Analysis of ASME B31.3 Appendix-S Examples with SIMFLEX-II Pipe Stress Software and Approach

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2-23-2013

Ref: ASME B31.3 "Process Piping", Appendix-S
"Piping System Stress Analysis Examples"

1. Introduction

ASME B31.3 Appendix-S outlines some approaches and methods of analyzing piping system to comply with code stress requirements. The following three examples are presented each with unique characteristics of code requirements to be complied.

A. Example 1 is just a routine simple piping system. The main idea here is to calculate sustained stress and displacement stress to meet the code requirements.
B. Example 2 emphasizes the potential of inactive resting supports during operating condition. These lift-off supports are to be considered inactive for the sustained stress calculation as the hot condition is the most critical for sustained stress
C. Example 3 presents the method of calculating displacement stress range of systems with stress reversal during different operating conditions.

The examples and expected analysis results are given in the attached duplicate of Appendix-S. This report presents the methods and results as analyzed by SIMFLEX-II program. The analyses can be handled by SIMFLEX-II very easily and the SIMFLEX-II results agree very well with Appendix-S results. The analyses are presented example by example in the following.

2. Example No.1

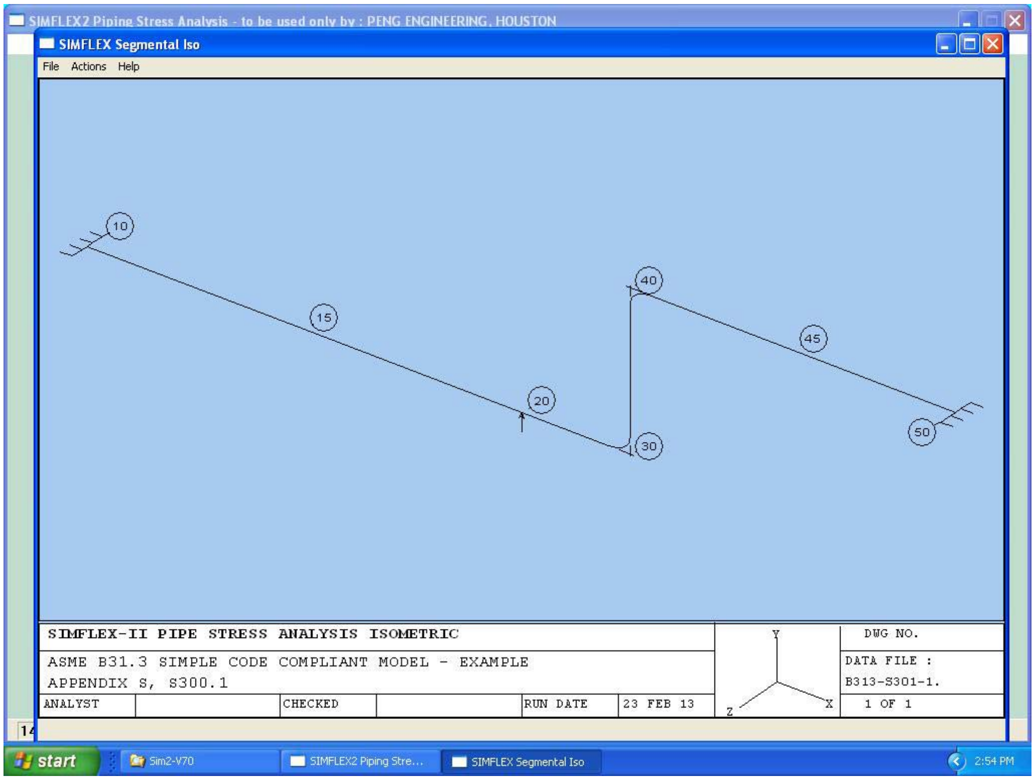
The system is as shown in Fig. S301.1 of the code attached. To describe the system to SIMFLEX-II, the following input data file is needed:

***** Input Data **

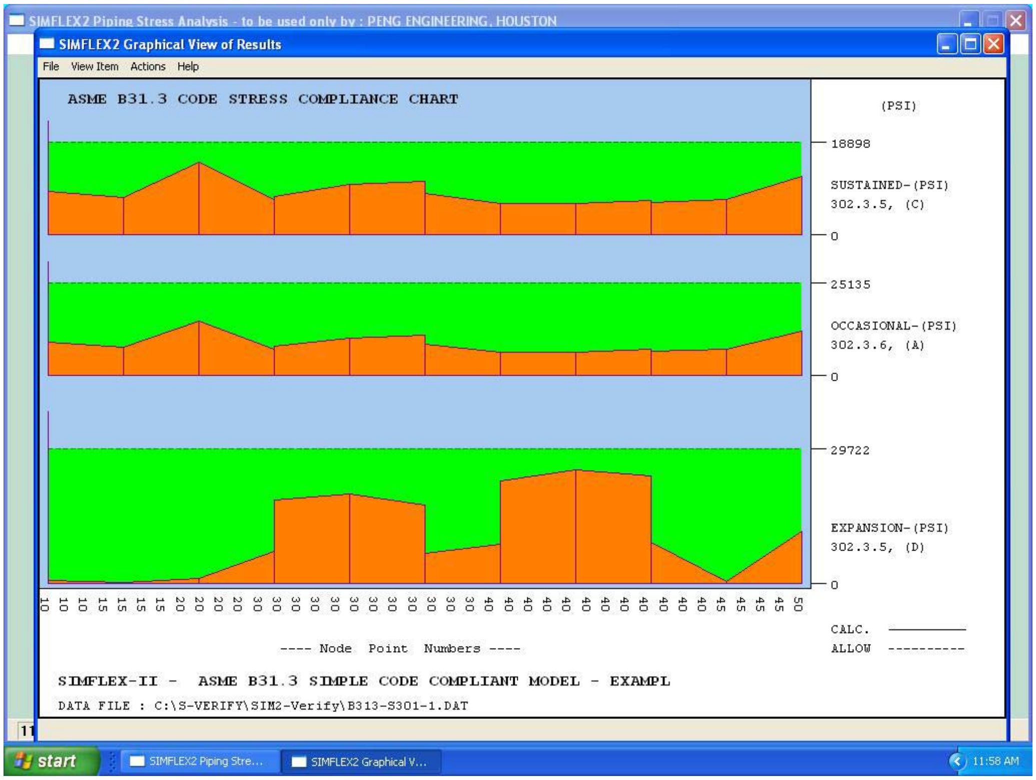
```
ASME B31.3 SIMPLE CODE COMPLIANT MODEL - EXAMPLE-1
APPENDIX S, S300.1
*****
************ COMMENTS (STARING WITH AN ASTERISK) *******************
** SIMFLEX USE SG=8.03 (0.29) FOR CARBON AND LOW ALLOY STEELS
** B31.3 EXAMPLE USES (0.283)= 7.836 (NEED MANUAL ENTRY)
** SIMFLEX DEFAULT WILL INCLUDE PRESSURE ELONGATION
** B31.3 EXAMPLE DOES NOT, MANUALLY SET PELONG=2
** SIMFLEX ADD 15% FOR MESH AND COVERING FOR INSULATION WEIGHT
** FOR IDEN=11, SET TO 11*0.85=9.35 TO GET EQUIVALENT NUMBER AS EXAMPLE
*****
** DISPLACEMENT STRESS RANGE ALLOWBLE
** B31.3 EXAMPLE USES 302.3.5 EQ.(1a) SA=f(1.25Sc + 0.25Sh)
** SIMFLEX DEFAULT USES EQ.(1b)       SA=f[1.25(Sc+Sh) - SL)
** TO MATCH EXAMPLE USE AN TALLOW=2 OPTION, WHICH HAS LESS ALLOWABLE
*****
*********************************************************************
OPTION, CODE=3, COMPL, TTWO, TW, AMB=70, PSIF, UNTOL=12.5, SUPPORT
        PELONG=2, TALLOW=2
SPIPE1, D=-16, THK=STD, ITHK=5, MATL=A106/B, SG=7.836, CSG=1.0
        TEMP=(500, 30), P=500, CA=0.063, IDEN=9.35
************
10, ANCH, PIPE1
15, X=20
20, X=20, STY
30, X=10, BR
40, Y=20, BR
45, X=15,
50, X=15, ANCH
END
```

The lines starting with an asterisk are comment lines, which are not needed but are used as comments. These data generate a system as shown on the isometric and resulting a code stress compliance chart shown in the following.

Isometric



Code Stress Compliance Chart, all stresses are within the allowable shown in green



2A – Operating Load Case Result (This is the TW-1 results)

The SIMFLEX-II result printouts are given as follows:

```
123 FEB 13  PENG ENGINEERING, HOUSTON   - SIMFLEX-II (RE-9.0 ) (ASME-B31.3)   PAGE  17
 ------------------------------------------------------------------------------------
 ASME B31.3 SIMPLE CODE COMPLIANT MODEL - EXAMPLE-1
 APPENDIX S, S300.1
                                                  DATA FILE : B313-S301-1.

 CASE  4 TH + WT  RESULTS          LOAD= THM,WGT,BWG,FOR,UFR,CSP,PRES
        ****************           MAX ECH = 1.000

0*** MEMBER FORCES (ACTING ON PIPE) AND DISPLACEMENT ***
```

MEMBER TYPE	DATA PT	FORCES (LBS) FX	FY	FZ	MOMENTS (FT-LBS) MX	MY	MZ	DISPLACEMENTS (IN) DX	DY	DZ	ROTATION (DEG) RX	RY	RZ
RUN	10	5980	2851	0	0	0	15874	.000	.000	.000	.000	.000	.000
	15	-5980	474	0	0	0	7898	.721	-.053	.000	.000	.000	.015
RUN	15	5980	-474	0	0	0	-7898	.721	-.053	.000	.000	.000	.015
	20	-5980	3799	0	0	0	-34826	1.443	.000	.000	.000	.000	-.063
RUN	20	5980	10347	0	0	0	34826	1.443	.000	.000	.000	.000	-.063
	30A	-5980	-9017	0	0	0	42628	1.731	-.142	.000	.000	.000	-.044
BEND	30A	5980	9017	0	0	0	-42628	1.731	-.142	.000	.000	.000	-.044
	30B	-5980	-8756	0	0	0	51703	1.760	-.087	.000	.000	.000	.311
BEND	30B	5980	8756	0	0	0	-51703	1.760	-.087	.000	.000	.000	.311
	30C	-5980	-8494	0	0	0	48325	1.629	.018	.000	.000	.000	.688
RUN	30C	5980	8494	0	0	0	-48325	1.629	.018	.000	.000	.000	.688
	40A	-5980	-5835	0	0	0	-47364	-.905	.594	.000	.000	.000	.692
BEND	40A	5980	5835	0	0	0	47364	-.905	.594	.000	.000	.000	.692
	40B	-5980	-5573	0	0	0	-52507	-1.038	.701	.000	.000	.000	.317
BEND	40B	5980	5573	0	0	0	52507	-1.038	.701	.000	.000	.000	.317
	40C	-5980	-5312	0	0	0	-48324	-1.010	.755	.000	.000	.000	-.060
RUN	40C	5980	5312	0	0	0	48324	-1.010	.755	.000	.000	.000	-.060
	45	-5980	-3151	0	0	0	6689	-.541	.342	.000	.000	.000	-.180
RUN	45	5980	3151	0	0	0	-6689	-.541	.342	.000	.000	.000	-.180
	50	-5980	-657	0	0	0	35253	.000	.000	.000	.000	.000	.000
MAXIMUM RESPONSE		5980	10346	0	0	0	52507	1.760	.755	.000	.000	.000	.692
AT POINTS		20	20	50	50	50	40B	30B	40C	50	50	50	40A

The results match almost exactly the results given in Table S301.5.1 of the code attached.

2B – Sustained Stress (W+P)

The SIMFLEX-II sustained stresses as printed are given as follows:

```
123 FEB 13  PENG ENGINEERING, HOUSTON   - SIMFLEX-II (RE-9.0 ) (ASME-B31.3)   PAGE   7
 ASME B31.3 SIMPLE CODE COMPLIANT MODEL - EXAMPLE-1
 APPENDIX S, S300.1
                                                         DATA FILE : B313-S301-1.

 CASE  1 WEIGHT   RESULTS          LOAD= WGT,FOR,UFR,PRES
         ****************          MAX ECH = 1.000

0***  PIPE  STRESSES  ***
```

MEMBER TYPE	DATA PT	PIPE OD (IN)	CROSS AREA (IN2)	SECTN MODUL (IN3)	-- FORCES --- AXIAL (LB)	SHEAR (LB)	---- MOMENTS ---- TORSION (FT-LB)	BENDING (FT-LB)	STRESS-INTN OUT-P	IN-P	---------- STRESSES ---------- HOOP (PSI)	LONGI (PSI)	TRESCA (PSI)	EQUIV (PSI)
RUN	10	16.00	15.38	59.2	-734	2611	0	12699	1.000	1.000	12621	8939	12652	2576
	15				-734	712	0	6290	1.000	1.000	12621	7639	12622	1276
RUN	15	16.00	15.38	59.2	-734	712	0	6290	1.000	1.000	12621	7639	12622	1276
	20				-734	4037	0	41216	1.000	1.000	12621	14723	14847	8361
RUN	20	16.00	15.38	59.2	-734	6307	0	41216	1.000	1.000	12621	14723	15006	8361
	30A				-734	4977	0	3920	1.000	1.000	12621	7158	12696	795
BEND	30A	16.00	15.38	59.2	-734	4977	0	3920	1.624	1.949	12621	7913	12708	1550
	30B				-3854	2814	0	10354	1.624	1.949	12621	10254	12676	4094
BEND	30B	16.00	15.38	59.2	-3854	2814	0	10354	1.624	1.949	12621	10254	12676	4094
	30C				-4454	734	0	12028	1.624	1.949	12621	10876	12626	4756
RUN	30C	16.00	15.38	59.2	-4454	734	0	12028	1.000	1.000	12621	8561	12623	2440
	40A				-1794	734	0	268	1.000	1.000	12621	6348	12622	54
BEND	40A	16.00	15.38	59.2	-1794	734	0	268	1.624	1.949	12621	6400	12622	106
	40B				-1604	564	0	177	1.624	1.949	12621	6376	12621	70
BEND	40B	16.00	15.38	59.2	-1604	564	0	177	1.624	1.949	12621	6376	12621	70
	40C				-734	1272	0	1719	1.624	1.949	12621	7042	12625	680
RUN	40C	16.00	15.38	59.2	-734	1272	0	1719	1.000	1.000	12621	6711	12625	349
	45				-734	888	0	4217	1.000	1.000	12621	7218	12623	855
RUN	45	16.00	15.38	59.2	-734	888	0	4217	1.000	1.000	12621	7218	12623	855
	50				-734	3382	0	27812	1.000	1.000	12621	12004	12849	5642
MAXIMUM STRESSES											12621	14723	15006	8361
AT POINTS											50	20	20	20

The axial forces and bending moments are almost exactly the same as the results given in Table S-301.6 of the code attached. The stresses, shown as "LONGI" stresses, are somewhat greater than those given in the code table. For instance the stress at support-20 is 14,724 psi vs. 14,370 psi of code. The stress at bend-30 is 10876 psi vs. 10,540 psi of the code. The likely reason is that SIMFLEX-II uses a conservative formula for calculating the longitudinal pressure stress.

