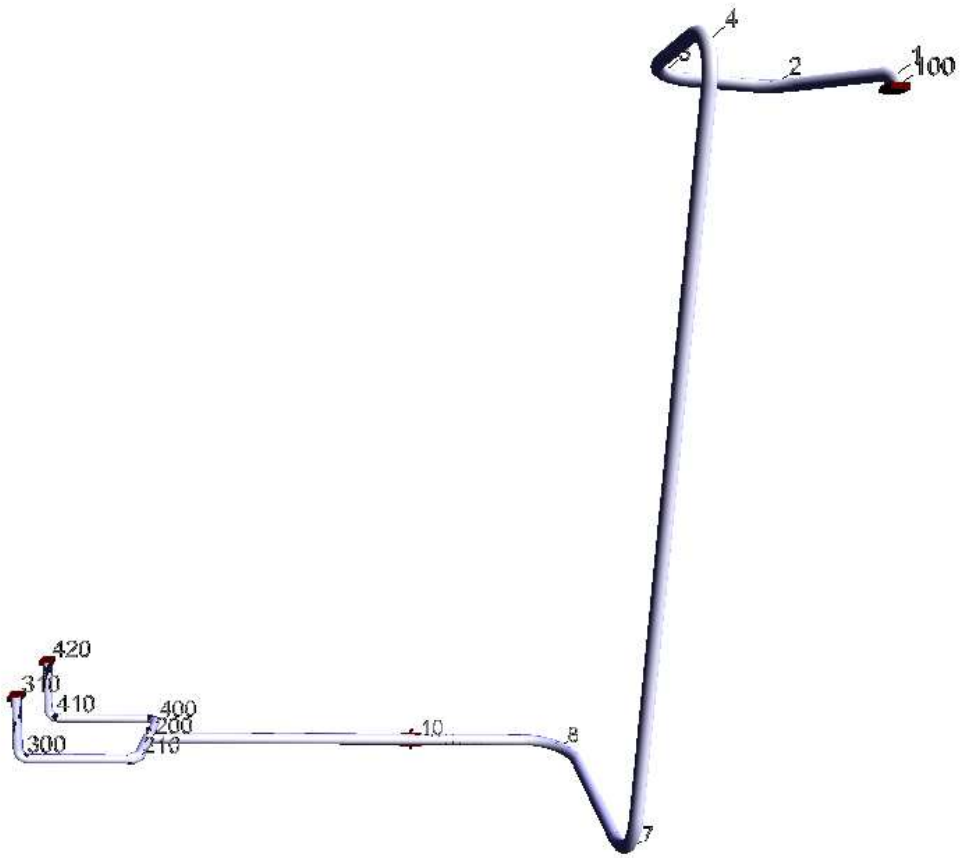
LV Pipe Validierung

Kellogg 5.16

Handberechnung nach Kellogg „Design of Piping Systems“ Abschnitt 5.16



Das Beispiel zeichnet sich durch eine Mischung aus Rohrbögen mit kleinen und sehr großen Radien aus. Zudem ist die Wanddicke mit 44mm sehr hoch, und stellt die FEM Elemente auf eine harte Probe.
Die Temperatur von 1000℉ =538℃ bewirkt zudem extreme Verschiebungen.
Das Modell verfügt über Teillager und unterschiedliche Rohrdurchmesser.
Die Lager 0 (Knoten 1), A‘ (Knoten 310) und B‘(Knoten 420) sind mit Anfangsverschiebungen beaufschlagt.

Randdaten:

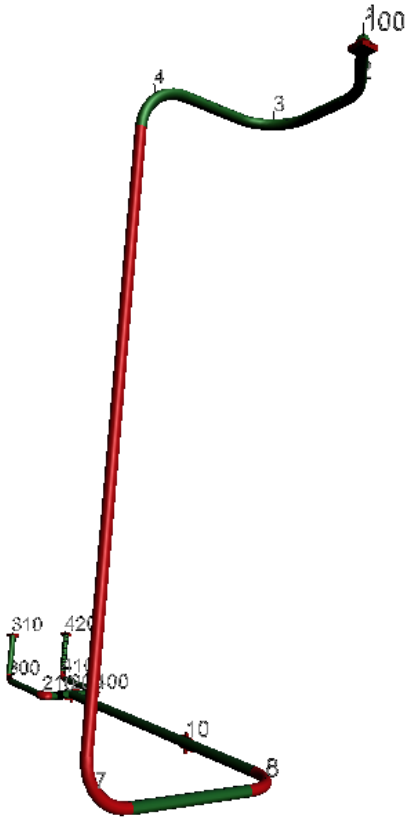
Abschnitt	100-1 (O’-1)	1-200 (1-O)	0-A	o-B
Da (mm)	346	346	266,7	266,7
Ws (mm)	42,8	42,8	36,7	36,7
Temperatur ℃	538	538	538	538
Radien	457	1828	381	381

Material 1 1/4 %Cr

Ergebnis:

Reaktionen der Auflager [lb bzw lb ft]

Knoten	FX	FY	FZ	MX	MY	MZ	
O´							
	-1.151	-3.772	-690	14.990	-23.686	42.115	LV
	-960	-3.170	-560	16.550	-16.200	35.025	Kellogg
C´							
	0	4.962	0	0	0	0	**LV**
	0	4.090	0	0	0	0	**Kellogg**
O							
	0	0	527	0	0	0	LV
	0	0	490	0	0	0	Kellogg
A´							
	-774	720	173	-6.715	-319	-5.752	LV
	-800	810	20	-5.925	-850	-3.500	Kellogg
B´							
	1.892	-1.908	-10	-4.125	1.193	-4.096	LV
	1.760	-1.730	-40	-6.300	625	-2.625	Kellogg



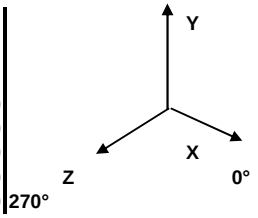
Spannungen:

Maximale Spannung nach Kellogg am Knoten **7 mit 43.7 MPa**
Maximale Spannung nach LV Pipe am Knoten **7 mit 44 MPa**

LV PIPE II Berechnung

Knotenverschiebungen und -rotationen [mm bzw. Grad]

[.0=Bogenmitte .1=Bog.anfang .2=Bog.ende]



Knoten	Lf	dX	dY	dZ	0X	0Y	0Z
100	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-12,6	0,0	0,0	0,0	0,0	0,0
	G+T	-12,6	0,0	0,0	0,0	0,0	0,0
1,1	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-12,6	0,0	0,0	0,0	0,0	0,0
	G+T	-12,6	0,0	0,0	0,0	0,0	0,0
1	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-13,3	2,2	-0,6	0,0	0,0	0,0
	G+T	-13,3	2,2	-0,6	0,0	0,0	0,0
1,2	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-14,8	3,2	-2,2	0,0	0,0	0,0
	G+T	-14,8	3,2	-2,2	0,0	0,0	0,0
2,1	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-29,2	4,0	-13,3	-0,1	0,0	-0,1
	G+T	-29,2	4,0	-13,3	-0,1	0,0	-0,1
2	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-33,4	4,2	-15,9	-0,1	0,0	-0,1
	G+T	-33,4	4,2	-15,9	-0,1	0,0	-0,1
2,2	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-38,3	6,0	-15,1	-0,2	0,0	-0,1
	G+T	-38,3	6,0	-15,1	-0,2	0,0	-0,1
3,1	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-51,8	11,0	-11,4	-0,3	0,1	-0,1
	G+T	-51,8	11,0	-11,4	-0,3	0,1	-0,1
3	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-59,5	17,2	-4,6	-0,4	0,1	0,0
	G+T	-59,5	17,2	-4,6	-0,4	0,1	0,0
3,2	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-60,0	28,1	5,6	-0,4	0,1	0,0
	G+T	-60,0	28,1	5,6	-0,4	0,1	0,0
4,1	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-53,3	50,4	23,1	-0,4	0,1	0,1
	G+T	-53,3	50,4	23,1	-0,4	0,1	0,1
4	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-47,9	58,1	36,8	-0,4	0,1	0,2
	G+T	-47,9	58,1	36,8	-0,4	0,1	0,2
4,2	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	-40,1	53,8	51,7	-0,4	0,0	0,3
	G+T	-40,1	53,8	51,7	-0,4	0,0	0,3
7,1	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	127,7	-90,9	79,3	0,4	0,0	0,3
	G+T	127,7	-90,9	79,3	0,4	0,0	0,3
7	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	137,0	-95,3	64,4	0,5	-0,1	0,3
	G+T	137,0	-95,3	64,4	0,5	-0,1	0,3
7,2	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	142,7	-86,9	50,4	0,5	-0,1	0,2
	G+T	142,7	-86,9	50,4	0,5	-0,1	0,2
8,1	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	152,8	-31,5	15,9	0,6	0,0	0,0
	G+T	152,8	-31,5	15,8	0,6	0,0	0,0
8	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	151,0	-16,1	6,1	0,6	0,0	0,0
	G+T	151,0	-16,1	6,1	0,6	0,0	0,0

Knotenverschiebungen und -rotationen [mm bzw. Grad]

[.0=Bogenmitte .1=Bog.anfang .2=Bog.ende]

