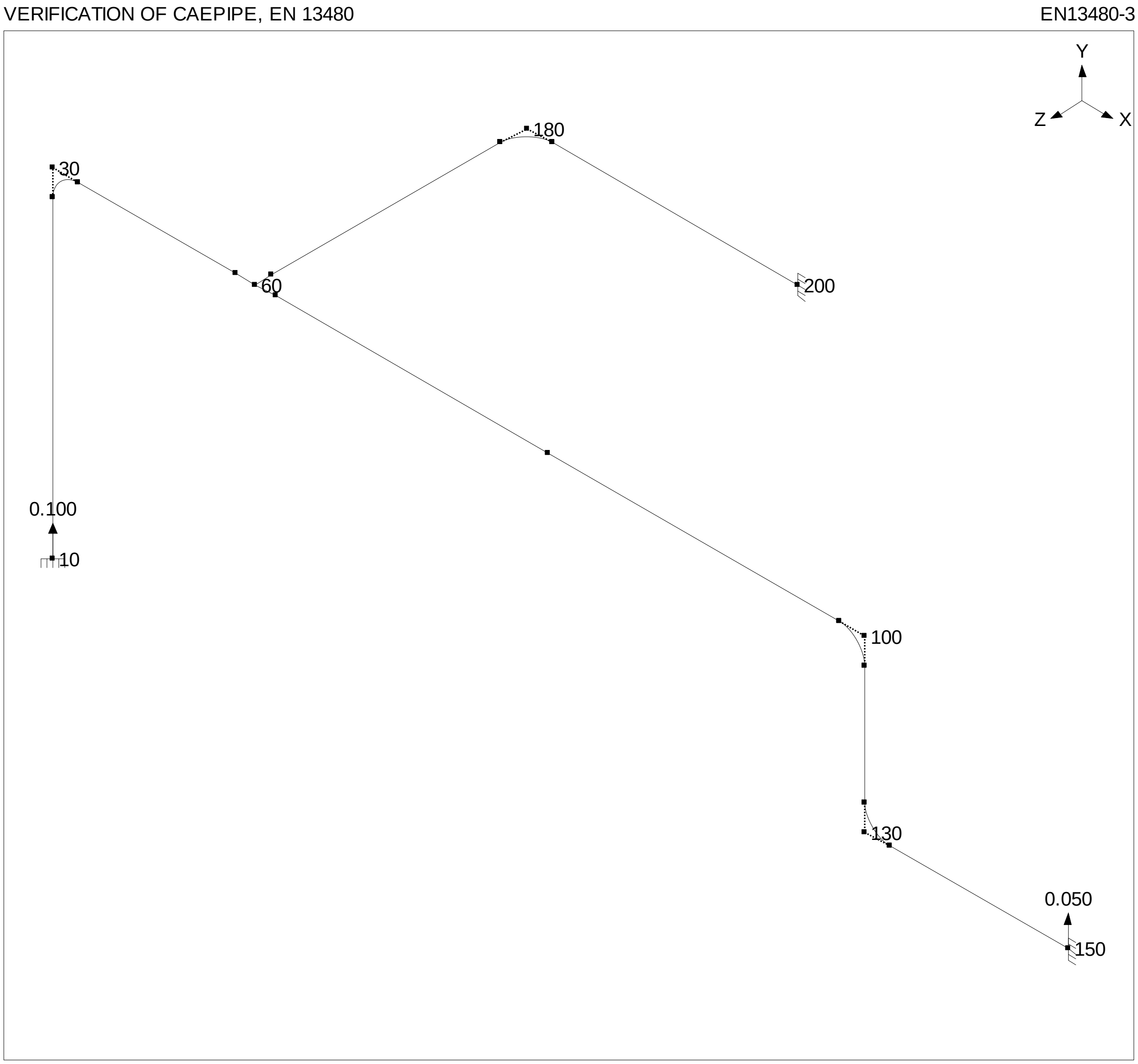
Element From To	Sustained(8)		Sustained (8) Excel Calculated		Occasional (9)		Occasional (9) Excel Calculated	
	SL	1.5SH	SL	1.5SH	SL+SO	1.8SH	SL+SO	1.8SH
	(psi)	(psi)			(psi)	(psi)	(psi)	(psi)
105	4942	25410			5426	30492		
2	4964	25410	4964	25410	5399	30492	5399	30492
9001A	391	25410	391	25410	1367	30492	1367	30492
9001B	529	25410			932	30492		
7008	9626	25410			9753	30492		
8	9254	25410	9254	25410	9430	30492	9430	30492
9002A	252	25410	252	25410	944	30492	944	30492
9002B	458	25410				30492		
9002B	4711	25410			4868	30492		
10	4970	25410	4970	25410	5433	30492	5433	30492
9003B	4846	25410			4969	30492		
13	6126	25410	6126	25410	6680	30492	6680	30492
1305	1998	25410	1998	25410	2117	30492	2117	30492
1306	2090	25410			2198	30492		

Table ND-17.320.3 Comparison of Expansion (10) and Expansion (11) Stresses for ASME Section III Subsection ND – Class 3 (2017) with MS-Excel calculations

Element From To	Expansion (10)		Expansion (10) Excel Calculated		Expansion (11)		Expansion (11) Excel Calculated	
	SE	SA	SE	SA	SL+SE	SH+SA	SL+SE	SH+SA
	(psi)	(psi)			(psi)	(psi)	(psi)	(psi)
2003	4504	29235			9804	46175		
3	1478	29235	1478	29235	6544	46175	6544	46175
9005A	2922	29235			7753	46175		
9005B	2137	29235	2137	29235	6599	46175	6599	46175
3	739	29235			5703	46175		
4	1098	29235	1098	29235	5955	46175	5955	46175
18	951	29235			6011	46175		
19	2374	29235	2375	29235	7845	46175	7845	46175
30	11875	29235	11875	29235	16604	46175	16604	46175
31	3654	29235			8197	46175		
20	550	29235			5553	46175		
21	2565	29235	2565	29235	7201	46175	7201	46175

Refer to P6-ASME-Class3-2017.xls available under the folder “CodeComplaince” for manual calculations.

EN 13480-3 (2020)



Problem SUMMARY	
What was compared	EN 13480-3 (2020) Code Compliance results
Load cases analyzed	Dead weight (DW), Thermal (T1), Seismic, Wind, Settlement and Creep
Filename	EN13480-3.mod
Manual Calculation using Excel	See files starting with name **EN13480-3.**xls from folder CodeCompliance for details

Options

Piping code = EN 13480 (2020)
Include axial force in stress calculations
Occasional load factor (k) = 1.20
Reference temperature = 70 (F)
Number of thermal cycles = 7000
Number of thermal loads = 1
Thermal = Operating - Sustained
Use temperature dependent modulus
Include hanger stiffness
Include Bourdon effect
Do not use pressure correction for bends
Peak pressure factor = 1.20
Cut off frequency = 33 Hz
Number of modes = 6
Include missing mass correction
Do not 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 CAEPIPE, EN 13480								
2	10	From							Anchor
3	20			4'7-1/2"		1	1	1	
4	30	Bend		0'4-1/2"		1	1	1	
5	40		0'4-1/2"			1	1	1	
6	50		2'4"			1	1	1	
7	60		0'3-1/2"			1	1	1	Welding tee
8	70		0'3-1/2"			1	1	1	
9	80		4.0213			1	1	1	
10	90		4.3120			1	1	1	
11	100	Bend	0'4-1/2"			1	1	1	
12	110			-0'4-1/2"		1	1	1	
13	120			-1'9"		1	1	1	
14	130	Bend		-0'4-1/2"		1	1	1	
15	140		0'4-1/2"			1	1	1	
16	150		2'7-1/2"			1	1	1	Anchor
17	60	From							
18	160				-0'2-7/8"	1	2	1	
19	170				-3'4-5/8"	1	2	1	
20	180	Bend			-0'4-1/2"	1	2	1	
21	190		0'4-1/2"			1	2	1	
22	200		3'7-1/2"			1	2	1	Anchor

Anchors

	(lb/inch)			(in-lb/deg)			Releases	CS Level
Node	KX/kx	KY/ky	KZ/kz	KXX/kxx	KYY/kyy	KZZ/kzz	X Y Z XXYYZZ	Tag
10	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
150	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
200	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)
30	4.5	U						
100	4.5	U						
130	4.5	U						
180	4.5	U						

Branch SIFs

Node	Type
60	Welding tee

Specified Displacements

Node	Type	Load	X(inch)	Y(inch)	Z(inch)	XX(deg)	YY(deg)	ZZ(deg)	Disp. in
10	Anchor	T1		0.100					GCS
150	Anchor	T1		0.050					GCS

Pipe material 1: Steel-Thermal loading case

Density = 0.403 (lb/in3), Nu = 0.300, Joint factor = 1.00
Tensile strength =

Temp (F)	E (psi)	Alpha (in/in/F)	All.(f) (psi)
180	30.0E+6	9.61E-6	15000

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)	Soil
1	3"	STD	3.5	0.216	0.05	12.5					
2	2-1/2"	STD	2.875	0.203	0.05	12.5					

Loads

Static seismic load: X = 0.30, Y = 0.20, Z = 0.30 (g's)
Acceleration load combination = Square Root of Sum of Squares

Wind Load 1

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

Elevation (feet)	Velocity (mph)
0	80
10	80

Wind Load 2

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

Elevation (feet)	Velocity (mph)
0	80
10	80

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	DT (F)	DP (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load	1234
1	180	50.0					180	50.0			Y	

Table EN13480-3.1 Comparison of Sustained Stress (S1) as per Eq. 12.3.2-1

Element Node # From – To	CAEPIPE S1 (psi)	Excel Calculated S1 (psi)
10	**1005**	**1006**
20	**1077**	**1077**
30A	**1378**	**1376**
30B	**1244**	**1242**
40	**983**	**983**
50	**753**	**753**
50	**753**	**753**
60	**881**	**881**
60	**510**	**510**
70	**599**	**599**
70	**599**	**599**
80	**1032**	**1032**
80	**1032**	**1032**
90	**572**	**571**
100A	**697**	**696**
100B	**716**	**715**
110	**584**	**584**
120	**581**	**581**
130A	**715**	**714**
130B	**590**	**589**
140	**491**	**491**
150	**2208**	**2208**
60	**675**	**673**
160	**783**	**783**
160	**783**	**783**
170	**682**	**682**

180A	**686**	**686**
180B	**727**	**727**
190	**724**	**724**
200	**1680**	**1679**

See file EN13480-3.xlsx from folder CodeCompliance for details on Manual Calculations.

Table EN13480-3.2 Comparison of Expansion Stress (S3) as per Eq. 12.3.4-1

Element Node # From – To	CAEPIPE S3 (psi)	Excel Calculated S3 (psi)
10	**6193**	**6193**
20	**2201**	**2201**
30A	**3718**	**3713**
30B	**4193**	**4186**
40	**2569**	**2569**
50	**1724**	**1724**
50	**1724**	**1724**
60	**1881**	**1879**
60	**1031**	**1032**
70	**859**	**860**
70	**859**	**860**
80	**1000**	**1000**
80	**1000**	**1000**
90	**1633**	**1633**
100A	**2888**	**2884**
100B	**2080**	**2076**
110	**1200**	**1200**
120	**1770**	**1770**
130A	**3138**	**3132**
130B	**4007**	**4000**
140	**2216**	**2216**
150	**1823**	**1823**

60	**3263**	**3263**
160	**2884**	**2885**
160	**2884**	**2885**
170	**1759**	**1759**
180A	**2029**	**2030**
180B	**1960**	**1961**
190	**1875**	**1875**
200	**4722**	**4722**

See file EN13480-3.xlsx from folder CodeCompliance for details on Manual Calculations.

Table EN13480-3.3 Comparison of Occasional Stress (S2) as per Clause 12.3.3

	Seismic Load case		Wind Load case	
Element Node # From – To	**CAEPIPE S2 (psi)**	**Excel Calculated S2 (psi)**	**CAEPIPE S2 (psi)**	**Excel Calculated S2 (psi)**
10	**1847**	**1848**	**860**	**861**
20	**1388**	**1388**	**1044**	**1045**
30A	**1771**	**1769**	**1319**	**1317**
30B	**1634**	**1632**	**1200**	**1196**
40	**1293**	**1293**	**962**	**960**
50	**999**	**998**	**829**	**826**
50	**999**	**998**	**829**	**826**
60	**1140**	**1139**	**953**	**951**
60	**740**	**740**	**597**	**594**
70	**813**	**814**	**682**	**679**
70	**813**	**814**	**682**	**679**
80	**1315**	**1315**	**1051**	**1048**
80	**1315**	**1315**	**1051**	**1048**
90	**935**	**935**	**720**	**718**
100A	**1159**	**1158**	**880**	**876**
100B	**1089**	**1088**	**878**	**876**

110	**878**	**878**	**717**	**717**
120	**896**	**896**	**680**	**679**
130A	**1098**	**1096**	**831**	**830**
130B	**1086**	**1084**	**768**	**759**
140	**901**	**901**	**638**	**630**
150	**2810**	**2811**	**2167**	**2160**
60	**1066**	**1064**	**629**	**627**
160	**1238**	**1237**	**724**	**724**
160	**1238**	**1237**	**724**	**724**
170	**1150**	**1150**	**677**	**677**
180A	**1179**	**1178**	**680**	**680**
180B	**1115**	**1114**	**742**	**735**
190	**1091**	**1092**	**740**	**734**
200	**2502**	**2502**	**1712**	**1705**

See file EN13480-3.xlsx from folder CodeCompliance for details on Manual Calculations.

Table EN13480-3.4 Comparison of Creep Stress (S5) as per Eq. 12.3.5-1

Element Node # From – To	CAEPIPE S5 (psi)	Excel Calculated S5 (psi)
10	**3070**	**3070**
20	**1811**	**1811**
30A	**2308**	**2305**
30B	**2325**	**2321**
40	**1840**	**1839**
50	**1328**	**1327**
50	**1328**	**1327**
60	**1444**	**1443**
60	**802**	**802**
70	**885**	**885**
70	**885**	**885**

80	**1365**	**1366**
80	**1365**	**1366**
90	**1116**	**1116**
100A	**1419**	**1417**
100B	**1236**	**1235**
110	**984**	**984**
120	**1171**	**1171**
130A	**1499**	**1497**
130B	**1584**	**1581**
140	**1230**	**1230**
150	**2816**	**2816**
60	**1532**	**1530**
160	**1745**	**1745**
160	**1745**	**1745**
170	**1269**	**1269**
180A	**1278**	**1277**
180B	**1354**	**1354**
190	**1349**	**1349**
200	**3254**	**3253**

See file EN13480-3.xlsx from folder CodeCompliance for details on Manual Calculations.

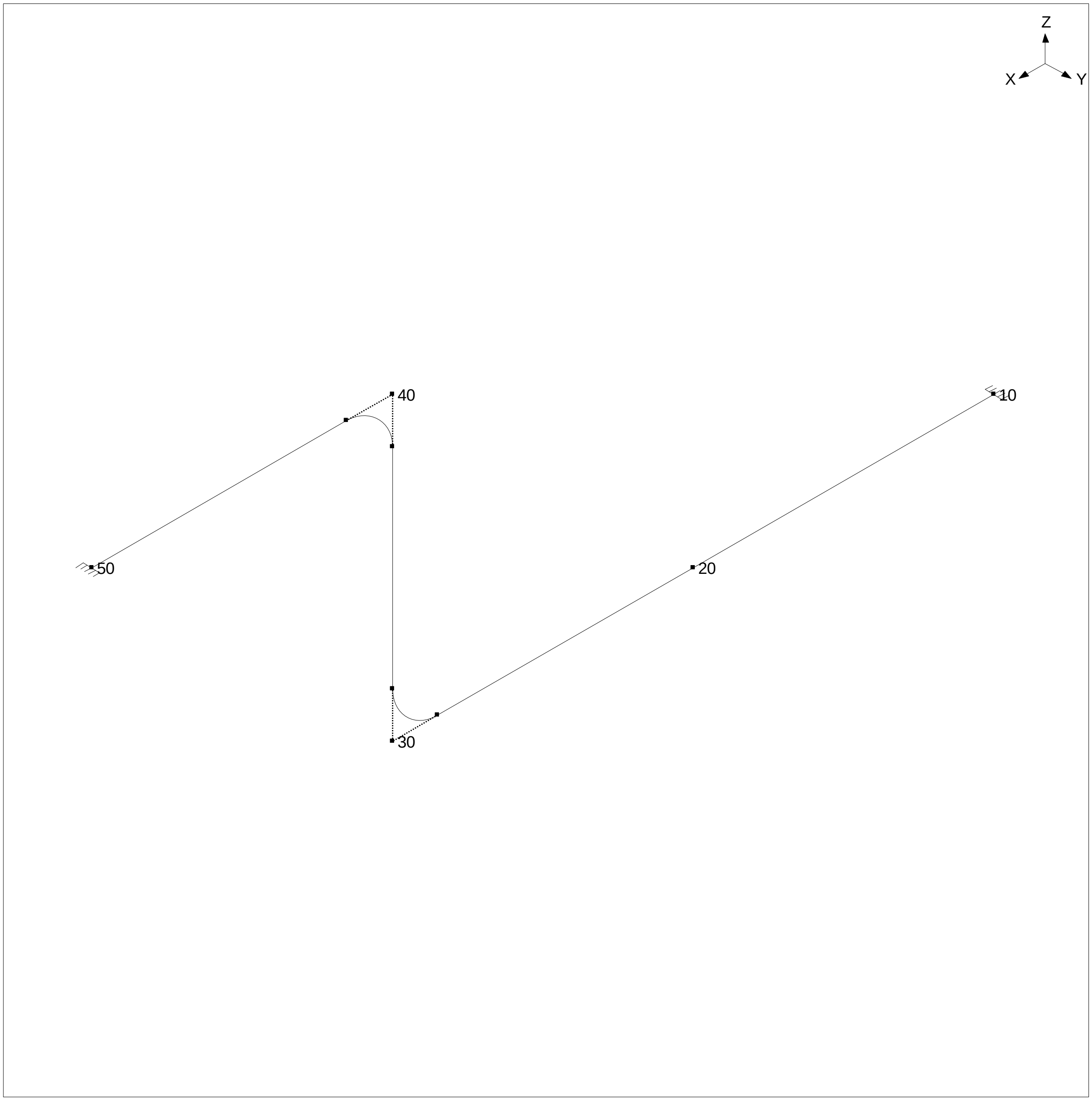
Table EN13480-3.5 Comparison of Settlement Stress (S5) as per Eq. 12.3.6-1

Element Node # From – To	CAEPIPE S6 (psi)	Excel Calculated S6 (psi)
10	**578**	**578**
20	**3566**	**3566**
30A	**6062**	**6055**
30B	**5354**	**5347**
40	**3544**	**3544**
50	**2619**	**2619**

50	**2619**	**2619**
60	**2970**	**2971**
60	**1226**	**1224**
70	**1073**	**1073**
70	**1073**	**1073**
80	**1210**	**1210**
80	**1210**	**1210**
90	**1370**	**1371**
100A	**2158**	**2155**
100B	**2285**	**2282**
110	**1358**	**1357**
120	**1239**	**1239**
130A	**2060**	**2058**
130B	**1868**	**1865**
140	**1230**	**1230**
150	**1326**	**1327**
60	**5808**	**5808**
160	**4997**	**4998**
160	**4997**	**4998**
170	**2642**	**2642**
180A	**3320**	**3320**
180B	**3724**	**3721**
190	**3359**	**3359**
200	**8332**	**8332**

See file EN13480-3.xlsx from folder CodeCompliance for details on Manual Calculations.