SIMFLEX-II longitudinal pressure stress is calculated by $S_{lp} = \frac{DP}{4(t-c)}$

2C – Displacements Stress Range (Part of Code Stress Compliance Table)

This stress range is the total between operating at 500-F and 30-F from installation temperature of 70-F. It is a combination of two load cases. It is more convenient to check with Simplex's unique Code Stress Compliance Table below: The Code Stress Compliance automatically combines the two described operating conditions.

```
123 FEB 13  PENG ENGINEERING, HOUSTON   - SIMFLEX-II (RE-9.0 ) (ASME-B31.3)   PAGE  25
 ------------------------------------------------------------------------------------
 ASME B31.3 SIMPLE CODE COMPLIANT MODEL - EXAMPLE-1
 APPENDIX S, S300.1
                                                      DATA FILE : B313-S301-1.

0 * EXPANSION STRESS IS THE COMBINATION OF (2) THERMAL CONDITION(S),  *
  *      PLUS EARTHQUAKE SUPPORT DISPLACEMENT, IF ANY.                *
  * OCCASIONAL STRESS IS THE SUM OF SUSTAINED, GREATER OF EARTHQUAKE  *
  *      INERTIA AND WIND, HARMONIC, AND OCCASIONAL FORCES, IF ANY    *
0*** PROCESS PIPING CODE COMPLIANCE ANALYSIS - ASME B31.3 ***
```

				/PAR.304.1.2-EQ.3/		/PAR.302.3.5, (C) /		/PAR.302.3.6, (A) /		/PAR.302.3.5, (D) /	
MEMBER	DATA	PIPE-(IN)		PRESSURE-(PSI)		SUSTAINED-(PSI)		OCCASIONAL-(PSI)		EXPANSION-(PSI)	
TYPE	PT	OD	THK	DESIGN	ALLOW	CALCULATED	ALLOW	CALCULATED	ALLOW	CALCULATED	ALLOW
0 RUN	10	16.00	.375	500	635	8939	18899	8939	25137	583	29724
	15	16.00	.375	500	635	7639	18899	7639	25137	295	29724
0 RUN	15	16.00	.375	500	635	7639	18899	7639	25137	295	29724
	20	16.00	.375	500	635	14723	18899	14723	25137	1173	29724
0 RUN	20	16.00	.375	500	635	14723	18899	14723	25137	1173	29724
	30A	16.00	.375	500	635	7158	18899	7158	25137	7105	29724
0 BEND	30A	16.00	.375	500	635	7913	18899	7913	25137	18464	29724
	30B	16.00	.375	500	635	10254	18899	10254	25137	19724	29724
0 BEND	30B	16.00	.375	500	635	10254	18899	10254	25137	19724	29724
	30C	16.00	.375	500	635	10876	18899	10876	25137	17314	29724
0 RUN	30C	16.00	.375	500	635	8561	18899	8561	25137	6662	29724
	40A	16.00	.375	500	635	6348	18899	6348	25137	8743	29724
0 BEND	40A	16.00	.375	500	635	6400	18899	6400	25137	22722	29724
	40B	16.00	.375	500	635	6376	18899	6376	25137	25131	29724
0 BEND	40B	16.00	.375	500	635	6376	18899	6376	25137	25131	29724
	40C	16.00	.375	500	635	7042	18899	7042	25137	23872	29724
0 RUN	40C	16.00	.375	500	635	6711	18899	6711	25137	9186	29724
	45	16.00	.375	500	635	7218	18899	7218	25137	454	29724
0 RUN	45	16.00	.375	500	635	7218	18899	7218	25137	454	29724
	50	16.00	.375	500	635	12004	18899	12004	25137	11576	29724
OVER STRESS POINTS:					0		0		0		0

```
*** ALL STRESSES ARE WITIN THE CODE ALLOWABLE
```

The SIMFLEX-II calculated displacement stresses are termed "EXPANSION" tabulated in the second column from the last. They are exactly the same as the ones given by the code in Table S301.7 attached. The deviations are negligible.

3. Example No.2

The system is as shown in Fig. S302.1 of the code attached. This example is used mainly to demonstrate the handling of the pipe lifted off from the supports during operation.

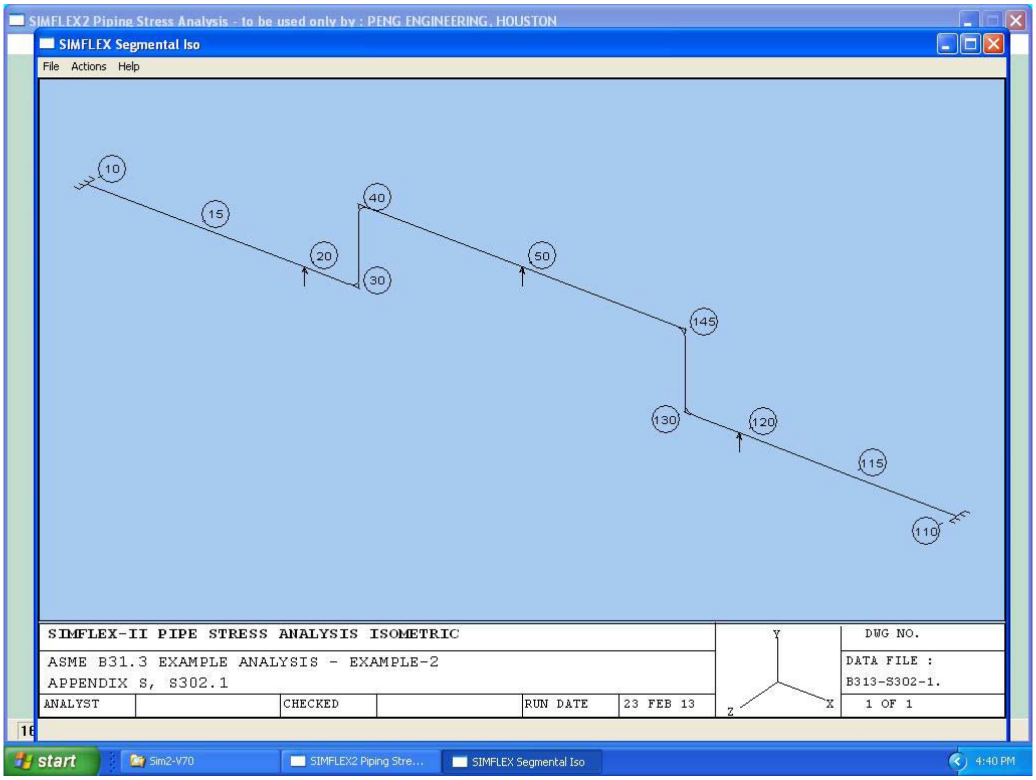
In SIMFLEX, the situation is handled automatically just by stating the support is a single acting support resisting the minus (-) direction movement. In this case it is described as LSY-, that is a limit stop in (-) Y- direction at point-50. To describe the system to SIMFLEX-II, the following input data file is needed:

***** Input Data ***

```
ASME B31.3 EXAMPLE ANALYSIS - EXAMPLE-2
APPENDIX S, S302.1
***********
************ COMMENTS (STARING WITH AN ASTERISK) *******************
** SIMFLEX USE SG=8.03 (0.29) FOR CARBON AND LOW ALLOY STEELS
** B31.3 EXAMPLE USES (0.283)= 7.836
** SIMFLEX DEFAULT WILL INCLUDE PRESSURE ELONGATION
** B31.3 EXAMPLE DOES NOT, MANUALLY SET PELONG=2
** SIMFLEX ADD 15% FOR MESH AND COVERING FOR INSULATION WEIGHT
** FOR IDEN=11, SET TO 11*0.85=9.35 TO GET EQUIVALENT NUMBER AS EXAMPLE
*****
** DISPLACEMENT STRESS RANGE ALLOWBLE
** B31.3 EXAMPLE USES 302.3.5 EQ.(1a) SA=f(1.25Sc + 0.25Sh)
** SIMFLEX DEFAULT USES EQ.(1b)       SA=f[1.25(Sc+Sh) - SL)
** TO MATCH EXAMPLE USE AN TALLOW=2 OPTION, WHICH HAS LESS ALLOWABLE
*****
******************************************************************
OPTION, CODE=3, COMPL, TTWO, TW, AMB=70, UNTOL=12.5, PSIF, SUPPORT
        PELONG=2, TALLOW=2
SPIPE1, D=-16, THK=STD, ITHK=5, MATL=A106/B, SG=7.836, CSG=1.0
        TEMP=(550, 30), P=550, CA=0.063, IDEN=9.35
************
10, ANCH, PIPE1
15, X=20
20, X=20, STY
30, X=10, BR
40, Y=20, BR
50, X=30, LSY-
145, X=30, BR
130, Y=-20, BR
120, X=10, STY
115, X=20
110, X=20, ANCH
END
```

The lines starting with an asterisk are comment lines, which are not needed but are used as comments. These data generate a system as shown on the isometric and resulting a code stress compliance chart shown in the following.

Isometric



Code Stress Compliance Chart. Sustained stress has 2 places overstress (noted with *)

3A – Operating Condition Support Load

This table shows support loads at operating condition. Special note is given to the support at point-50, where the pipe is lifting off the support, therefore, does not provide any support load.

```
123 FEB 13  PENG ENGINEERING, HOUSTON   - SIMFLEX-II (RE-9.0 ) (ASME-B31.3)   PAGE  19
 -------------------------------------------------------------------------------
 ASME B31.3 EXAMPLE ANALYSIS - EXAMPLE-2
 APPENDIX S, S302.1
                                                       DATA FILE : B313-S302-1.

 CASE  4 TH + WT  RESULTS          LOAD= THM,WGT,BWG,FOR,UFR,CSP,PRES
        ****************           MAX ECH = 1.000

0*** ANCHOR AND SUPPORT FORCES - INCLUDING FRICTION (ACTING ON SUPPORT) ***
```

		/------------- SUPPORT FORCE AND MOMENT -------------//						--------- FRICTION ---------//				---- DEFLECTION ---/			
SUPT	DATA	--- FORCES (LBS) ---			--- MOMENTS (FT-LBS) ---			-- FORCES (LBS) --			T(FT-LB)	(IN)			NOTES
TYPE	PT	FX	FY	FZ	MX	MY	MZ	FFX	FFY	FFZ	FMT	DX	DY	DZ	
0ANCH	10	-5995	-3163	0	0	0	-20032	0	0	0	0	.00	.00	.00	
0STY	20	0	-13174	0	0	0	0	0	0	0	0	1.64	.00	.00	
0LSY	50	0	0	0	0	0	0	0	0	0	0	.00	.77	.00	INACTIVE
0STY	120	0	-13174	0	0	0	0	0	0	0	0	-1.64	.00	.00	
0ANCH	110	5996	-3163	0	0	0	20033	0	0	0	0	.00	.00	.00	
NET FORCES		1	-32674	0				0	0	0	0				

This is the operating condition when the pipe has its lowest allowable stress. Therefore, the sustained stress should be calculated under this condition with suppot-50 inactive.

The support loads calculated by SIMFLEX are almost exactly the same as the ones given by Table S302.5.1 of the code attached.

3B – Sustained Stresses

SIMFLEX automatically inactivate support-50 resulting the sustained stresses as shown in the following table:

123 FEB 13 PENG ENGINEERING, HOUSTON - SIMFLEX-II (RE-9.0) (ASME-B31.3) PAGE 8

ASME B31.3 EXAMPLE ANALYSIS - EXAMPLE-2
APPENDIX S, S302.1
DATA FILE : B313-S302-1.