Knoten	Lf	dX	dY	dZ	0X	0Y	0Z
8,2	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	142,7	-8,2	0,7	0,5	0,0	-0,1
	G+T	142,7	-8,2	0,7	0,5	0,0	-0,1
10	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	111,8	0,0	-1,7	0,4	0,0	0,0
	G+T	111,8	0,0	-1,7	0,4	0,0	0,0
200	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	42,2	-4,9	0,0	0,1	0,0	0,0
	G+T	42,2	-4,9	0,0	0,1	0,0	0,0
210,1	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	42,1	-7,5	8,7	0,1	0,0	0,0
	G+T	42,1	-7,5	8,7	0,1	0,0	0,0
210	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	41,3	-8,1	10,6	0,1	0,0	0,0
	G+T	41,3	-8,1	10,6	0,1	0,0	0,0
210,2	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	39,4	-8,5	11,3	0,1	0,0	0,0
	G+T	39,4	-8,5	11,3	0,1	0,0	0,0
300,1	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	15,7	-10,1	11,4	0,0	0,0	0,0
	G+T	15,7	-10,1	11,4	0,0	0,0	0,0
300	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	13,8	-9,4	11,4	0,0	0,0	0,0
	G+T	13,8	-9,4	11,4	0,0	0,0	0,0
300,2	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	13,0	-7,5	11,6	0,0	0,0	0,0
	G+T	13,0	-7,5	11,6	0,0	0,0	0,0
310	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	12,6	6,3	12,1	0,0	0,0	0,0
	G+T	12,6	6,3	12,1	0,0	0,0	0,0
400,1	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	42,5	-2,7	-8,7	0,0	0,0	0,1
	G+T	42,5	-2,7	-8,7	0,0	0,0	0,1
400	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	41,9	-2,5	-10,6	0,0	0,0	0,1
	G+T	41,9	-2,5	-10,6	0,0	0,0	0,1
400,2	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	40,0	-2,9	-11,5	0,0	0,0	0,1
	G+T	40,0	-2,9	-11,5	0,0	0,0	0,1
410,1	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	16,3	-9,7	-12,4	0,0	0,0	0,0
	G+T	16,3	-9,7	-12,4	0,0	0,0	0,0
410	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	14,3	-9,3	-12,4	0,0	0,0	0,0
	G+T	14,3	-9,3	-12,4	0,0	0,0	0,0
410,2	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	13,3	-7,5	-12,4	0,0	0,0	0,0
	G+T	13,3	-7,5	-12,4	0,0	0,0	0,0
420	G	0,0	0,0	0,0	0,0	0,0	0,0
	T	12,6	6,3	-12,1	0,0	0,0	0,0
	G+T	12,6	6,3	-12,1	0,0	0,0	0,0

Rohrkräfte und -momente in [N bzw. Nm]

(Im lokalen Rohrkoordinatensystem)

Rohr	Lf	Knoten	FX	FY	FZ	MX	MY	MZ
1	G	100	3,1	0,0	-0,5	-4,8	-1,7	-16,3
		1,1	-3,1	0,0	0,5	4,8	1,7	16,3
	T	100	-16.780,0	5.120,0	-3.068,0	-32.030,0	-20.270,0	56.950,0
		1,1	16.780,0	-5.120,0	3.068,0	32.030,0	20.270,0	-56.950,0
	G+T	100	-16.780,0	4.864,0	-3.069,0	-32.030,0	-20.270,0	56.940,0
		1,1	16.780,0	-4.864,0	3.069,0	32.030,0	20.270,0	-56.930,0
2	G	1,1	3,0	-0,9	0,3	-0,5	-0,3	-17,0
		1	-3,0	0,9	-0,3	0,5	0,2	16,7
	T	1,1	-13.330,0	9.489,0	-6.934,0	-50.480,0	-10.450,0	44.970,0
		1	13.330,0	-9.489,0	6.934,0	50.480,0	12.940,0	-41.560,0
	G+T	1,1	-13.330,0	9.488,0	-6.934,0	-50.480,0	-10.450,0	44.950,0
		1	13.330,0	-9.488,0	6.934,0	50.480,0	12.940,0	-41.540,0
3	G	1	1,5	-2,7	0,6	7,6	3,3	-14,5
		1,2	-1,5	2,7	-0,6	-7,6	-3,5	13,6
	T	1	-1.171,0	17.000,0	-5.063,0	-62.360,0	16.210,0	17.080,0
		1,2	1.171,0	-17.000,0	5.063,0	62.360,0	-14.400,0	-10.980,0
	G+T	1	-1.169,0	16.990,0	-5.062,0	-62.350,0	16.220,0	17.070,0
		1,2	1.169,0	-16.990,0	5.062,0	62.350,0	-14.400,0	-10.970,0
4	G	1,2	0,4	-3,1	-0,4	10,1	4,6	-11,4
		2,1	-0,4	2,8	0,4	-10,1	-3,6	3,6
	T	1,2	5.685,0	16.780,0	1.346,0	-53.970,0	32.660,0	15.400,0
		2,1	-5.685,0	-16.780,0	-1.346,0	53.970,0	-36.250,0	29.340,0
	G+T	1,2	5.686,0	16.780,0	1.346,0	-53.960,0	32.660,0	15.390,0
		2,1	-5.686,0	-16.780,0	-1.346,0	53.960,0	-36.250,0	29.340,0
5	G	2,1	0,3	-2,8	-0,4	9,9	3,6	-4,2
		2	-0,3	2,7	0,4	-9,9	-3,3	2,2
	T	2,1	5.751,0	16.780,0	1.032,0	-55.500,0	36.250,0	-26.330,0
		2	-5.751,0	-16.780,0	-1.032,0	55.500,0	-36.990,0	38.380,0
	G+T	2,1	5.751,0	16.780,0	1.031,0	-55.490,0	36.250,0	-26.330,0
		2	-5.751,0	-16.780,0	-1.031,0	55.490,0	-36.990,0	38.380,0
6	G	2	0,0	-2,7	-0,5	6,4	3,3	-7,9
		2,2	0,0	2,7	0,5	-6,4	-2,9	5,9
	T	2	5.133,0	16.780,0	-2.790,0	-67.310,0	36.990,0	4.751,0
		2,2	-5.133,0	-16.780,0	2.790,0	67.310,0	-34.980,0	7.298,0
	G+T	2	5.133,0	16.780,0	-2.791,0	-67.300,0	36.990,0	4.743,0
		2,2	-5.133,0	-16.780,0	2.791,0	67.300,0	-34.990,0	7.304,0
7	G	2,2	0,0	-2,7	-0,5	6,0	2,9	-6,3
		3,1	0,0	2,5	0,5	-6,0	-1,8	1,2
	T	2,2	4.972,0	16.780,0	-3.068,0	-67.610,0	34.980,0	-3.588,0
		3,1	-4.972,0	-16.780,0	3.068,0	67.610,0	-28.890,0	36.940,0
	G+T	2,2	4.972,0	16.780,0	-3.069,0	-67.600,0	34.990,0	-3.594,0
		3,1	-4.972,0	-16.780,0	3.069,0	67.600,0	-28.890,0	36.940,0
8	G	3,1	-0,2	-2,5	-0,5	5,1	1,8	-3,4
		3	0,2	2,3	0,5	-5,1	-1,1	0,0
	T	3,1	3.419,0	16.780,0	-4.737,0	-76.600,0	28.890,0	-8.255,0
		3	-3.419,0	-16.780,0	4.737,0	76.600,0	-22.090,0	32.350,0
	G+T	3,1	3.419,0	16.780,0	-4.738,0	-76.590,0	28.890,0	-8.258,0
		3	-3.419,0	-16.780,0	4.738,0	76.590,0	-22.090,0	32.350,0
9	G	3	-0,5	-2,3	-0,2	3,6	1,1	-3,6
		3,2	0,5	2,2	0,2	-3,6	-0,8	0,4
	T	3	-932,0	16.780,0	-5.768,0	-77.040,0	22.090,0	31.290,0
		3,2	932,0	-16.780,0	5.768,0	77.040,0	-13.810,0	-7.188,0
	G+T	3	-932,6	16.780,0	-5.768,0	-77.030,0	22.090,0	31.280,0
		3,2	932,6	-16.780,0	5.768,0	77.030,0	-13.810,0	-7.187,0
10	G	3,2	-0,5	2,2	0,0	3,2	-0,8	1,8
		4,1	0,5	-1,9	0,0	-3,2	0,9	3,5
	T	3,2	-3.068,0	-16.780,0	4.972,0	-68.420,0	-13.810,0	-36.120,0
		4,1	3.068,0	16.780,0	-4.972,0	68.420,0	916,1	-7.390,0
	G+T	3,2	-3.069,0	-16.780,0	4.972,0	-68.420,0	-13.810,0	-36.120,0
		4,1	3.069,0	16.780,0	-4.972,0	68.420,0	917,0	-7.387,0

Rohrkräfte und -momente in [N bzw. Nm]

(Im lokalen Rohrkoordinatensystem)