CSA Z662 (2019)



Problem SUMMARY	
What was compared	CSA Z662 (2019) Code Compliance results
Load cases analyzed	SL+SO and SE for Un-buried and Combined stress for Buried Piping
Filename	Z662.mod
Manual Calculation using Excel	See Z662_2019.xls from folder CodeCompliance for details

Options

Piping code = Z662 (2019)
Include axial force in stress calculations
Reference temperature = 32 (F)
Number of thermal cycles = 7000
Number of thermal loads = 3
Solve thermal case
Use modulus at reference temperature
Include hanger stiffness
Do not include Bourdon effect
Do not 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
Do not use friction in dynamic analysis
Vertical direction = Z

#	Node	Type	DX(ft'in")	DY(ft'in")	DZ(ft'in")	Mat	Sec	Load	Data
1	Title =								
2	10	From							Anchor
3	20		3.2808			A16	4IN	L1	
4	30	Bend	3.2808			A16	4IN	L1	
5	40	Bend			3.2808	A16	4IN	LW	
6	50		3.2808			A16	4IN	LW	Anchor

Anchors

	(lb/inch)			(in-lb/deg)			Releases	CS Level
Node	KX/kx	KY/ky	KZ/kz	KXX/kxx	KYY/kyy	KZZ/kzz	X Y Z XXYYZZ	Tag
10	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
50	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)
30	6 L							
40	6 L							

Pipe material A16: A106 Grade C

Density = 0.283 (lb/in3), Nu = 0.300, Joint factor = 1.00, Type = CS
Yield strength = 30000 (psi)

Temp (F)	E (psi)	Alpha (in/in/F)	Allowable (psi)
-20	29.5E+6	6.50E-6	40000
70	29.5E+6	6.50E-6	40000
100	29.3E+6	6.50E-6	40000
150	29.1E+6	6.50E-6	40000
200	28.8E+6	6.50E-6	40000
250	28.6E+6	6.50E-6	40000

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)	Soil
4IN	4"	5S	4.5	0.083	0	0.0					S1

Soils

Name	Type	Density (lb/ft3)	Strength (psi)	Delta (deg)	Ks	Gr.Level (ft'in")	Include Ins. Thk	Depth of Soil (ft'in")
S1	Cohesionless	62.428		30	0.30	2.4606	No	

Buried Sections

Section	Soil
4IN	S1

Wind Load 1

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

Elevation (feet)	Velocity (mph)
0	50
10	50

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	DT (F)	DP (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind 1 Load
L1	250	43.5	200	29.0	-186	21.8	250	43.5	0.600		
LW	250	43.5	200	29.0	-186	21.8	250	43.5	0.600		Y

Values shown in Tables below under CAEPIPE are rounded off when displayed on screen.

Table Z662-1 Comparison of SL+SO for Un-buried piping per Clause 4.8.5

Node # Element From – To	CAEPIPE (SL+SO) (psi)	Excel Calculated (SL+SO) (psi)
40B (40A-40B)	669	671*

* Refer to Sheet (SL+SO) in Z662_2019.xls for details.

Table Z662-2 Comparison of SE for Un-buried piping per Clause 4.8.4

Node # Element From – To	Load Case in CAEPIPE	Stress from CAEPIPE Element force results (psi)	Excel Calculated (SL+SO) (psi)*
40B (40A-40B)	Expansion T1	8604	8605
	Expansion T2	6630	6630
	Expansion T3	8603	8602
	Expansion T1-T2	1973	1974
	Expansion T1-T3	17207	17207
	Expansion T2-T3	15233	15232

* Refer to Sheets T1, T2, T3, T1-T2, T1-T2 and T2-T3 in Z662_2019.xls for details.

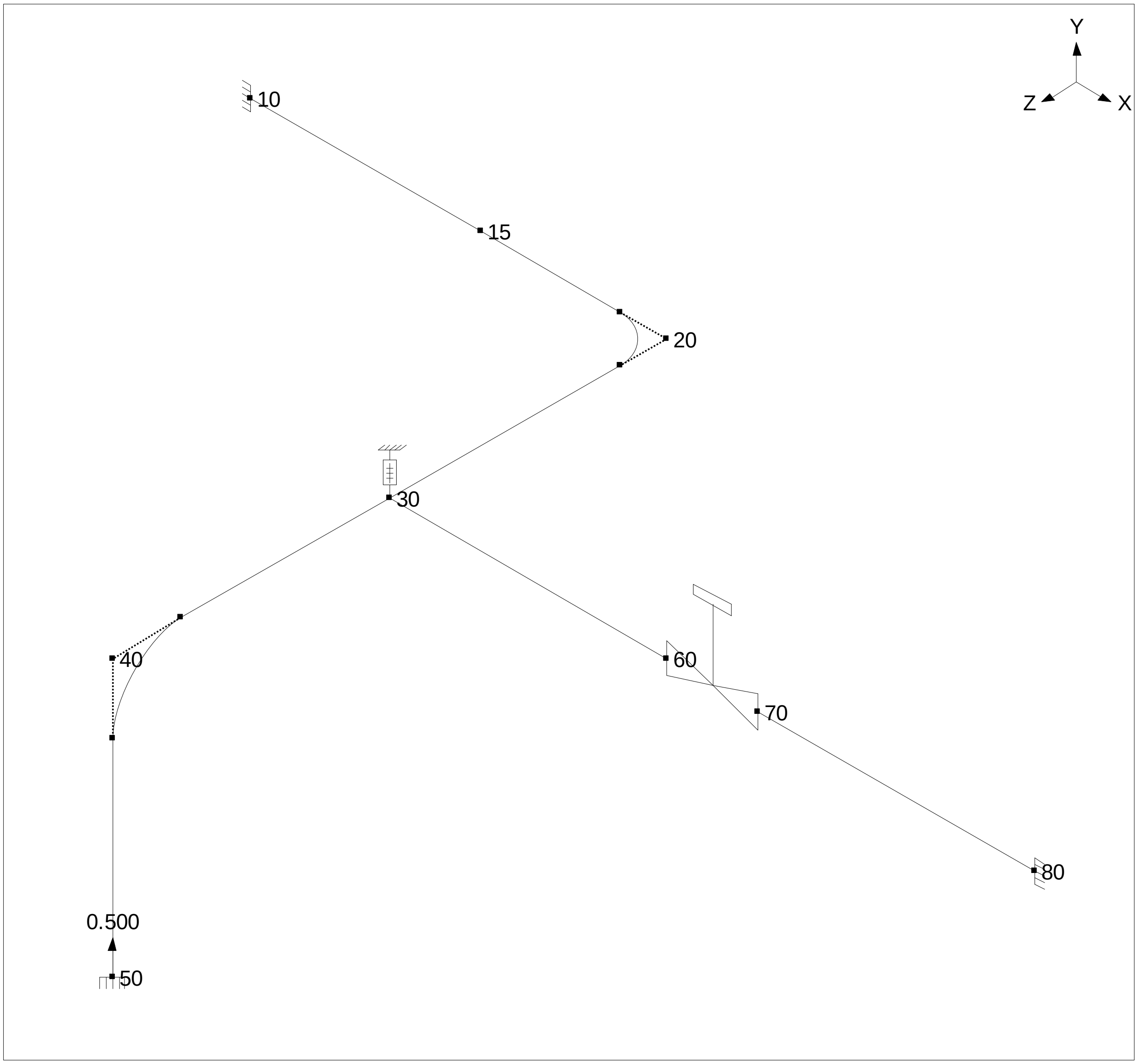
Table Z662-2 Comparison of Combined Stress (Sh-SL+SB) for Buried piping as per Clause 4.7.2.1

Node # Element From – To	Load Case in CAEPIPE	Stress from CAEPIPE Element force results (psi)	Excel Calculated (SL+SO) (psi)*
20 (10-20)	Expansion T1	42709	42709
	Expansion T2	33122	33122
	Expansion T3	0	0
	Expansion T1-T2	10495	10495
	Expansion T1-T3	84507	84511
	Expansion T2-T3	74920	74923

* Refer to Sheets Res-T1, Res-T2, Res-T3, Res T1-T2, Res-T1-T2 and Res-T2-T3 in Z662_2019.xls for details.

Von Mises Stresses

Sample problem VonMises



Problem SUMMARY	
What was compared	Von Mises results
Load cases analyzed	Static Load
Filename	VonMises.mod
Manual Calculation using Excel	See VonMises.xls from folder CodeCompliance for details

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Options

Piping code = None
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
Do not 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 = Sample problem								
2	10	From							Anchor
3	15		5'0"			A53	8	1	
4	20	Bend	4.0000			A53	8	1	
5	30				6'0"	A53	8	1	Hanger
6	40	Bend			6'0"	A53	8	1	
7	50			-6'0"		A53	8	1	Anchor
8	6" std pipe								
9	30	From							
10	60		6'0"			A53	6	1	
11	70	Valve	2'0"			A53	6	1	
12	80		6'0"			A53	6	1	Anchor

Anchors

	(lb/inch)			(in-lb/deg)			Releases	CS Level
Node	KX/kx	KY/ky	KZ/kz	KXX/kxx	KYY/kyy	KZZ/kzz	X Y Z XXYYZZ	Tag
10	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
50	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
80	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	12	L						
40	18	U						

Hangers

Node	Type	No. of	Load var(%)	Short Range	SpringRate (lb/inch)	HangerLoad (lb)	Load type	Level Tag
30	Grinnell	1	25					

Specified Displacements

Node	Type	Load	X(inch)	Y(inch)	Z(inch)	XX(deg)	YY(deg)	ZZ(deg)	Disp. in
50	Anchor	T1		0.500					GCS

Valves

From	To	Weight (lb)	Length (inch)	Thick X	Insul Wgt X	Add Wght (lb)	DX (inch)	DY (inch)	DZ (inch)
60	70	200		3.00	1.75	50	0	18	0

Pipe material A53: A53 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	20000
500	27.3E+6	7.02E-6	18900
600	26.7E+6	7.23E-6	17300
650	26.1E+6	7.33E-6	17000
700	25.5E+6	7.44E-6	16500
750	24.9E+6	7.54E-6	13000
800	24.2E+6	7.65E-6	10800
850	23.3E+6	7.75E-6	8700
900	22.4E+6	7.84E-6	6500
950	21.4E+6	7.91E-6	4500
1000	20.4E+6	7.97E-6	2500
1050	19.2E+6	8.05E-6	1600
1100	18.0E+6	8.12E-6	1000

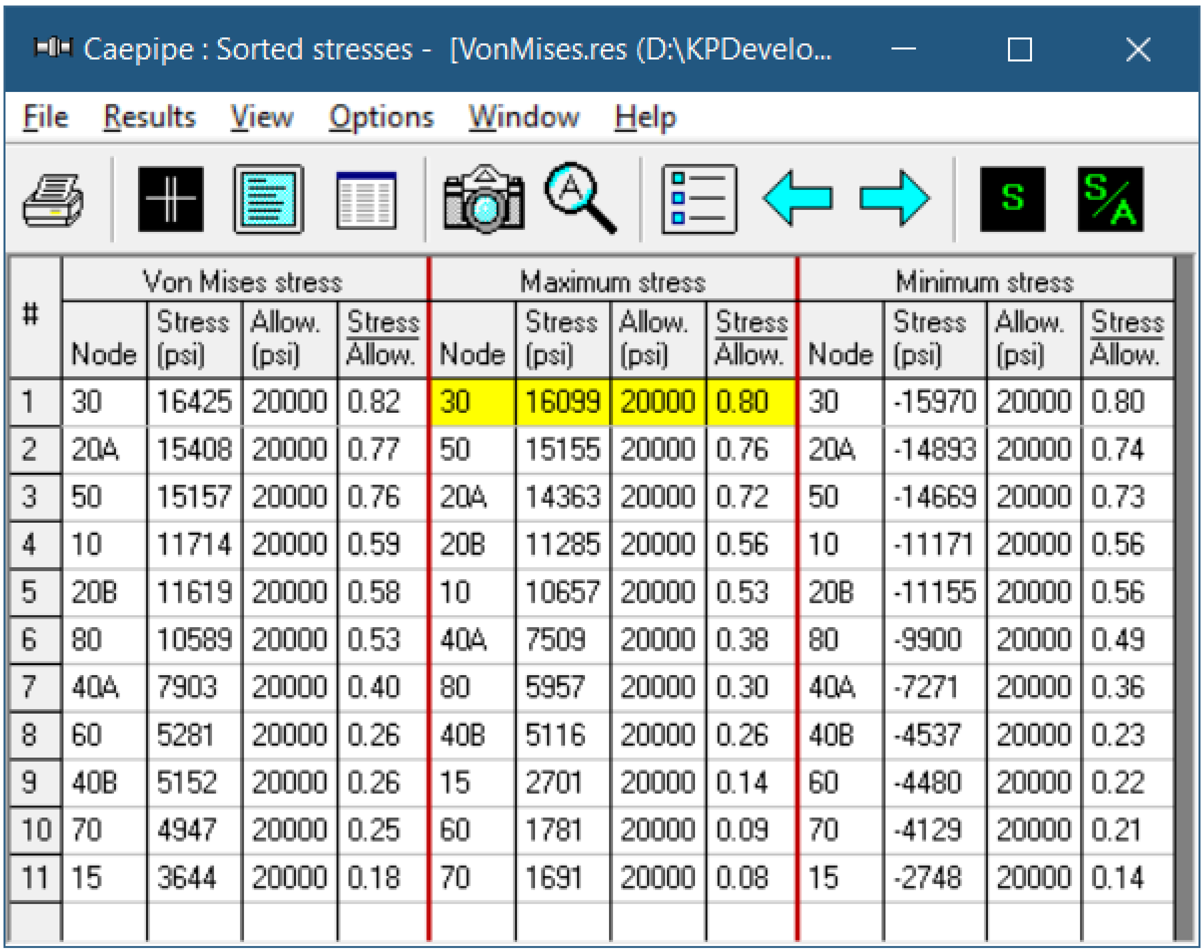
Pipe Sections

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)	Soil
8	8"	80	8.625	0.5	0	0.0	11	2			
6	6"	STD	6.625	0.28	0	0.0	11	2			

Caepipe   VonMises   Page 3
Version 10.50   Sample problem   Dec 22,2021

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	DT (F)	DP (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind 1 Load
1	250	100					250	100	0.800		



#	Von Mises stress				Maximum stress				Minimum stress			
	Node	Stress (psi)	Allow. (psi)	Stress / Allow.	Node	Stress (psi)	Allow. (psi)	Stress / Allow.	Node	Stress (psi)	Allow. (psi)	Stress / Allow.
1	30	16425	20000	0.82	30	16099	20000	0.80	30	-15970	20000	0.80
2	20A	15408	20000	0.77	50	15155	20000	0.76	20A	-14893	20000	0.74
3	50	15157	20000	0.76	20A	14363	20000	0.72	50	-14669	20000	0.73
4	10	11714	20000	0.59	20B	11285	20000	0.56	10	-11171	20000	0.56
5	20B	11619	20000	0.58	10	10657	20000	0.53	20B	-11155	20000	0.56
6	80	10589	20000	0.53	40A	7509	20000	0.38	80	-9900	20000	0.49
7	40A	7903	20000	0.40	80	5957	20000	0.30	40A	-7271	20000	0.36
8	60	5281	20000	0.26	40B	5116	20000	0.26	40B	-4537	20000	0.23
9	40B	5152	20000	0.26	15	2701	20000	0.14	60	-4480	20000	0.22
10	70	4947	20000	0.25	60	1781	20000	0.09	70	-4129	20000	0.21
11	15	3644	20000	0.18	70	1691	20000	0.08	15	-2748	20000	0.14

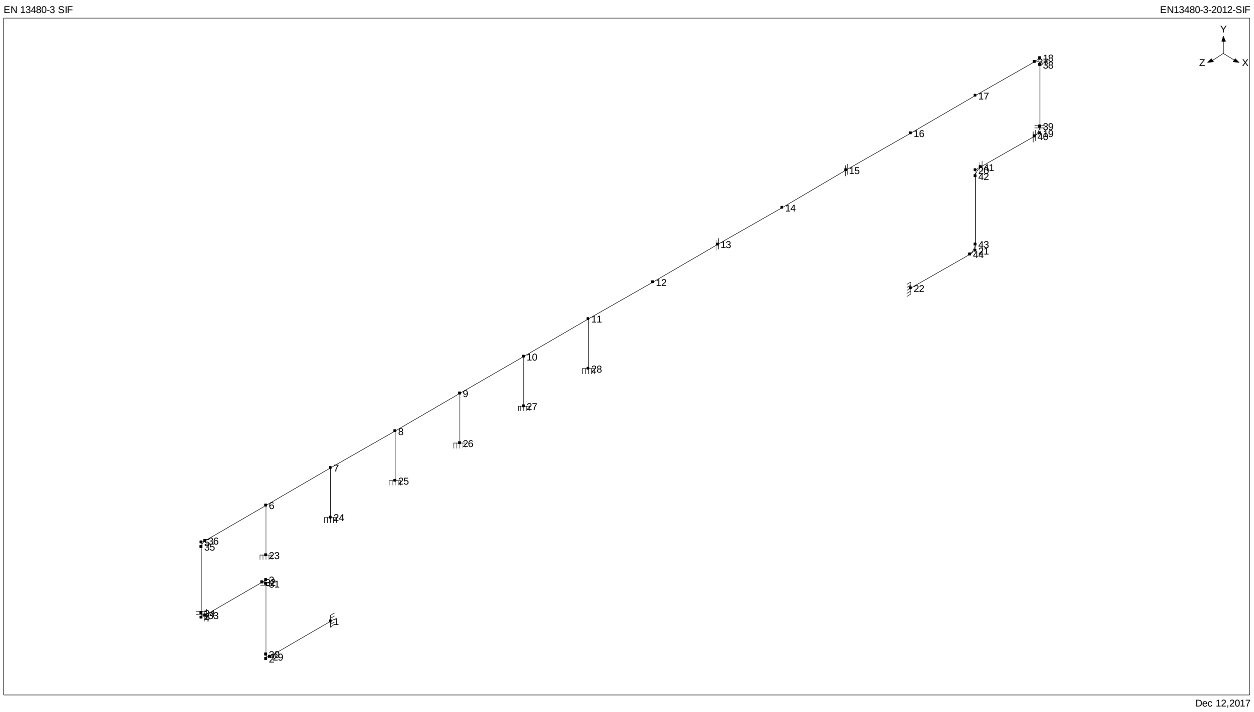
Code = NONE (Von Mises Stresses)			
Node Number	20A (Element 20A-20B)		
Outer Diameter (OD) (in)	8.625	Wall Thickness (Thk) (in)	0.500
Pressure (psi)	100	Mill Tollerance (%)	0.000
Corrosion Allowance	0.000	Minimum Thk (tm)	0.500
Inplane SIF	1.76	Outplane SIF	1.47
Axial force (fx) (lbs)	-9015	Inplane Moment (mi) (in-lb)	201936
Outplane Moment (mo) (in-lb)	-6772	Torsional Moment (mt) (in-lb)	-67334
Area of Cross Section (in2)	12.763	Section Modulus (in3)	24.514
PD/2tm (SH)	862.5	PD/4t	431.250
F/A	-706.354	Bending Stress (SB)	14498.937
Torsional Stress	1373.384	SA	-275.104
T1	-6680.666	U1	6820.373
Sigma1	14363.539	Sigma2	722.793
Vonmises_t	14016.127	Max_t	14363.539
Min_t	722.793		
T2	7818.270	U2	7937.981
Sigma1	982.210	Sigma2	-14893.751
Vonmises_b	15408.353	Max_b	982.210
Min_b	-14893.751		
Von Mises Stress*	15408	Maximum Principal Stress*	14364
Minimum Principal Stress*	-14894		

* Values match with the corresponding CAEPIPE Results. See file VonMises.xls from folder CodeCompliance for details on Manual Calculations.

Code = NONE (Von Mises Stresses)			
Node Number	15 (Element 15 - 20A)		
Outer Diameter (OD) (in)	8.625	Wall Thickness (t) (in)	0.500
Pressure (psi)	100	Mill Tollerance (%)	0.000
Corrosion Allowance	0.000	Minimum Thk (t_m)	0.500
Inplane SIF	1.000	Outplane SIF	1.000
Axial force (fx) (lbs)	-9015	Inplane Moment (mi) (in-lb)	-33138
Outplane Moment (mo) (in-lb)	34477	Torsional Moment (mt) (in-lb)	-67334
Area of Cross Section (in2)	12.763	Section Modulus (in3)	24.514
PD/2t_m (SH)	862.5	PD/4t	431.250
F/A	-706.354	Bending Stress (SB)	1950.746
Torsional Stress	1373.384	SA	-275.104
T1	-406.571	U1	1432.300
Sigma1	2701.371	Sigma2	-163.229
Vonmises_t	2786.573	Max_t	2701.371
Min_t	-163.229		
T2	1544.175	U2	2066.558
Sigma1	1384.882	Sigma2	-2748.233
Vonmises_b	3643.715	Max_b	1384.882
Min_b	-2748.233		
Von Mises Stress*	**3644**	Maximum Principal Stress*	**2701**
Minimum Principal Stress*	**-2748**		

* Values match with the corresponding CAEPIPE Results. See file VonMises.xls from folder CodeCompliance for details on Manual Calculations.