CASE 1 WEIGHT RESULTS LOAD= WGT,FOR,UFR,PRES
**************** MAX ECH = 1.000

0*** PIPE STRESSES ***

MEMBER TYPE	DATA PT	PIPE OD (IN)	CROSS AREA (IN2)	SECTN MODUL (IN3)	-- FORCES --- AXIAL (LB)	SHEAR (LB)	---- MOMENTS ---- TORSION (FT-LB)	BENDING (FT-LB)	STRESS-INTN OUT-P	IN-P	---------- STRESSES ---------- HOOP (PSI)	LONGI (PSI)	TRESCA (PSI)	EQUIV (PSI)
RUN	10	16.00	15.38	59.2	-2824	1879	0	2976	1.000	1.000	13883	7471	13892	604
	15				-2824	1445	0	1368	1.000	1.000	13883	7145	13888	278
RUN	15	16.00	15.38	59.2	-2824	1445	0	1368	1.000	1.000	13883	7145	13888	278
	20				-2824	4770	0	60784	1.000	1.000	13883	19198	19385	12330
RUN	20	16.00	15.38	59.2	-2824	9689	0	60784	1.000	1.000	13883	19198	19509	12330
	30A				-2824	8359	0	11410	1.000	1.000	13883	9182	14122	2315
BEND	30A	16.00	15.38	59.2	-2824	8359	0	11410	1.593	1.912	13883	11293	14279	4425
	30B				-7723	3728	0	21403	1.593	1.912	13883	14850	15665	8301
BEND	30B	16.00	15.38	59.2	-7723	3728	0	21403	1.593	1.912	13883	14850	15665	8301
	30C				-7837	2824	0	22103	1.593	1.912	13883	15114	15931	8573
RUN	30C	16.00	15.38	59.2	-7837	2824	0	22103	1.000	1.000	13883	11025	13929	4484
	40A				-5177	2824	0	23091	1.000	1.000	13883	11399	13936	4684
BEND	40A	16.00	15.38	59.2	-5177	2824	0	23091	1.593	1.912	13883	15670	16140	8956
	40B				-5473	1478	0	24156	1.593	1.912	13883	16064	16561	9369
BEND	40B	16.00	15.38	59.2	-5473	1478	0	24156	1.593	1.912	13883	16064	16561	9369
	40C				-2824	4654	0	19055	1.593	1.912	13883	14258	14704	7390
RUN	40C	16.00	15.38	59.2	-2824	4654	0	19055	1.000	1.000	13883	10733	13995	3865
	50				-2824	0	0	46112	1.000	1.000	13883	16222	16369	9354
RUN	50	16.00	15.38	59.2	-2824	0	0	46112	1.000	1.000	13883	16222	16369	9354
	145A				-2824	4654	0	19055	1.000	1.000	13883	10733	13995	3865
BEND	145A	16.00	15.38	59.2	-2824	4654	0	19055	1.593	1.912	13883	14258	14704	7390
	145B				-5473	1478	0	24156	1.593	1.912	13883	16064	16561	9369
************* Part of the table removed to fit the paper -------------														
RUN	120	16.00	15.38	59.2	-2824	4770	0	60784	1.000	1.000	13883	19198	19385	12330
	115				-2824	1445	0	1368	1.000	1.000	13883	7145	13888	278
RUN	115	16.00	15.38	59.2	-2824	1445	0	1368	1.000	1.000	13883	7145	13888	278
	110				-2824	1879	0	2976	1.000	1.000	13883	7471	13892	604
MAXIMUM STRESSES											13883	19198	19509	12330
AT POINTS											110	120	120	120

The sustained longitudinal stresses as shown as "LONGI" stresses are somewhat higher than the stresses given by the code table S302.3.1 attached. This is again likely due to the conservative formula used in calculating the longitudinal pressure stress.

The Fy force, 14515 lbs, on code Table S302.3.1 appears to be inconsistent. (SIMFLEX value is 9689 lbs)

3C – Code Stress Compliance Table – Example 2

123 FEB 13 PENG ENGINEERING, HOUSTON - SIMFLEX-II (RE-9.0) (ASME-B31.3) PAGE 26

ASME B31.3 EXAMPLE ANALYSIS - EXAMPLE-2
APPENDIX S, S302.1

DATA FILE : B313-S302-1.

```
0 * EXPANSION STRESS IS THE COMBINATION OF (2) THERMAL CONDITION(S),  *
  *       PLUS EARTHQUAKE SUPPORT DISPLACEMENT, IF ANY.               *
  * OCCASIONAL STRESS IS THE SUM OF SUSTAINED, GREATER OF EARTHQUAKE  *
  *       INERTIA AND WIND, HARMONIC, AND OCCASIONAL FORCES, IF ANY   *
0*** PROCESS PIPING CODE COMPLIANCE ANALYSIS - ASME B31.3 ***
```

				/PAR.304.1.2-EQ.3/		/PAR.302.3.5, (C) /		/PAR.302.3.6, (A) /		/PAR.302.3.5, (D) /	
MEMBER	DATA	PIPE-(IN)		PRESSURE-(PSI)		SUSTAINED-(PSI)		OCCASIONAL-(PSI)		EXPANSION-(PSI)	
TYPE	PT	OD	THK	DESIGN	ALLOW	CALCULATED	ALLOW	CALCULATED	ALLOW	CALCULATED	ALLOW
0 RUN	10	16.00	.375	550	608	7471	18099	7471	24072	2955	29524
	15	16.00	.375	550	608	7145	18099	7145	24072	1496	29524
0 RUN	15	16.00	.375	550	608	7145	18099	7145	24072	1496	29524
	20	16.00	.375	550	608	19198OVER	18099	19198	24072	5946	29524
0 RUN	20	16.00	.375	550	608	19198OVER	18099	19198	24072	5946	29524
	30A	16.00	.375	550	608	9182	18099	9182	24072	6363	29524
0 BEND	30A	16.00	.375	550	608	11293	18099	11293	24072	16220	29524
	30B	16.00	.375	550	608	14850	18099	14850	24072	15498	29524
0 BEND	30B	16.00	.375	550	608	14850	18099	14850	24072	15498	29524
	30C	16.00	.375	550	608	15114	18099	15114	24072	13379	29524
0 RUN	30C	16.00	.375	550	608	11025	18099	11025	24072	5248	29524
	40A	16.00	.375	550	608	11399	18099	11399	24072	4502	29524
0 BEND	40A	16.00	.375	550	608	15670	18099	15670	24072	11475	29524
	40B	16.00	.375	550	608	16064	18099	16064	24072	13594	29524
0 BEND	40B	16.00	.375	550	608	16064	18099	16064	24072	13594	29524
	40C	16.00	.375	550	608	14258	18099	14258	24072	14317	29524
0 RUN	40C	16.00	.375	550	608	10733	18099	10733	24072	5616	29524
	50	16.00	.375	550	608	16222	18099	16222	24072	4969	29524
0 RUN	50	16.00	.375	550	608	16222	18099	16222	24072	4969	29524
	145A	16.00	.375	550	608	10733	18099	10733	24072	5616	29524
********* Part of the table removed to fit the page											
0 BEND	130B	16.00	.375	550	608	14850	18099	14850	24072	15498	29524
	130C	16.00	.375	550	608	11293	18099	11293	24072	16220	29524
0 RUN	130C	16.00	.375	550	608	9182	18099	9182	24072	6363	29524
	120	16.00	.375	550	608	19198OVER	18099	19198	24072	5946	29524
0 RUN	120	16.00	.375	550	608	19198OVER	18099	19198	24072	5946	29524
	115	16.00	.375	550	608	7145	18099	7145	24072	1496	29524
0 RUN	115	16.00	.375	550	608	7145	18099	7145	24072	1496	29524
	110	16.00	.375	550	608	7471	18099	7471	24072	2955	29524
OVER STRESS POINTS:					0		4		0		0

*** OVER STRESS AT 4 LOCATIONS

The sustained stress has two overstress points (4 ends) in this piping system. The calculated stress is somewhat higher than the ones given by the Table S302.6.3.1 of the code attached. The difference 19198 psi (SIMFLEX) vs. 18850 psi (Code Book) is about 2%.

4. Example No. 3

The system is as shown in Fig. S303.1 of the code attached. This example is used mainly to demonstrate the treatment of moment reversal between different operating conditions. This simple loop system has two alternate operating condition. The moment generated in one condition is the same but in opposite direction of the other condition.

In SIMFLEX, the operation conditions are assigned as T-1 and T-2 without combining the sustained load, and TW-1 and TW-2 to include the sustained loads. To describe the two operating conditions, the pipe is separated into Pipe1 for the header with temperature the same at 250-F for both operating conditions; Pipe2 for the East branch having ambient temperature for the first operating condition and 250-F temperature at second operating condition; and Pipe3 for West branch with 250-F for the first operating and ambient for the second operating condition. These temperatures are described as TEMP(t1, t2, t3, …)

To describe the system to SIMFLEX-II, the following input data file is needed:

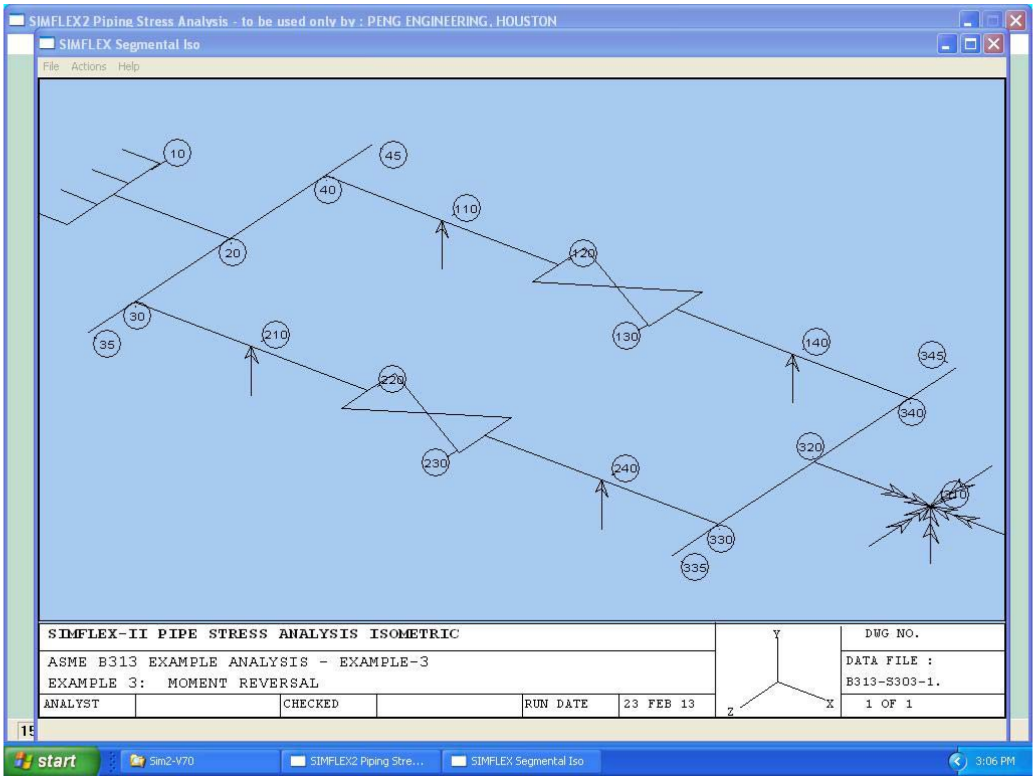
*** Input Data ***************************

```
ASME B313 EXAMPLE ANALYSIS - EXAMPLE-3
EXAMPLE 3:  MOMENT REVERSAL
*****
****** COMMENTS (STARTING WITH AN ASTERIK) ********************
*****
*** ALLOWABLE FOR DISPLACEMENT STRESS RANGE :
*** SIMFLEX DEFAULT USES EQ.(1b):      SA=f[1.25(Sc+Sh) - SL]
*** B31.3 EXAMPLE ALSO USES EQ.(1b) FOR POINTS 20 AND 220
*****
*** THE USE OF f=1.2 IS NOT RECOMMENDED, BUT USED HERE TO MATCH
*****
***************************************************************
OPTION, CODE=3, COMPL, TTWO, TW, UNTOL=12.5, AMB=40, PELONG=2
        F=1.2
*********
SPIPE1, D=-24, THK=STD, MATL=A53/B/S, TEMP=(250, 250), P=300
        CSG=0.0, CLASS=300
SPIPE2, D=-20, THK=STD, MATL=A53/B/S, TEMP=(40, 250), P=300
        CSG=0.0, CLASS=300
SPIPE3, D=-20, THK=STD, MATL=A53/B/S, TEMP=(250, 40), P=300
        CSG=0.0, CLASS=300
*********
10, ANCH, PIPE1
20, X=5, TEE
30, Z=5, TEE
35, Z=2.5
40, FROM=20, Z=-5, TEE
45, Z=-2.5
*********
** EAST BRANCH
*********
```

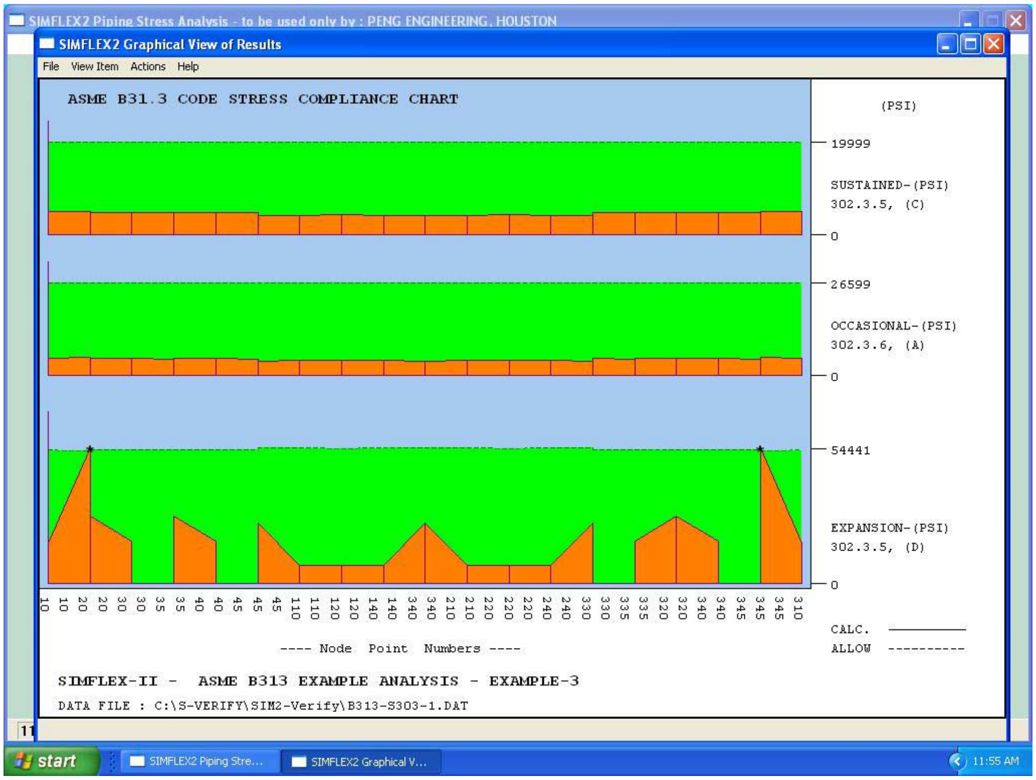
```
110, FROM=40, PIPE2, X=5, STY
120, X=5
130, X=5, GTV(2000, 5, 1000)
140, X=5, STY
340, X=5, TEE
*********
** WEST BRANCH
*********
210, FROM=30, PIPE3, X=5, STY
220, X=5
230, X=5, GTV(2000, 5, 1000)
240, X=5, STY
330, X=5, TEE
*********
** SOUTH HEADER
*********
335, FROM=330, Z=2.5, PIPE1
***
320, FROM=330, Z=-5, TEE, PIPE1
340, Z=-5
345, Z=-2.5
310, FROM=320, PIPE1, X=5.0, STY, STZ, SRX, SRY, SRZ
END
```

The lines starting with an asterisk are comment lines, which are not needed but are used as comments. The valve is modeled as 1000 times as stiff as the connecting pipe of the same length. This is SIMFLEX default for rigid bodies. SIMFLEX default stiffness for valves is 3 times as stiff as the pipe. These data generates a system as shown on the isometric and resulting a code stress compliance chart shown in the following.