Rohr	Lf	Knoten	FX	FY	FZ	MX	MY	MZ
11	G	4,1	-1,2	0,0	1,6	3,3	3,5	0,4
		4	1,2	0,0	-1,4	-3,3	-5,7	-0,3
	T	4,1	3.588,0	-4.972,0	-16.680,0	-62.860,0	-7.390,0	-27.030,0
		4	-3.588,0	4.972,0	16.680,0	62.860,0	31.340,0	19.890,0
	G+T	4,1	3.587,0	-4.972,0	-16.680,0	-62.860,0	-7.387,0	-27.030,0
		4	-3.587,0	4.972,0	16.680,0	62.860,0	31.330,0	19.890,0
12	G	4	-1,8	0,0	0,2	2,1	5,7	2,6
		4,2	1,7	0,0	-0,1	-2,1	-5,9	-2,5
	T	4	14.330,0	-4.972,0	-9.258,0	-30.390,0	-31.340,0	-58.520,0
		4,2	-14.330,0	4.972,0	9.258,0	30.390,0	44.630,0	51.380,0
	G+T	4	14.330,0	-4.972,0	-9.258,0	-30.380,0	-31.330,0	-58.520,0
		4,2	-14.330,0	4.972,0	9.258,0	30.380,0	44.620,0	51.380,0
13	G	4,2	-1,6	0,0	-0,5	1,0	5,9	3,1
		7,1	-0,5	0,0	0,5	-1,0	5,8	-2,5
	T	4,2	16.780,0	-4.972,0	-3.068,0	-8.410,0	-44.630,0	-59.100,0
		7,1	-16.780,0	4.972,0	3.068,0	8.410,0	110.300,0	-47.370,0
	G+T	4,2	16.780,0	-4.972,0	-3.069,0	-8.409,0	-44.620,0	-59.090,0
		7,1	-16.780,0	4.972,0	3.069,0	8.409,0	110.300,0	-47.370,0
14	G	7,1	0,7	0,0	-0,3	-0,1	-5,8	2,7
		7	-0,8	0,0	0,2	0,1	6,2	-2,6
	T	7,1	16.680,0	-4.972,0	3.588,0	-25.900,0	-110.300,0	40.540,0
		7	-16.680,0	4.972,0	-3.588,0	25.900,0	105.200,0	-47.680,0
	G+T	7,1	16.680,0	-4.972,0	3.588,0	-25.900,0	-110.300,0	40.550,0
		7	-16.680,0	4.972,0	-3.588,0	25.900,0	105.200,0	-47.690,0
15	G	7	0,8	0,0	0,4	-1,9	-6,2	1,8
		7,2	-0,8	0,0	-0,5	1,9	5,5	-1,8
	T	7	9.258,0	-4.972,0	14.330,0	-52.030,0	-105.200,0	15.400,0
		7,2	-9.258,0	4.972,0	-14.330,0	52.030,0	84.600,0	-22.540,0
	G+T	7	9.259,0	-4.972,0	14.330,0	-52.030,0	-105.200,0	15.410,0
		7,2	-9.259,0	4.972,0	-14.330,0	52.030,0	84.610,0	-22.540,0
16	G	7,2	0,5	-0,8	0,0	-2,4	-0,9	-5,5
		8,1	-0,5	1,3	0,0	2,4	0,8	0,0
	T	7,2	3.068,0	-16.780,0	-4.972,0	-56.700,0	-916,1	-84.600,0
		8,1	-3.068,0	16.780,0	4.972,0	56.700,0	26.310,0	-1.114,0
	G+T	7,2	3.069,0	-16.790,0	-4.972,0	-56.700,0	-917,0	-84.610,0
		8,1	-3.069,0	16.790,0	4.972,0	56.700,0	26.310,0	-1.114,0
17	G	8,1	0,5	1,3	-0,2	-2,2	0,8	1,0
		8	-0,5	-1,5	0,2	2,2	-0,4	1,0
	T	8,1	4.737,0	16.780,0	3.419,0	-52.810,0	26.310,0	20.670,0
		8	-4.737,0	-16.780,0	-3.419,0	52.810,0	-31.220,0	3.431,0
	G+T	8,1	4.738,0	16.790,0	3.419,0	-52.810,0	26.310,0	20.670,0
		8	-4.738,0	-16.790,0	-3.419,0	52.810,0	-31.220,0	3.432,0
18	G	8	0,2	1,5	-0,5	-2,3	0,4	0,9
		8,2	-0,2	-1,6	0,5	2,3	0,3	1,3
	T	8	5.768,0	16.780,0	-932,0	-39.770,0	31.220,0	34.910,0
		8,2	-5.768,0	-16.780,0	932,0	39.770,0	-29.880,0	-10.820,0
	G+T	8	5.768,0	16.790,0	-932,6	-39.770,0	31.220,0	34.910,0
		8,2	-5.768,0	-16.790,0	932,6	39.770,0	-29.880,0	-10.810,0
19	G	8,2	0,0	1,6	-0,5	-2,6	-0,3	-0,4
		10	0,0	-2,1	0,5	2,6	2,8	8,8
	T	8,2	4.972,0	16.780,0	-3.068,0	-32.600,0	29.880,0	25.210,0
		10	-4.972,0	-16.780,0	3.068,0	32.600,0	-15.850,0	51.540,0
	G+T	8,2	4.972,0	16.790,0	-3.069,0	-32.600,0	29.880,0	25.210,0
		10	-4.972,0	-16.790,0	3.069,0	32.600,0	-15.840,0	51.550,0
20	G	10	0,0	-1,5	-0,5	-2,6	-2,8	-8,8
		200	0,0	0,4	0,5	2,6	8,4	-1,1
	T	10	4.972,0	-5.285,0	-3.068,0	-32.600,0	15.850,0	-51.540,0
		200	-4.972,0	5.285,0	3.068,0	32.600,0	15.720,0	-2.830,0
	G+T	10	4.972,0	-5.287,0	-3.069,0	-32.600,0	15.840,0	-51.550,0
		200	-4.972,0	5.286,0	3.069,0	32.600,0	15.720,0	-2.831,0

Rohrkräfte und -momente in [N bzw. Nm]

(Im lokalen Rohrkoordinatensystem)

Rohr	Lf	Knoten	FX	FY	FZ	MX	MY	MZ
21	G	200	0,4	-0,4	-2,0	1,4	4,7	-1,2
		210,1	-0,4	0,5	2,0	-1,4	-2,2	0,6
	T	200	-768,3	-3.202,0	-3.445,0	13.070,0	2.947,0	-12.600,0
		210,1	768,3	3.202,0	3.445,0	-13.070,0	1.516,0	8.452,0
	G+T	200	-767,9	-3.203,0	-3.447,0	13.070,0	2.951,0	-12.600,0
		210,1	767,9	3.203,0	3.447,0	-13.070,0	1.513,0	8.453,0
22	G	210,1	-0,4	0,5	2,0	1,1	-2,2	1,1
		210	0,4	-0,6	-2,0	-1,1	1,6	-0,9
	T	210,1	-2.028,0	3.202,0	2.888,0	8.843,0	1.516,0	12.810,0
		210	2.028,0	-3.202,0	-2.888,0	-8.843,0	-2.380,0	-11.850,0
	G+T	210,1	-2.028,0	3.203,0	2.890,0	8.844,0	1.513,0	12.810,0
		210	2.028,0	-3.203,0	-2.890,0	-8.844,0	-2.378,0	-11.850,0
23	G	210	-1,7	0,6	1,1	0,1	-1,6	1,4
		210,2	1,7	-0,6	-1,1	-0,1	1,3	-1,2
	T	210	-3.476,0	3.202,0	608,4	-2.129,0	2.380,0	14.630,0
		210,2	3.476,0	-3.202,0	-608,4	2.129,0	-2.562,0	-13.680,0
	G+T	210	-3.478,0	3.203,0	609,5	-2.128,0	2.378,0	14.640,0
		210,2	3.478,0	-3.203,0	-609,5	2.128,0	-2.561,0	-13.680,0
24	G	210,2	-2,0	0,6	0,4	-0,3	-1,3	1,2
		300,1	2,0	-0,9	-0,4	0,3	0,0	1,5
	T	210,2	-3.445,0	3.202,0	-768,3	-7.200,0	2.562,0	11.820,0
		300,1	3.445,0	-3.202,0	768,3	7.200,0	131,0	-595,9
	G+T	210,2	-3.447,0	3.203,0	-767,9	-7.201,0	2.561,0	11.820,0
		300,1	3.447,0	-3.203,0	767,9	7.201,0	131,0	-594,4
25	G	300,1	-2,2	0,1	0,4	-0,3	-0,1	-1,5
		300	2,2	-0,1	-0,4	0,3	0,0	1,6
	T	300,1	-4.408,0	1.640,0	-768,3	-6.602,0	-2.876,0	595,9
		300	4.408,0	-1.640,0	768,3	6.602,0	3.106,0	-105,1
	G+T	300,1	-4.410,0	1.640,0	-767,9	-6.602,0	-2.877,0	594,4
		300	4.410,0	-1.640,0	767,9	6.602,0	3.106,0	-103,5
26	G	300	-1,7	-1,5	0,4	-0,2	-0,2	-1,6
		300,2	1,7	1,4	-0,4	0,2	0,1	1,1
	T	300	-4.277,0	-1.957,0	-768,3	-2.472,0	-6.865,0	105,1
		300,2	4.277,0	1.957,0	768,3	2.472,0	7.095,0	-690,7
	G+T	300	-4.278,0	-1.958,0	-767,9	-2.472,0	-6.865,0	103,5
		300,2	4.278,0	1.958,0	767,9	2.472,0	7.095,0	-689,6
27	G	300,2	-1,0	-2,0	0,4	-0,2	-0,2	-1,1
		310	1,2	2,0	-0,4	0,2	-0,5	-2,9
	T	300,2	-3.202,0	-3.445,0	-768,3	431,4	-7.501,0	690,7
		310	3.202,0	3.445,0	768,3	-431,4	9.081,0	-7.778,0
	G+T	300,2	-3.203,0	-3.447,0	-767,9	431,3	-7.501,0	689,6
		310	3.203,0	3.447,0	767,9	-431,3	9.081,0	-7.781,0
28	G	200	-0,1	0,9	-1,9	0,3	3,7	1,5
		400,1	0,1	-0,7	1,9	-0,3	-1,1	-0,4
	T	200	-43,9	8.488,0	-8.416,0	10.240,0	12.770,0	20.000,0
		400,1	43,9	-8.488,0	8.416,0	-10.240,0	-1.866,0	-9.004,0
	G+T	200	-44,0	8.489,0	-8.418,0	10.240,0	12.770,0	20.000,0
		400,1	44,0	-8.488,0	8.418,0	-10.240,0	-1.867,0	-9.004,0
29	G	400,1	0,7	-0,7	1,8	0,1	-1,1	-0,5
		400	-0,7	0,7	-1,8	-0,1	0,6	0,3
	T	400,1	3.180,0	-8.488,0	7.793,0	6.017,0	-1.866,0	-12.240,0
		400	-3.180,0	8.488,0	-7.793,0	-6.017,0	-465,8	9.698,0
	G+T	400,1	3.181,0	-8.488,0	7.794,0	6.017,0	-1.867,0	-12.240,0
		400	-3.181,0	8.488,0	-7.794,0	-6.017,0	-465,2	9.698,0
30	G	400	1,8	-0,7	0,8	-0,2	-0,6	-0,3
		400,2	-1,8	0,7	-0,8	0,2	0,3	0,1
	T	400	7.759,0	-8.488,0	3.261,0	-2.603,0	465,8	-11.110,0
		400,2	-7.759,0	8.488,0	-3.261,0	2.603,0	-1.442,0	8.573,0
	G+T	400	7.761,0	-8.488,0	3.262,0	-2.603,0	465,2	-11.110,0
		400,2	-7.761,0	8.488,0	-3.262,0	2.603,0	-1.441,0	8.573,0