EN 13480-3 (2020) – Stress Intensification Factor (SIF)



Problem SUMMARY	
What was compared	Stress Intensification Factors (SIFs)
Load cases analyzed	Not applicable
Filename	EN13480-3-2017-SIF.mod

Options

Piping code = EN 13480 (2020)
Do not include axial force in stress calculations
Occasional load factor (k) = 1.20
Reference temperature = 70 (F)
Number of thermal cycles = 7000
Number of thermal loads = 1
Solve thermal case
Use modulus at reference temperature
Include hanger stiffness
Include Bourdon effect
Do not use pressure correction for bends
Peak pressure factor = 1.00
Cut off frequency = 33 Hz
Number of modes = 6
Include missing mass correction
Do not 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 = EN 13480-3 SIF								
2	SIF CHECK: 0 PSIG, 70 Deg F								
3	1	From							Anchor
4	29				2'10"	1	1	1	
5	2	Bend			0'2"	1	1	1	
6	30			0'2"		1	1	1	
7	31			2'10"		1	1	1	
8	3	Bend		0'2"		1	1	1	
9	32				0'2"	1	1	1	
10	33				2'8"	1	1	1	
11	4	Bend			0'2"	1	1	1	
12	34			0'2"		1	1	1	
13	35			2'8"		1	1	1	
14	5	Bend		0'2"		1	1	1	
15	36				-0'2"	1	1	1	
16	6				-2'10"	1	1	1	Welding tee
17	7				-3'0"	1	1	1	Reinf tee
18	8				-3'0"	1	1	1	Unreinf tee
19	9				-3'0"	1	1	1	Extruded tee
20	10				-3'0"	1	1	1	Sweepolet
21	11				-3'0"	1	1	1	Weldolet
22	12				-3'0"	1	1	1	
23	13				-3'0"	1	1	1	Flange
24	14				-3'0"	1	1	1	Fillet weld
25	15				-3'0"	1	1	1	Flange
26	16				-3'0"	1	1	1	Threaded joint
27	17				-3'0"	1	1	1	User SIF
28	37				-2'9"	1	1	1	
29	18	Bend			-0'3"	1	1	1	
30	38			-0'3"		1	1	1	
31	39			-2'6"		1	1	1	
32	19	Bend		-0'3"		1	1	1	
33	40				0'3"	1	1	1	

#	Node	Type	DX(ft'in")	DY(ft'in")	DZ(ft'in")	Mat	Sec	Load	Data
34	41				2'6"	1	1	1	
35	20	Bend			0'3"	1	1	1	
36	42			-0'3"		1	1	1	
37	43			-2'9"		1	1	1	
38	21	Bend		-0'3"		1	1	1	
39	44				0'3"	1	1	1	
40	22				2'9"	1	1	1	Anchor
41	6	From							
42	23			-2'0"		1	1	1	Anchor
43	7	From							
44	24			-2'0"		1	1	1	Anchor
45	8	From							
46	25			-2'0"		1	1	1	Anchor
47	9	From							
48	26			-2'0"		1	1	1	Anchor
49	10	From							
50	27			-2'0"		1	1	1	Anchor
51	11	From							
52	28			-2'0"		1	1	1	Anchor
53	3A	Location							Flange
54	4A	Location							Flange
55	4B	Location							Flange
56	19A	Location							Flange
57	19B	Location							Flange
58	20A	Location							Flange

Anchors

Node	KX/kx	KY/ky (lb/inch)	KZ/kz	KXX/kxx	KYY/kyy (in-lb/deg)	KZZ/kzz	Releases X Y Z XXYYZZ	Anchor In Pipe
1	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
22	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
23	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
24	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
25	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
26	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
27	Rigid	Rigid	Rigid	Rigid	Rigid	Rigid		GCS
28	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)
2	2	U						
3	2	U						
4	2	U						
5	2	U						
18	3	U						
19	3	U						
20	3	U						
21	3	U						

Branch SIFs

Node	Type
6	Welding tee
7	Reinforced fabricated tee, pad thickness = 0.5 (inch)
8	Unreinforced fabricated tee
9	Extruded welding tee, crotch radius = 0.5 (inch)
10	Sweepolet (Welded-in contour insert)
11	Weldolet (Branch welded-on fitting)

Flanges

Node	Type	Weight (lb)	Gasket Dia (inch)	Allowable pressure (psi)
13	Double welded slip on	0		
15	Lap joint	0		
3A	Weld neck	0		
4A	Weld neck	0		
4B	Weld neck	0		
19A	Weld neck	0		
19B	Weld neck	0		
20A	Weld neck	0		

Threaded Joints

Node
16

User SIFs

Node	In plane	Out plane	Axial	Torsion
17	2.70	2.70		

Welds

Node	Type
14	Fillet weld

Pipe material 1: Carbon Steel, Carbon <= 0.3%

Density = 0.284 (lb/in3), Nu = 0.292, Joint factor = 1.00
Tensile strength =

Temp (F)	E (psi)	Alpha (in/in/F)	All.(f) (psi)
70	27.9E+6	6.07E-6	16000

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)
1	2"	STD	2.375	0.154	0	12.5	8.9999	4		

Pipe Loads

Load Name	T1 (F)	P1 (psi)	T2 (F)	P2 (psi)	T3 (F)	P3 (psi)	DT (F)	DP (psi)	Specific gravity	Add.Wgt (lb/ft)	Wind Load
1	70	0					70	0	1.000		Y

Pipe Section: 2”	(T, P) – (70° F, 0 PSIG)

This problem compares the manually calculated nodal and elbow SIFs to those obtained from CAEPIPE. The SIF type designations are given below. (SR=Short radius, LR=Long radius)

Node	SIF Type Description
2	Welding elbow (SR)
3	Welding elbow (SR), one flange
4	Welding elbow (SR), two flanges
6	Welding Tee
7	Reinforced Fabricated Tee, pad thickness = 0.5 inch
8	Un-reinforced fabricated tee
9	Extruded welding tee, crotch radius = 0.5 inch
10	Sweepolet
11	Weldolet
13	Double-welded slip-on flange
14	Fillet Weld
15	Lap joint flange
16	Threaded pipe joint or flange
17	User SIF
19	Welding elbow (LR), two flanges
20	Welding elbow (LR), one flange
21	Welding elbow (LR)

OD	Thickness (t)	Pad thickness (t_e)	Crotch radius (r_x)	Mean radius (r_m)
2.375”	0.154”	0.5”	0.5”	1.11”

Table EN13480.3.5 Comparison of Nodal SIFs for EN13480-3 (2020) with manual calculations

Node	EN 13480-3 SIF			
	CAEPIPE Inplane	CAEPIPE Outplane	Manual Calc Inplane	Manual Calc Outplane
6	1.19	1.25	1.19	1.25
7	1.24	1.32	1.24	1.32
8	2.77	3.36	2.77	3.36
9	2.22	2.62	2.22	2.62
10	1.19	1.25	1.19	1.25
11	1.52	1.52	1.52	1.52
12*	1.00	1.00	1.00	1.00
13	1.20	1.20	1.20	1.20
14	2.10	2.10	2.10	2.10
15	1.60	1.60	1.60	1.60
16	2.30	2.30	2.30	2.30
17	2.70	2.70	2.70	2.70

* A “blank” SIF in CAEPIPE results is the same as “1.00”

Table EN13480.3.6 Comparison of Elbow SIFs for EN 13480-3 (2020) with manual calculations

Elbow @ Node	EN 13480-3 SIF			
	CAEPIPE Inplane	CAEPIPE Outplane	Manual Calc Inplane	Manual Calc Outplane
2	2.27	1.89	2.27	1.89
3	1.80	1.50	1.80	1.50
4	1.43	1.19	1.43	1.19
19	1.25	1.04	1.25	1.04
20	1.47	1.23	1.47	1.23
21	1.73	1.44	1.73	1.44

Refer to EN13480-3-2017-SIF.xls available under the folder “SIF” for manual calculations.

Pressure Design - EN 13480-3 (2017)

Pressure Design of Pipe and Pipe Fittings can be performed using the pre-processor modules added in CAEPIPE which are independent of the flexibility analysis.

These modules can be launched through Layout frame > Misc > Internal Pressure Design: EN 13480-3 and Layout frame > Misc > External Pressure Design: EN 13480-3 respectively.

Internal pressure design calculations of pipe and pipe fittings according to EN 13480-3 are independent of lengths of pipes defined in CAEPIPE stress model. Hence, these calculations can be performed directly from the existing stress model developed for flexibility analysis.

On the other hand, the external pressure design requires the calculation of collapse pressure, which is a function of length between the stiffeners placed on the piping (shown in figures below). Hence, ensure that the nodes are defined in CAEPIPE model only at locations where the stiffeners are provided along the piping in the field. In other words, the existing CAEPIPE stress model (developed for flexibility analysis) need to be edited before performing the external pressure design.

Internal Pressure Design of Pipe and Pipe Fittings

CAEPIPE model file for internal design pressure verification is available in the verification package. See file Verification_Internal_Pressure.mod for details on input shown below.

Straight Pipe due to Internal Pressure
according to SS-EN 13480-3:2017 (E) Issue 1 (2017-06), Chapter 6.1

General

Material	EN 10216-2 10CrMo9-10 W1.7380
Design Temperature (Deg.C)	T_d
Design Stress (MPa)	f
Design Pressure (MPa)	P_c
Weld efficiency factor for longitudinal weld (Z)	1.00
Outer Diameter (mm)	D_o
Nominal Wall Thickness in Straight Pipe (mm)	e_{nom}
Corrosion Allowance (mm)	$C_0 =$ 1.00
Negative Tolerance	C_1
Thinning allowance due to manufacturing	C_2

Set parameter "Uniform Bend" below to "Yes" or "No" or "NA"

Input

DN :=	Td :=
25	221
50	221
150	221
200	221
300	221
350	221
400	221
500	221

DN :=	f :=	Pc :=
25	132.8	2.26
50	132.8	2.26
150	132.8	2.26
200	132.8	2.26
300	132.8	2.26
350	132.8	2.26
400	132.8	2.26
500	132.8	2.26

DN :=	Do :=	enom :=
25	33.7	2.6
50	60.3	2.9
150	168.3	4.5
200	219.1	6.3
300	323.9	7.1
350	355.6	8
400	406.4	8.8
500	508	11

	DN :=		C_1 :=		C_2 :=
	25		0.325		0
	50		0.3625		0
DN :=	150	C_1 :=	0.5625	C_2 :=	0
	200		0.7875		0
	300		0.8875		0
	350		1		0
	400		1.1		0
	500		1.375		0

Result

Straight Pipe

Minimum required wall thickness e_p

Analysis wall thickness e_a

Utilization factor shall be less than or equal to 1 : Up = ep/ea

	25		1.28		1.18
	50		1.54		1.11
DN :=	150	e_a :=	2.94	$\frac{D_0}{D_0-2e_{nom}}$:=	1.06
	200		4.51		1.06
	300		5.21		1.05
	350		6.00		1.05
	400		6.70		1.05
	500		8.63		1.05

if $\frac{D_0}{D_0-2e_{nom}} < 1.7, then\ e = \frac{P_c D_0}{2fz+P_c}$ (6.1-1) else $e = \frac{D_o}{2}\left[1-\sqrt{\frac{fz-p_c}{fz+p_c}}\right]$(6.1-3)

	25		0.28		0.22
	50		0.51		0.33
DN :=	150	e_p :=	1.42	U_p :=	0.48
	200		1.85		0.41
	300		2.73		0.52
	350		3.00		0.50
	400		3.43		0.51
	500		4.29		0.50

Bend with Uniform Thickness due to Internal Pressure according to Chapter 6.2.3.3 of SS-EN 13480-3:2017(E) Issue 1 (2017-06)

General

Material	EN 10216-2 10CrMo9-10 W1.7380	
Design Temperature (Deg.C)	T_d	
Design Stress (MPa)	f	
Design Pressure (MPa)	P_c	
Weld efficiency factor for longitudinal weld	z	1.00
Outer Diameter (mm)	D_o	
Nominal Wall Thickness of bend intrados (mm)	e_{intnom}	
Nominal Wall Thickness of bend extrados (mm)	e_{extnom}	
Bend Radius (mm)	R_1	
Corrosion Allowance (mm)	C_0 =	1.00
Negative Tolerance	C_1	
Thinning allowance due to	C_2	

Set parameter "Uniform Bend" below to "Yes" or "No" or "NA"

Input

DN :=	150	Uniform Bend :=	Yes	Td :=	221
	200		Yes		221
	300		Yes		221
	350		Yes		221
	350		Yes		221
	400		Yes		221
	500		Yes		221

	150		132.8		2.26
DN :=	200	f :=	132.8	Pc :=	2.26
	300		132.8		2.26
	350		132.8		2.26
	350		132.8		2.26
	400		132.8		2.26
	500		132.8		2.26

	150		168.3	e_{intnom} =	4.5
DN :=	200	Do :=	219.1	e_{extnom} :=	6.3
	300		323.9		7.1
	350		355.6		8
	350		355.6		8
	400		406.4		8.8
	500		508		11

	150		229		0.5625
DN :=	200	R1 :=	305	C_1 :=	0.7875
	300		457		0.8875
	350		533		1
	350		356		1
	400		610		1.1
	500		762		1.375

	150		0
DN :=	200	C_2 :=	0
	300		0
	350		0
	350		0
	400		0
	500		0

Minimum required wall thickness of pipe e

Analysis wall thickness e_a

Utilization factor shall be less than or equal to 1 : $U_f = ep / ea$

	150		2.94	$\frac{D_0}{D_0-2e_a}$:=	1.04
DN :=	200	e_a :=	4.51		1.04
	300		5.21		1.03
	350		6.00		1.03
	350		6.00		1.03
	400		6.70		1.03
	500		8.63		1.04

if $\frac{D_0}{D_0-2e_{nom}} < 1.7, then\ e = \frac{P_c D_0}{2fz+P_c}$ (6.1-1) else $e = \frac{D_o}{2}\left[1-\sqrt{\frac{fz-p_c}{fz+p_c}}\right]$(6.1-3)

DN :=	150	e :=	1.42
	200		1.85
	300		2.73
	350		3.00
	350		3.00
	400		3.43
	500		4.29

Result

Pipe Bend with Uniform Thickness

$e_{int} = e\ B_{int}$

$e_{ext} = e\ B_{ext}$

$$B_{int} = \frac{D_0}{2e} + \frac{r}{e} - \left[\frac{D_o}{2e} + \frac{r}{e} - 1\right]\sqrt{\frac{\left(\frac{r}{e}\right)^2 - \left(\frac{D_o}{2e}\right)^2}{\left(\frac{r}{e}\right)^2 - \frac{D_o}{2e}\left(\frac{D_o}{2e} - 1\right)}} \quad \text{(B.4.1-3)}$$

$$\frac{r}{e} = \sqrt{\frac{1}{2}\left\{\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2\right\} + \sqrt{\frac{1}{4}\left(\left(\frac{D_o}{2e}\right)^2 + \left(\frac{R}{e}\right)^2\right)^2 - \frac{D_o}{2e}\left(\frac{D_o}{2e} - 1\right)\left(\frac{R}{e}\right)^2}} \quad \text{(B.4.1-4)}$$

DN :=	150	R/e :=	161.27	$D_0/2e$:=	59.26	r/e :=	161.48
	200		164.99		59.26		165.20
	300		167.23		59.26		167.43
	350		177.65		59.26		177.84
	350		118.66		59.26		118.99
	400		177.90		59.26		178.09
	500		177.78		59.26		177.97

DN :=		B_{int} :=		e_{int} :=
150		1.29		1.83
200		1.28		2.36
300		1.27		3.48
350		1.25		3.75
350		1.49		4.47
400		1.25		4.28
500		1.25		5.35

DN :=		U_{f1} :=
150		0.62
200		0.52
300		0.67
350		0.62
350		0.75
400		0.64
500		0.62

$$B_{ext} = \frac{D_0}{2e} - \frac{r}{e} - \left[\frac{D_O}{2e} - \frac{r}{e} - 1\right]\sqrt{\frac{\left(\frac{r}{e}\right)^2 - \left(\frac{D_O}{2e}\right)^2}{\left(\frac{r}{e}\right)^2 - \frac{D_O}{2e}\left(\frac{D_O}{2e} - 1\right)}} \quad \text{(B.4.1-9)}$$

DN :=		B_{ext} :=		e_{ext} :=
150		0.86		1.23
200		0.87		1.60
300		0.87		2.37
350		0.87		2.62
350		0.83		2.50
400		0.87		3.00
500		0.87		3.75

DN :=		U_{f2} :=
150		0.42
200		0.36
300		0.46
350		0.44
350		0.42
400		0.45
500		0.43

Reducer without knuckle due to Internal Pressure according to Chapter 6.4 of SS-EN 13480-3:2017(E) Issue 1 (2017-06)

Input

Material	EN 10216-2 10CrMo9-10 W1.7380	
Design Temperature (Deg.C)	T_d	
Design Stress (MPa)	f	
Design Pressure (MPa)	P_c	
Weld efficiency factor for longitudinal weld (Z)	1.00	
Large Pipe Outer Diameter (mm)	D	
Small Pipe Outer Diameter (mm)	D_1	
Nominal Wall Thickness in Large Pipe (mm)	T	
Nominal Wall Thickness in Small Pipe (mm)	T_1	
Nominal Wall Thickness of Reducer	e_{nom}	
Assumed minimum Wall Thickness at the Junction of Large End of Cone	e_{aj}	
Semi Angle of Reducer at Apex	α	
Weld effeciency factor for Longitudinal Weld	Z	1.00
Corrosion Allowance (mm)	C_0 =	1.00
Negative Tolerance in Large Pipe	C_{l1}	
Negative Tolerance in Small Pipe	C_{s1}	
Negative Tolerance in Reducer	C_1	
Thinning allowance due to manufacturing	C_2	

Input

DN :=	Reducer Type :=	Td :=	f :=
200x150	E	221	132.8
400x200	E	221	132.8
400x350	E	221	132.8
500x300	C	221	132.8
500x300	E	221	132.8
500x400	E	221	132.8

DN :=	D1 :=	T :=	enom :=
200x150	219.1	6.3	6.3
400x200	406.4	8.8	8.8
400x350	406.4	8.8	8.8
500x300	508	11	11
500x300	508	11	11
500x400	508	11	11

DN :=	D2 :=	T1 :=	L :=
200x150	168.3	4.5	152
400x200	219.1	6.3	356
400x350	355.6	8	356
500x300	323.9	7.1	508
500x300	323.9	7.1	508
500x400	406.4	8.8	508

DN :=	α :=	Cl1 :=	Cs1 :=
200x150	31.00	0.7875	0.5625
400x200	46.00	1.1	0.7875
400x350	8.00	1.1	1
500x300	20.00	1.375	0.8875
500x300	32.00	1.375	0.8875
500x400	18.00	1.375	1.1

DN :=	C1 :=	C2 :=	Pc :=
200x150	0.7875	0	2.26
400x200	1.1	0	2.26
400x350	1.1	0	2.26
500x300	1.375	0	2.26
500x300	1.375	0	2.26
500x400	1.375	0	2.26

DN :=	ej :=	ea1 :=	ea2 :=
200x150	1.55	4.51	2.94
400x200	4.12	6.70	4.51
400x350	0.96	6.70	6.00
500x300	2.53	8.63	5.21
500x300	3.71	8.63	5.21
500x400	2.33	8.63	6.70

Result

Reducers Concentric and Eccentric

6.4.6 Junction between the large end of a cone and a cylinder without a knuckle

6.4.6.2 Design

$$e_{p2} = \max(e_1, e_{cyl})$$

$$e_j = \frac{p_c D_c \beta}{2f}; \beta = \frac{1}{3}\sqrt{\frac{D_c}{e_j}}\frac{\tan\alpha}{1+\frac{1}{\sqrt{\cos\alpha}}}$$

$$e_{cyl} = \frac{p_c D_o}{2fZ + p_c}$$

$$e_{p1} = \max(e_j, e_{con})$$

$$e_{con} = \frac{p_c D_e}{2fZ + p_c}\frac{1}{COS(\alpha)}$$

6.4.8 Junction between the small end ofa cone and a cylinder

6.4.8.2 Design

$s = \frac{e_2}{e_1}$ when s < 1; $\tau = s\sqrt{\frac{s}{\cos\alpha}}+\sqrt{\frac{1+s^2}{2}}$ when s >= 1; $\tau = 1+\sqrt{s\frac{1+s^2}{2\cos\alpha}}$

$$\beta_H = 0.4\sqrt{\frac{D_c}{e_1}\frac{\tan\alpha}{\tau}}+0.5$$

$$p_c = \frac{2fze_1}{D_c\beta_H}$$

Conditions of Applicability

	200x150		Valid		1.71
	400x200		Valid		4.52
DN :=	400x350	Equ. 6.4.1-1 :=	Valid	e_j :=	1.04
	500x300		Valid		2.78
	500x300		Valid		4.08
	500x400		Valid		2.56

	0.935646		1.71		1.80		2.16
	1.329566		4.52		3.35		4.94
β :=	0.311309	e_j :=	1.06	ecyl :=	3.35	econ :=	3.46
	0.655057		2.78		4.19		4.56
	0.95975		4.08		4.19		5.05
	0.601375		2.56		4.19		4.51

Reducer at the Junction to the Larger Pipe :

	200x150		2.16		3.43		**0.48**
	400x200		4.94		6.55		**0.74**
						Uf1:=	
DN :=	400x350		3.46		4.90	ep1/ea1	**0.52**
	500x300	ep1 :=	4.56	e1rednom:=	6.13		**0.53**
	500x300		5.05		6.69		**0.59**
	500x400		4.51		6.07		**0.52**