Isometric



Code Stress Compliance Chart. Displacement (Expansion) has two over stress locations



4A – First Condition Displacement Stress

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ASME B313 EXAMPLE ANALYSIS - EXAMPLE-3
EXAMPLE 3: MOMENT REVERSAL
DATA FILE : B313-S303-1.

CASE 2 THERMAL RESULTS LOAD= THM,BWG,
**************** MAX ECH = 1.000

0*** PIPE STRESSES ***

MEMBER TYPE	DATA PT	PIPE OD (IN)	CROSS AREA (IN2)	SECTN MODUL (IN3)	-- FORCES --- AXIAL (LB)	SHEAR (LB)	---- MOMENTS ---- TORSION (FT-LB)	BENDING (FT-LB)	STRESS-INTN OUT-P	IN-P	---------- STRESSES ---------- HOOP (PSI)	LONGI (PSI)	TRESCA (PSI)	EQUIV (PSI)
RUN	10	24.00	27.83	161.9	0	0	0	108429	1.000	1.000	0	8039	8039	8039
	20				0	0	0	108429	4.223	3.417	0	27468	27468	27468
RUN	20	24.00	27.83	161.9	0	17637	0	54214	4.223	3.417	0	13734	13966	13734
	30				0	17637	0	33973	4.223	3.417	0	8606	8972	8606
RUN	30	24.00	27.83	161.9	0	0	0	0	4.223	3.417	0	0	0	0
	35				0	0	0	0	1.000	1.000	0	0	0	0
RUN	20	24.00	27.83	161.9	0	17637	0	54214	4.223	3.417	0	13734	13966	13734
	40				0	17637	0	33973	4.223	3.417	0	8606	8972	8606
RUN	40	24.00	27.83	161.9	0	0	0	0	4.223	3.417	0	0	0	0
	45				0	0	0	0	1.000	1.000	0	0	0	0
RUN	40	20.00	23.12	111.3	17637	0	0	33973	4.145	3.354	0	13044	13044	12281
	110				17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	110	20.00	23.12	111.3	17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	120				17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	130	20.00	23.12	111.3	17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	140				17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	140	20.00	23.12	111.3	17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	340				17637	0	0	33973	4.145	3.354	0	13044	13044	12281
********** Part of the table removed to fit the page														
RUN	30	20.00	23.12	111.3	-17637	0	0	33973	4.145	3.354	0	13044	13044	12281
	210				-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	210	20.00	23.12	111.3	-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	220				-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	230	20.00	23.12	111.3	-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	240				-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	240	20.00	23.12	111.3	-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	330				-17637	0	0	33973	4.145	3.354	0	13044	13044	12281
RUN	340	24.00	27.83	161.9	0	0	0	0	4.223	3.417	0	0	0	0
	345				0	0	0	0	1.000	1.000	0	0	0	0
RUN	320	24.00	27.83	161.9	0	0	0	108429	4.223	3.417	0	27468	27468	27468
	310				0	0	0	108429	1.000	1.000	0	8039	8039	8039
MAXIMUM STRESSES											0	27468	27468	27468
AT POINTS											310	320	320	320

The displacement stress given as “EQUIV” stresses agree very well with the code stress given in Table S303.7.1 attached. However, since the bending moment normally is the combination of the in-plane and out-plane moments that the sign is lost in this table. The moment component sign in the next table should be used to calculate the stress range. This is done automatically in SIMFLEX.

4B – Displacement Forces, Moments, and Displacements for First Operating Condition

```
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 --------------------------------------------------------------------------------
 ASME B313 EXAMPLE ANALYSIS - EXAMPLE-3
 EXAMPLE 3:  MOMENT REVERSAL
                                                      DATA FILE : B313-S303-1.

 CASE  2 THERMAL  RESULTS          LOAD= THM,BWG,
           ****************        MAX ECH = 1.000

0*** MEMBER FORCES (ACTING ON PIPE) AND DISPLACEMENT ***
```

MEMBER TYPE	DATA PT	FORCES (LBS) FX	FY	FZ	MOMENTS (FT-LBS) MX	MY	MZ	DISPLACEMENTS (IN) DX	DY	DZ	ROTATION (DEG) RX	RY	RZ
RUN	10	0	0	0	0	108430	0	.000	.000	.000	.000	.000	.000
	20	0	0	0	0	-108430	0	.080	.000	.041	.000	-.078	.000
RUN	20	17638	0	0	0	54215	0	.080	.000	.041	.000	-.078	.000
	30	-17638	0	0	0	33974	0	-.017	.000	.121	.000	-.085	.000
RUN	30	0	0	0	0	0	0	-.017	.000	.121	.000	-.085	.000
	35	0	0	0	0	0	0	-.062	.000	.161	.000	-.085	.000
RUN	20	-17638	0	0	0	54215	0	.080	.000	.041	.000	-.078	.000
	40	17638	0	0	0	33974	0	.178	.000	-.040	.000	-.085	.000
RUN	40	0	0	0	0	0	0	.178	.000	-.040	.000	-.085	.000
	45	0	0	0	0	0	0	.222	.000	-.080	.000	-.085	.000
RUN	40	-17638	0	0	0	-33974	0	.178	.000	-.040	.000	-.085	.000
	110	17638	0	0	0	33974	0	.179	.000	.027	.000	-.043	.000
RUN	110	-17638	0	0	0	-33974	0	.179	.000	.027	.000	-.043	.000
	120	17638	0	0	0	33974	0	.181	.000	.049	.000	.000	.000
GTV	120	-17638	0	0	0	-33974	0	.181	.000	.049	.000	.000	.000
	130	17638	0	0	0	33974	0	.181	.000	.049	.000	.000	.000
RUN	130	-17638	0	0	0	-33974	0	.181	.000	.049	.000	.000	.000
	140	17638	0	0	0	33974	0	.182	.000	.027	.000	.043	.000
RUN	140	-17638	0	0	0	-33974	0	.182	.000	.027	.000	.043	.000
	340	17638	0	0	0	33974	0	.184	.000	-.040	.000	.085	.000
RUN	30	17638	0	0	0	-33974	0	-.017	.000	.121	.000	-.085	.000
	210	-17638	0	0	0	33974	0	.062	.000	.188	.000	-.043	.000
RUN	210	17638	0	0	0	-33974	0	.062	.000	.188	.000	-.043	.000
	220	-17638	0	0	0	33974	0	.141	.000	.210	.000	.000	.000
GTV	220	17638	0	0	0	-33974	0	.141	.000	.210	.000	.000	.000
	230	-17638	0	0	0	33974	0	.221	.000	.210	.000	.000	.000
RUN	230	17638	0	0	0	-33974	0	.221	.000	.210	.000	.000	.000
	240	-17638	0	0	0	33974	0	.300	.000	.188	.000	.043	.000
RUN	240	17638	0	0	0	-33974	0	.300	.000	.188	.000	.043	.000
********** Part of table removed to fit the page													
	330	-17638	0	0	0	33974	0	.379	.000	.121	.000	.085	.000
RUN	320	17638	0	0	0	-54215	0	.281	.000	.041	.000	.078	.000
	340	-17638	0	0	0	-33974	0	.184	.000	-.040	.000	.085	.000
RUN	340	0	0	0	0	0	0	.184	.000	-.040	.000	.085	.000
	345	0	0	0	0	0	0	.139	.000	-.080	.000	.085	.000
RUN	320	0	0	0	0	108430	0	.281	.000	.041	.000	.078	.000
	310	0	0	0	0	-108430	0	.362	.000	.000	.000	.000	.000
MAXIMUM RESPONSE		17637	0	0	0	108429	0	.423	.000	.210	.000	.085	.000
AT POINTS		330	310	20	310	320	310	335	310	230	310	335	310

At the critical stress location point-20 end, the moment sign is (-). The sign of second operating condition shall be checked to determine the stress range calculated by taking the difference.

4C – Displacement Stress of the Second Operating Condition

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ASME B313 EXAMPLE ANALYSIS - EXAMPLE-3
EXAMPLE 3: MOMENT REVERSAL

DATA FILE : B313-S303-1.

CASE 3 THERML-2 RESULTS LOAD= THM,BWG,
**************** MAX ECH = 1.000

0*** PIPE STRESSES ***

MEMBER TYPE	DATA PT	PIPE OD (IN)	CROSS AREA (IN2)	SECTN MODUL (IN3)	-- FORCES --- AXIAL (LB)	SHEAR (LB)	---- MOMENTS ---- TORSION (FT-LB)	BENDING (FT-LB)	STRESS-INTN OUT-P	IN-P	---------- STRESSES ---------- HOOP (PSI)	LONGI (PSI)	TRESCA (PSI)	EQUIV (PSI)
RUN	10	24.00	27.83	161.9	0	0	0	108429	1.000	1.000	0	8039	8039	8039
	20				0	0	0	108429	4.223	3.417	0	27468	27468	27468
RUN	20	24.00	27.83	161.9	0	17637	0	54214	4.223	3.417	0	13734	13966	13734
	30				0	17637	0	33973	4.223	3.417	0	8606	8972	8606
RUN	30	24.00	27.83	161.9	0	0	0	0	4.223	3.417	0	0	0	0
	35				0	0	0	0	1.000	1.000	0	0	0	0
RUN	20	24.00	27.83	161.9	0	17637	0	54214	4.223	3.417	0	13734	13966	13734
	40				0	17637	0	33973	4.223	3.417	0	8606	8972	8606
RUN	40	24.00	27.83	161.9	0	0	0	0	4.223	3.417	0	0	0	0
	45				0	0	0	0	1.000	1.000	0	0	0	0
RUN	40	20.00	23.12	111.3	-17637	0	0	33973	4.145	3.354	0	13044	13044	12281
	110				-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	110	20.00	23.12	111.3	-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	120				-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	130	20.00	23.12	111.3	-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	140				-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	140	20.00	23.12	111.3	-17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	340				-17637	0	0	33973	4.145	3.354	0	13044	13044	12281
RUN	30	20.00	23.12	111.3	17637	0	0	33973	4.145	3.354	0	13044	13044	12281
	210				17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	210	20.00	23.12	111.3	17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	220				17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	230	20.00	23.12	111.3	17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	240				17637	0	0	33973	1.000	1.000	0	4424	4424	3661
RUN	240	20.00	23.12	111.3	17637	0	0	33973	1.000	1.000	0	4424	4424	3661
	330				17637	0	0	33973	4.145	3.354	0	13044	13044	12281
********** Part of table removed to fit the page														
RUN	340	24.00	27.83	161.9	0	0	0	0	4.223	3.417	0	0	0	0
	345				0	0	0	0	1.000	1.000	0	0	0	0
RUN	320	24.00	27.83	161.9	0	0	0	108429	4.223	3.417	0	27468	27468	27468
	310				0	0	0	108429	1.000	1.000	0	8039	8039	8039
MAXIMUM STRESSES											0	27468	27468	27468
AT POINTS											310	320	320	320

The displacement stresses termed “EQUIV” as calculated by SIMFLEX are very close to the ones given by Table S303.7.2 of the code attached. Again the sign of the moment component will be checked next to decide the stress range calculation. This is done automatically by SIMFLEX.

4D – Displacement Loads, Moments and Displacements for Second Operating Condition

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 -------------------------------------------------------------------------------
 ASME B313 EXAMPLE ANALYSIS - EXAMPLE-3
 EXAMPLE 3:  MOMENT REVERSAL
                                                    DATA FILE : B313-S303-1.