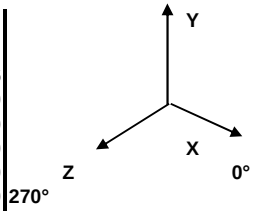
Rohrkräfte und -momente in [N bzw. Nm]

(Im lokalen Rohrkoordinatensystem)

Rohr	Lf	Knoten	FX	FY	FZ	MX	MY	MZ
31	G	400,2	1,9	-0,7	0,1	-0,2	-0,3	0,0
		410,1	-1,9	0,3	-0,1	0,2	0,0	-1,7
	T	400,2	8.416,0	-8.488,0	43,9	-5.685,0	1.442,0	-6.924,0
		410,1	-8.416,0	8.488,0	-43,9	5.685,0	-1.596,0	-22.830,0
	G+T	400,2	8.418,0	-8.488,0	44,0	-5.685,0	1.441,0	-6.924,0
		410,1	-8.418,0	8.488,0	-44,0	5.685,0	-1.596,0	-22.830,0
32	G	410,1	1,9	0,5	0,1	-0,2	-0,1	1,7
		410	-1,9	-0,5	-0,1	0,2	0,0	-1,6
	T	410,1	11.020,0	-4.621,0	43,9	-5.863,0	-701,5	22.830,0
		410	-11.020,0	4.621,0	-43,9	5.863,0	688,3	-24.210,0
	G+T	410,1	11.030,0	-4.620,0	44,0	-5.863,0	-701,5	22.830,0
		410	-11.030,0	4.620,0	-44,0	5.863,0	688,4	-24.210,0
33	G	410	1,0	1,7	0,1	-0,1	-0,1	1,6
		410,2	-1,0	-1,7	-0,1	0,1	0,1	-1,1
	T	410	11.060,0	4.528,0	43,9	-3.659,0	-4.633,0	24.210,0
		410,2	-11.060,0	-4.528,0	-43,9	3.659,0	4.619,0	-22.860,0
	G+T	410	11.060,0	4.529,0	44,0	-3.659,0	-4.633,0	24.210,0
		410,2	-11.060,0	-4.529,0	-44,0	3.659,0	4.619,0	-22.860,0
34	G	410,2	0,3	1,9	0,1	-0,1	-0,1	1,1
		420	-0,1	-1,9	-0,1	0,1	-0,1	2,9
	T	410,2	8.488,0	8.416,0	43,9	-1.613,0	-5.668,0	22.860,0
		420	-8.488,0	-8.416,0	-43,9	1.613,0	5.578,0	-5.539,0
	G+T	410,2	8.488,0	8.418,0	44,0	-1.613,0	-5.668,0	22.860,0
		420	-8.488,0	-8.418,0	-44,0	1.613,0	5.578,0	-5.536,0

Reaktionen der Auflager [N bzw Nm]

Knoten	Lf	FX	FY	FZ	MX	MY	MZ
O´	G	0	3	-1	2	-5	-16
	T	-5.120	-16.780	-3.068	20.270	-32.030	56.950
	G+T	-4.864	-16.780	-3.069	20.270	-32.030	56.940
C´	G	0	4	0	0	0	0
	T	0	22.070	0	0	0	0
	G+T	0	22.070	0	0	0	0
O	G	0	0	1	0	0	0
	T	0	0	2.344	0	0	0
	G+T	0	0	2.345	0	0	0
A´	G	-2	1	0	1	0	-3
	T	-3.445	3.202	768	-9.081	-431	-7.778
	G+T	-3.447	3.203	768	-9.081	-431	-7.781
B´	G	2	0	0	0	0	3
	T	8.416	-8.488	-44	-5.578	1.613	-5.539
	G+T	8.418	-8.488	-44	-5.578	1.613	-5.536



Summe der externen Kräfte [N]

G	0	8	0
T	-148	0	0
G+T	108	8	0

Lagerinformationen

Knoten	Lager Typ	X	Y	Z
O´	Anc	0	0	0
C´	G	-13.716	-24.613	-5.258
O	1Hor.Ver.	-24.003	-24.613	-5.258
A´	Anc	-28.270	-22.174	-3.581
B´	Anc	-28.270	-22.174	-6.934

Legende

Anc	Festpunkt (6/6)
G	Gewichtsaufnahme
Hor.Ver	ten horizontalen Verschiebungen
Rot.	r blockierten Rotationen
Feder	ßpunkt der Feder
singulär	l oder einseitig wirksam

Spannungen in den Rohren [N/mm^2] bei Lastfall G

(SLa und SLe =Longitudinalsp. nach ANSI B31.3)

Rohr	von	nach	Sa	Se	SLa	SLe	SIFi	SIFa	Sig_Zul
1	100	1,1	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
2	1,1	1	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
3	1	1,2	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
4	1,2	2,1	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
5	2,1	2	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
6	2	2,2	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
7	2,2	3,1	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
8	3,1	3	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
9	3	3,2	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
10	3,2	4,1	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
11	4,1	4	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
12	4	4,2	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
13	4,2	7,1	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
14	7,1	7	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
15	7	7,2	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
16	7,2	8,1	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
17	8,1	8	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
18	8	8,2	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
19	8,2	10	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
20	10	200	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
21	200	210,1	0,5	0,5	0,5	0,5	1,0 1,1	1,0 1,0	
22	210,1	210	0,5	0,5	0,5	0,5	1,1 1,1	1,0 1,0	
23	210	210,2	0,5	0,5	0,5	0,5	1,1 1,0	1,0 1,0	
24	210,2	300,1	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
25	300,1	300	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
26	300	300,2	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
27	300,2	310	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
28	200	400,1	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
29	400,1	400	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
30	400	400,2	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
31	400,2	410,1	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
32	410,1	410	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
33	410	410,2	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	
34	410,2	420	0,5	0,5	0,5	0,5	1,0 1,0	1,0 1,0	

Maximale Spannungen (N/mm^2)

Nr	Knoten	Spannung
1	2	0,5
2	2,1	0,5
3	2,1	0,5
4	1,2	0,5
5	1,2	0,5
6	1	0,5
7	1	0,5
8	1,1	0,5
9	1,1	0,5
10	100	0,5

Spannungen in den Rohren [N/mm^2] bei Lastfall T

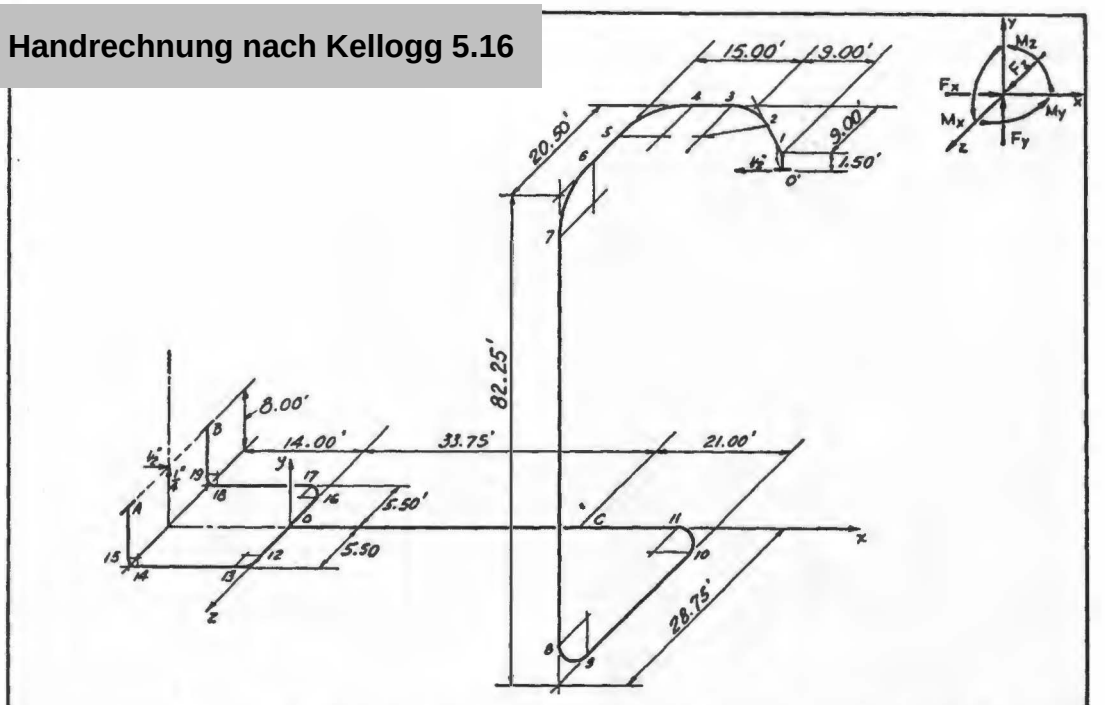
(SLa und SLe =Longitudinalsp. nach ANSI B31.3)