Reducer at the Junction to the Small Pipe :

	200x150		2.16		2.14		1.01
	400x200		4.94		3.01		1.64
DN :=	400x350		3.46		2.31		1.50
	500x300	e2 :=	4.56	e1 :=	2.91	s:=	1.57
	500x300		5.05		3.90		1.30
	500x400		4.51		3.77		1.20

	200x150		2.09		1.51
	400x200		3.09		1.63
DN :=	400x350		2.57		0.77
	500x300	z :=	2.70	Bh :=	1.06
	500x300		2.43		1.43
	500x400		2.24		1.10

	200x150		2.13		1.38		2.16
	400x200		2.99		1.80		4.94
DN :=	400x350		2.31		2.93		3.46
	500x300	e1 :=	2.90	ecyl :=	2.67	econ :=	4.56
	500x300		3.88		2.67		5.05
	500x400		3.76		3.35		4.51

	200x150		2.13		3.40		**0.73**
	400x200		2.99		4.37		**0.66**
DN :=	400x350		2.93		4.30		**0.49**
						Uf2:=	
	500x300	ep2 :=	2.90	e1spnom:=	4.27	ep2/ea2	**0.56**
	500x300		3.88		5.37		**0.75**
	500x400		3.76		5.23		**0.56**

Internal Pressure Design Results from CAEPIPE

Caepipe | Pressure Design (Internal) | Page 1

Pipe material 1: EN 10216-2 10CrMo9-10 Seamless

Density = 7850 (kg/m3), Nu = 0.300, Joint factor = 0.80, Type = CS
Tensile strength = 229.8 (N/mm2)

Temp (C)	E (kN/mm2)	Alpha (mm/mm/C)	ff (N/mm2)	fCR (N/mm2)
20	211	11.51E-6	137.1	
50	209	11.78E-6	136.9	
100	206	12.10E-6	136.5	
150	203	12.43E-6	132.8	
200	199	12.75E-6	132.8	
250	196	13.08E-6	132.8	
300	192	13.22E-6	132.8	

Pipe Sections (8)

Name	Nom Dia	Sch	OD (mm)	Thk (mm)	Cor.Al (mm)	M.Tol (%)	Ins.Dens (kg/m3)	Ins.Thk (mm)	Lin.Dens (kg/m3)	Lin.Thk (mm)	Soil
25	25	3	33.7	2.6	1	12.5					
50	50	3	60.3	2.9	1	12.5					
150	150	3	168.3	4.5	1	12.5	150	100	2700	1	
200	200	3	219.1	6.3	1	12.5	150	120	2700	1	
300	300	3	323.9	7.1	1	12.5	150	140	2700	1	
350	350	3	355.6	8	1	12.5	150	140	2700	1	
400	400	3	406.4	8.8	1	12.5	150	140	2700	1	
500	500	3	508	11	1	12.5	200	140	2700	1	

Caepipe | Pressure Design (Internal) | Page 1

Internal Pressure Design: EN 13480-3 (2017) (179)

From	To	Element Type	Des.Temp (C)	Des.Press (bar)	All.Stress (N/mm2)	OD1 (mm)	OD2 (mm)	Cor.All (mm)	Radius (mm)	Cone Angle (deg)	ea1 (mm)	ea2 (mm)	ep1 (mm)	ep2 (mm)	Uf1 (ep1/ea1)	Uf2 (ep2/ea2)
10	20	Elbow	221	22.6	132.8	355.6	355.6	1	356		6	6	4.4417	4.4417	0.74	0.74
		Bend	221	22.6	132.8	355.6	355.6	1	356		6	6	4.4824	2.4943	0.75	0.42
20	30	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
30	40	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
40	50	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
50	60	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
60	70	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
70	80	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
80	90	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
90	100	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
100	110	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
120	130	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
140	150	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
150	160	Reducer	221	22.6	132.8	406.4	355.6	1		8	6.7	6	3.4289	3.0003	0.51	0.50
160	170	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
170	180	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
180	190	Reducer	221	22.6	132.8	406.4	219.1	1		46	6.7	4.5125	4.4882	2.9294	0.67	0.65
190	200	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
200	210	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
210	220	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
220	230	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
230	240	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
240	250	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
250	260	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41

Caepipe Pressure Design (Internal) Page 2

Internal Pressure Design: EN 13480-3 (2017) (179)

From	To	Element Type	Des.Temp (C)	Des.Press (bar)	All.Stress (N/mm2)	OD1 (mm)	OD2 (mm)	Cor.All (mm)	Radius (mm)	Cone Angle (deg)	ea1 (mm)	ea2 (mm)	ep1 (mm)	ep2 (mm)	Uf1 (ep1/ea1)	Uf2 (ep2/ea2)
260	270	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
280	290	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
300	310	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
310	320	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
320	330	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
330	340	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
340	350	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
350	360	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
360	370	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
370	380	Reducer	221	22.6	132.8	219.1	168.3	1		31	4.5125	2.9375	1.8486	2.0994	0.41	0.71
380	390	Pipe	221	22.6	132.8	168.3	168.3	1			2.9375	2.9375	1.42	1.42	0.48	0.48
390	400	Elbow	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.821	1.821	0.62	0.62
		Bend	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.8298	1.2277	0.62	0.42
400	410	Elbow	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.821	1.821	0.62	0.62
		Bend	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.8298	1.2277	0.62	0.42
410	420	Elbow	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.821	1.821	0.62	0.62
		Bend	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.8298	1.2277	0.62	0.42
420	430	Pipe	221	22.6	132.8	168.3	168.3	1			2.9375	2.9375	1.42	1.42	0.48	0.48
360	500	Elbow	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.821	1.821	0.62	0.62
		Bend	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.8298	1.2277	0.62	0.42
500	510	Elbow	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.821	1.821	0.62	0.62
		Bend	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.8298	1.2277	0.62	0.42
510	520	Pipe	221	22.6	132.8	168.3	168.3	1			2.9375	2.9375	1.42	1.42	0.48	0.48
1000	1010	Elbow	221	22.6	132.8	355.6	355.6	1	356		6	6	4.4417	4.4417	0.74	0.74
		Bend	221	22.6	132.8	355.6	355.6	1	356		6	6	4.4824	2.4943	0.75	0.42
1010	1020	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1020	1030	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44

Caepipe Pressure Design (Internal) Page 3

Internal Pressure Design: EN 13480-3 (2017) (179)

From	To	Element Type	Des.Temp (C)	Des.Press (bar)	All.Stress (N/mm2)	OD1 (mm)	OD2 (mm)	Cor.All (mm)	Radius (mm)	Cone Angle (deg)	ea1 (mm)	ea2 (mm)	ep1 (mm)	ep2 (mm)	Uf1 (ep1/ea1)	Uf2 (ep2/ea2)
1030	1040	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1040	1050	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1050	1060	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
1060	1070	Elbow	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7316	3.7316	0.62	0.62
		Bend	221	22.6	132.8	355.6	355.6	1	533		6	6	3.7468	2.6225	0.62	0.44
1070	1080	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1080	1090	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1090	1100	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1110	1120	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1130	1140	Pipe	221	22.6	132.8	355.6	355.6	1			6	6	3.0003	3.0003	0.50	0.50
1140	1150	Reducer	221	22.6	132.8	406.4	355.6	1		8	6.7	6	3.4289	3.0003	0.51	0.50
1150	1160	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
1160	1170	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
1170	1180	Reducer	221	22.6	132.8	406.4	219.1	1		46	6.7	4.5125	4.4882	2.9294	0.67	0.65
1180	1190	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
1190	1200	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
1200	1210	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
1210	1220	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
1220	1230	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
1230	1240	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
1240	1250	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
1250	1260	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
1270	1280	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
1290	1300	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
1300	1310	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36

Internal Pressure Design: EN 13480-3 (2017) (179)

From	To	Element Type	Des.Temp (C)	Des.Press (bar)	All.Stress (N/mm2)	OD1 (mm)	OD2 (mm)	Cor.All (mm)	Radius (mm)	Cone Angle (deg)	ea1 (mm)	ea2 (mm)	ep1 (mm)	ep2 (mm)	Uf1 (ep1/ea1)	Uf2 (ep2/ea2)
1310	1320	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
1320	1330	Elbow	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3525	2.3525	0.52	0.52
		Bend	221	22.6	132.8	219.1	219.1	1	305		4.5125	4.5125	2.3634	1.6025	0.52	0.36
1330	1340	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
1340	1350	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
1350	1360	Pipe	221	22.6	132.8	219.1	219.1	1			4.5125	4.5125	1.8486	1.8486	0.41	0.41
1360	1370	Reducer	221	22.6	132.8	219.1	168.3	1		31	4.5125	2.9375	1.8486	2.0994	0.41	0.71
1370	1380	Pipe	221	22.6	132.8	168.3	168.3	1			2.9375	2.9375	1.42	1.42	0.48	0.48
1380	1390	Elbow	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.821	1.821	0.62	0.62
		Bend	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.8298	1.2277	0.62	0.42
1390	1400	Elbow	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.821	1.821	0.62	0.62
		Bend	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.8298	1.2277	0.62	0.42
1400	1410	Elbow	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.821	1.821	0.62	0.62
		Bend	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.8298	1.2277	0.62	0.42
1410	1420	Pipe	221	22.6	132.8	168.3	168.3	1			2.9375	2.9375	1.42	1.42	0.48	0.48
1350	1500	Elbow	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.821	1.821	0.62	0.62
		Bend	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.8298	1.2277	0.62	0.42
1500	1510	Elbow	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.821	1.821	0.62	0.62
		Bend	221	22.6	132.8	168.3	168.3	1	229		2.9375	2.9375	1.8298	1.2277	0.62	0.42
1510	1520	Pipe	221	22.6	132.8	168.3	168.3	1			2.9375	2.9375	1.42	1.42	0.48	0.48
170	1600	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
1600	1610	Elbow	221	22.6	132.8	406.4	406.4	1	610		6.7	6.7	4.2629	4.2629	0.64	0.64
		Bend	221	22.6	132.8	406.4	406.4	1	610		6.7	6.7	4.2803	2.9976	0.64	0.45
1610	1620	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
1160	1850	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
1620	1800	Reducer	221	22.6	132.8	508	406.4	1		18	8.625	6.7	4.2861	3.7079	0.50	0.55
1800	1810	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1810	1820	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1820	1830	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1830	1840	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50

Internal Pressure Design: EN 13480-3 (2017) (179)

From	To	Element Type	Des.Temp (C)	Des.Press (bar)	All.Stress (N/mm2)	OD1 (mm)	OD2 (mm)	Cor.All (mm)	Radius (mm)	Cone Angle (deg)	ea1 (mm)	ea2 (mm)	ep1 (mm)	ep2 (mm)	Uf1 (ep1/ea1)	Uf2 (ep2/ea2)
1840	1850	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1850	1860	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1860	1870	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
1870	1880	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1880	1890	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
1890	1900	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
1900	1910	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
1910	1920	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
1920	1930	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1930	1940	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1950	1960	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1960	1970	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
1970	1980	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1980	1985	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1985	1990	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1990	2000	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
2000	2010	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
2010	2020	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
2020	2030	Reducer	221	22.6	132.8	508	406.4	1		18	8.625	6.7	4.2861	3.7079	0.50	0.55
2030	2040	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
2040	2045	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
2045	2050	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
2050	2055	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
2055	2060	Elbow	221	22.6	132.8	406.4	406.4	1	610		6.7	6.7	4.2629	4.2629	0.64	0.64
		Bend	221	22.6	132.8	406.4	406.4	1	610		6.7	6.7	4.2803	2.9976	0.64	0.45

Internal Pressure Design: EN 13480-3 (2017) (179)																
From	To	Element Type	Des.Temp (C)	Des.Press (bar)	All.Stress (N/mm2)	OD1 (mm)	OD2 (mm)	Cor.All (mm)	Radius (mm)	Cone Angle (deg)	ea1 (mm)	ea2 (mm)	ep1 (mm)	ep2 (mm)	Uf1 (ep1/ea1)	Uf2 (ep2/ea2)
2060	2070	Elbow	221	22.6	132.8	406.4	406.4	1	610		6.7	6.7	4.2629	4.2629	0.64	0.64
		Bend	221	22.6	132.8	406.4	406.4	1	610		6.7	6.7	4.2803	2.9976	0.64	0.45
2070	2080	Elbow	221	22.6	132.8	406.4	406.4	1	406		6.7	6.7	5.083	5.083	0.76	0.76
		Bend	221	22.6	132.8	406.4	406.4	1	406		6.7	6.7	5.1299	2.8498	0.77	0.43
2080	2090	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
2090	2100	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
2110	2120	Reducer	221	22.6	132.8	508	406.4	1		18	8.625	6.7	4.2861	3.7079	0.50	0.55
2120	2130	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
2130	2140	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
2010	2200	Elbow	221	22.6	132.8	406.4	406.4	1	610		6.7	6.7	4.2629	4.2629	0.64	0.64
		Bend	221	22.6	132.8	406.4	406.4	1	610		6.7	6.7	4.2803	2.9976	0.64	0.45
2200	2220	Elbow	221	22.6	132.8	406.4	406.4	1	406		6.7	6.7	5.083	5.083	0.76	0.76
		Bend	221	22.6	132.8	406.4	406.4	1	406		6.7	6.7	5.1299	2.8498	0.77	0.43
2220	2230	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
2230	2240	Pipe	221	22.6	132.8	406.4	406.4	1			6.7	6.7	3.4289	3.4289	0.51	0.51
2250	2260	Reducer	221	22.6	132.8	508	406.4	1		18	8.625	6.7	4.2861	3.7079	0.50	0.55
2260	2270	Elbow	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3297	5.3297	0.62	0.62
		Bend	221	22.6	132.8	508	508	1	762		8.625	8.625	5.3514	3.7467	0.62	0.43
2270	2280	Pipe	221	22.6	132.8	508	508	1			8.625	8.625	4.2861	4.2861	0.50	0.50
1990	2500	Pipe	221	22.6	132.8	60.3	60.3	1			1.5375	1.5375	0.50877	0.50877	0.33	0.33
2000	2600	Pipe	221	22.6	132.8	60.3	60.3	1			1.5375	1.5375	0.50877	0.50877	0.33	0.33
2090	2700	Pipe	221	22.6	132.8	33.7	33.7	1			1.275	1.275	0.28434	0.28434	0.22	0.22
2230	2800	Pipe	221	22.6	132.8	33.7	33.7	1			1.275	1.275	0.28434	0.28434	0.22	0.22

External Pressure Design of Pipe and Pipe Fittings

CAEPIPE model file for external design pressure verification is available in the verification package. See file Verification_External_Pressure.mod for details on input shown below.

Calculation of Straight Pipe and Elbows due to External Pressure according to Chapter 9.3 of SS-EN 13480-3:2017 (E) Issue 1 (2017-06)

General

Material	EN 10216-2 10CrMo9-10 W1.7380	
Type	Non-austenitic steels; Enter "NS" Austenitic steels; Enter "AS"	
Design Temperature (Deg.C)	T_d	
Yield strength at design temperature	$R_{p0.2T}$	In CAEPIPE, this value is computed as "f x 1.5", where f = allowable stress at design temperature
Design Pressure (MPa)	P_c	
Modulus of Elasticity at Design Temperature	E_t	
Outer Diameter (mm)	D_o	
Nominal Wall Thickness in Straight Pipe	e_{nom}	
Bend Radius (mm)	R	
Corrosion Allowance (mm)	C_0 =	1.00
Negative Tolerance	C_1	
Thinning allowance due to manufacturing	C_2	
No. of circumferential waves for an unstiffned length of shell	n_{cyl}	
Unstiffend length of shell	L	
Poisson's ratio	v	0.3

Input

DN :=	Material :=	Td :=	Rp0.2T :=
Pipe: 350	NS	221	199.2
Elbow: 350	NS	221	199.2
Pipe: 350	NS	221	199.2
Pipe: 400	NS	221	199.2
Pipe: 500	NS	221	199.2
Elbow: 150	NS	221	199.2

DN :=	Pc :=	Et :=
Pipe: 350	0.10	198000
Elbow: 350	0.10	198000
Pipe: 350	0.10	198000
Pipe: 400	0.10	198000
Pipe: 500	0.10	198000
Elbow: 150	0.10	198000

DN :=	Do :=	enom :=	L :=
Pipe: 350	355.6	8	1467
Elbow: 350	355.6	8	1116.52
Pipe: 350	355.6	8	467
Pipe: 400	406.4	8.8	1500
Pipe: 500	508	11	1000
Elbow: 150	168.3	4.5	491.895

DN :=	C1 :=	C2 :=	Initial ncyl :=
Pipe: 350	1	0	2
Elbow: 350	1	0	2
Pipe: 350	1	0	2
Pipe: 400	1.1	0	2
Pipe: 500	1.375	0	2
Elbow: 150	0.5625	0	2

Result

Lower Bound Collapse Pressure	Pr
Utilization factor shall be equal to or greater than 1	Pr/kPc

9.3.2 Interstiffener collapse

$P_y = \frac{Se_a}{R_m}$ where $R_m = mean\ radius\ of\ the\ cylinder$ (9.3.2-1)

$P_m = \frac{E_t e_a \varepsilon}{R_m}$ (9.3.2-2)

$\varepsilon = \frac{1}{n_{cyl^2} - 1 + \frac{Z^2}{2}} \left\{ \frac{1}{\left(\frac{n_{cyl^2}}{Z^2} + 1\right)^2} + \frac{e_a{}^2}{12 R_m{}^2 (1 - \nu^2)} \left(n_{cyl^2} - 1 + Z^2\right)^2 \right\}$ (9.3.2-3)

$Z = \frac{\pi R_m}{L}$ (9.3.2-4)

	Pipe: 350		6.00		173.80		199.2
	Elbow: 350		6.00		173.80		199.2
DN :=	Pipe: 350	ea :=	6.00	Rm :=	173.80	S :=	199.2
	Pipe: 400		6.70		198.80		199.2
	Pipe: 500		8.63		248.50		199.2
	Elbow: 150		2.94		81.90		199.2

	Pipe: 350		6.88		0.37		0.0007
	Elbow: 350		6.88		0.49		0.0014
DN :=	Pipe: 350	Py :=	6.88	Z :=	1.17	E :=	0.0182
	Pipe: 400		6.71		0.42		0.0009
	Pipe: 500		6.91		0.78		0.0057
	Elbow: 150		7.14		0.52		0.0017

	Pipe: 350		4.89		2		0.0007
	Elbow: 350		9.48		3		0.0010
DN :=	Pipe: 350	Initial Pm :=	124.25	Final ncyl:=	4	Final E :=	0.0023
	Pipe: 400		5.99		2		0.0009
	Pipe: 500		39.34		3		0.0015
	Elbow: 150		12.14		3		0.0011

	Pipe: 350		4.89		0.711
	Elbow: 350		6.80		0.989
DN :=	Pipe: 350	Pm :=	15.44	Pm/Py:=	2.246
	Pipe: 400		5.99		0.893
	Pipe: 500		10.10		1.460
	Elbow: 150		7.80		1.091

	Pipe: 350		0.356		0.15		2.45
	Elbow: 350		0.494		0.15		3.40
DN :=	Pipe: 350	Pr/Py :=	0.780	kPc :=	0.15	Pr :=	5.36
	Pipe: 400		0.446		0.15		3.00
	Pipe: 500		0.668		0.15		4.62
	Elbow: 150		0.538		0.15		3.84

	Pipe: 350		**16.30**
	Elbow: 350		**22.65**
DN :=	Pipe: 350	**Pr/kPc :=**	**35.74**
	Pipe: 400		**19.97**
	Pipe: 500		**30.77**
	Elbow: 150		**25.62**

Concentric and Eccentric Reducer without knuckle due to External Pressure according to Chapter 9.4 of SS-EN 13480-3: 2017 (E) Issue 1 (2017-06)

Input

Material	EN 10216-2 10CrMo9-10 W1.7380		
Type	Non-austenitic steels; Enter "NS" Austenitic steels; Enter "AS"		
Design Temperature (Deg.C)	T_d		
Design Stress (MPa)	f		
Design Pressure (MPa)	P_c		
Yield strength at design temperature	$R_{p0.2T}$	In CAEPIPE, this value is computed as "f x 1.5", where f = allowable stress at design temperature	
Modulus of Elasticity at Design	E_t		
Small Pipe Outer Diameter	D_1		
Nominal Wall Thickness in Small Pipe (mm)	e_{n1}		
Nominal Wall Thickness of Reducer	e_{nom}		
Semi Angle of Reducer at Apex	α		
Corrosion Allowance (mm)	C_0 =	1.00	
Negative Tolerance in Small Pipe	C_{s1}		
Negative Tolerance in Reducer	C_1		
Thinning allowance due to manufacturing, Small Pipe	Cs_2		
Thinning allowance due to manufacturing, Reducer	C_2		
Number of circumferential waves for an unstiffend part of the cylinder	n_{cyl}		
Unstiffend length of shell	L		
Poisson's ratio	v		0.3