 CASE  3 THERML-2 RESULTS         LOAD= THM,BWG,
          ****************        MAX ECH = 1.000

0*** MEMBER FORCES (ACTING ON PIPE) AND DISPLACEMENT ***
 ----------------------------------------------------------------------------------------------------------------------
 MEMBER  DATA             ----- FORCES (LBS) -----     ---- MOMENTS (FT-LBS) ----     DISPLACEMENTS (IN)       ROTATION (DEG)
  TYPE    PT                  FX       FY       FZ          MX        MY        MZ       DX      DY      DZ      RX      RY      RZ
 ----------------------------------------------------------------------------------------------------------------------

 RUN     10                    0        0        0           0   -108430         0     .000    .000    .000    .000    .000    .000
         20                    0        0        0           0    108430         0     .080    .000   -.041    .000    .078    .000
 RUN     20               -17638        0        0           0    -54215         0     .080    .000   -.041    .000    .078    .000
         30                17638        0        0           0    -33974         0     .178    .000    .040    .000    .085    .000
 RUN     30                    0        0        0           0         0         0     .178    .000    .040    .000    .085    .000
         35                    0        0        0           0         0         0     .222    .000    .080    .000    .085    .000

 RUN     20                17638        0        0           0    -54215         0     .080    .000   -.041    .000    .078    .000
         40               -17638        0        0           0    -33974         0    -.017    .000   -.121    .000    .085    .000
 RUN     40                    0        0        0           0         0         0    -.017    .000   -.121    .000    .085    .000
         45                    0        0        0           0         0         0    -.062    .000   -.161    .000    .085    .000

 RUN     40                17638        0        0           0     33974         0    -.017    .000   -.121    .000    .085    .000
        110               -17638        0        0           0    -33974         0     .062    .000   -.188    .000    .043    .000
 RUN    110                17638        0        0           0     33974         0     .062    .000   -.188    .000    .043    .000
        120               -17638        0        0           0    -33974         0     .141    .000   -.210    .000    .000    .000
 GTV    120                17638        0        0           0     33974         0     .141    .000   -.210    .000    .000    .000
        130               -17638        0        0           0    -33974         0     .221    .000   -.210    .000    .000    .000
 RUN    130                17638        0        0           0     33974         0     .221    .000   -.210    .000    .000    .000
        140               -17638        0        0           0    -33974         0     .300    .000   -.188    .000   -.043    .000
 RUN    140                17638        0        0           0     33974         0     .300    .000   -.188    .000   -.043    .000
        340               -17638        0        0           0    -33974         0     .379    .000   -.121    .000   -.085    .000

 RUN     30               -17638        0        0           0     33974         0     .178    .000    .040    .000    .085    .000
        210                17638        0        0           0    -33974         0     .179    .000   -.027    .000    .043    .000
 RUN    210               -17638        0        0           0     33974         0     .179    .000   -.027    .000    .043    .000
        220                17638        0        0           0    -33974         0     .181    .000   -.049    .000    .000    .000
 GTV    220               -17638        0        0           0     33974         0     .181    .000   -.049    .000    .000    .000
        230                17638        0        0           0    -33974         0     .181    .000   -.049    .000    .000    .000
 RUN    230               -17638        0        0           0     33974         0     .181    .000   -.049    .000    .000    .000
        240                17638        0        0           0    -33974         0     .182    .000   -.027    .000   -.043    .000
********** Part of table removed to fit the page ---------------------------------------------------------------------------
 RUN    320               -17638        0        0           0     54215         0     .281    .000   -.041    .000   -.078    .000
        340                17638        0        0           0     33974         0     .379    .000   -.121    .000   -.085    .000
 RUN    340                    0        0        0           0         0         0     .379    .000   -.121    .000   -.085    .000
        345                    0        0        0           0         0         0     .423    .000   -.161    .000   -.085    .000