Rohr	von	nach	Sa	Se	SLa	SLe	SIFi		SIFa		Sig_Zul
1	100	1,1	25,2	25,3	25,2	25,3	1,0	1,0	1,0	1,0	
2	1,1	1	25,2	24,6	25,2	24,6	1,0	1,0	1,0	1,0	
3	1	1,2	24,6	24,0	24,6	24,0	1,0	1,0	1,0	1,0	
4	1,2	2,1	24,0	26,3	24,0	26,3	1,0	1,0	1,0	1,0	
5	2,1	2	26,3	28,3	26,3	28,3	1,0	1,0	1,0	1,0	
6	2	2,2	28,3	28,1	28,3	28,1	1,0	1,0	1,0	1,0	
7	2,2	3,1	28,1	30,2	28,1	30,2	1,0	1,0	1,0	1,0	
8	3,1	3	30,2	31,6	30,2	31,6	1,0	1,0	1,0	1,0	
9	3	3,2	31,6	28,9	31,6	28,9	1,0	1,0	1,0	1,0	
10	3,2	4,1	28,9	25,4	28,9	25,4	1,0	1,0	1,0	1,0	
11	4,1	4	25,4	26,9	25,4	26,9	1,0	1,0	1,0	1,0	
12	4	4,2	26,9	27,4	26,9	27,4	1,0	1,0	1,0	1,0	
13	4,2	7,1	27,4	44,0	27,4	44,0	1,0	1,0	1,0	1,0	
14	7,1	7	44,0	43,3	44,0	43,3	1,0	1,0	1,0	1,0	
15	7	7,2	43,3	37,3	43,3	37,3	1,0	1,0	1,0	1,0	
16	7,2	8,1	37,3	23,1	37,3	23,1	1,0	1,0	1,0	1,0	
17	8,1	8	23,1	22,7	23,1	22,7	1,0	1,0	1,0	1,0	
18	8	8,2	22,7	18,9	22,7	18,9	1,0	1,0	1,0	1,0	
19	8,2	10	18,9	23,3	18,9	23,3	1,0	1,0	1,0	1,0	
20	10	200	23,3	13,6	23,3	13,6	1,0	1,0	1,0	1,0	
21	200	210,1	7,2	6,4	7,2	6,4	1,0	1,1	1,0	1,0	
22	210,1	210	6,7	6,4	6,7	6,4	1,1	1,1	1,0	1,0	
23	210	210,2	6,6	5,6	6,6	5,6	1,1	1,0	1,0	1,0	
24	210,2	300,1	11,0	5,9	11,0	5,9	1,0	1,0	1,0	1,0	
25	300,1	300	5,9	5,9	5,9	5,9	1,0	1,0	1,0	1,0	
26	300	300,2	5,9	6,1	5,9	6,1	1,0	1,0	1,0	1,0	
27	300,2	310	6,1	9,4	6,1	9,4	1,0	1,0	1,0	1,0	
28	200	400,1	19,8	10,8	19,8	10,8	1,0	1,0	1,0	1,0	
29	400,1	400	10,8	9,0	10,8	9,0	1,0	1,0	1,0	1,0	
30	400	400,2	9,0	7,3	9,0	7,3	1,0	1,0	1,0	1,0	
31	400,2	410,1	7,3	18,1	7,3	18,1	1,0	1,0	1,0	1,0	
32	410,1	410	18,1	19,1	18,1	19,1	1,0	1,0	1,0	1,0	
33	410	410,2	19,1	18,1	19,1	18,1	1,0	1,0	1,0	1,0	
34	410,2	420	18,1	6,5	18,1	6,5	1,0	1,0	1,0	1,0	

Maximale Spannungen (N/mm^2)

Nr	Knoten	Spannung
1	7,1	44
2	7,1	44
3	7	43,3
4	7	43,3
5	7,2	37,3
6	7,2	37,3
7	3	31,6
8	3	31,6
9	3,1	30,2
10	3,1	30,2

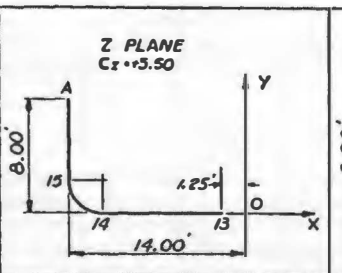
Handrechnung nach Kellogg 5.16

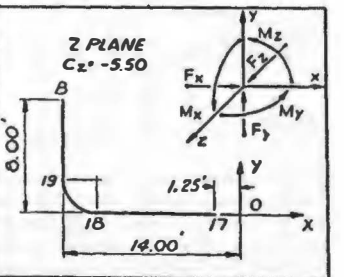


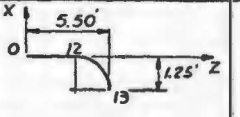
THE M.W. KELLOGG CO | PIPING FLEXIBILITY AND STRESS ANALYSIS SKETCH | CALC. N.S. CHECKED C.R. DATE 1-6-54 | FORM A-1 CALC. NO. 5.8

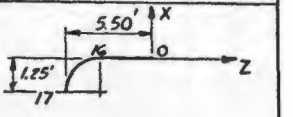
PIPE AND EXPANSION DATA

MEMBERS	A-0 ; B-0	1-0	0'-1
D	10.50	13.625	13.625
t	1.432	1.6075	1.6875
I	429.8	1149.9	1149.9
Z	81.8	168.8	168.8
R	1.25	6.00	1.50
h	1.09	3.41	.85
k	1.65	1.07	1.95
β	< 1	< 1	< 1
$E_h \cdot 10^{-6}$	22.70	22.70	22.70
$E_c \cdot 10^{-6}$	29.00	29.00	29.00
$E_h I/144$		181 268 960	
Q	2.68	1.00	1.00
MATERIAL	1¼ % CR.	1¼ % CR.	1¼ % CR.
TEMP.	1000 F	1000 F	1000 F
e	.00726	.00726	.00726
BRANCH	0'-A		0'-B
Δ_x	-92.75(.00726)-.04167 = -.75671		
Δ_y	-72.75 (.00726) -.02083 = -.54900		
Δ_z	-17.25 (.00726) = -.12524		
$E_h I \Delta x/144$	-137 168 030		
$E_h I \Delta y/144$	- 99 516 660		
$E_h I \Delta z/144$	- 22 702 120		









Y PLANE
Cy = 0

-Y PLANE
Cy = 0

RESULTS

COLD SPRING FACTOR C=0	MOMENTS (FT-LB) AND FORCES (LB) ACTING ON RESTRAINTS				
	COLD CONDITION			HOT CONDITION	
POINT				0'	A	B
Mx				- 9875	+ 2075	+ 3175
My				+ 8000	+ 400	+ 425
Mz				+ 2400	-22225	-20650
Fx				+ 870	- 240	- 630
Fy				+ 1110	- 880	- 230
Fz				+ 260	- 100	- 180

S_h = 7800 psi
S_c = 15,000 psi
S_E = MAX. COMPUTED EXPANSION STRESS = 9175 psi AT POINT A
S_A = ALLOWABLE STRESS RANGE = 20,700 psi

THE M.W. KELLOGG CO | PIPING FLEXIBILITY AND STRESS ANALYSIS ORIGINAL DATA AND RESULTS | CALC. A.M.C. CHECKED M.J.B. DATE 11/23/53 | FORM A CALC NO. 58

"A" BRANCH

PLANE	Z																	Y								
MEMBER	A-15			15-14			14-13			A-13								13-12			12-0			13-0		
SHAPE																										
k					1	65													1	65						
Q		2	68		2	68		2	68										2	68			2	68		
R					1	25													1	25						
L		6	75					11	50													4	25			
a	-	14	00	-	12	75	-	7	00										4	25		2	13			
b		4	63		1	25		0										-	1	25		0				
c		5	50		5	50		5	50										0			0				
$L^2/12$		3	80					11	02													1	51			
s		18	09		8	69		30	82		57	60							8	69		11	39		20	08
s_a	-	253	26	-	117	71	-	215	74	-	586	71							43	84		24	26		68	10
s_b		83	76		3	95		0			87	71						-	3	95		0		-	3	95
q		0			0			0			0								0			0			0	
cq		0			0			0			0								0			0			0	
u		23	52		7	76		30	82		62	10							7	76		11	39		19	15
u_o	-	329	28	-	104	39	-	215	74	-	649	41							38	43		24	26		62	69
cu		129	36		42	68		169	51		341	55							0			0			0	
v		18	09		7	76		40	07		65	92							7	76		14	81		22	57
V_o		83	76		4	25		0			88	01						-	4	25		0		-	4	25
cv		99	50		42	68		220	39		362	57							0			0			0	
$S_{ab}+c^2q$	-	1172	59	-	54	74		0		-	1227	33						-	21	09		0		-	21	09
cu_o	-	1811	04	-	574	15	-	1186	57	-	3571	76							0			0			0	
cv_o		460	68		23	38		0			484	06							0			0			0	
$S_{aa}+c^2v$	4	092	89	1	830	39	3	061	96	8	985	24							222	47		68	87		291	34
$S_{bb}+c^2u$	1	168	03		237	81		932	31	2	338	15							3	07		0			3	07
$u_{oo}+V_{oo}$	5	066	47	1	409	63	1	849	82	8	325	92							195	66		68	87		264	53

THE M.W. KELLOGG CO. | PIPING FLEXIBILITY AND STRESS ANALYSIS SHAPE COEFFICIENTS | CALC. A.M.C. CHECKED M.J.B. DATE 11-23-53 | FORM D-2 CALC. NO. 5.8

"B" BRANCH

PLANE	Z																	Y								
MEMBER	B-19			19-18			18-17			B-17								17-16			16-0			17-0		
SHAPE																										
k					1	65													1	65						
Q		2	68		2	68		2	68										2	68		2	68			
R					1	25													1	25						
L		6	75					11	50													4	25			
a	-	14	00	-	12	75	-	7	00									-	4	25	-	2	13			
b		4	63		1	25		0										-	1	25		0				
c	-	5	50	-	5	50	-	5	50										0			0				
$L^2/12$		3	80					11	02													1	51			
s		18	09		8	69		30	82		57	60							8	69		11	39		20	08
s_a	-	253	24	-	117	71	-	215	74	-	586	71						-	43	84	-	24	26	-	68	10
s_b		83	76		3	95		0			87	71						-	3	95		0		-	3	95
q		0			0			0			0								0			0			0	
cq		0			0			0			0								0			0			0	
u		23	52		7	76		30	82		62	10							7	76		11	39		19	15
u_o	-	329	28	-	104	39	-	215	74	-	649	41						-	38	43	-	24	26	-	62	69
cu	-	129	36	-	42	68	-	169	51	-	341	55							0			0			0	
v		18	09		7	76		40	07		65	92							7	76		14	81		22	57
V_o		83	76		4	25		0			88	01						-	4	25		0		-	4	25
cv	-	99	50	-	42	68	-	220	39	-	362	57							0			0			0	
$S_{ab}+c^2q$	-	1172	59	-	54	74		0		-	1227	33							21	09		0			21	09
cu_o	1	811	04		574	15	1	186	57	3	571	76							0			0			0	
cv_o	-	460	68	-	23	38		0		-	484	06							0			0			0	
$S_{aa}+c^2v$	4	092	89	1	830	39	3	061	96	8	985	24							222	47		68	87		291	34
$S_{bb}+c^2u$	1	168	03		237	81		932	31	2	338	15							3	07		0			3	07
$u_{oo}+V_{oo}$	5	066	47	1	409	63	1	849	82	8	325	92							195	66		68	87		264	53