Enter "Reducer Type" as E for "Eccentric" and C for "Concentric"

Input

DN :=	Reducer Type :=	Type :=	Td :=
200x150	C	NS	221
400x200	C	NS	221
400x350	C	NS	221
500x400	C	NS	221

DN :=	D :=	e :=	Cl1 :=
200x150	219.1	6.3	0.7875
400x200	406.4	8.8	1.1
400x350	406.4	8.8	1.1
500x400	508	11	1.375

DN :=	D1 :=	e1 :=	enom :=
200x150	168.3	4.5	4.5
400x200	219.1	6.3	6.3
400x350	355.6	8	8
500x400	406.4	8.8	8.8

DN :=	α :=	C1 :=	Cs1 :=
200x150	30	0.5625	0.563
400x200	46	0.7875	0.788
400x350	8	1	1.000
500x400	18	1.1	1.100

DN :=	Cs2 :=	C2 :=	Pc :=
200x150	0	0	0.100
400x200	0	0	0.100
400x350	0	0	0.100
500x400	0	0	0.100

DN :=	L :=	ncyl :=	Rp0.2T :=
200x150	152	2	199.200
400x200	356	2	199.200
400x350	356	2	199.200
500x400	508	2	199.200

DN :=	Et :=	f :=
200x150	198000	132.8
400x200	198000	132.8
400x350	198000	132.8
500x400	198000	132.8

Result

Reducers Concentric and Eccentric

Lower Bound Collapse Pressure	Pr
Utilization factor shall be equal to or greater than 1	Pr/kP

9.3.2 Interstiffener collapse

$P_y = \frac{S e_a}{R_m}$ where $R_m = mean\ radius\ of\ the\ cylinder$ (9.3.2-1)

$P_m = \frac{E_t e_a \varepsilon}{R_m}$ (9.3.2-2)

$\varepsilon = \frac{1}{n_{cyl^2} - 1 + \frac{Z^2}{2}} \left\{ \frac{1}{\left(\frac{n_{cyl^2}}{Z^2} + 1\right)^2} + \frac{e_{a^2}}{12 R_{m^2 (1-\nu^2)}} \left(n_{cyl^2} - 1 + Z^2\right)^2 \right\}$ (9.3.2-3)

$Z = \frac{\pi R_m}{L}$ (9.3.2-4)

200x150		4.51		193.70		223.665
400x200		6.70		312.75		450.221
DN := 400x350	ea :=	6.70	Dm := (D+D1)/2.0	381.00	Deq :=	384.744
500x400		8.63		457.20		480.729
200x150		2.94		114.12		199.2
400x200		4.51		247.02		199.2
DN := 400x350	e1a :=	6.00	Rm :=	181.54	S :=	199.2
500x400		6.70		226.73		199.2
200x150		7.88		2.36		0.060
400x200		5.40		2.18		0.056
DN := 400x350	Py :=	7.35	Z :=	1.60	E :=	0.037
500x400		7.58		1.40		0.028
200x150		472.49		5		0.006
400x200		298.54		5		0.003
DN := 400x350	Initial Pm :=	267.22	Final ncyl	4	Final E :=	0.004
500x400		211.54		4		0.003
200x150		**46.27**		5.87		7.336
400x200		**16.53**		3.06		4.532
DN := 400x350	Pm :=	**25.85**	Pm/Py :=	3.52	Pr:=	6.337
500x400		**23.62**		3.12		6.380
200x150		0.931		0.15		**7.34**
400x200		0.839		0.15		**4.53**
DN := 400x350	Pr/Py (from Table 9.3.2-1) :=	0.862	kPc :=	0.15	Pr :=	**6.34**
500x400		0.842		0.15		**6.38**

DN :=		Pr/kPc :=
200x150		**48.91**
400x200		**30.21**
400x350		**42.25**
500x400		**42.54**

9.4 Reducers (Conical Shells)

$$I_x = 0.18 D_{eq} L D_{s^2} \frac{p_c}{E_t} \qquad \textbf{(9.4.2-1)}$$

$$I_{cone} = \left(\sqrt{D_{eq} e_1} \cdot e_1\right)\left(\frac{D_{mcon}}{2}\right)^2$$

$$I_{Cyl} = \left(\sqrt{D_{eq} e_2} \cdot e_2\right)\left(\frac{D_{mcyl}}{2}\right)^2$$

$$I_{stiff} = \left(A_{cone} + A_{cyl}\right)\left(\frac{D_s}{2}\right)^2$$

From the above,

$$I_{cone} + I_{Cyl} = I_{stiff}$$

and

$$D_s = 2\sqrt{\frac{I_{stiff}}{(A_{cone} + A_{cyl})}}$$

DN :=	Dm,con:=	Icone:=	Icyl:=
200x150	214.59	1650343	514731.0597
400x200	399.70	14697164	2341465.127
400x350	399.70	13586469	8808375.744
500x400	499.38	34624396	15186946.3

DN :=	Ds :=	Ix :=	Ixa :=
200x150	199.02	122.4123	514731.0597
400x200	345.37	1738.027	2341465.127
400x350	377.54	1774.869	8808375.744
500x400	461.47	4727.797	15186946.3

DN :=	Ix < Ixa :=
200x150	Valid
400x200	Valid
400x350	Valid
500x400	Valid

External Pressure Design Results from CAEPIPE

Caepipe External Pressure Design Page 1

Pipe material 1: EN 10216-2 10CrMo9-10 Seamless

Density = 7850 (kg/m3), Nu = 0.300, Joint factor = 0.80, Type = CS
Tensile strength = 229.8 (N/mm2)

Temp (C)	E (kN/mm2)	Alpha (mm/mm/C)	f (N/mm2)	fCR (N/mm2)
20	211	11.51E-6	137.1	
50	209	11.78E-6	136.9	
100	206	12.10E-6	136.5	
150	203	12.43E-6	132.8	
200	199	12.75E-6	132.8	
250	196	13.08E-6	132.8	
300	192	13.22E-6	132.8	

Pipe Sections (5)

Name	Nom Dia	Sch	OD (mm)	Thk (mm)	Cor.Al (mm)	M.Tol (%)	Ins.Dens (kg/m3)	Ins.Thk (mm)	Lin.Dens (kg/m3)	Lin.Thk (mm)	Soil
150	150	3	168.3	4.5	1	12.5	150	100	2700	1	
200	200	3	219.1	6.3	1	12.5	150	120	2700	1	
350	350	3	355.6	8	1	12.5	150	120	2700	1	
400	400	3	406.4	8.8	1	12.5	150	140	2700	1	
500	500	3	508	11	1	12.5	200	140	2700	1	

Caepipe : External Pressure Design: EN 13480-3 (2017) (13) - [Verification_External_Pressure.mod (D:\KPDevelopment\CAEPIPEVerificationManual10.30Rev24\Models)]

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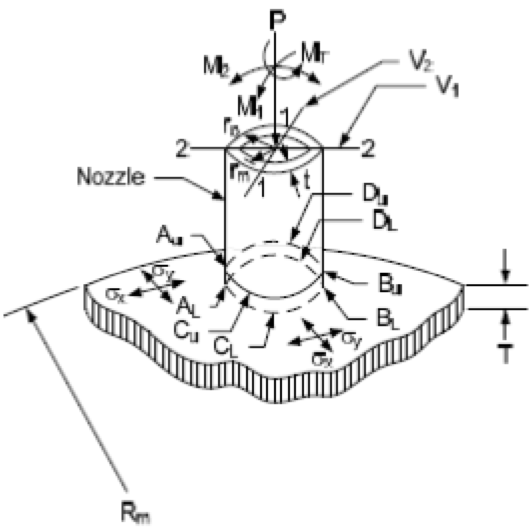
#	From	To	Element Type	Temp (C)	Press (Pc) (MPa)	All.Stress (N/mm2)	Yield (N/mm2)	E (kN/mm2)	OD1 (mm)	OD2 (mm)	Thk1 (mm)	Thk2 (mm)	Cor.All (mm)	Radius (mm)	Length (mm)	ncyl	Cone Angle (deg)	Pr (MPa)	K.Pc (MPa)	(Pr/K.Pc)	Ix (mm4)	Ixa (mm4)
1	10	11A	Pipe	221	0.100	132.8	199.2	198	355.6	355.6	8	8	1		1467	2		2.44	0.15	16.27		
2	11A	11B	Elbow	221	0.100	132.8	199.2	198	355.6	355.6	8	8	1	533	1116.52	3		3.39	0.15	22.60		
3	11B	12	Pipe	221	0.100	132.8	199.2	198	355.6	355.6	8	8	1		467	4		5.36	0.15	35.72		
4	12	20	Reducer	221	0.100	132.8	199.2	198	406.4	355.6	8.8	8	1		356	4	8	6.33	0.15	42.21	1778.71	8.8084E+6
5	20	25	Pipe	221	0.100	132.8	199.2	198	406.4	406.4	8.8	8.8	1		1500	2		2.99	0.15	19.93		
6	25	30	Reducer	221	0.100	132.8	199.2	198	508	406.4	11	8.8	1		508	4	18	6.38	0.15	42.51	4738.02	1.5187E+7
7	30	35	Pipe	221	0.100	132.8	199.2	198	508	508	11	11	1		1000	3		4.61	0.15	30.73		
8	35	40	Reducer	221	0.100	132.8	199.2	198	508	406.4	11	8.8	1		508	4	18	6.38	0.15	42.51	4738.02	1.5187E+7
9	40	50	Reducer	221	0.100	132.8	199.2	198	406.4	219.1	8.8	6.3	1		356	5	46	4.53	0.15	30.20	1741.79	2.3415E+6
10	50	60	Reducer	221	0.100	132.8	199.2	198	219.1	168.3	6.3	4.5	1		152	5	30	7.33	0.15	48.90	122.677	514731
11	60	70A	Pipe	221	0.100	132.8	199.2	198	168.3	168.3	4.5	4.5	1		2771	2		1.26	0.15	8.42		
12	70A	70B	Elbow	221	0.100	132.8	199.2	198	168.3	168.3	4.5	4.5	1	229	491.895	3		3.84	0.15	25.57		
13	70B	80	Pipe	221	0.100	132.8	199.2	198	168.3	168.3	4.5	4.5	1		2771	2		1.26	0.15	8.42		

7 - Verification of Local Shell Stresses at Nozzles as per WRC-537

Local Stresses in Spherical Shells at Hollow Circular Nozzles



V_1	concentrated external shear load in 2-2 direction
V_2	concentrated external shear load in 1-1 direction
M_1	external overturning moment in 1-1 direction
M_2	external overturning moment in 2-2 direction
R_m	mean radius of spherical shell
T	thickness of spherical shell
r_0	outside radius of cylindrical attachment
r_m	mean radius of hollow cylindrical attachment
t	thickness of hollow cylindrical attachment
Υ	r_m / t
ρ	T / t
U	$r_0 / \sqrt{R_m T}$
N_x	membrane force in shell wall in the radial direction, respectively (see Figure 1)
N_y	membrane force in shell wall in the circumferential direction (see Figure 1)
M_x	bending moment in shell wall in the radial direction (see Figure 1)
M_y	bending moment in shell wall in the circumferential direction (see Figure 1)
σ_x	normal stress in radial direction (see Figure 1)
σ_y	normal stress in circumferential direction (see Figure 1)
τ_{xy}	shear stress on the x-face in the y-direction
τ_{yx}	shear stress on the y-face in the x-direction
τ_1	shear stress on the 1-1 face
τ_2	shear stress on the 2-2 face

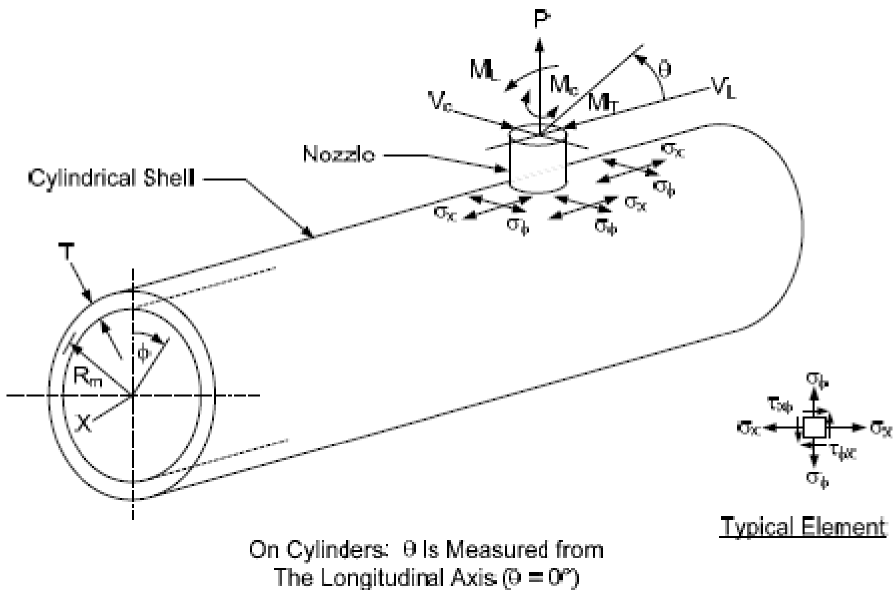
Problem SUMMARY	
What was compared	Local Shell Stresses computed as per WRC-537 for Nozzle attached to Spherical Vessel
Load cases analyzed	Operating
Filename	1. WRC-537\WRC-537_Nozzle_Spherical.noz – CAEPIPE Input and Results file 2. WRC-537\WRC-537_Nozzle_Spherical.pdf – Softcopy output of CAEPIPE Input and Results. 3. WRC-537\WRC-537_Nozzle_Spherical.xlsx – Manual calculations using MS-Excel for verification.

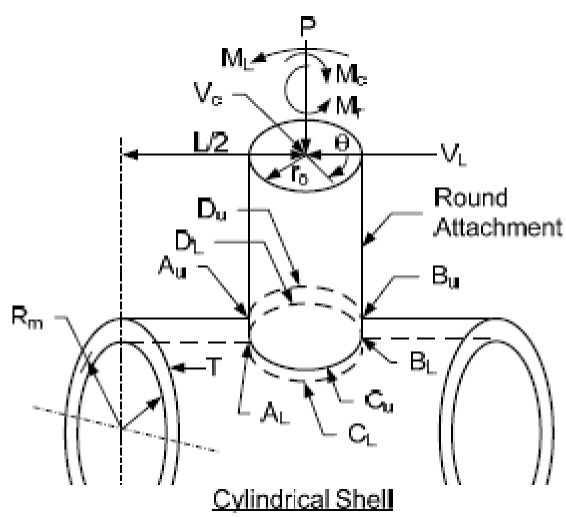
Input:

```
Caepipe                 WRC-537_Nozzle_Spherical.noz             Page 1
Version 10.50                                                    Dec 21,2021
-----------------------------------------------------------------------------------
                           Local Shell Stresses at Nozzles
-----------------------------------------------------------------------------------
Input Data:
Local Shell Stresses at Nozzles attached to Spherical Shells
Load Case: Operating
Radial Load [P]:                                                    137    (lb)
Shear Load [V1]:                                                   -847    (lb)
Shear Load [V2]:                                                    332    (lb)
Overturning Moment [M1]:                                            828    (ft-lb)
Overturning Moment [M2]:                                           3986    (ft-lb)
Torsional Moment [MT]:                                           -17117    (ft-lb)
Vessel Thickness [T]:                                              0.35    (inch)
Vessel Mean Radius: [Rm]:                                        31.325    (inch)
Nozzle Thickness [t]:                                              0.25    (inch)
Nozzle Outside Radius [ro]:                                          11    (inch)
Nozzle Mean Radius [rm]:                                         10.875    (inch)
Fillet Radius [r]:                                                    1    (inch)
Pressure Stress at Shell [Pm]:                                     1343    (psi)
Bending Stress at Shell [Pb]:                                     20245    (psi)
Operating Allowable [All]:                                       106200    (psi)
Stress Conc. Factor - Tension [Kn]:                                0.00
Stress Conc. Factor - Bending [Kb]:                                0.00
```

See Excel file and PDF file mentioned above from the folder “WRC-537” for manual calculations and CAEPIPE results.

Local Stresses in Cylindrical Shells at Solid Circular Attachments





V_c	concentrated shear load in the circumferential direction, lb
V_L	concentrated shear load in the longitudinal direction
M_c	external overturning moment in the circumferential direction with respect to the shell
M_L	external overturning moment in the longitudinal direction with respect to the shell
R_m	mean radius of cylindrical shell
l	length of cylindrical shell
r_0	outside radius of cylindrical attachment
T	wall thickness of cylindrical shell
β	attachment parameter

Problem SUMMARY	
What was compared	Local Shell Stresses computed as per WRC-537 for Nozzle attached to Cylindrical Vessel
Load cases analyzed	Operating
Filename	1. WRC-537\ WRC-537_Nozzle_Cylindrical.noz – CAEPIPE Input and Results file 2. WRC-537\ WRC-537_Nozzle_Cylindrical.pdf – Softcopy output of CAEPIPE Input and Results. 3. WRC-537\ WRC-537_Nozzle_Cylindrical.xlsx – Manual calculations using MS-Excel for verification.

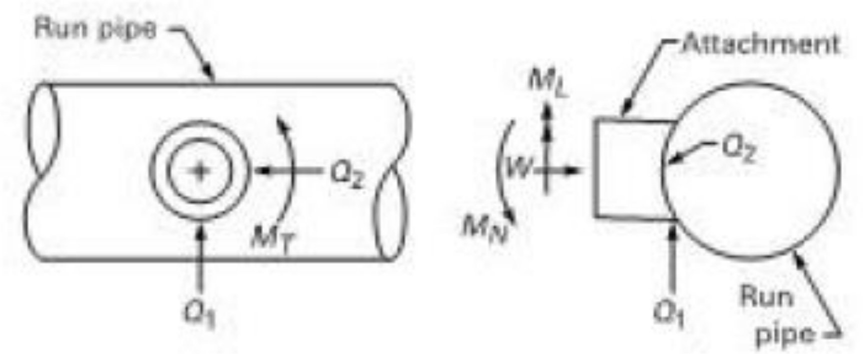
Input:

```
Caepipe                WRC-537_Nozzle_Cylindrical.noz            Page 1
Version 10.50                                                    Dec 21,2021
--------------------------------------------------------------------------------
                           Local Shell Stresses at Nozzles
--------------------------------------------------------------------------------
Input Data:
Local Shell Stresses at Nozzles attached to Cylindrical Shells
Load Case : Operating
Radial Load [P]:                                                   137    (lb)
Shear Load [VC]:                                                  -847    (lb)
Shear Load [VL]:                                                   332    (lb)
Circumferential Moment [MC]:                                       828    (ft-lb)
Longitudinal Moment [ML]:                                         3986    (ft-lb)
Torsional Moment [MT]:                                          -17117    (ft-lb)
Vessel Thickness [T]:                                             0.35    (inch)
Vessel Radius: [Rm]:                                            31.325    (inch)
Attachment Radius [ro]:                                             11    (inch)
Fillet Radius [r]:                                                   1    (inch)
Pressure Stress at Shell [Pm]:                                    1343    (psi)
Bending Stress at Shell [Pb]:                                    20245    (psi)
Operating Allowable [All]:                                      106200    (psi)
Stress Conc. Factor - Tension [Kn]:                               0.00
Stress Conc. Factor - Bending [Kb]:                               0.00
```

See Excel file and PDF file mentioned above from the folder “WRC-537” for manual calculations and CAEPIPE results.

8 - Verification of Local Pipe Stresses at Attachments (Lugs)

Hollow Circular Welded Attachments to Piping as per ASME Section III, Division 1, NC & ND (2010) and EN13480-3 (2017)



The notations described below are used in the formulas for the design.