 RUN    320                    0        0        0           0   -108430         0     .281    .000   -.041    .000   -.078    .000
        310                    0        0        0           0    108430         0     .362    .000    .000    .000    .000    .000
 **********************************************************************************************************************
 MAXIMUM RESPONSE          17637        0        0           0    108429         0     .423    .000   -.210    .000    .085    .000
 AT POINTS                   220      310       20         310        20       310      345     310     120     310      30     310
```

The sign of the most critical moment at point-20 end is (+) which is in opposite to the one for the first operating condition given in the previous pages. Therefore the stress range shall be the absolute sum of the stresses generated for both operating conditions. That is the stress range is 27468 + 27468 = 54936 psi. This is calculated automatically by SIMFLEX in Code Stress Compliance.

4E – Code Stress Compliance Table for Example – 3

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ASME B313 EXAMPLE ANALYSIS - EXAMPLE-3
EXAMPLE 3: MOMENT REVERSAL

DATA FILE : B313-S303-1.

0 * EXPANSION STRESS IS THE COMBINATION OF (2) THERMAL CONDITION(S), *
* PLUS EARTHQUAKE SUPPORT DISPLACEMENT, IF ANY. *
* OCCASIONAL STRESS IS THE SUM OF SUSTAINED, GREATER OF EARTHQUAKE *
* INERTIA AND WIND, HARMONIC, AND OCCASIONAL FORCES, IF ANY *
0*** PROCESS PIPING CODE COMPLIANCE ANALYSIS - ASME B31.3 ***

MEMBER TYPE	DATA PT	PIPE-(IN) OD	THK	/PAR.304.1.2-EQ.3/ PRESSURE-(PSI) DESIGN	ALLOW	/PAR.302.3.5, (C) / SUSTAINED-(PSI) CALCULATED	ALLOW	/PAR.302.3.6, (A) / OCCASIONAL-(PSI) CALCULATED	ALLOW	/PAR.302.3.5, (D) / EXPANSION-(PSI) CALCULATED	ALLOW
0 RUN	10	24.00	.375	300	553	4968	20000	4968	26600	16078	54038
	20	24.00	.375	300	553	5127	20000	5127	26600	54936OVER	53847
0 RUN	20	24.00	.375	300	553	4891	20000	4891	26600	27468	54130
	30	24.00	.375	300	553	4888	20000	4888	26600	17213	54134
0 RUN	30	24.00	.375	300	553	4871	20000	4871	26600	0	54154
	35	24.00	.375	300	553	4800	20000	4800	26600	0	54240
0 RUN	20	24.00	.375	300	553	4891	20000	4891	26600	27468	54130
	40	24.00	.375	300	553	4888	20000	4888	26600	17213	54134
0 RUN	40	24.00	.375	300	553	4871	20000	4871	26600	0	54154
	45	24.00	.375	300	553	4800	20000	4800	26600	0	54240
0 RUN	40	20.00	.375	300	665	4234	20000	4234	26600	24561	54919
	110	20.00	.375	300	665	4293	20000	4293	26600	7323	54848
0 RUN	110	20.00	.375	300	665	4293	20000	4293	26600	7323	54848
	120	20.00	.375	300	665	4355	20000	4355	26600	7323	54774
0 RUN	130	20.00	.375	300	665	4355	20000	4355	26600	7323	54774
	140	20.00	.375	300	665	4293	20000	4293	26600	7323	54848
0 RUN	140	20.00	.375	300	665	4293	20000	4293	26600	7323	54848
	340	20.00	.375	300	665	4234	20000	4234	26600	24561	54919
0 RUN	30	20.00	.375	300	665	4234	20000	4234	26600	24561	54919
	210	20.00	.375	300	665	4293	20000	4293	26600	7323	54848
0 RUN	210	20.00	.375	300	665	4293	20000	4293	26600	7323	54848
	220	20.00	.375	300	665	4355	20000	4355	26600	7323	54774
0 RUN	230	20.00	.375	300	665	4355	20000	4355	26600	7323	54774
	240	20.00	.375	300	665	4293	20000	4293	26600	7323	54848
0 RUN	240	20.00	.375	300	665	4293	20000	4293	26600	7323	54848
	330	20.00	.375	300	665	4234	20000	4234	26600	24561	54919
0 RUN	320	24.00	.375	300	553	4891	20000	4891	26600	27468	54130

********** Part of table removed to fit the page ----------

	340	24.00	.375	300	553	4888	20000	4888	26600	17213	54134
0 RUN	340	24.00	.375	300	553	4871	20000	4871	26600	0	54154
	345	24.00	.375	300	553	4800	20000	4800	26600	0	54240
0 RUN	320	24.00	.375	300	553	5127	20000	5127	26600	54936OVER	53847
	310	24.00	.375	300	553	4968	20000	4968	26600	16078	54038
OVER STRESS POINTS:				0		0		0		2	

*** OVER STRESS AT 2 LOCATIONS

The displacement stress range is automatically calculated in this Code Stress Compliance Table. It shows overstress at two locations. The allowable for is example uses B31.3 Par 302.3.5 Eq.(1b). That is SA=f[1.25(Sc+Sh) – SL]. The allowable varies point by point depending on the sustained stress of the point. In this example, the sustained stresses are fairly uniform. This make the allowable stresses also all about the same.

Attachments:

1. ASME B31.3 *Process Piping*, Appendix S, “Piping System Stress Analysis Examples”

APPENDIX S
PIPING SYSTEM STRESS ANALYSIS EXAMPLES

S300 INTRODUCTION

The example in this Appendix is intended to illustrate the application of the rules and definitions in Chapter II, Part 5, Flexibility and Support; and the stress limits of para. 302.3.5. The loadings and conditions necessary to comply with the intent of the Code are presented.

(06) S300.1 Definitions and Nomenclature

global axes: These are Cartesian X, Y, and Z axes. In this Appendix, vertically upward is taken to be the +Y direction with gravity acting in the −Y direction.

A_{sf}: cross-sectional area of the conveyed fluid, considering nominal pipe thickness less allowances

A_{sp}: cross-sectional area of the pipe, considering nominal pipe thickness less allowances

F_{sa}: sustained axial force including the effects of weight, other sustained loads, and internal pressure

$i_{s,i}$: in-plane sustained stress index ≥ 1.00 (The stress index equals $0.75i_i$ for all components included in Appendix D in the absence of more applicable data and in accordance with para. 319.3.6.)

$i_{s,o}$: out-plane sustained stress index ≥ 1.00 (The stress index equals $0.75i_o$ for all components included in Appendix D in the absence of more applicable data and in accordance with para. 319.3.6.)

$M_{s,i}$: in-plane bending moment for the sustained condition being evaluated

$M_{s,o}$: out-plane bending moment for the sustained condition being evaluated

M_{st}: torsional moment for the sustained condition being evaluated

P_j: piping internal pressure; see para. 301.2; when more than one condition exists for the piping system, each is subscripted (e.g., P_1, P_2, ...)

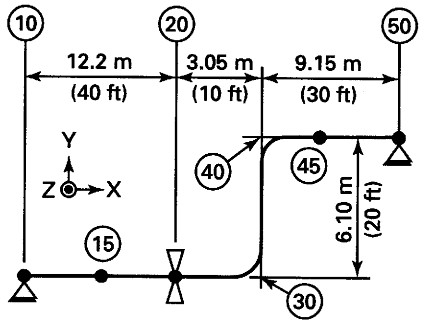
S_{sa}: stress due to the sustained axial force summation, F_{sa}/A_{sp}

S_{sb}: stress due to the indexed sustained bending moments' vector summation

S_{st}: stress due to sustained torsional moment

T_j: pipe maximum or minimum metal temperature; see paras. 301.3 and 319.3.1(a); when more than one condition exists for the piping system, each is subscripted (e.g., T_1, T_2, ...)

Fig. S301.1 Simple Code Compliant Model



Y+: a "single acting support" that provides support in only the vertically upward direction and is considered to be "active" when the pipe exerts a downward force on the support. The pipe is free to move upward, i.e., the pipe "lifts off" the support; the support in the "lift-off" situation is considered to be "removed" from providing support, i.e., inactive, during the load condition considered.

S301 EXAMPLE 1: CODE COMPLIANT PIPING SYSTEM

S301.1 Example Description

This example is intended to illustrate the design of an adequately supported and sufficiently flexible piping system. The piping system in Fig. S301.1 is fabricated from ASTM A 106 Grade B seamless pipe (i.e., E = 1.00); the pipe is DN 400 (NPS 16) with a nominal wall thickness of 9.53 mm (0.375 in.), 127 mm (5 in.) thickness of calcium silicate insulation, and 1.59 mm (0.063 in.) corrosion allowance; the fluid has a specific gravity of 1.0. The equivalent number of cycles expected for the piping system is fewer than 7,000 [i.e., f = 1.00 in accordance with para. 302.3.5(d)].

The piping system is in normal fluid service. The installation temperature is 21°C (70°F). The reference modulus of elasticity used for the piping analysis is 203.4 GPa (29.5 Msi) from Appendix C, Table C-6 in accordance with paras. 319.3.2 and 319.4.4, and Poisson's ratio is 0.3 in accordance with para. 319.3.3.

The piping internal pressure, maximum and minimum metal temperatures expected during normal operation, and the design conditions are listed in

Table S301.1 Temperature/Pressure Combinations

Conditions	Pressure	Temperature
Design conditions	3 795 kPa (550 psi)	288°C (550°F)
Operating (P_1,T_1) maximum metal temperature	3 450 kPa (500 psi)	260°C (500°F)
Operating (P_2,T_2) minimum metal temperature	0 kPa (0 psi)	−1°C (30°F)
Installation temperature	0 kPa (0 psi)	21°C (70°F)

Table S301.1. The design conditions are set sufficiently in excess of the operating conditions so as to provide additional margin on the allowable stress for pressure design as required by the owner.

S301.2 Design Conditions

The design conditions establish the pressure rating, flange ratings, component ratings, and minimum required pipe wall thickness in accordance with para. 301.2.1. For example, ASME B16.5 requires a minimum of Class 300 for ASTM A 105 flanges. Also, the minimum required pipe wall thickness, t_m, is determined from the design conditions by inserting eq. (3a) into eq. (2); terms are defined in para. 304.1.1 and Appendix J:

E = 1.0
P = design pressure
= 3 795 kPa (550 psi)
S = allowable stress from Appendix A, Table A-1
= 125 MPa (18.1 ksi) at design temperature 288°C (550°F)
Y = 0.4 from Table 304.1.1

Insert eq. (3a) into eq. (2):

$$t_m = t + c = \frac{PD}{2(SE + PY)} + c$$

$$= \frac{(3795 \text{ kPa})(406.4 \text{ mm})}{2[(125 \text{ MPa})(1.00) + (3795 \text{ kPa})(0.4)]} + 1.59 \text{ mm}$$

$$= 6.10 \text{ mm} + 1.59 \text{ mm} = 7.69 \text{ mm } (0.303 \text{ in.})$$

In accordance with para. 304.1.2(a), t must be less than $D/6$ for eq. (3a) to be appropriate without considering additional factors to compute the pressure design thickness, t (i.e., $t < D/6$, or 7.69 mm < 406.4 mm/6). Since 7.69 mm (0.303 in.) < 67.7 mm (2.67 in.), eq. (3a) is applicable without special consideration of factors listed in para. 304.1.2(b).

Now select a pipe schedule of adequate thickness. Determine the specified minimum pipe wall thickness,

Table S301.3.1 Generic Pipe Stress Model Input

Term	Value
Operating conditions:	
internal pressure, P_1	3 450 kPa (500 psi)
maximum metal temp., T_1	260°C (500°F)
minimum metal temp., T_2	−1°C (30°F)
installation temperature	21°C (70°F)
Line size	DN 400 (NPS 16)
Pipe	Schedule 30/STD, 9.53 mm (0.375 in.)
Mechanical allowance, c	1.59 mm (0.063 in.)
Mill tolerance	12.5%
Elbows	Long radius
Fluid specific gravity	1.0
Insulation thickness	127 mm (5 in.)
Insulation density	176 kg/m^3 (11.0 lbm/ft^3)
Pipe material	ASTM A 106 Grade B
Pipe density	7 833.4 kg/m^3 (0.283 lbm/in.^{3})
Total weight	7 439 kg (16,400 lbm)
Unit weight	248.3 kg/m (166.9 lbm/ft)

T, from nominal pipe wall thickness, $\overline{T}$, considering a mill tolerance of 12.5%.

Select DN 400 (NPS 16) Schedule 30/STD nominal wall thickness from ASME B36.10M:

$\overline{T}$ = 9.53 mm (0.375 in.)
T = (9.53 mm)(1.00 − 0.125) = 8.34 mm (0.328 in.)

Since $T \geq t_m$ (i.e., 8.34 mm > 7.69 mm), the selection of the nominal pipe wall thickness, $\overline{T}$, for Schedule 30/STD pipe is acceptable. The long radius elbows specified for this piping system are in accordance with ASME B16.9 and are specified to be for use with Schedule 30/STD wall thickness pipe.

S301.3 Computer Model Input

Tables S301.3.1 and S301.3.2 list the "node numbers," lengths, etc., for each piping element displayed in Fig. S301.1. A bend radius of 1.5 times the nominal pipe diameter [i.e., 609.6 mm (24 in.)] and nominal wall thickness of 9.53 mm (0.375 in.) are used for the elbows in the computer model.

Generic computer program option "flags" are as follows:

(a) include pressure stiffening on elbows — PSIF

(b) exclude pressure thrust and Bourdon effects NO-PECONG

(c) use nominal section properties for both the stiffness matrix and the displacement stress analysis

(d) use "nominal less allowances" section properties for sustained stress, S_L

(e) include axial load and internal pressure force in the sustained stress, S_L P + FX

Table S301.3.2 Element Connectivity, Type, and Lengths

From	To	D_X, m (ft)	D_Y, m (ft)	Element Type
10	15	6.10 (20)	. . .	10 anchor 15 bisection node
15	20	6.10 (20)	. . .	20 Y support
20	30	3.05 (10)	. . .	Three-node elbow [Note (1)]
30	40	. . .	6.10 (20)	Three-node elbow [Note (1)]
40	45	3.05 (10)	. . .	Informational node
45	50	6.10 (20)	. . .	50 anchor

GENERAL NOTE: This piping system is planar, i.e., D_Z = 0 m (ft) for each piping element.

NOTE:

(1) The specified element lengths are measured to and/or from each elbow's tangent intersection point.

(*f*) intensify the elbows' in-plane bending moments[1] by $0.75i_i$ ($\geq$ 1.0) in the calculation of the elbows' effective sustained longitudinal stress, S_L

S301.4 Pressure Effects

For the operating, sustained, and displacement stress range load cases, the effect of pressure stiffening on the elbows is included to determine the end reactions in accordance with Appendix D, Note (7). The effects of pressure-induced elongation and Bourdon effects are not included, as both are deemed negligible for this particular example.

S301.5 The Operating Load Case

The operating load case is used to determine the operating position of the piping and reaction loads for any attached equipment, anchors, supports, guides, or stops. The operating load case is based on the temperature range from the installation temperature of 21°C (70°F) to the maximum operating metal temperature of 260°C (500°F), in accordance with para. 319.3.1(b). The operating load case in this example also includes the effects of internal pressure, pipe weight, insulation weight, and fluid weight on the piping system. Both pipe stiffness and stress are based on the nominal thickness of the pipe. Pipe deflections and internal reaction loads for the operating load case are listed in Table S301.5.1. Piping loads acting on the anchors and support structure are listed in Table S301.5.2.

S301.6 The Sustained Load Case

Sustained stresses due to the axial force, internal pressure, and intensified bending moment in this example are combined to determine the sustained longitudinal stress, S_L. The sustained load case excludes thermal effects and includes the effects of internal pressure [P_1 = 3450 kPa (500 psi)], pipe weight, insulation weight, and fluid weight on the piping system.

Nominal section properties are used to generate the stiffness matrix and sustained loads for the computer model in accordance with para. 319.3.5. The nominal thickness, less allowances, is used to calculate the section properties for the sustained stress, S_L, in accordance with para. 302.3.5(c).

A summary of the sustained load case internal reaction forces, moments, and sustained stresses, S_L, is provided in Table S301.6. Since this example model lies in only one plane, only the sustained bending stress due to the in-plane bending moment is not zero. The in-plane bending moment is intensified[1] at each elbow by the appropriate index $0.75i_i$ ($\geq$ 1.0), where i_i is the in-plane stress intensification factor from Appendix D for an unflanged elbow. Note that sustained stresses for the nodes listed in Table S301.6 do not exceed the 130 MPa (18,900 psi) sustained allowable stress, S_h, for A 106 Grade B piping at the maximum metal temperature, T_1 = 260°C (500°F), from Appendix A, Table A-1. By limiting S_L to the sustained allowable, S_h, the piping system is deemed adequately protected against collapse.

S301.7 The Displacement Stress Range Load Case