THE M.W. KELLOGG CO. | PIPING FLEXIBILITY AND STRESS ANALYSIS SHAPE COEFFICIENTS | CALC. A.M.C. CHECKED M.J.B. DATE 11-23-53 | FORM D-2 CALC. NO. 5.8

PLANE	M_x		M_y		M_z		F_x		F_y		F_z	
	+230 04		0		+ 93		+ 75 92		+ 3 342 58		- 7 690 54	
x	+s							+s_b			-s_a	
y	+u	+ 19 15	0	+q	0	-cq	0	+u_o	+ 62 69		-cu	0
z	+v	+ 65 92	0		0	-cq	0	+cv	+ 362 57		-v_o	- 88 01
Σ	+A_{xx}	+ 315 11	0	+A_{xy}	0	+A_{xz}	+ 93	+B_{xx}	+ 75 92	+B_{xy}	+ 3 767 84	+B_{xz}	- 7 778 55
			+ 231 95		0		- 4 029 69			0		+ 11 616 17
	x	+v		+q		-v_o		-cq			+cv	
	y	+s	+ 20 08		0	-s_a	- 68 10			0	+s_b	- 3 95
	z	+u	+ 62 10		0	-cu	- 341 55	+cq		0	+u_o	- 649 41
	Σ	+A_{yy}	+ 314 13	+A_{yz}	0	+B_{yx}	- 4 439 34	+B_{yy}		0	+B_{yz}	+ 10 962 81
				+ 222 53			+ 7 772 78		- 11 129 94			- 75 92
		x	+u		+u_o			-cu			+cq	
		y	+v	+ 22 57	+cv		0	-v_o	+ 4 25		-cq	0
		z	+s	+ 57 60	+s_b	+	87 71	-s_a	+ 586 71			0
		Σ	+A_{zz}	+ 302 70	+B_{zx}	+ 7	860 49	+B_{zy}	- 10 538 98		+B_{zz}	- 75 92
						+ 649	192 10		- 462 300 40			- 231 994 55
			x	+u_{oo}+v_{oo}				-cu_o			-cv_o	
			y	+s_{aa}+c^2v	+	291 34		-cv_o		0	-s_{ab}-c^2q	+ 21 09
			z	+s_{bb}+c^2u	+ 2	338 15		-s_{ab}-c^2q	+ 1	227 33	-cu_o	+ 3 571 76
			Σ	+C_{xx}	+ 651	821 59		+C_{xy}	- 461 073 07		+C_{xz}	- 228 401 70
									+ 698 525 27			- 148 339 27
							x	+s_{bb}+c^2u			-s_{ab}-c^2q	
							y	+u_{oo}+v_{oo}	+ 264 53		-cu_o	0
							z	+s_{aa}+c^2v	+ 8 985 24		-cv_o	- 484 06
							Σ	+C_{yy}	+ 707 775 04		+C_{yz}	- 148 823 33
												+ 1177 673 51
										x	+s_{aa}+c^2v	
										y	+s_{bb}+c^2u	+ 3 07
										z	+u_{oo}+v_{oo}	+ 8 325 92
										Σ	+C_{zz}	+ 1186 002 50

"A" BRANCH -- MEMBERS O'-A

THE M.W. KELLOGG CO. | PIPING FLEXIBILITY AND STRESS ANALYSIS PLANE SUMMATION OF SHAPE COEFFICIENTS | CALC. A.M.C. CHECKED M.K.B. DATE 11-23-38 | FORM D-3 CALC. NO. 5.8

PLANE	M_x		M_y		M_z		F_x		F_y		F_z	
	+230 04		0		+ 93		+ 75 92		+ 3 342 58		- 7 690 54	
x	+s							+s_b			-s_a	
y	+u	+ 19 15	0	+q	0	+cq	0	+u_o	- 62 69		-cu	0
z	+v	+ 65 92	0		0	-cq	0	+cv	- 362 57		-v_o	- 88 01
Σ	+A_{xx}	+ 315 11	+A_{xy}	0	+A_{xz}	+ 93	+B_{xx}	+ 75 92	+B_{xy}	+ 2 917 32	+B_{xz}	- 7 778 55
			+ 231 95		0		- 4 029 69			0		+ 11 616 17
	x	+v		+q		-v_o		-cq			+cv	
	y	+s	+ 20 08		0	-s_a	+ 68 10			0	+s_b	- 3 95
	z	+u	+ 62 10		0	-cu	- 341 55	+cq		0	+u_o	- 649 41
	Σ	+A_{yy}	+ 314 13	+A_{yz}	0	+B_{yx}	- 3 620 04	+B_{yy}		0	+B_{yz}	+ 10 962 81
				+ 222 53			+ 7 772 78		- 11 129 94			- 75 92
		x	+u		+u_o			-cu			+cq	
		y	+v	+ 22 57	+cv		0	-v_o	+ 4 25		-cq	0
		z	+s	+ 57 60	+s_b	+	87 71	-s_a	+ 586 71			0
		Σ	+A_{zz}	+ 302 70	+B_{zx}	+ 7	860 49	+B_{zy}	- 10 538 98		+B_{zz}	- 75 92
						+ 649	192 10		- 462 300 40			- 231 994 55
			x	+u_{oo}+v_{oo}				-cu_o			-cv_o	
			y	+s_{aa}+c^2v	+	291 34		-cv_o		0	-s_{ab}-c^2q	- 21 09
			z	+s_{bb}+c^2u	+ 2	338 15		-s_{ab}-c^2q	+ 1	227 33	-cu_o	- 3 571 76
			Σ	+C_{xx}	+ 651	821 59		+C_{xy}	- 461 073 07		+C_{xz}	- 235 587 40
									+ 698 525 27			- 148 339 27
							x	+s_{bb}+c^2u			-s_{ab}-c^2q	
							y	+u_{oo}+v_{oo}	+ 264 53		-cu_o	0
							z	+s_{aa}+c^2v	+ 8 985 24		-cv_o	+ 484 06
							Σ	+C_{yy}	+ 707 775 04		+C_{yz}	- 147 855 21
												+ 1177 673 51
										x	+s_{aa}+c^2v	
										y	+s_{bb}+c^2u	+ 3 07
										z	+u_{oo}+v_{oo}	+ 8 325 92
										Σ	+C_{zz}	+ 1186 002 50

"B" BRANCH - MEMBERS - O'-B

THE M.W. KELLOGG CO. | PIPING FLEXIBILITY AND STRESS ANALYSIS PLANE SUMMATION OF SHAPE COEFFICIENTS | CALC. A.M.C. CHECKED M.K.B. DATE 11-23-38 | FORM D-3 CALC. NO. 5.8