R = mean run pipe radius

R_o = run pipe outside radius

r_o = attachment outside radius

r_i = attachment inside radius

D_o = outside diameter of run pipe

d_o = outside diameter of attachment

T = nominal run pipe wall thickness

t = nominal attachment wall thickness

$A_T = \pi({r_o}^2 - {r_i}^2)$ = cross-sectional area of the circular attachment

$I_T = \frac{\pi}{4}({r_o}^4 - {r_i}^4)$

$Z_T = \frac{I_T}{r_o}$

$J = \min(\pi {r_o}^2 T,\ Z_T)$

$\gamma = \frac{R_o}{T}$

$\beta = \frac{d_o}{D_o}$

$\tau = \frac{t}{T}$

Limits of Applicability

$\mathbf{4.0 \leq \gamma \leq 50}$

$0.2 \leq \tau \leq 1.0$

$0.3 \leq \beta \leq 1.0$

M_L = bending moment applied to the attachment as shown in figure above
M_N = bending moment applied to the attachment as shown in figure above
M_T = torsional moment applied to the attachment as shown in figure above
Q_1 = shear load applied to the attachment as shown in figure above.
Q_2 = shear load applied to the attachment as shown in figure above
W = thrust load applied to the attachment as shown in figure above

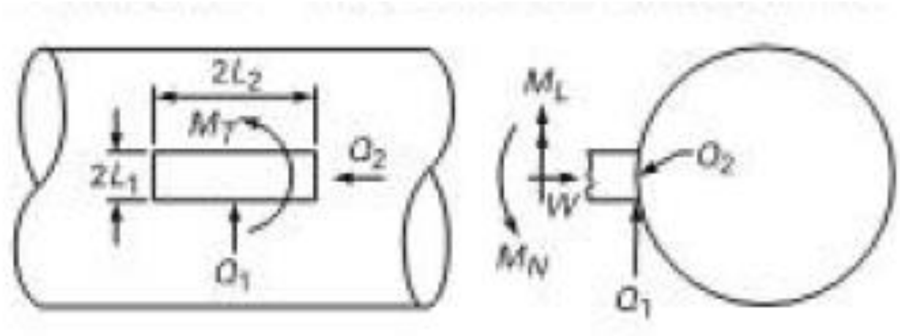
M_L, M_N, M_T, Q_1, Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L**, M_N**, M_T**, Q_1**, Q_2** and W** are absolute values of maximum loads occurring simultaneously under all service loading conditions.

Problem SUMMARY	
What was compared	Local Pipe Stresses computed as per ASME Section III, Division 1 NC & ND (2010) and EN 13480-3 (2017) for Hollow Circular attachment welded to Piping.
Load cases analyzed	Operating
Files for ASME Section III, Division 1, NC (2010)	1. Lug\HollowCircular\LUG_XEE03_ASME_HC_NC.lug – CAEPIPE Input and Results file. 2. Lug\HollowCircular\LugEvaluation_ASME_Section III, Division 1, Appendix Y-HC-NC.pdf – Softcopy output of CAEPIPE Input and Results. 3. Lug\HollowCircular\LugEvaluation_ASME_Section III, Division 1, Appendix Y-HC-NC.xlsx – Manual calculations using MS-Excel for verification.
Files for ASME Section III, Division 1, ND (2010)	1. Lug\HollowCircular\LUG_XEE03_ASME_HC_ND.lug – CAEPIPE Input and Results file. 2. Lug\HollowCircular\LugEvaluation_ASME_Section III, Division 1, Appendix Y-HC-ND.pdf – Softcopy output of CAEPIPE Input and Results. 3. Lug\HollowCircular\LugEvaluation_ASME_Section III, Division 1, Appendix Y-HC-ND.xlsx – Manual calculations using MS-Excel for verification.
Files for EN 13480-3 (2017)	1. Lug\HollowCircularLUG_XEE03_EN13480_HC.lug – CAEPIPE Input and Results file. 2. Lug\HollowCircular\LugEvaluation_EN13480-3(2017)-Section11-HC.pdf – Softcopy output of CAEPIPE Input and Results. 3. Lug\HollowCircular\LugEvaluation_EN13480-3(2017)-Section11-HC.xlsx – Manual calculations using MS-Excel for verification.

See Excel files and PDF files mentioned above from the folder "Lug\HollowCircular" for manual calculations and CAEPIPE results.

Rectangular Welded Attachments to Piping as per ASME Section III, Division 1, NC & NC (2010) and EN13480-3 (2017)



The notations described below are used in the formulas for the design.

$L1$ = half length of attachment in circumferential direction of the run pipe

$L2$ = half length of attachment in longitudinal direction of the run pipe

R = mean pipe radius

D_o= outside diameter of run pipe

T = nominal run pipe wall thickness

L_a = lesser of L_2 and T

L_b = lesser of L_1 and T

L_c = lesser of L_1 and L_2

L_d = greater of L_1 and L_2

$A_T = 4.L_1.L_2$ = cross-sectional area of the rectangular attachment

$Z_{tL} = \left(\frac{4}{3}\right).L_1.{L_2}^2$

$Z_{tN} = \left(\frac{4}{3}\right).{L_1}^2.L_2$

$\beta_1 = \frac{L_1}{R}$

$\beta_2 = \frac{L_2}{R}$

$\gamma = \frac{R}{T}$

Limits of Applicability

$\boldsymbol{\beta_1} \leq \mathbf{0.5}$

$\boldsymbol{\beta_2} \leq \mathbf{0.5}$

$\boldsymbol{\beta_1}.\boldsymbol{\beta_2} \leq \mathbf{0.75}$

M_L = bending moment applied to the attachment as shown in figure above
M_N = bending moment applied to the attachment as shown in figure above

M_T = torsional moment applied to the attachment as shown in figure above
Q_1 = shear load applied to the attachment as shown in figure above.
Q_2 = shear load applied to the attachment as shown in figure above
W = thrust load applied to the attachment as shown in figure above

M_L, M_N, M_T, Q_1, Q_2 and W are determined at the surface of the pipe. The values of attachment loads used in the stress calculation are based on the loads used in the different code equations.

M_L**, M_N**, M_T**, Q_1**, Q_2** and W** are absolute values of maximum loads occurring simultaneously under all service loading conditions.

Problem SUMMARY	
What was compared	Local Pipe Stresses computed as per ASME Section III, Division 1 and EN 13480-3 (2017) for Rectangular attachment welded to Piping.
Load cases analyzed	Operating
Files for ASME Section III, Division 1, NC (2010)	1. Lug\Rectangular\LUG_XEE03_ASME_RA_NC.lug – CAEPIPE Input and Results file. 2. Lug\Rectangular\LugEvaluation_ASME Section III, Division 1, Appendix Y-RT-NC.pdf – Softcopy output of Input and Results. 3. Lug\Rectangular\LugEvaluation_ASME Section III, Division 1, Appendix Y-RT-NC.xlsx – Manual calculations using MS-Excel for verification.
Files for ASME Section III, Division 1, ND (2010)	4. Lug\Rectangular\LUG_XEE03_ASME_RA_ND.lug – CAEPIPE Input and Results file. 5. Lug\Rectangular\LugEvaluation_ASME Section III, Division 1, Appendix Y-RT-ND.pdf – Softcopy output of Input and Results. 6. Lug\Rectangular\LugEvaluation_ASME Section III, Division 1, Appendix Y-RT-ND.xlsx – Manual calculations using MS-Excel for verification.
Files for EN 13480-3 (2017)	1. Lug\Rectangular\LUG_XEE03_EN13480_RA.lug – CAEPIPE Input and Results file. 2. Lug\ Rectangular LugEvaluation_EN13480-3(2017)-Section11-RT.pdf – Softcopy output of Input and Results. 3. Lug\Rectangular\ LugEvaluation_EN13480-3(2017)-Section11-RT.xlsx – Manual calculations using MS-Excel for verification.

See Excel files and PDF files mentioned above from the folder “Lug\Rectangular” for manual calculations and CAEPIPE results.

9 - Verification for Computation of Wind Forces as per ASCE/SEI 7-16

Design Wind Forces are computed and applied to each element internally in CAEPIPE as per Chapter 29 of ASCE/SEI 7-16.

To verify the implementation, a few models were created in CAEPIPE as described below.

1. Wind Velocity Pressure is calculated manually (using Excel) as per ASCE/SEI 7-16. Excel utility "Wind-ASCE.xlsm" provided under the directory "ASCE-Wind" can be used to compute the Velocity Pressure by entering the parameters given below for each model.
2. Wind Velocity Pressure thus calculated for each model is then input into each CAEPIPE model under the Wind Load profile for Wind1.
3. A copy of the model stated in Point 2 above is created by replacing the Wind Load profile (manually entered) with the option "Use ASCE/SEI 7-16" turned ON for Wind Load 1. ASCE Wind parameters are defined through Layout Window > Misc > Wind Load – ASCE/SEI 7-16. The resulting model is then saved as a new model.
4. Anchor Loads obtained from both models (obtained from Point 2 and Point 3 above) for Wind Load Case are compared against each other and found them to be identical as shown below under each model.

Input and Output obtained as explained above for each model is given below.

Model 1: "01_Manual_Wind_NoHill.mod" and "01_ASCE_Wind_NoHill.mod"

The Design Wind Load - ASCE/SEI 7-16			
Sl. No.	Parameters	Value	Units
1	Occupancy Category	III	
2	Basic Wind Speed	120	mph
3	Wind Directionality Factor K(d)	0.95	
4	Exposure Category	B	
5	Hill Type	No Hill	
6	Height of Hill or Escarpment (H)	0	feet
7	Crest Distance (Lh)	0	feet
8	Height above Ground Level (z)	0	feet
9	Distance from Crest to Site (x)	0	feet
10	Type of Surface	Moderately Smooth	
11	Gust-effect Factor G	0.85	
12	Pipe Diameter including Insulation Thickness (Section Property: NS = 20", OD = 20", Schedule = STD, Insulation Thickness = 8")	36.00	inch
13	Elevation of Pipe	90	feet

Enter the values shown below in CAEPIPE Wind Load Input under Pressure Vs Elevation		
Sl. No.	Elevation (ft'in")	Pressure (lb/ft^2)
1	0	19.981
2	90	19.981

Wind: Loads on anchors from Model "01_Manual_Wind_NoHill.mod"							
Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10		46		664		-1536	
50		-182		663		3417	
60		-76		983		-4087	
Wind: Loads on anchors from Model "01_ASCE_Wind_NoHill.mod"							
Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10		46		664		-1536	
50		-182		663		3417	
60		-76		983		-4087	

Model 2: "02_Manual_Wind_ExpB_2DRidge" and "02_ASCE_Wind_ExpB_2DRidge.mod"

The Design Wind Load - ASCE/SEI 7-16			
Sl. No.	Parameters	Value	Units
1	Occupancy Category	III	
2	Basic Wind Speed	120	mph
3	Wind Directionality Factor K(d)	0.95	
4	Exposure Category	B	
5	Hill Type	2D Ridge	
6	Height of Hill or Escarpment (H)	100	feet
7	Crest Distance (Lh)	200	feet
8	Height above Ground Level (z)	300	feet
9	Distance from Crest to Site (x)	400	feet
10	Type of Surface	Moderately Smooth	
11	Gust-effect Factor G	0.85	
12	Pipe Diameter including Insulation Thickness (Section Property: NS = 20", OD = 20", Schedule = STD, Insulation Thickness = 8")	36.00	inch
13	Elevation of Pipe	90	feet

Enter the values shown below in CAEPIPE Wind Load Input under Pressure Vs Elevation		
Sl. No.	**Elevation (ft'in")**	**Pressure (lb/ft^2)**
1	0	19.885
2	90	19.885

Wind: Loads on anchors from Model "02_Manual_Wind_ExpB_2DRidge.mod"							
Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10		46		661		-1528	
50		-181		660		3400	
60		-76		978		-4067	
Wind: Loads on anchors from Model "02_ASCE_Wind_ExpB_2DRidge.mod"							
Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10		46		661		-1528	
50		-181		660		3400	
60		-76		978		-4067	

Model 3: "03_Manual_Wind_ExpC_2DEscarp.mod" and "03_ASCE_ Wind_ExpC_2DEscarp.mod"

The Design Wind Load - ASCE/SEI 7-16			
Sl. No.	Parameters	Value	Units
1	Occupancy Category	III	
2	Basic Wind Speed	120	mph
3	Wind Directionality Factor K(d)	0.95	
4	Exposure Category	C	
5	Hill Type	2D Escarp	
6	Height of Hill or Escarpment (H)	100	feet
7	Crest Distance (Lh)	200	feet
8	Height above Ground Level (z)	300	feet
9	Distance from Crest to Site (x)	400	feet
10	Type of Surface	Rough	
11	Gust-effect Factor G	0.85	
12	Pipe Diameter including Insulation Thickness (Section Property: NS = 20", OD = 20", Schedule = STD, Insulation Thickness = 8")	36.00	inch
13	Elevation of Pipe	90	feet

Enter the values shown below in CAEPIPE Wind Load Input under Pressure Vs Elevation		
Sl. No.	Elevation (ft'in")	Pressure (lb/ft^2)
1	0	33.496
2	90	33.496

Wind: Loads on anchors from Model "03_Manual_Wind_ExpC_2DEscarp.mod"							
Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10		78		1113		-2575	
50		-305		1111		5728	
60		-128		1648		-6851	
Wind: Loads on anchors from Model "03_ASCE_Wind_ExpC_2DEscarp.mod"							
Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10		78		1113		-2575	
50		-305		1111		5728	
60		-128		1648		-6851	

Model 4: "04_Manual_Wind_ExpD_3DAxissym.mod" and "04_ASCE_ Wind_ ExpD_3DAxissym.mod"

The Design Wind Load - ASCE/SEI 7-16			
Sl. No.	Parameters	Value	Units
1	Occupancy Category	III	
2	Basic Wind Speed	120	mph
3	Wind Directionality Factor K(d)	0.95	
4	Exposure Category	D	
5	Hill Type	3D Axissym Hill	
6	Height of Hill or Escarpment (H)	100	feet
7	Crest Distance (Lh)	200	feet
8	Height above Ground Level (z)	300	feet
9	Distance from Crest to Site (x)	400	feet
10	Type of Surface	Very Rough	
11	Gust-effect Factor G	0.85	
12	Pipe Diameter including Insulation Thickness (Section Property: NS = 20", OD = 20", Schedule = STD, Insulation Thickness = 8")	36.00	inch
13	Elevation of Pipe	90	feet

Enter the values shown below in CAEPIPE Wind Load Input under Pressure Vs Elevation		
Sl. No.	**Elevation (ft'in")**	**Pressure (lb/ft^2)**
1	0	50.209
2	90	50.209

Wind: Loads on anchors from Model "04_Manual_Wind_ExpD_3DAxissym.mod"							
Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10		117		1668		-3859	
50		-457		1666		8586	
60		-192		2470		-10270	
Wind: Loads on anchors from Model "04_ASCE_Wind_ ExpD_3DAxissym.mod"							
Node	Tag	FX (lb)	FY (lb)	FZ (lb)	MX (ft-lb)	MY (ft-lb)	MZ (ft-lb)
10		117		1668		-3859	
50		-457		1666		8586	
60		-192		2470		-10270	

10 - Verification for Computation of Static Seismic g's as per ASCE/SEI 7-16

Static Seismic g's are computed and applied to stress model in CAEPIPE as per ASCE/SEI 7-16.

To verify the implementation, a sample model was created in CAEPIPE by referring to the parameters listed below in Seminar Notes of Ron Haupt. The Static Seismic g-load values computed by CAEPIPE are then compared against the document shown below and found that they are identical.

DETERMINE THE DESIGN EARTHQUAKE LOAD

(Ref: Para. 101.5.3 and ASCE/SEI 7-16)

Method from ASCE/SEI 7-10, Minimum Design Loads for Buildings and Other Structures, Chapter 13 (p. 143)

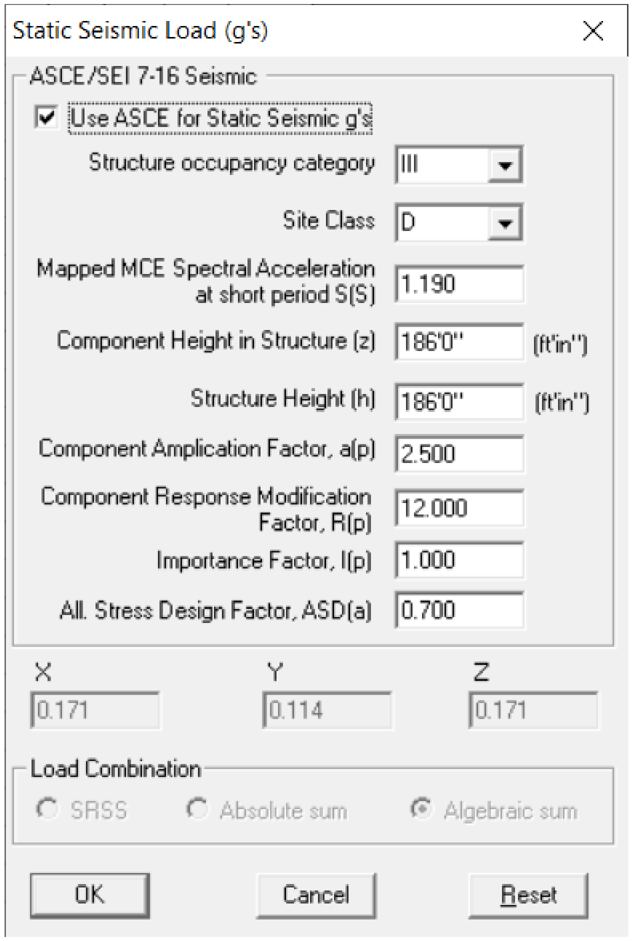
Chapter 13, "Seismic Design Requirements for Nonstructural Components" provides seismic design requirements for architectural, mechanical and electrical components, including specific references to ASME boilers, pressure vessels, and piping

Location =	**Centralia, WA**		Given
Type of Structure =	**Power plant boiler support structure**		Given
Type of Component =	**B31.1 Main steam piping**		Given
Structure Occupancy Category =	**III**		[Table 1.5-1, p. 2]
Site Class =	D	(Note 1)	[Para. 11.4.2, p. 65]
Site Latitude =	**46.75** deg		Given
Site Longitude =	**-122.90** deg		Given
Mapped MCE Spectral Acceleration at Short Periods, S(S) =	**1.190** g	(Note 2)	Given
Site Coefficient at Short Period, F(a) =	**1.024**	Interpolated	[Table 11.4-1, p. 66]
Maximum MCE Spectral Acceleration at Short Periods, S(MS) =	F(a)*S(S)		[Eq. 11.4-1, p. 65]
Maximum MCE Spectral Acceleration at Short Periods, S(MS) =	1.219 g		Calculated
Design Spectral Acceleration at Short Periods, S(DS) =	(2/3)*S(MS)		[Eq. 11.4-3, p. 65]
Design Spectral Acceleration at Short Periods, S(DS) =	0.812 g		Calculated
Mechanical Component Type =	**B31 welded piping**		Given
Component Amplification Factor, a(p) =	**2.50**	(Note 3)	[Table 13.6-1, p. 120]
Component Response Modification Factor, R(p) =	**12.00**	(Note 3)	[Table 13.6-1, p. 120]
Importance Factor, I(p) =	**1.00**		[Para. 13.1.3, p. 111]
Component Height in Structure, z =	**186** ft	(Note 4)	Given
Structure Height, h =	**186** ft	(Note 5)	Given
Seismic Force, F(p) =	0.4*S(DS)*(a(p)/R(p))*I(p)*(1+2*(z/h))*W(p)		[Eq. 13.3-1, p. 113]
Seismic Force, F(p) =	0.203 W(p)		Calculated
Maximum Seismic Force, F(p,max) =	1.6*S(DS)*I(p)*W(p)		[Eq. 13.3-2, p. 113]
Maximum Seismic Force, F(p,max) =	1.300 W(p)		Calculated
Seismic Force, F(p) =	If F(p,max) < F(p), F(p) = F(p,max)		[Para. 13.3.1, p. 113]
Seismic Force, F(p) =	0.203 W(p)		Calculated
Minimum Seismic Force, F(p,min) =	0.3*S(DS)*I(p)*W(p)		[Eq. 13.3-3, p. 113]
Minimum Seismic Force, F(p,min) =	0.244 W(p)		Calculated
Seismic Force, F(p) =	If F(p,min) > F(p), F(p) = F(p,min)		[Para. 13.3.1, p. 113]
Seismic Force, F(p) =	0.244 W(p)		Calculated
Allowable Stress Design Factor, ASD(a) =	**0.70**		[Para. 13.1.7, p. 112]
Allowable Stress Design Seismic Force, F'(p) =	ASD(a)*F(p)		
Allowable Stress Design Seismic Force, F'(p) =	0.171 W(p)	(Note 6)	Calculated
Vertical Seismic Force, V(p) =	0.2*S(DS)		[Para. 13.3.1, p. 114]
Vertical Seismic Force, V(p) =	0.162 W(p)		Calculated
Allowable Stress Design Vertical Seismic Force, V'(p) =	A(SD)*F"(p)		
Allowable Stress Design Vertical Seismic Force, V'(p) =	0.114 W(p)	(Note 6)	Calculated

Notes:

1. Para. 11.4.2 states "Where the soil properties are not known in sufficient detail to determine the site class, Site Class D shall be used..."
2. The USGS maintains a website at http://earthquake.usgs.gov/designmaps/ which with site latitude and longitude, values of S(S) can be retrieved.
3. The a(p) and R(p) values are based on it being "Piping in accordance with ASME B31, including in-line components with joints made by welding or brazing."
4. The component height is taken at the top of the boiler SH outlet piping at approximately El. 414'; the ground taken as approximately El. 228'.
5. The building height is taken at the top of the boiler SH outlet piping at approximately El. 414'-6"; the ground taken as approximately El. 228'.
6. Para. 2.4.1 states "Increases in allowable stress shall not be used with the loads or load combinations given in this standard unless it can be demonstrated that such an increase is justified by structural behavior caused by rate or duration of load."