The displacement stress range, S_E, in this example is based on the temperature range from the installation [21°C (70°F)] to minimum metal temperature [T_2 = −1°C (30°F)] and from the installation [21°C (70°F)] to maximum metal temperature for the thermal cycles under analysis [T_1 = 260°C (500°F)], in accordance with para. 319.3.1(a). The displacement stress range, S_E, for each element is calculated in accordance with eq. (17) and is listed in Table S301.7, along with the internal reaction loads. Nominal section properties are used to generate

[1] ASME B31.3 does not address the issue of using a stress intensification factor as the stress index to be applied to piping components for sustained loads; stress intensification factors are based on fatigue test results. Establishing the proper index is the responsibility of the designer. This example uses 0.75 times the stress intensification factor for the sustained case.

For TW-1

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

Node Number	Axial Force, N (lb) (Signed) [Note (1)]	Bending Moment, N-m (ft-lb) (Unsigned) [Note (1)]	Horizontal Deflection, mm (in.) [Note (1)]	Vertical Deflection, mm (in.) [Note (1)]
10	+26 500 (+5,960)	21 520 (15,870)	0.00	0.00
15	−26 500 (−5,960)	10 710 (7,900)	18.3 (0.72)	−1.3 (−0.05)
20	−26 500 (−5,960)	47 560 (35,080)	36.7 (1.44)	0.00
30 near	−26 500 (−5,960)	57 530 (42,440)	44.0 (1.73)	−3.7 (−0.14)
30 mid	−46 300 (−10,410)	69 860 (51,530)	44.7 (1.76)	−2.3 (−0.09)
30 far	−37 800 (−8,500)	65 320 (48,180)	41.4 (1.63)	0.4 (0.02)
40 near	−25 920 (−5,830)	63 930 (47,160)	−23.0 (−0.91)	15.1 (0.59)
40 mid	−36 250 (−8,150)	70 860 (52,270)	−26.4 (−1.04)	17.8 (0.70)
40 far	−26 500 (−5,960)	65 190 (48,080)	−25.7 (−1.01)	19.2 (0.75)
45	−26 500 (−5,960)	14 900 (10,990)	−18.3 (−0.72)	13.5 (0.53)
50	−26 500 (−5,960)	47 480 (35,030)	0.00	0.00

NOTE:
(1) Loads and deflections are averaged from commercial programs with a variance within units' conversion tolerance.

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

	Global Axis Forces and Moments		
Node	F_X, N (lb) (Signed) [Note (1)]	F_Y, N (lb) (Signed) [Note (1)]	M_Z, N-m (ft-lb) (Unsigned) [Note (1)]
10 anchor	−26 500 (−5,960)	−12 710 (−2,860)	21 520 (15,870)
20 support	...	−63 050 (−14,180)	...
50 anchor	+26 500 (+5,960)	+2 810 (+630)	47 480 (35,030)

NOTE:
(1) Loads and deflections are averaged from commercial programs with a variance within units' conversion tolerance.

Table S301.6 Sustained Forces and Stresses [Allowable, S_h = 130 MPa (18,900 psi)]

Oper P.
Not D.P.

Node	Axial Force, N (lb) (Signed) [Note (1)]	Bending Moment, N-m (ft-lb) (Unsigned) [Note (1)]	Sustained Stress, S_L, kPa (psi) [Note (2)]
10 anchor	+3 270 (+735)	17 260 (12,730)	59 100 (8,560)
20 support	−3 270 (−735)	56 130 (41,400)	99 200 (14,370)
30 far	−19 880 (−4,470)	16 320 (12,040)	72 700 (10,540)
40 far	+3 270 (+735)	2 340 (1,730)	46 050 (6,680)
50 anchor	+3 270 (+735)	37 860 (27,930)	80 350 (11,650)

NOTES:
(1) Loads, deflections, and stresses are averaged from commercial programs with a variance within units' conversion tolerance.
(2) Axial forces have their sign retained and do not include the signed axial pressure force, which is also included in the sustained stress, S_L.

Table S301.7 Displacement Stress Range [S_A = 205 MPa (29,725 psi)]

	Global Axis Forces and Moments			
Node	F_X, N (lb) (Unsigned) [Note (1)]	F_Y, N (lb) (Unsigned) [Note (1)]	M_Z, N-m (ft-lb) (Unsigned) [Note (1)]	S_E From Eq. (17), kPa (psi) [Note (1)]
10 anchor	25 070 (5,640)	1 130 (260)	4 600 (3,390)	4 000 (580)
20 support	25 070 (5,640)	1 130 (260)	9 250 (6,820)	8 040 (1,170)
30 mid	25 070 (5,640)	19 330 (4,350)	60 250 (44,440)	137 000 (19,870)
40 mid	25 070 (5,640)	19 330 (4,350)	76 740 (56,600)	174 500 (25,300)
50 anchor	25 070 (5,640)	19 330 (4,350)	92 110 (67,940)	79 900 (11,600)

NOTE:
(1) Loads, deflections, and stresses are averaged from commercial programs with a variance within units' conversion tolerance.

the stiffness matrix and displacement stress in the piping in accordance with para. 319.3.5. Since this example model lies in only one plane, only the in-plane bending moment is not zero. The in-plane moment is intensified at each elbow by the appropriate Appendix D stress intensification factor, i_i, for an unflanged elbow.

For simplicity, the allowable displacement stress range, S_A, is calculated in accordance with eq. (1a). Though eq. (1a) is used in this example, it is also acceptable to calculate S_A in accordance with eq. (1b), which permits S_A to exceed the eq. (1a) value for each piping element, based on the magnitude of each element's sustained stress, S_L.

The following terms are as defined in para. 302.3.5(d) and Appendix J:

f = 1.00 for ≤ 7000 equivalent cycles, from Fig. 302.3.5 or eq. (1c)

S_A = $f\,(1.25S_c + 0.25S_h)$
= (1.00)[(1.25)(138 MPa) + (0.25)(130 MPa)]
= 205 MPa (29,725 psi)

S_c = allowable stress from Appendix A, Table A-1
= 138 MPa (20.0 ksi) at T_2

S_h = allowable stress from Appendix A, Table A-1
= 130 MPa (18.9 ksi) at T_1

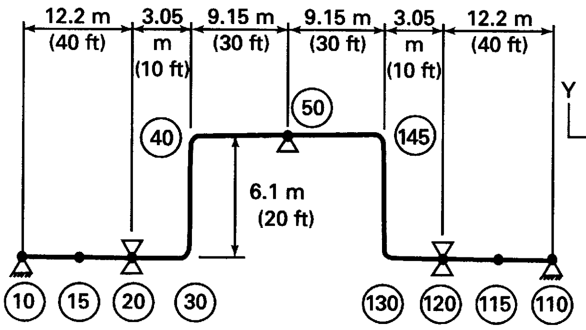
T_1 = maximum metal temperature
= 260°C (500°F)

T_2 = minimum metal temperature
= −1°C (30°F)

Note that each piping element's displacement stress range, based on minimum to maximum metal temperature for the thermal cycles under analysis, S_E, does not exceed the eq. (1a) allowable, S_A. By limiting S_E to S_A, the piping system is deemed adequate to accommodate up to 7000 full excursion equivalent cycles.

Considering both the sustained and displacement stress range load cases, the piping system is compliant with the requirements of the Code; redesign of the piping system is not required unless the sustained or operating reaction loads at either anchor data point 10 or 50 exceed the allowable loads for the attached equipment nozzle or the support structure at node 20 is overloaded. The nozzle load and support structure analyses are beyond the scope of this Appendix and are not addressed.

Fig. S302.1 Lift-Off Model



S302 EXAMPLE 2: ANTICIPATED SUSTAINED CONDITIONS CONSIDERING PIPE LIFT-OFF (06)

S302.1 Example Description

This example is intended to illustrate the analysis of a piping system in which a portion of the piping lifts off at least one Y+ support in at least one operating condition. The emphasis of this example is to describe the effect this removal of support has on the determination of anticipated sustained conditions. The same principles utilized for this example would also apply for guides and stops (single directional or gap-type) that are not engaged during any anticipated operating condition's thermal excursion.

The examples in this Appendix are intended for illustration purposes only and are not intended to portray the same as either adequate or even acceptable piping geometries and/or support scenarios. The piping system in Fig. S302.1 is the same in material and dimensional properties as in Example 1; see para. S301.1. Note

Table S302.1 Temperature/Pressure Combinations

Conditions	Pressure	Temperature
Design conditions	3 968 kPa (575 psi)	302°C (575°F)
Operating (P_1, T_1) maximum metal temperature (Operating Case 1)	3 795 kPa (550 psi)	288°C (550°F)
Operating (P_2, T_2) minimum metal temperature (Operating Case 2)	0 kPa (0 psi)	−1°C (30°F)
Installation temperature	...	21°C (70°F)

that both the design and operating conditions are well below the creep regime; therefore, the piping system will not develop any permanent creep-related displacements, relaxation, or sag.

S302.2 Design Conditions

The design conditions are similar to those in the Example 1 model; see para. S301.2 and Table S302.1. Note that the minimum thickness remains unchanged from Example 1 even though the design conditions have increased slightly. The hydrotest pressure does increase from 6 039 kPa (875 psi) to 6 729 kPa (975 psi).

S302.3 Computer Model Input

Table S302.3 lists the node numbers, lengths, etc., for each piping component that is displayed in Fig. S302.1. The computer-based options are the same as those for the Example 1 model; see para. S301.3.

S302.4 Pressure Effects

The pressure effect considerations are the same as those for Example 1; see para. 301.4.

S302.5 The Operating Load Case

The operating condition evaluated and discussed in this example, Operating Case 1, includes the effects of pipe weight, insulation weight, fluid weight, internal pressure [P_1 = 3 795 kPa (550 psi)], and temperature [T_1 = 288°C (550°F)]. An operating load case is evaluated to determine the operating position of the piping and determine the reaction loads for any attached equipment, anchors, supports, guides, or stops. In particular, each operating load case's support scenario is evaluated or assessed by the designer in order to determine whether any anticipated sustained conditions need to be evaluated with one or more Y+ supports removed. Further operating load case discussion can be found in para. S301.5.

Piping loads acting on the anchors and support structure for Operating Case 1 are listed in Table S302.5.1. Note that only nodes 10 through 50 are listed in the following tables; this is both for convenience, since the model is symmetric, and for comparison to Example 1, e.g., the loads, deflections, and stresses for nodes 10 through 40 are the same as for nodes 110 through 140 except that some signs may be reversed.

S302.6 Sustained Conditions

S302.6.1 The Sustained Stress, S_L, Calculations. Sustained stresses due to the following are combined to determine the sustained stress, S_L, for each sustained condition that is evaluated; see para. S302.6.2:

Table S302.3 Generic Pipe Stress Model Input: Component Connectivity, Type, and Lengths

From	To	D_X, m (ft)	D_Y, m (ft)	Component Type
10	15	6.10 (20)	...	10 anchor 15 informational node
15	20	6.10 (20)	...	20 *Y* support
20	30	3.05 (10)	...	Three node elbow [Note (1)]
30	40	...	6.10 (20)	Three node elbow [Note (1)]
40	45	3.05 (10)	...	Informational node
45	50	6.10 (20)	...	50 *Y*+ support
110	115	−6.10 (−20)	...	110 anchor 115 informational node
115	120	−6.10 (−20)	...	120 *Y* support
120	130	−3.05 (−10)	...	Three node elbow [Note (1)]
130	140	...	6.10 (20)	Three node elbow [Note (1)]
140	145	−3.05 (−10)	...	Informational node
145	50	−6.10 (−20)	...	...

NOTE:
(1) The specified component lengths are measured to and/or from each elbow's tangent intersection point.

Table S302.5.1 Results for Operating Case 1: Reaction Loads on Support and Anchors

Node	F_x, N (lb) (Signed) [Note (1)]	F_y, N (lb) (Signed) [Note (1)]	M_z, N-m (ft-lb) (Unsigned) [Note (1)]
10 anchor	−26 600 (−5,975)	−14 050 (−3,150)	27 000 (19,900)
20 support	...	−58 900 (−13,250)	...
50 *Y*+	...	0 [Note (2)]	...

NOTES:
(1) Loads and deflections are averaged from commercial programs with a variance within units' convergence tolerances. Magnitudes of loads for nodes 10 and 20 are the same for 110 and 120, but may differ in sign.
(2) No support is provided at the node 50 *Y*+ restraint for Operating Case 1.

(*a*) the absolute value of the sustained axial mechanical and pressure force summation

(*b*) the vector summation of indexed sustained bending moments

(*c*) the sustained torsional moment

The sustained stress, S_L, is computed in the manner described in Example 1 and illustrated in eqs. (S1), (S2), and (S3). Terms not defined below are described in para. 319.4.4, Appendix J, and para. S300.1.

$$S_L = \sqrt{(|S_{sa}| + S_{sb})^2 + 4S_{st}^2} \quad \text{(S1)}$$

where

S_{sa} = stress due to sustained axial force for the sustained condition being evaluated
= F_{sa}/A_{sp}

A_{sp} = cross-sectional area of the pipe, considering nominal pipe thickness less allowances

F_{sa} = sustained axial force, which includes both the sustained axial mechanical force and the longitudinal pressure force for the sustained condition being evaluated

The longitudinal pressure force is $P_j \times A_{sf}$ for piping systems that contain no expansion joints, where

A_{sf} = cross-sectional area of the conveyed fluid considering nominal pipe thickness less allowances
= $\pi d^2/4$

d = pipe inside diameter considering pipe wall thickness less allowances

NOTE: For piping systems with expansion joints, it is the responsibility of the designer to determine the axial force due to the longitudinal pressure in the piping system.

$$S_{sb} = \frac{\sqrt{(i_{s,i}M_{s,i})^2 + (i_{s,o}M_{s,o})^2}}{Z} \quad \text{(S2)}$$

where

$i_{s,i}$ = sustained in-plane stress index ≥ 1.00

$i_{s,o}$ = sustained out-plane stress index ≥ 1.00

$M_{s,i}$ = sustained in-plane bending moment for the sustained condition being evaluated

$M_{s,o}$ = sustained out-plane bending moment for the sustained condition being evaluated

NOTE: The stress index equals $0.75i_x$ (where $x = o$ or i) for all components included in Appendix D in the absence of more applicable data and in accordance with para. 319.3.6.

$$S_{st} = M_{st}/2Z \quad \text{(S3)}$$

where

M_{st} = torsional moment for the sustained condition being evaluated

S302.6.2 Anticipated Sustained Conditions. All anticipated sustained conditions utilizing all possible support scenarios should be considered and either evaluated or "Approved By Inspection." The designer has identified four anticipated sustained conditions for this piping system; each is listed in Table S302.6.2.1, along with the support status of the node 50 *Y*+ support, as either assessed by analysis or determined by the designer. The designer has deemed the Sustained Condition 3 as both controlling the sustained design and requiring evaluation; the designer has deemed the other conditions to be "Approved By Inspection."

S302.6.3 Results for the Evaluated Sustained Condition. The Sustained Condition 3 reflects the support scenario of the Operating Case 1, excludes thermal effects, and includes the effects of internal pressure [P_1 = 3 795 kPa (550 psi)], pipe weight, insulation weight, and fluid weight on the piping system. A summary of the Sustained Condition 3 internal reaction forces, moments, and sustained stresses, S_L, appears in Table S302.6.3.1. See para. S301.6 for additional information concerning the sustained stress determination.

S302.7 Displacement Stress Range Load Cases

The displacement stress range load cases are not listed, since they are not the subject of this example and each indicates the piping system is compliant with the fatigue-based requirements of the Code.

Table S302.6.2.1 Sustained Load Condition Listing

Sustained Condition	Node 50's Support Status (Active/Removed)
1: As installed [Note (1)]	Active
2: P_1 [Note (2)]	Active
3: P_1 [Note (2)]	Inactive
4: P_2 [Note (2)]	Active

NOTES:
(1) The original (as-installed) condition considers only pipe weight and insulation weight without fluid contents or internal pressure.
(2) The Sustained Conditions reflect the support scenario of the related Operating Conditions, exclude thermal effects, and include the effects of the related internal pressure, pipe weight, insulation weight, and fluid weight on the piping system.

Table S302.6.3.1 Sustained Forces and Stresses for Sustained Condition 3 With Node 50 Support Removed [Allowable S_h = 124.5 MPa (18,100 psi)): Fails]

	Global Axis Forces and Moments [Note (1)]			
Node	F_x, N (lb) (Signed) [Note (2)]	F_y, N (lb) (Signed) [Note (2)]	M_z, N-m (ft-lb) (Unsigned)	Sustained S_L, kPa (psi) [Notes (2), (3)]
10 anchor	12 575 (2,825)	8 385 (1,885)	3 995 (2,945)	48 645 (7,055)
20 support	12 575 (2,825)	64 565 (14,515)	82 845 (61,095)	129 975 (18,850)