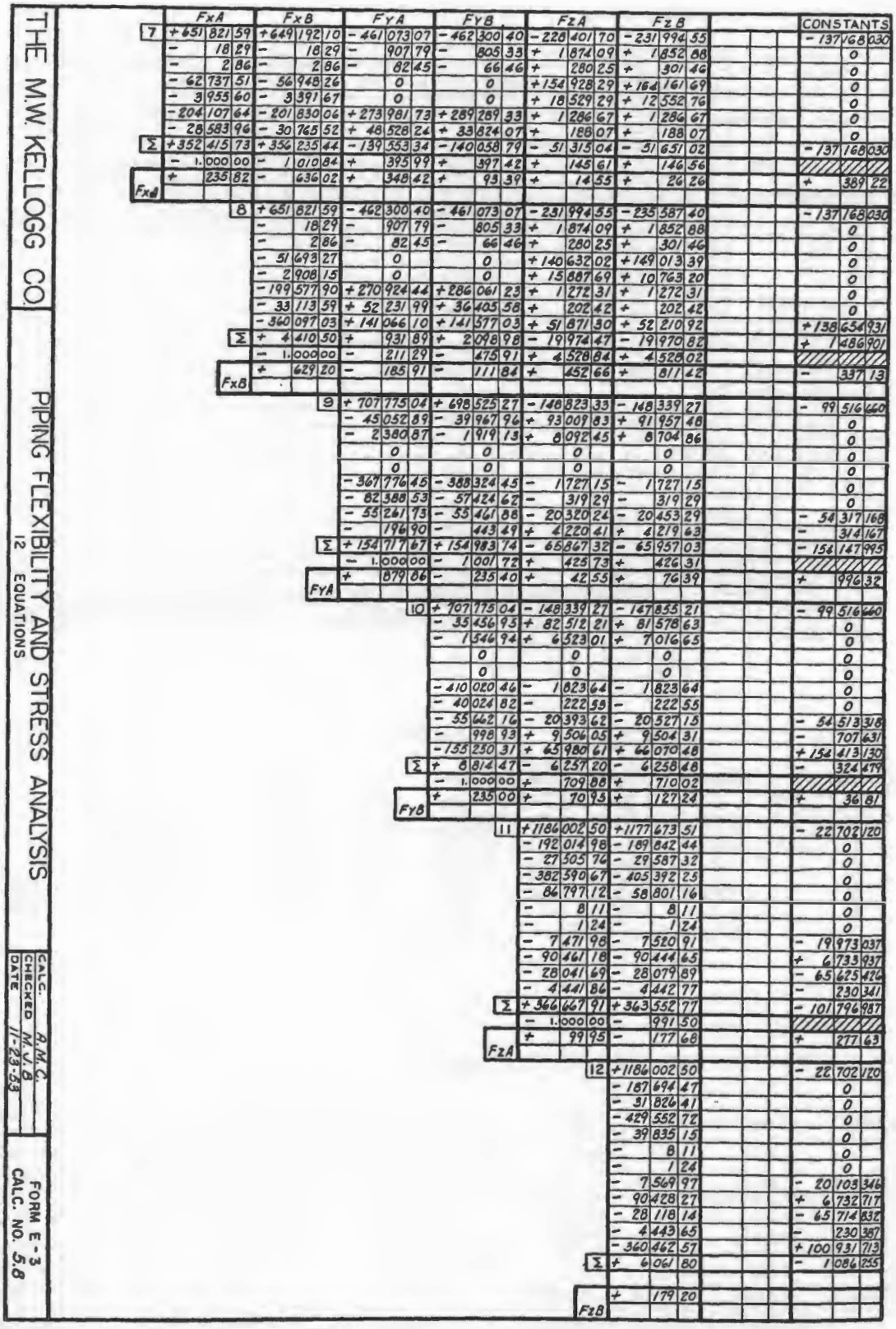
	MXA	MXB	MYA	MYB	MZA	MZB	FXA	FXB	FYA	FYB	FZA	FZB	CONSTANTS
1	+ 315 11	+ 230 04	0	0	+- 93	+ 93	+ 75 92	+ 75 92	+ 3 767 84	+ 3 342 58	- 7 778 55	- 7 690 54	0
1'	- 1. 000 00	- 730 03	0	0	- 002 95	- 002 93	- 240 93	- 240 93	- 11 957 22	- 10 607 66	+ 24 685 19	+ 24 445 89	ENTER BELOW
MXA	- 6 109 50	+ 331 60	0	0	- 23 64	- 36 39	- 56 82	- 151 59	- 10 520 68	- 2 492 80	+ 2 467 28	+ 4 373 54	0
2	+ 315 11	0	0	0	+ 93	+ 93	+ 75 92	+ 75 92	+ 3 342 58	+ 2 917 32	- 7 690 54	- 7 778 55	0
	- 167 94	0	0	0	- 68	- 68	- 55 42	- 55 42	- 2 750 64	- 2 440 18	+ 5 678 57	+ 5 614 32	0
Σ	+ 147 17	0	0	0	+ 25	+ 25	+ 20 50	+ 20 50	+ 591 94	+ 477 14	- 2 011 97	- 2 164 23	0
2'	- 1. 000 00	0	0	0	- 001 70	- 001 70	- 139 29	- 139 29	- 4 022 15	- 3 242 10	+ 13 671 06	+ 14 705 65	
MXB	- 454 23	0	0	0	- 13 62	- 20 97	- 32 85	- 87 64	- 3 538 93	- 761 89	+ 1 366 42	+ 2 635 25	0
3	+ 314 13	+ 231 95	0	0	0	0	- 4 439 34	- 4 029 68	0	0	+ 10 962 81	+ 11 616 17	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
Σ	+ 314 13	+ 231 95	0	0	0	0	- 4 439 34	- 4 029 68	0	0	+ 10 962 81	+ 11 616 17	0
3'	- 1. 000 00	- 738 39	0	0	0	0	+ 14 132 17	+ 12 828 10	0	0	- 34 898 96	- 36 978 86	
MYA	+ 2 305 58	+ 1 016 25	0	0	0	0	+ 3 332 65	+ 8 071 44	0	0	- 3 488 15	- 6 626 61	0
4	+ 314 13	0	0	0	0	0	- 4 029 69	- 3 620 04	0	0	+ 11 616 17	+ 10 962 81	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	0	0
	- 141 27	0	0	0	0	0	+ 3 277 96	+ 2 975 48	0	0	- 8 094 83	- 8 577 26	0
Σ	+ 142 86	0	0	0	0	0	- 751 73	- 644 56	0	0	+ 3 521 34	+ 2 385 55	0
4'	- 1. 000 00	0	0	0	0	0	+ 5 262 00	+ 4 511 83	0	0	- 29 648 89	- 16 698 52	
MYB	- 1 370 31	0	0	0	0	0	+ 1 240 88	+ 2 838 89	0	0	- 2 463 66	- 2 992 37	0
5	+ 302 70	+ 222 53	+ 7 860 49	+ 7 772 78	- 10 538 98	- 11 129 94	- 75 92	- 75 92	0
	0	0	- 22	- 22	- 11 12	- 9 86	+ 22 95	+ 22 69	0
	0	0	- 03	- 03	- 1 01	- 81	+ 3 42	+ 3 68	0
	0	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0	0
Σ	+ 302 70	+ 222 53	+ 7 860 24	+ 7 772 53	- 10 551 11	- 11 140 61	- 49 55	- 49 55	0
5'	- 1. 000 00	- 735 15	- 25 967 10	- 25 677 34	+ 34 856 66	+ 36 804 13	+ 163 69	+ 163 69	
MZA	+ 8 014 34	- 9 069 56	- 6 123 56	- 16 156 18	+ 30 668 98	+ 8 648 77	+ 16 36	+ 29 33	0
6	+ 302 70	+ 7 772 78	+ 7 860 49	- 11 129 99	- 10 538 98	- 75 92	- 75 92	0
	0	- 22	- 22	- 11 12	- 9 86	+ 22 95	+ 22 69	0
	0	- 03	- 03	- 1 01	- 81	+ 3 42	+ 3 68	0
	0	0	0	0	0	0	0	0
	0	0	0	0	0	0	0	0
	- 163 59	- 5 778 46	- 5 713 98	+ 7 756 65	+ 8 190 02	+ 36 43	+ 36 43	0
Σ	+ 139 11	+ 1 994 07	+ 2 146 26	- 3 385 42	- 2 357 43	- 13 12	- 13 12	0
6'	- 1. 000 00	- 14 334 48	- 15 428 51	+ 24 334 28	+ 16 962 33	+ 094 31	+ 094 31	
MZB	+ 12 337 02	- 3 384 36	- 9 707 62	+ 21 412 53	+ 3 986 15	+ 9 43	+ 16 90	0

THE M.W. KELLOGG CO.

PIPING FLEXIBILITY AND STRESS ANALYSIS

CALC. A.M.C.
CHECKED M.J.B. D.W.
DATE 11-23-53

FORM E-2
CALC. No. 5.8


THE M.W. KELLOGG CO.
PIPING FLEXIBILITY AND STRESS ANALYSIS
12 EQUATIONS
CALC.
CHECKED R.M.C.
DATE 11-23-53 M.J.B.
FORM E-3
CALC. NO. 5.8
FxA
FxB
FyA
FyB
FzA
FzB
CONSTANTS

CONVERSION TO CODE RULES			POINT	A		B		O'			
$\frac{E_c}{E_h} = 1.277$			x	-14.00		-14.00		+78.75			
			y	+ 8.00		+ 8.00		+80.75			
			z	+ 5.50		- 5.50		+17.25			
$S_E = \frac{E_c}{E_h} \cdot S'_E$			F_x	+235.82		+629.20		+865.02			
			F_y	+879.86		+235.00		+1114.86			
$S_E = 4175$ PSI			F_z	+ 99.95		+179.20		+279.15			
$\frac{R_c}{R'} = \frac{E_c}{E_h} \cdot C$ OR			M_x	- 6110		- 454		- 6564			
$\frac{R_c}{R'} = \frac{E_c}{E_h} \cdot \frac{S'_h - S_h}{S'_E}$			$+F_y$-z	+ 4839		- 1293		+19231			
			$-F_z$-y	- 800		- 1439		-22541			
WHICHEVER IS GREATER			M'_x	- 2071		- 3181		- 9874			
$\frac{R_c}{R'} = 0$			M_y	+ 2306		- 1376		+ 930			
			$+F_z$-x	- 1399		- 2509		+21983			
			$-F_x$-z	- 1297		+ 3461		-14922			
$\frac{R_h}{R'} = (1 - \frac{2}{3}C)$			M_y	- 390		- 424		+ 7991			
			M_z	+8014		+12337		+20351			
$\frac{R_h}{R'} = 1$			$+F_y$-y	+1887		+ 5034		+69850			
			$-F_y$-x	+12318		+ 3290		- 87795			
R' = CALCULATED REACTIONS BASED ON HOT MODULUS, E_h			M'_z	+22219		+20661		+2406			
			SIN α	1		1					
			COS α	0		0					
x	y	z	PLANE	Z		Z					
M'_x	M'_y	M'_z	M_b	22219		20661					
M'_z	$+M'_x$	$+M'_y$	x COS α	0		0					
$-M'_y$	$-M'_z$	$-M'_x$	x SIN α	2071		3181					
Σ	Σ	Σ	M'_b	2071		3181					
$+M'_z$	$+M'_x$	$+M'_y$	x SIN α	390		424					
$+M'_y$	$+M'_z$	$+M'_x$	x COS α	0		0					
Σ	Σ	Σ	M_t	390		424					
PIPE	Z	f=12/Z		.14670		.14670					
		β		1.00		1.00					
		$S_b = f\beta M_b$		3260		3031					
		$S'_b = f\beta M'_b$		304		467					
		$2S_t = fM_t$		57		62					
		$S_b^2 + S'^2_b + 4S_t^2$		10.72×10^6		940×10^6					
$\sqrt{S_b^2 + S'^2_b + 4S_t^2} = S'_E$				3275		3066					
THE M.W. KELLOGG CO.			PIPING FLEXIBILITY AND STRESS ANALYSIS MOMENTS AND STRESSES					CALC. M.S. CHECKED J.H.C. DATE 4-15-34		FORM F-1 CALC. NO. 5.8	