With the parameters given above, g-loads computed by CAEPIPE are shown below.



CAEPIPE Output

Minimum Design Earthquake Load as per ASCE/SEI 7-16
Structure Occupancy Category: III Site Class: D Component Height in Structure (z) = 186'0" (ft'in") Structure Height (h) = 186'0" (ft'in") Component Amplication Factor, a(p) = 2.500 Component Response Modification Factor, R(p) = 12.000 Importance Factor, I(p) = 1.000 Allowable Stress Design Factor, ADS(a) = 0.700 Mapped MCE Spectral Acceleration at Short Periods S(S) = 1.19 g Maximum MCE Spectral Acceleration at Short Periods S(MS) = 1.22 g Design Spectral Acceleration at Short Periods S(DS) = 0.81 g Maximum Horizontal Seismic g-load value (Hg_Max) = 1.30 g Minimum Horizontal Seismic g-load value (Hg_Min) = 0.24 g Horizontal Seismic g-load value (Hg) = 0.24 g Vertical Seismic g-load value (Vg) = 0.16 g Allowable Stress Design Horizontal Seismic g-load value = 0.17 g Allowable Stress Design Vertical Seismic g-load value = 0.11 g Static seismic load: X = 0.17, Y = 0.11, Z = 0.17 (g's) Seismic load combination = Algebraic sum

From the results, the Static Seismic g-load values computed by CAEPIPE are identical to the values shown in the Seminar Notes of Ron Haupt.

11 - Verification for Computation of Wind Forces as per EN 1991-1-4 (2010)

Design Wind Forces are computed and applied to each element internally in CAEPIPE as per Clause 4 of EN 1991-1-4 (2010).

To verify the implementation, a CAEPIPE model was created as described below.

1. Wind Velocity Pressure is calculated manually (using Excel) as per EN 1991-1-4 (2010). Excel utility "Wind-EN1991.xlsx" provided under the directory "EN1991_Wind" can be used to compute the Velocity Pressure by entering the required parameters. To validate the excel computation, a sample problem is listed in the excel sheet.
2. Wind Velocity Pressure thus calculated manually is then input into CAEPIPE model under the Wind Load profile for Wind1.
3. A copy of the model stated in Point 2 above is created by replacing the Wind Load profile (manually entered) with the code "EN 1991-1-4 (2010)" for Wind Load 1 available in the Wind1 Load. EN 1991-1-4 Wind parameters are defined through Layout Window > Misc > Wind Load – EN 1991-1-4 (2010). The resulting model is then saved as a new model.
4. Anchor Loads obtained from both models (obtained from Point 2 and Point 3 above) for Wind Load Case are compared against each other and found them to be identical as shown below.

Input and Output obtained as explained above for CAEPIPE model is given below.

Comparison 1: "01_Wind_Manual_Entry.mod" and "01_EN1991_Wind.mod"

The Design Wind Load - EN 1991-1-4 (2010)			
Sl. No.	Parameters	Value	Units
1	Basic Wind Speed (Vb,0)	30	m/sec
2	Air Density (p)	1.25	kg/m3
3	Terrain Category (Zo)	III	
4	Directional Factor (Cdir)	1	
5	Season Factor (Cseason)	1	
6	Terrain Oragraphy [Co(z)]	1	
7	Turbulance Factor (Kt)	1	
8	Roughness Length (Z0)	0.3	m
9	Minimum Height (Zmin)	5	m
10	Maximum Height (Zmax)	200	m
11	Roughness length for Terrain Category II (Z0,II)	0.05	m

Enter the values shown below in CAEPIPE Wind Load Input under Pressure Vs Elevation		
Sl. No.	**Elevation (m)**	**Pressure (kPa)**
1	0	0.72048
2	5	0.72048
3	10	0.96142
4	20	1.22743
5	25	1.31840

Wind: Loads on anchors from Model “01_Wind_Manual_Entry.mod”							
Node	Tag	FX (N)	FY (N)	FZ (N)	MX (Nm)	MY (Nm)	MZ (Nm)
10		1153		-42		269	
50		1530		-283		-894	
60		3658		-884		1570	
Wind: Loads on anchors from Model “01_EN1991_Wind.mod”							
Node	Tag	FX (N)	FY (N)	FZ (N)	MX (Nm)	MY (Nm)	MZ (Nm)
10		1153		-42		269	
50		1530		-283		-894	
60		3658		-884		1570	

12 - Verification of Local Loads on Nozzles as per EN 13445-3:2014/A8:2019

Local Load on Nozzle connected to Spherical Shell

Problem SUMMARY	
What was compared	Local Loads on Nozzle connected to Spherical Shell computed as per EN 13445-3:2014/A8:2019
Filename	1. EN13445\SphericalNozzle.noz – CAEPIPE Input and Results file 2. EN13445\Nozzle_SphericalShell_Qualification_EN13445-3.xlsx - Manual calculations using MS-Excel for verification.

Input:

```
Caepipe                      SphericalShell.noz                 Page 1
Version 10.50                                                   Mar 21,2021
---------------------------------------------------------------------------------
             Allowable Loads on Nozzles as per EN 13445-3:2014/A8:2019
---------------------------------------------------------------------------------
Input Data:
Local Loads on Nozzle attached to Spherical Vessel
Mean Shell Radius [R]:                                      2194.8    (mm)
Nominal Shell Thk. [e]:                                       10.5    (mm)
Nozzle OD [de]:                                              406.4    (mm)
Nozzle Thickness [eb]:                                        12.5    (mm)
Mean Nozzle Dia. [d]:                                        393.9    (mm)
Rein. Pad Thk. [e2]:                                            12    (mm)
Rein. Pad OD [d2]:                                           626.4    (mm)
Shell Design Stress [f]:                                     117.1    (MPa)
Rein. Pad Design Stress [f2]:                                117.1    (MPa)
Nozzle Design Stress [fb]:                                   124.0    (MPa)
Corrosion Allowance [c]:                                         1    (mm)
---------------------------------------------------------------------------------
    Allowable Loads on Nozzles-to-Spherical Shells as per EN 13445-3:2014/A8:2019
---------------------------------------------------------------------------------
---------------------------------------------------------------------------------
                    Clause 16.4.3: Conditions of applicability
---------------------------------------------------------------------------------
---------------------------------------------------------------------------------
     Analysis Shell Thk.[ea]/Mean Shell Radius [R] should be >= 0.001 and <= 0.1
---------------------------------------------------------------------------------
a) ea/R = 0.004 which is >= 0.001 and <= 0.1. Condition Passed.
b) Distances to any other local load in any direction shall not be less than SQRT(R.ec) =
   217.23 (mm)
c) Nozzle thickness shall be maintained over a distance of SQRT(D.eb) = 70.169 (mm)
---------------------------------------------------------------------------------
                 Clause 16.4.5: Maximum allowable individual loads
---------------------------------------------------------------------------------
Allowable radial nozzle load [Fz.Max]: 394163.31 (N)

Allowable bending moment [Mb.Max]: 50963.70 (Nm)
```

See Excel file mentioned above from the folder “EN13445” for manual calculations and CAEPIPE results.

Local Loads on Nozzle connected to Cylindrical Shell

Problem SUMMARY	
What was compared	Local Loads on Nozzle connected to Cylindrical Shell computed as per EN 13445-3:2014/A8:2019
Filename	3. EN13445\CylindricalNozzle.noz – CAEPIPE Input and Results file 4. EN13445\ Nozzle_CylindricalShell_Qualification_EN13445-3.xlsx - Manual calculations using MS-Excel for verification.

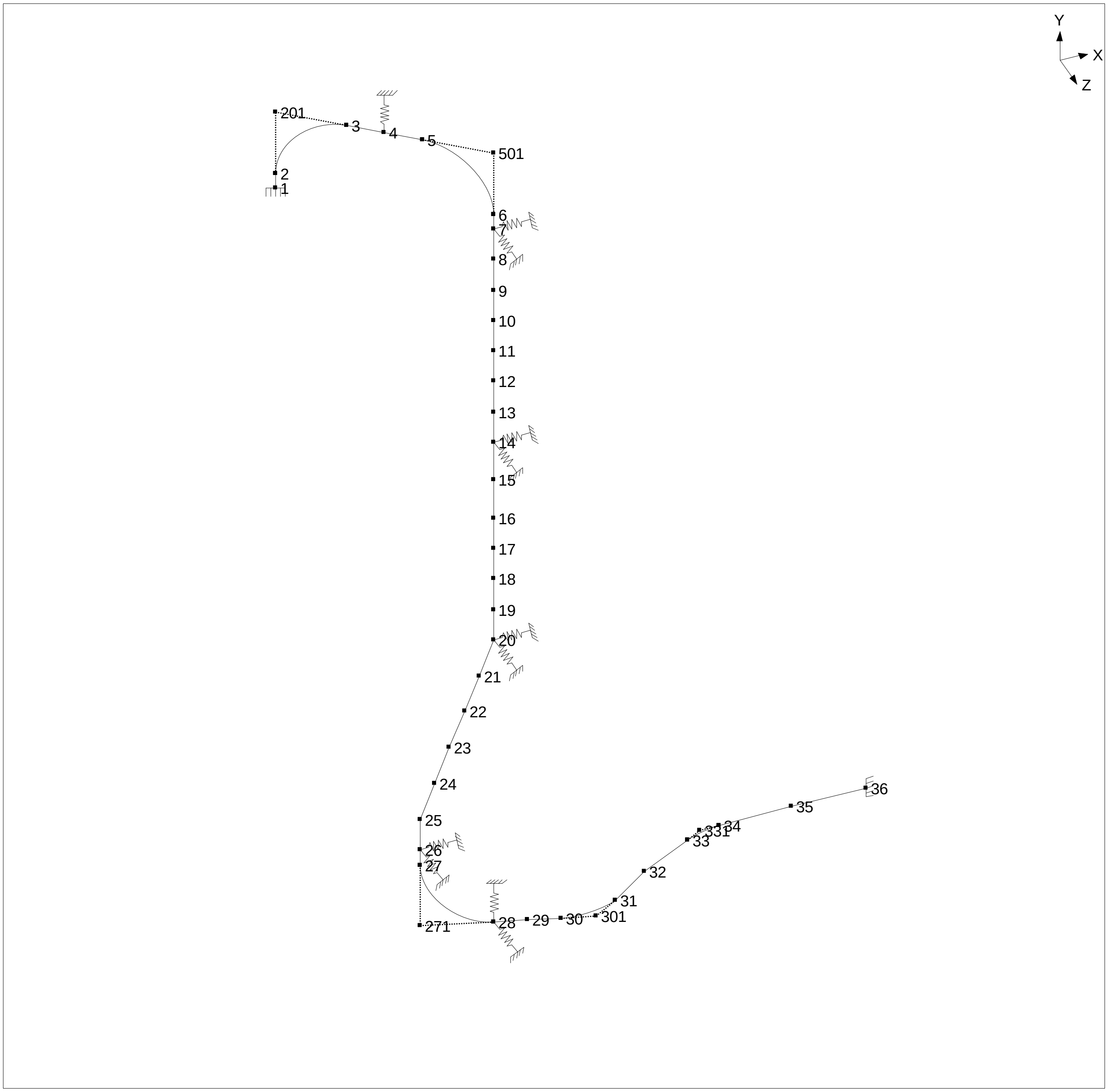
Input:

```
Caepipe                      CylindricalShell.noz                 Page 1
Version 10.50                                                     Mar 21,2021
-----------------------------------------------------------------------------------
              Allowable Loads on Nozzles as per EN 13445-3:2014/A8:2019
-----------------------------------------------------------------------------------
Input Data:
Local Loads on Nozzle attached to Cylindrical Vessel
Mean Shell Diameter [D]:                                      2188    (mm)
Nominal Shell Thk. [e]:                                         12    (mm)
Nozzle OD [de]:                                                273    (mm)
Nozzle Thickness [eb]:                                         5.3    (mm)
Mean Nozzle Dia. [d]:                                        266.7    (mm)
Rein. Pad Thk. [e2]:                                            10    (mm)
Rein. Pad OD [d2]:                                             373    (mm)
Shell Design Stress [f]:                                     117.1    (MPa)
Rein. Pad Design Stress [f2]:                                117.1    (MPa)
Nozzle Design Stress [fb]:                                   124.0    (MPa)
Corrosion Allowance [c]:                                         1    (mm)
-----------------------------------------------------------------------------------
   Allowable Loads on Nozzles-to-Cylindrical Shells as per EN 13445-3:2014/A8:2019
-----------------------------------------------------------------------------------
-----------------------------------------------------------------------------------
                     Clause 16.5.3: Conditions of applicability
-----------------------------------------------------------------------------------
-----------------------------------------------------------------------------------
  a) Analysis Shell Thk.[ea]/Mean Shell Diameter [D] should be >= 0.001 and <= 0.1
-----------------------------------------------------------------------------------
a) ea/D = 0.005 which is >= 0.001 and <= 0.1. Condition Passed.
b) Lambda C should be <= 10.0
Lambda C = 1.244 which is <= 10.0 Condition Passed.
c) Distances to any other local load in any direction shall not be less than SQRT(D.ec):
   214.35 (mm)
d) Nozzle thickness shall be maintained over a distance of SQRT(D.eb): 37.597 (mm)
-----------------------------------------------------------------------------------
                  Clause 16.5.5: Maximum allowable individual loads
-----------------------------------------------------------------------------------
16.4.5.5: Allowable radial nozzle load [Fz.Max]: 93470.30 (N)

16.5.5.5: Allowable circumferential moment [Mx.Max]: 16871.55 (Nm)

16.5.5.6: Allowable longitudinal moment [My.Max]: 21387.49 (Nm)
```

See Excel file mentioned above from the folder “EN13445” for manual calculations and CAEPIPE results.

13 - Verification of Response Spectrum Analysis

MLRSA Verification - NRC V2 Problem 1 P1-Final



Jan 1,2022

Problem SUMMARY	
What was compared	Modal frequencies, participation factors, displacements & support loads
Load cases analyzed	Response Spectrum (Uniform), (Multi-level)
Filename	P1-USM.mod, P1-ISM.mod
This problem may be found in US NRC publication V2 [ref. 22, Benchmark problem 1].	

Results of Uniform Support Motion

Table P1.1 **Comparison of modal frequencies and participation factor**

Mode No.	Program	Frequency	Modal Participation Factor		
		(Hz)	X	Y	Z
1	CAE	6.041	-0.0430	-0.0971	-0.5171
	NRC	6.042	0.0430	0.0976	0.5177
2	CAE	6.256	0.0684	0.1118	-0.5142
	NRC	6.256	0.0685	0.1113	-0.5135
3	CAE	7.760	0.2631	-0.0182	-0.3080
	NRC	7.760	-0.2631	0.0182	0.3080
4	CAE	8.942	0.2028	-1.1989	0.0793
	NRC	8.943	-0.2028	1.1999	-0.0798
5	CAE	12.443	0.1881	-0.1067	-0.2129
	NRC	12.440	-0.1882	0.1068	0.2130
6	CAE	12.830	0.0628	-0.0368	-0.1013
	NRC	12.830	-0.0627	0.0368	0.1011

Table P1.2 **Comparison of displacements**

Node No.	Program	DX (inch)	DY (inch)	DZ (inch)
3	CAE	0.0471	0.0083	0.0524
	NRC	0.0471	0.0083	0.0524
6	CAE	0.0101	0.0658	0.0106
	NRC	0.0101	0.0658	0.0106
12	CAE	0.0234	0.0659	0.0221
	NRC	0.0234	0.0659	0.0221
18	CAE	0.0206	0.0659	0.0143
	NRC	0.0205	0.0659	0.0143
24	CAE	0.0243	0.0591	0.0195
	NRC	0.0243	0.0591	0.0196
27	CAE	0.0087	0.0606	0.0068
	NRC	0.0087	0.0606	0.0068
29	CAE	0.0514	0.0205	0.0211
	NRC	0.0514	0.0205	0.0211
33	CAE	0.0052	0.1127	0.0703
	NRC	0.0052	0.1127	0.0703

Results of Multi-level Response Spectrum Analysis (MLRSA) – SRSS (Level sum)

Table P1.3 Multi-level Participation Factors – SRSS (Level sum)

Level 1	Frequency	CAEPIPE			NUREG		
Mode	(Hz)	pfx	pfy	pfz	pfx	pfy	pfz
1	6.0420	-0.0046	0.3557	-0.0044	0.0046	-0.3547	0.0044
2	6.2560	0.0019	-0.2852	0.0032	0.0018	-0.2861	0.0032
3	7.7600	0.3507	-0.0120	-0.3870	-0.3507	-0.1201	0.3870
4	8.9430	0.0063	-0.4211	0.0360	-0.0063	0.4211	-0.0360
5	12.4440	0.2186	0.0074	-0.2206	-0.2187	-0.0074	0.2207
6	12.8300	-0.0118	-0.0724	-0.1241	0.0119	0.0725	0.1240
7	14.3030	-0.1471	-0.0158	0.1168	0.1471	0.0158	-0.1169
8	15.0486	0.0960	-0.0184	-0.1363	0.0958	-0.0184	-0.1361
9	16.3710	-0.0640	-0.0351	0.0732	0.0639	0.0350	-0.0732
10	18.5043	-0.0942	0.0148	0.0268	0.0942	-0.0148	-0.0268
11	19.4990	-0.0015	-0.0139	-0.0859	-0.0015	-0.0139	-0.0859
12	23.2430	-0.3399	-0.0011	-0.3159	0.3396	0.0011	0.3156
13	24.1050	0.2825	0.0529	0.2416	-0.2828	-0.0529	-0.2419
14	32.6360	-0.0110	0.0002	0.0121	-0.0110	0.0002	0.0121
15	33.8370	-0.0006	0.0019	-0.0010	0.0006	-0.0019	0.0010

Level 2	Frequency	CAEPIPE			NUREG		
Mode	(Hz)	pfx	pfy	pfz	pfx	pfy	pfz
1	6.0420	-0.0384	-0.4529	-0.5127	0.0382	0.4523	0.5133
2	6.2560	0.0666	0.3970	-0.5174	0.0667	0.3974	-0.5167
3	7.7600	-0.0875	-0.0062	0.0790	0.0875	0.0062	-0.0790
4	8.9430	0.1965	-0.7778	0.0433	-0.1965	0.7778	-0.0438
5	12.4440	-0.0305	-0.1141	0.0077	0.0300	0.1142	-0.0077
6	12.8300	0.0746	0.0357	0.0229	-0.0746	-0.0357	-0.0230
7	14.3030	-0.0967	0.0053	0.0202	0.0966	-0.0046	-0.0201
8	15.0486	-0.0640	0.0619	0.1675	-0.0641	0.0616	0.1675
9	16.3710	0.0059	-0.2279	0.0696	-0.0061	0.2277	-0.0694
10	18.5043	-0.0744	0.0159	0.7557	0.0744	-0.0159	-0.7557
11	19.4990	0.4964	-0.2641	0.0076	0.4965	-0.2641	0.0076
12	23.2430	0.3896	0.2404	-0.0775	-0.3901	-0.2405	0.0775
13	24.1050	0.6509	0.2486	0.1176	-0.6504	-0.2483	-0.1175
14	32.6360	-0.0940	-0.0014	0.1067	-0.0939	-0.0014	0.1068
15	33.8370	-0.0945	0.2457	-0.1306	0.0950	-0.2456	0.1308

Results of Multi-level Response Spectrum Analysis (MLRSA) – SRSS (Level sum)

Table P1.4 Comparison of displacement for MLRSA – SRSS (Level sum)

Node No.	Program	DX (inch)	DY (inch)	DZ (inch)
3	CAE	0.0622	0.0069	0.0689
	NRC	0.0622	0.0069	0.0689
6	CAE	0.0125	0.0566	0.0137
	NRC	0.0125	0.0565	0.0137
12	CAE	0.0256	0.0568	0.0272
	NRC	0.0256	0.0567	0.0272
18	CAE	0.0182	0.0569	0.0161
	NRC	0.0182	0.0568	0.0161
24	CAE	0.0200	0.0536	0.0280
	NRC	0.0199	0.0535	0.0279
27	CAE	0.0075	0.0542	0.0108
	NRC	0.0075	0.0541	0.0108
29	CAE	0.0365	0.0380	0.0428
	NRC	0.0365	0.0379	0.0427
33	CAE	0.0088	0.1879	0.1911
	NRC	0.0088	0.1875	0.1909

Table P1.5 Comparison of support loads

Node No	Load	CAE (lb)	NRC (lb)
1	FX	87	86
	FY	93	93
	FZ	82	81
4	FY	202	202
7	FX	84	84
	FZ	74	74
14	FX	55	55
	FZ	34	34
20	FX	57	57
	FZ	26	26
26	FX	136	136
	FZ	53	53
28	FY	152	152
	FZ	95	95
36	FX	84	84
	FY	67	67
	FZ	74	74