30 far	12 575 (2,825)	34 985 (7,865)	29 985 (22,115)	101 920 (14,780)
40 mid	12 575 (2,825)	21 950 (4,935)	32 770 (24,165)	108 525 (15,740)
50 *Y*+	12 575 (2,825)	0 [Note (4)]	62 885 (46,375)	109 385 (15,865)

NOTES:
(1) Loads and deflections are averaged from commercial programs with a variance within units' convergence tolerance. The magnitude of loads and stresses for nodes 10 through 40 are the same for 110 and 140, though the loads may differ in sign.
(2) Forces have their sign retained, but do not include the signed axial pressure force necessary to compute the axial stress, which is included in the sustained stress, S_L.
(3) Stress may differ by slightly more than units' conversion tolerance.
(4) No support is provided at the node 50 *Y*+ restraint for Sustained Condition 3.

S302.8 Code Compliance: Satisfying the Intent of the Code

The piping system is compliant with the fatigue-based requirements of the Code. The Sustained Condition 3 results indicate that the piping system is not protected against collapse for the cycles under analysis when considering the Operating Case 1. Therefore, redesign of the piping system is required.

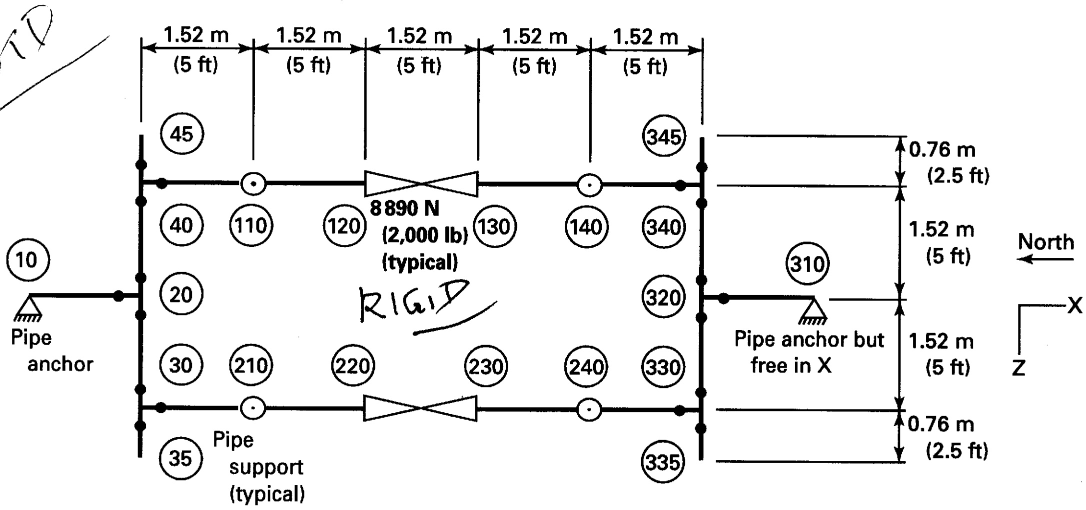
If the piping system is redesigned such that it is compliant with the intent of the Code, then the piping system would require no further attention unless the sustained, hydrotest, or operating reaction loads at either anchor data point 10 or 110 exceed the allowable loads for the attached equipment nozzle, or the support structure at either node 20 or 120 is overloaded. The nozzle loads and support structure analyses are beyond the scope of this Appendix and are not addressed. Although the occasional load cases are important to the design and analysis of a piping system, they are not discussed in this example.

S303 EXAMPLE 3: MOMENT REVERSAL (06)

S303.1 Example Description

This example is intended to illustrate the flexibility analysis required for a piping system that is designed for more than one operating condition and also experiences a "reversal of moments" between any two of the anticipated operating conditions. The examples in this Appendix are intended for illustration purposes only and are not intended to portray the same as either

Fig. S303.1 Moment Reversal Model



adequate or even acceptable piping geometries and/or support scenarios. Both the design and operating conditions are well below the creep regime.

The piping system in Fig. S303.1 consists of two headers and two branches, which are referred to as gas "meter runs." Only one of the branches is in service (operating) at a given time; the out-of-service branch is purged and at ambient condition. The design specification calls for each of the meter run branches to alternate in and out of service once per week for the piping system's planned 20-year service life, i.e., $f = 1.20$ in accordance with para. 302.3.5(d). The piping system is fabricated from ASTM A 53 Grade B pipe ($E = 1.00$), both piping headers are DN 600 (NPS 24) and the branches are DN 500 (NPS 20), and both branch and header are 9.53 mm (0.375 in.) thick. For simplicity, each piping segment or component is 1.524 m (5 ft) in length.

The piping system is in normal fluid service. The fluid is gaseous; is considered to add no weight; and to be neither a corrosive nor an erosive hazard, i.e., there is no corrosion allowance. The line is not insulated. The installation temperature is 4.5°C (40°F). The reference modulus of elasticity used is 203.4 GPa (29.5 Msi) and Poisson's ratio is 0.3. Consideration is given to the close proximity of the three tees in each header in accordance with the guidance in para. 319.3.6, and the stress intensification factors from Appendix D are considered to adequately represent the header tees for this piping system. The piping internal pressure, and minimum and maximum metal temperatures, expected during normal operation for each meter run and the design conditions, are listed in Table S303.1. The design conditions are set sufficiently in excess of the operating conditions so as to provide additional margin on the allowable as required by the owner.

S303.2 Design Conditions

The design conditions establish the pressure rating, flange ratings, components ratings, and minimum required pipe wall thickness. ASME B16.5 requires a minimum of Class 300 for ASTM A 105 flanges. The minimum required wall thickness for both the branch and header is 4.4 mm (0.171 in.), considering a 12.5% mill tolerance; therefore, selection of the standard wall thickness of 9.5 mm (0.375 in.) is acceptable.

S303.3 Computer Model Input

Table S303.3 lists the node numbers, lengths, etc., for each piping component that is displayed in Fig. S303.1. Note that flanges and valve components are not explicitly included in the model listing in Table S303.3. For simplicity, an entire branch (from tee centerline to tee centerline) is considered to be at the operating conditions listed in Table S303.1, e.g., the East meter run branch from nodes 40 through 340 operates at 1 724 kPa (250 psi) and 121°C (250°F) for Operating Case 2. The computer-based options are the same as those for the Example 1 model, except that pressure stiffening is not included in the analyses for this example; see para. S301.3.

S303.4 Pressure Effects

Neither pressure stiffening nor Bourdon effects are included in the analyses.

S303.5 Operating Load Case(s)

The operating load case is used to determine the operating position of the piping and reaction loads for any attached equipment, anchors, supports, guides, or stops. The owner has mandated in the design specification that the meter runs and piping be more than adequately supported. Therefore, the operating load case, while necessary to set the limits of the strain ranges, does not contribute to the emphasis of this example, and its output is not included.

Table S303.1 Pressure/Temperature Combinations

Condition	Header(s)		West Branch		East Branch	
	Pressure	Temperature	Pressure	Temperature	Pressure	Temperature
Design	2 069 kPa (300 psi)	149°C (300°F)	2 069 kPa (300 psi)	149°C (300°F)	2 069 kPa (300 psi)	149°C (300°F)
Operating Case 1 [Note (1)]	1 724 kPa (250 psi)	121°C (250°F)	1 724 kPa (250 psi)	121°C (250°F)	0 kPa (0 psi)	4.5°C (40°F)
Operating Case 2 [Note (2)]	1 724 kPa (250 psi)	121°C (250°F)	0 kPa (0 psi)	4.5°C (40°F)	1 724 kPa (250 psi)	121°C (250°F)
Installation temperature	...	4.5°C (40°F)	...	4.5°C (40°F)	...	4.5°C (40°F)

GENERAL NOTE: For computer based temperature and pressure data input, consider the West Branch temperature and pressure to be in effect from nodes 30 through 330 as listed in Table S303.3. Likewise, consider the East Branch temperature and pressure to be in effect from nodes 40 through 340 as listed in Table S303.3; see para. S303.3.

NOTES:
(1) East Branch is at ambient conditions.
(2) West Branch is at ambient conditions.

Table S303.3 Generic Pipe Stress Model Input: Component Connectivity, Type, and Lengths

From	To	D_X, m (ft)	D_Z, m (ft)	Component Type
10	20	1.52 (5)	...	10 anchor (DN 600 Header) 20 welding tee
20	30	...	1.52 (5)	30 welding tee
30	35	...	0.76 (2.5)	35 simulated end cap
20	40	...	−1.52 (−5)	40 welding tee
40	45	...	−0.76 (−2.5)	45 end cap
40	110	1.52 (5)	...	(East DN 500 Branch) 110 Y support
110	120	1.52 (5)	...	120 pipe segment
120	130	1.52 (5)	...	8 890 N (2,000 lb) meter
130	140	1.52 (5)	...	140 pipe segment
140	340	1.52 (5)	...	340 welding tee
30	210	1.52 (5)	...	(West DN 500 Branch) 210 Y support
210	220	1.52 (5)	...	220 pipe segment
220	230	1.52 (5)	...	8 890 N (2,000 lb) meter
230	240	1.52 (5)	...	240 pipe segment
240	330	1.52 (5)	...	330 welding tee
310	320	−1.52 (−5)	...	(DN 600 Header) 310 anchor [free in the X (axial) direction] 320 welding tee
320	330	...	1.52 (5)	330 welding tee
330	335	...	0.76 (2.5)	335 end cap
320	340	...	−1.52 (−5)	340 welding tee
340	345	...	−0.76 (−2.5)	345 end cap

GENERAL NOTE: This piping system is planar, i.e., D_Y = 0 m (0 ft) for each piping component.

Table S303.7.1 Case 1: Displacement Stress Range [Eq. (1a) Allowable S_A = 248.2 MPa (36 ksi): Passes]

	Global Axis Forces and Moments		
Node	F_x, N (lb) (Signed) [Note (1)]	M_y, N-m (ft-lb) (Signed) [Note (1)]	Eq. (17) S_E, kPa (psi) [Note (2)]
10 anchor	0	147 470 (108,755)	55 610 (8,065)
20 tee	0	−147 470 (−108,755)	189 945 (27,550)
30 tee	−78 485 (−17,645)	45 900 (33,850)	84 360 (12,235)
40 tee	78 485 (17,645)	45 900 (33,850)	84 360 (12,235)
110 *Y*	78 485 (17,645)	45 900 (33,850)	25 155 (3,650)
120	78 485 (17,645)	45 900 (33,850)	25 155 (3,650)
130 meter	78 485 (17,645)	45 900 (33,850)	25 155 (3,650)
140 *Y*	78 485 (17,645)	45 900 (33,850)	25 155 (3,650)
340 tee	78 485 (17,645)	45 900 (33,850)	84 360 (12,235)
210 *Y*	−78 485 (−17,645)	45 900 (33,850)	25 155 (3,650)
220	−78 485 (−17,645)	45 900 (33,850)	25 155 (3,650)
230 meter	−78 485 (−17,645)	45 900 (33,850)	25 155 (3,650)
240 *Y*	−78 485 (−17,645)	45 900 (33,850)	25 155 (3,650)
330 tee	−78 485 (−17,645)	45 900 (33,850)	84 360 (12,235)
310 anchor	0	−147 470 (−108,755)	55 610 (8,065)
320 tee	0	147 470 (108,755)	189 945 (27,550)

NOTES:

(1) Loads are averaged from commercial programs and are directly affected by the stiffness chosen for valves, flanges, and other relatively stiff components.

(2) Stress may differ by slightly more than units' conversion tolerance.

S303.6 Sustained Load Case

Sustained stresses due to the axial force, internal pressure, and intensified bending moment in this example are combined to determine the sustained stress, S_L. For reasons similar to those expressed for the operating load case, the sustained load case output is not included.

S303.7 Displacement Stress Range Load Cases

The displacement stress range, S_E, is computed in accordance with para. 319.2.3(b), in which the strains evaluated for the original (as-installed) condition (for this particular example) are algebraically subtracted from the strains evaluated for the Operating Case 1 as listed in Table S303.1. Similarly, the displacement stress range, S_E, is computed from the algebraic strain difference evaluated from the as-installed condition to the Operating Case 2 as listed in Table S303.1. The individual displacement stress range, S_E, along with the internal reaction loads, is evaluated for each piping component in accordance with eq. (17) and is listed in Tables S303.7.1 and S303.7.2 for Operating Cases 1 and 2, respectively.

The algebraic strain difference between the two resultant case evaluations discussed above produces the largest overall stress differential for the piping system in accordance with paras. 319.2.1(d), 319.2.3(b), and 319.3.1(b), i.e., S_E, the "stress range corresponding to the total displacement strains." The resulting load combination and S_E for each piping component are listed in Table S303.7.3.

S303.8 Code Compliance: Satisfying the Intent of the Code

The piping system is compliant with the sustained load requirements of the Code. The displacement stress range from the original (as-installed) condition to each of the operating cases indicates the piping system is in compliance with the intent of the Code even when limited to the eq. (1a) allowable, S_A. But, the "stress range corresponding to the total displacement strains," which considers the algebraic strain difference between the two operating cases, indicates that the piping system is not protected against fatigue for the cycles under analysis even when considering the eq. (1b) allowable, S_A. Therefore, redesign of the piping system is required.

The redesign should consider the additional impact of average axial displacement stresses in accordance

Table S303.7.2 Case 2: Displacement Stress Range [Eq. (1a) Allowable S_A = 248.2 MPa (36 ksi): Passes]

	Global Axis Forces and Moments		
Node	F_x, N (lb) (Signed) [Note (1)]	M_y, N-m (ft-lb) (Signed) [Note (1)]	Eq. (17) S_E, kPa (psi) [Note (2)]
10 anchor	0	−147 470 (−108,755)	55 610 (8,065)
20 tee	0	147 470 (108,755)	189 945 (27,550)
30 tee	78 485 (17,645)	−45 900 (−33,850)	84 360 (12,235)
40 tee	−78 485 (−17,645)	−45 900 (−33,850)	84 360 (12,235)
110 *Y*	−78 485 (−17,645)	−45 900 (−33,850)	25 155 (3,650)
120	−78 485 (−17,645)	−45 900 (−33,850)	25 155 (3,650)
130 meter	−78 485 (−17,645)	−45 900 (−33,850)	25 155 (3,650)
140 *Y*	−78 485 (−17,645)	−45 900 (−33,850)	25 155 (3,650)
340 tee	−78 485 (−17,645)	−45 900 (−33,850)	84 360 (12,235)
210 *Y*	78 485 (17,645)	−45 900 (−33,850)	25 155 (3,650)
220	78 485 (17,645)	−45 900 (−33,850)	25 155 (3,650)
230 meter	78 485 (17,645)	−45 900 (−33,850)	25 155 (3,650)
240 *Y*	78 485 (17,645)	−45 900 (−33,850)	25 155 (3,650)
330 tee	78 485 (17,645)	−45 900 (−33,850)	84 360 (12,235)
310 anchor	0	147 470 (108,755)	55 610 (8,065)
320 tee	0	−147 470 (−108,755)	189 945 (27,550)

NOTES:
(1) Loads are averaged from commercial programs and are directly affected by the stiffness chosen for valves, flanges, and other relatively stiff components.
(2) Stress may differ by slightly more than units' conversion tolerance.

with the recommendations in para. 319.2.3(c). If the piping system is redesigned such that it is compliant with the intent of the code, then the piping system would require no further attention unless the sustained, hydrotest, or operating reaction loads at either anchor data point 10 or 310, or meter runs 130 or 230, exceeded the allowable loads for the attached equipment, nozzles, or support structure. The meter loads, nozzle loads, and support structure analyses are beyond the scope of this Appendix and are not addressed. Although the occasional load cases are important to the design and analysis of a piping system, they are not discussed in this example.

Table S303.7.3 Load Combination Considering Cases 1 and 2, Total Strain Based: Displacement Stress Range [Eq. (1b) Allowable S_A = 379.8 MPa (55.1 ksi): Fails]

Node	Global Axis Forces and Moments [Note (1)]		Eq. (17) S_E, kPa (psi) [Notes (2), (3)]
	F_x, N (lb) (Signed)	M_y, N-m (ft-lb) (Signed)	
10 anchor	0	294 940 (217,510)	111 220 (16,130)
20 tee	0	−294 940 (−217,510)	379 890 (55,100)
30 tee	−156 970 (−35,290)	91 800 (67,700)	168 720 (24,470)
40 tee	156 970 (35,290)	91 800 (67,700)	168 720 (24,470)
110 *Y*	156 970 (35,290)	91 800 (67,700)	50 310 (7,300)
120	156 970 (35,290)	91 800 (67,700)	50 310 (7,300)
130 meter	156 970 (35,290)	91 800 (67,700)	50 310 (7,300)
140 *Y*	156 970 (35,290)	91 800 (67,700)	50 310 (7,300)
340 tee	156 970 (35,290)	91 800 (67,700)	168 720 (24,470)
210 *Y*	−156 970 (−35,290)	91 800 (67,700)	50 310 (7,300)
220	−156 970 (−35,290)	91 800 (67,700)	50 310 (7,300)
230 meter	−156 970 (−35,290)	91 800 (67,700)	50 310 (7,300)
240 *Y*	−156 970 (−35,290)	91 800 (67,700)	50 310 (7,300)
330 tee	−156 970 (−35,290)	91 800 (67,700)	168 720 (24,470)
310 anchor	0	−294 940 (−217,510)	111 220 (16,130)
320 tee	0	294 940 (217,510)	379 890 (55,100)

GENERAL NOTE: The sustained stress used in determining the eq. (1b) allowable for nodes 20 and 320 is S_L = 28 380 kPa (4,115 psi).

NOTES:

(1) Loads are averaged from commercial programs and are directly affected by the stiffness chosen for valves, flanges, and other relatively stiff components.

(2) Stress may differ by slightly more than units' conversion tolerance.

(3) The additional impact of average axial displacement stresses in accordance with the recommendations in para. 319.2.3(c) has not been included in determining the displacement stress range.