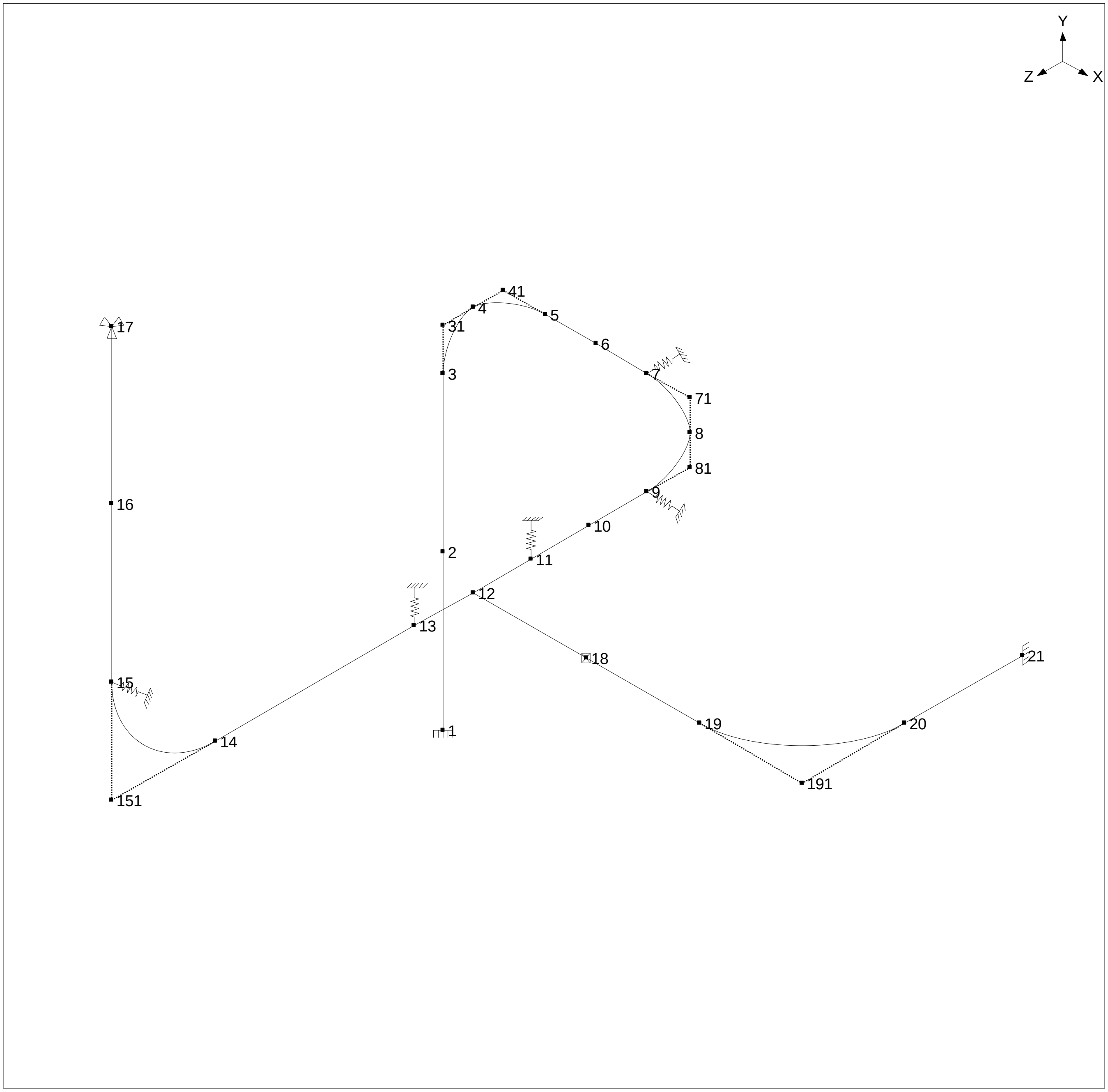
Results of Multi-level Response Spectrum Analysis (MLRSA) – ABS (Level sum)

Table P1.6 Comparison of displacement for MLRSA – ABS (Level sum)

Node No.	Program	DX (inch)	DY (inch)	DZ (inch)
3	CAE	0.0724	0.0095	0.0800
	NRC	0.0724	0.0095	0.0800
6	CAE	0.0147	0.0780	0.0161
	NRC	0.0147	0.0779	0.0161
12	CAE	0.0303	0.0783	0.0322
	NRC	0.0303	0.0782	0.0322
18	CAE	0.0204	0.0784	0.0199
	NRC	0.0204	0.0783	0.0199
24	CAE	0.0256	0.0738	0.0383
	NRC	0.0256	0.0737	0.0382
27	CAE	0.0100	0.0747	0.0150
	NRC	0.0100	0.0746	0.0149
29	CAE	0.0500	0.0527	0.0594
	NRC	0.0499	0.0526	0.0593
33	CAE	0.0122	0.2604	0.2654
	NRC	0.0122	0.2600	0.2652

Table P1.7 Comparison of support loads

Node No	Load	CAE	NRC
		(lb)	(lb)
1	FX	117	117
	FY	128	128
	FZ	109	109
4	FY	278	278
7	FX	113	113
	FZ	100	100
14	FX	65	65
	FZ	44	44
20	FX	63	63
	FZ	35	35
26	FX	185	185
	FZ	72	72
28	FY	204	204
	FZ	131	131
36	FX	116	116
	FY	92	92
	FZ	103	103



Jan 1,2022

Problem SUMMARY	
What was compared	Modal frequencies, displacements & support loads
Load cases analyzed	Response Spectrum (Uniform), (Multi-level)
Filename	P2-USM.mod, P2-ISM.mod
This problem may be found in US NRC publication V2 [ref. 22, Benchmark problem 2].	

Uniform Support Motion Analysis

Table P2.1 **Comparison of modal frequencies and participation factor**

Mode No.	Program	Frequency	Modal Participation Factor		
		(Hz)	X	Y	Z
1	CAE	9.363	-1.0032	0.0705	-0.9745
	NRC	9.360	-1.0400	0.0702	-0.9739
2	CAE	12.705	0.2525	1.8317	-0.044
	NRC	12.706	0.2524	1.8320	-0.0442
3	CAE	15.376	-1.4273	0.2044	0.2253
	NRC	15.377	1.4270	-0.2045	-0.2254
4	CAE	17.797	-0.2012	-0.226	-0.0509
	NRC	17.797	0.2013	0.2259	0.0510
5	CAE	21.609	-0.4658	-0.0279	-0.7799
	NRC	21.603	0.4652	0.0279	0.7775
6	CAE	25.101	-0.1305	0.0934	-1.336
	NRC	25.098	0.1314	-0.0933	1.3370
7	CAE	32.033	-0.2259	0.2364	0.4693
	NRC	32.035	0.2258	-0.2363	-0.4693
8	CAE	38.07	-0.1063	-0.0018	-0.1092
	NRC	38.069	-0.1061	-0.0017	-0.1092
9	CAE	40.292	-0.8222	0.018	0.4207
	NRC	40.293	0.8223	-0.0180	-0.4207
10	CAE	48.897	-0.4551	-0.2188	0.1603
	NRC	48.898	0.4552	0.2188	-0.1601
11	CAE	57.513	-0.193	-0.2248	0.4096
	NRC	57.515	-0.1926	-0.2249	0.4098
12	CAE	61.498	0.1504	-0.3586	-0.1601
	NRC	61.500	0.1503	-0.3584	-0.1604

Table P2.2 Comparison of displacements

Node No.	Program	DX (inch)	DY (inch)	DZ (inch)
3	CAE	0.0321	0	0.0771
	NRC	0.0321	0	0.0771
4	CAE	0.0431	0.0049	0.0907
	NRC	0.0431	0.0049	0.0907
5	CAE	0.0474	0.017	0.063
	NRC	0.0474	0.017	0.063
10	CAE	0.0108	0.0249	0.0631
	NRC	0.0108	0.0249	0.0631
12	CAE	0.0285	0.0186	0.0632
	NRC	0.0285	0.0186	0.0632
14	CAE	0.0848	0.0085	0.0634
	NRC	0.0849	0.0085	0.0634
15	CAE	0.0891	0.0002	0.0636
	NRC	0.0892	0.0002	0.0636

Node No.	Program	DX (inch)	DY (inch)	DZ (inch)
19	CAE	0.0285	0.0329	0.0181
	NRC	0.0285	0.0329	0.0181

Results of Multi-level Response Spectrum Analysis (MLRSA) – SRSS (Level Sum)

Table P2.3 Comparison of displacements for MLRSA – SRSS (Level sum)

Node No.	Program	DX (inch)	DY(inch)	DZ(inch)
3	CAE	0.0197	0	0.0488
	NRC	0.0197	0	0.0488
4	CAE	0.0267	0.0031	0.0574
	NRC	0.0267	0.0031	0.0574
5	CAE	0.0295	0.0109	0.0399
	NRC	0.0295	0.0109	0.0399
10	CAE	0.0029	0.0152	0.0399
	NRC	0.0029	0.0152	0.0399
12	CAE	0.0103	0.011	0.04
	NRC	0.0103	0.011	0.04
14	CAE	0.053	0.0053	0.0401
	NRC	0.053	0.0053	0.0401
15	CAE	0.0564	0.0001	0.0403
	NRC	0.0565	0.0001	0.0403
19	CAE	0.0103	0.0195	0.0111
	NRC	0.0103	0.0195	0.0111

Table P2.4 Comparison of support loads

Node No	Load	CAE	NRC
		(lb)	(lb)
1	FX	53	53
	FY	46	46
	FZ	113	113
7	FZ	441	441
9	FX	257	257
11	FY	123	123
13	FY	98	98
15	FX	111	111
	FY	111	111
	FZ	155	156
17	FX	32	32
	FY	124	124
	FZ	66	66
21	FX	103	103
	FY	114	114
	FZ	116	116

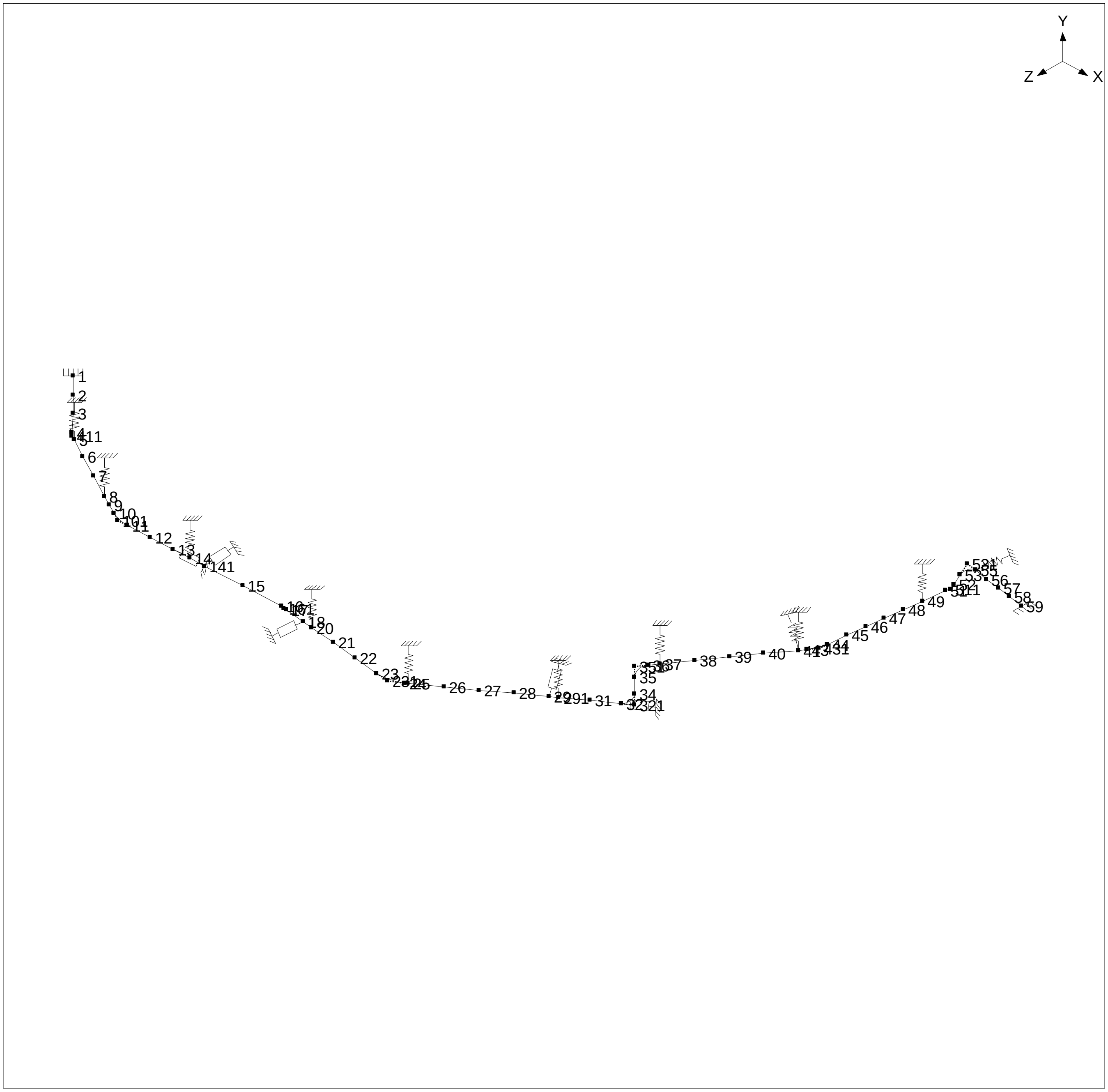
Results of Multi-level Response Spectrum Analysis (MLRSA) – ABS (Level Sum)

Table P2.5 Comparison of displacements for MLRSA – ABS (Level sum)

Node No.	Program	DX (inch)	DY(inch)	DZ(inch)
3	CAE	0.0276	0	0.068
	NRC	0.276	0	0.068
4	CAE	0.0373	0.0044	0.08
	NRC	0.0373	0.0044	0.08
5	CAE	0.0411	0.0157	0.0557
	NRC	0.0411	0.0157	0.0557
10	CAE	0.0043	0.0227	0.0556
	NRC	0.0043	0.0227	0.0556
12	CAE	0.0148	0.0165	0.0558
	NRC	0.0148	0.0165	0.0558
14	CAE	0.0739	0.0074	0.056
	NRC	0.0740	0.0074	0.056
15	CAE	0.0788	0.0001	0.0563
	NRC	0.0789	0.0001	0.0563
19	CAE	0.0148	0.0292	0.0155
	NRC	0.0148	0.0292	0.0155

Table P2.6 Comparison of support loads

Node No	Load	CAE	NRC
		(lb)	(lb)
1	FX	76	76
	FY	70	70
	FZ	156	156
7	FZ	607	607
9	FX	350	350
11	FY	184	184
13	FY	146	146
15	FX	151	151
	FY	151	151
	FZ	212	212
17	FX	45	45
	FY	169	169
	FZ	91	91
21	FX	152	152
	FY	170	170
	FZ	158	158



Problem SUMMARY	
What was compared	Modal frequencies, displacements & support loads
Load cases analyzed	Response Spectrum (Multi-level)
Filename	P3-MLRSA.mod
This problem may be found in US NRC publication V2 [ref. 22, Benchmark problem 3].	

Table P3.1 Comparison of modal frequencies and participation factors

Mode No.	Program	Frequency	Modal Participation Factor		
		(Hz)	X	Y	Z
1	CAE	7.244	-0.5049	-0.8646	-1.5465
	NRC	7.238	0.4990	0.8669	1.548
2	CAE	10.151	-1.0765	2.1663	-0.4593
	NRC	10.145	1.081	-2.165	0.4608
3	CAE	14.612	-0.4479	-0.335	-2.076
	NRC	14.579	0.4339	0.3304	2.093
4	CAE	16.022	2.2149	0.6765	-1.6156
	NRC	15.991	-2.225	-0.6837	1.595
5	CAE	17.201	1.0541	-0.0519	-0.5211
	NRC	17.198	-1.058	0.0511	0.5219
6	CAE	17.994	-2.0317	-0.1791	-0.4535
	NRC	17.987	-2.024	-0.1782	-0.4537
7	CAE	22.277	0.1598	-0.7448	0.1491
	NRC	22.282	-0.1599	0.7471	-0.1475
8	CAE	23.641	0.4185	-0.1556	-0.394
	NRC	23.632	-0.4155	0.1511	0.3934
9	CAE	27.866	-1.0216	0.3113	-1.4541
	NRC	27.864	1.022	-0.3121	1.455
10	CAE	29.21	0.7242	0.568	-0.1195
	NRC	29.211	-0.7249	-0.5677	-0.07557
11	CAE	29.481	0.0362	0.0928	1.8851
	NRC	29.514	-0.01924	0.0801	-1.885
12	CAE	31.568	-0.1541	0.1526	-0.3757
	NRC	31.554	0.1570	-0.1508	0.3720

Results of Multi-level Response Spectrum Analysis (MLRSA) – SRSS (Level Sum)

Table P3.2 Comparison of displacements for MLRSA – SRSS (Level sum)

Node No.	Program	DX (inch)	DY(inch)	DZ(inch)
6	CAE	0.0265	0.0049	0.028
	NRC	0.0265	0.0048	0.028
11	CAE	0.0014	0.0229	0.0254
	NRC	0.0014	0.0227	0.0254
15	CAE	0.0014	0.0338	0.0108
	NRC	0.0014	0.0337	0.0108
22	CAE	0.0055	0.0222	0.0146
	NRC	0.0054	0.0222	0.0146
27	CAE	0.0538	0.0288	0.0777
	NRC	0.0538	0.0287	0.0776
31	CAE	0.0891	0.0184	0.1243
	NRC	0.0889	0.0184	0.1241
39	CAE	0.283	0.0303	0.317
	NRC	0.2823	0.0304	0.3169

Node No.	Program	DX (inch)	DY(inch)	DZ(inch)
45	CAE	0.2340	0.1640	0.0549
	NRC	0.2342	0.1640	0.0557
51	CAE	0.193	0.3886	0.0587
	NRC	0.1943	0.3888	0.0584
57	CAE	0.0006	0.0817	0.0028
	NRC	0.0006	0.0817	0.0028

P3.3 Comparison of support loads

Node No	Load	CAE (lb)	NRC (lb)
1	FX	3135	3160
	FY	110	109
	FZ	2391	2408
5	FY	529	524
8	FY	1154	1144
14	FY	1078	1068
13	FX	4923	4948
	FZ	227	230
29	FX	2567	2562
	FZ	3597	3591
41	FX	2519	2522
	FY	2920	2923
	FZ	1804	1803
55	FX	958	956
	FZ	6774	6778
59	FX	2826	2843
	FY	4925	4923
	FZ	800	803

Results of Multi-level Response Spectrum Analysis (MLRSA) – ABS (Level Sum)

Table P3.4 Compaison of displacements for MLRSA – ABS (Level sum)

Node No.	Program	DX (inch)	DY(inch)	DZ(inch)
6	CAE	0.0427	0.0076	0.0443
	NRC	0.0427	0.0076	0.0443
11	CAE	0.0022	0.0361	0.0407
	NRC	0.0022	0.0357	0.0407
15	CAE	0.002	0.0547	0.0163
	NRC	0.002	0.0545	0.0163
22	CAE	0.0076	0.0357	0.0205
	NRC	0.0076	0.0355	0.0205
27	CAE	0.0757	0.0426	0.1093
	NRC	0.0757	0.0425	0.1093
31	CAE	0.1267	0.0259	0.1767
	NRC	0.1266	0.0259	0.1766

Node No.	Program	DX (inch)	DY(inch)	DZ(inch)
39	CAE	0.4110	0.0421	0.4625
	NRC	0.4102	0.0423	0.4626
45	CAE	0.3403	0.2305	0.0714
	NRC	0.3408	0.2307	0.0724
51	CAE	0.2752	0.5468	0.0769
	NRC	0.2773	0.5475	0.0779
57	CAE	0.0008	0.1139	0.0035
	NRC	0.0008	0.1139	0.0035

Table P3.5 Comparison of support loads

Node No	Load	CAE (lb)	NRC (lb)
1	FX	4330	4353
	FY	169	168
	FZ	3360	3376
5	FY	840	832
8	FY	1843	1828
14	FY	1705	1689
13	FX	6830	6859
	FZ	315	318
29	FX	3683	3677
	FZ	5161	5155
41	FX	3450	3458
	FY	4002	4011
	FZ	2470	2472
55	FX	1327	1325
	FZ	9382	9386
59	FX	3924	3937
	FY	6815	6819
	FZ	1064	1069

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