Table 5.13

Equation	M_{xP}	F_{xP}	F_{yP}	M_{xR}	F_{xR}	F_{yR}	Constant
1	$+A_P$	$+B_P$	$+D_P$	$+A_R$	$+B_R$	$+D_R$	0
2	$+B_P$	$+C_P$	$+G_P$	$+B_R$	$+C_R$	$+G_R$	$+EI^*\Delta_{xP}$
3	$+D_P$	$+G_P$	$+H_P$	$+D_R$	$+G_R$	$+H_R$	$+EI^*\Delta_{yP}$
4	$+A_R$	$+B_R$	$+D_R$	$+A_R$	$+B_R$	$+D_R$	$-EI^*\theta_{xR}$
5	$+B_R$	$+C_R$	$+G_R$	$+B_R$	$+C_R$	$+G_R$	$+EI^*(+\Delta_{xR} - y_R\theta_{xR})$
6	$+D_R$	$+G_R$	$+H_R$	$+D_R$	$+G_R$	$+H_R$	$+EI^*(+\Delta_{yR} + x_R\theta_{xR})$
7	$M'_{xR} = M_{xR} + y_R F_{xR} - x_R F_{yR} = 0$						

Table 5.14

Equation	M_{xP}	F_{xP}	F_{yP}	$M_{xR} = (-y_R F_{xR} + x_R F_{yR})$	F_{xR}	F_{yR}	Constant
5	$+B_R$	$+C_R$	$+G_R$	$+B_R$	$+C_R$	$+G_R$	$EI^*(+\Delta_{xR} - y_R\theta_{xR})$
$-y_R \times$ Eq. 4	$-y_R A_R$	$-y_R B_R$	$-y_R D_R$	$-y_R A_R$	$-y_R B_R$	$-y_R D_R$	$EI^*(+y_R\theta_{xR})$
$\Sigma = 5'$	$+B_R$ $-y_R A_R$	$+C_R$ $-y_R B_R$	$+G_R$ $-y_R D_R$	$+B_R$ $-y_R A_R$	$+C_R$ $-y_R B_R$	$+G_R$ $-y_R D_R$	$EI^*(+\Delta_{xR})$
6	$+D_R$	$+G_R$	$+H_R$	$+D_R$	$+G_R$	$+H_R$	$EI^*(+\Delta_{yR} + x_R\theta_{xR})$
$+x_R \times$ Eq. 4	$+x_R A_R$	$+x_R B_R$	$+x_R D_R$	$+x_R A_R$	$+x_R B_R$	$+x_R D_R$	$EI^*(-x_R\theta_{xR})$
$\Sigma = 6'$	$+D_R$ $+x_R A_R$	$+G_R$ $+x_R B_R$	$+H_R$ $+x_R D_R$	$+D_R$ $+x_R A_R$	$+G_R$ $+x_R B_R$	$+H_R$ $+x_R D_R$	$EI^*(+\Delta_{yR})$

at a point R with coordinates x_R, y_R, z_R in reference to the origin.

If the stops are located at the coordinate origin, the eliminations are obviously unnecessary and the equations may be written directly.

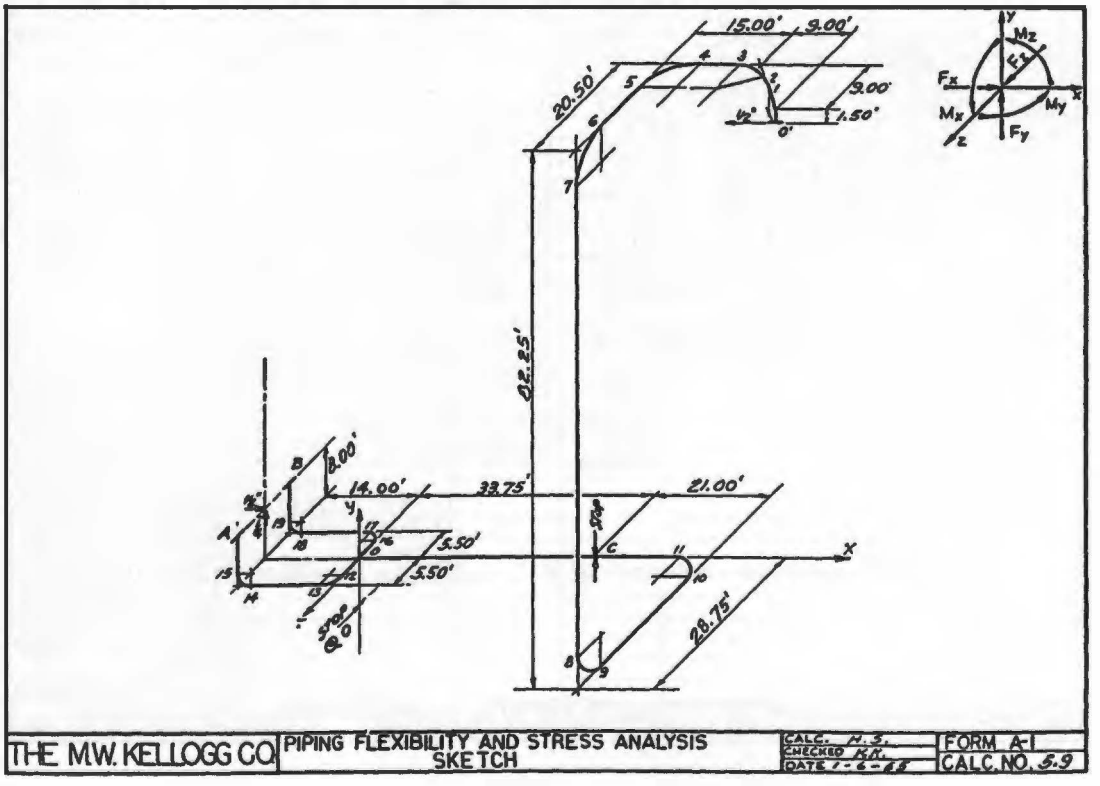
Sample Calculation 5.9 uses the piping of Sample Calculation 5.8 with a z-stop at the origin and y-stop at point C. The summation of the shape coefficients for O'–C is shown on Form D-3; the other summations are shown in previous examples. The elimination of the rotation equation at C is shown on Form J. The equation solution is omitted.

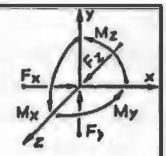
5.17 Calculation of Deformations at any Point

After the simultaneous equations have been solved, and consequently the moments and forces are known, it is a simple matter to calculate the deflections and rotations at any given point in the piping. By summing the shape coefficients from the terminal to the point in question and arranging them in

Table 5.15

Equation	M_{zP}	F_{xP}	F_{yP}	F_{xR}	F_{yR}	Constant
1	$+A_P$	$+B_P$	$+D_P$	$\begin{bmatrix}+B_R\\-y_RA_R\end{bmatrix}$	$\begin{bmatrix}+D_R\\+x_RA_R\end{bmatrix}$	0
2	$+B_P$	$+C_P$	$+G_P$	$\begin{bmatrix}+C_R\\-y_RB_R\end{bmatrix}$	$\begin{bmatrix}+G_R\\+x_RB_R\end{bmatrix}$	$+EI^*\Delta x_P$
3	$+D_P$	$+G_P$	$+H_P$	$\begin{bmatrix}+G_R\\-y_RD_R\end{bmatrix}$	$\begin{bmatrix}+H_R\\+x_RD_R\end{bmatrix}$	$+EI^*\Delta y_P$
5′	$\begin{bmatrix}+B_R\\-y_RA_R\end{bmatrix}$	$\begin{bmatrix}+C_R\\-y_RB_R\end{bmatrix}$	$\begin{bmatrix}+G_R\\-y_RD_R\end{bmatrix}$	$\begin{bmatrix}+C_R\\-2y_RB_R\\+y_R^2A_R\end{bmatrix}$	$\begin{bmatrix}+G_R\\-y_RD_R\\+x_RB_R\\-x_Ry_RA_R\end{bmatrix}$	$+EI^*\Delta x_R$
6′	$\begin{bmatrix}+D_R\\+x_RA_R\end{bmatrix}$	$\begin{bmatrix}+G_R\\+x_RB_R\end{bmatrix}$	$\begin{bmatrix}+H_R\\+x_RD_R\end{bmatrix}$	$\begin{bmatrix}+G_R\\+x_RB_R\\-y_RD_R\\-x_Ry_RA_R\end{bmatrix}$	$\begin{bmatrix}+H_R\\+2x_RD_R\\+x_R^2A_R\end{bmatrix}$	$+EI^*\Delta y_R$





PIPE AND EXPANSION DATA

MEMBERS	A-0	B-0	1'-0	0'-1
D	10.50	10.50	13.625	13.625
t	1.432	1.432	1.6875	1.6875
I	429.8	429.8	1149.9	1149.9
Z	81.8	81.8	168.8	168.8
R	1.25	1.25	6.00	1.50
h	1.04	1.04	3.41	.85
k	1.65	1.65	1.07	1.95
β	∠1	∠1	∠1	∠1
$E_h \times 10^{-6}$	22.70	22.70	22.70	22.70
$E_c \times 10^{-6}$	29.00	29.00	29.00	29.00
$E_h I/144$			181268960	
Q	2.68	2.68	1.00	1.00
MATERIAL	1¼% CR.	1¼% CR.	1¼% CR.	1¼% CR.
TEMP.	1000 F	1000 F	1000 F	1000 F
e	.00726	.00726	.00726	.00726

BRANCH	0-A	0'-B	0'-0	0'-C
Δ_x	-92.75(.00726)-.04167 = -.75671 →	→		
Δ_y	-72.75(.00726)-.02083 = .59900 →	→		-80.75(.00726)=.58625
Δ_z	-17.25(.00726)=-.12524 →	→	-17.25(.00726)= -.12529	
$E_h I \Delta x/144$	-137168830	→	→	
$E_h I \Delta y/144$	-99516660	→	→	-106 268 930
$E_h I \Delta z/144$	-22702120	→	→	→

RESULTS

COLD SPRING FACTOR C = 0 — MOMENTS (FT-LB) AND FORCES (LB) ACTING ON RESTRAINTS

COLD CONDITION — HOT CONDITION

POINT	0'	A	B	C	0
Mx	-16550	+5925	+6300		
My	+16200	-850	-625		
Mz	-35025	+3500	+2625		
Fx	+960	+800	-1760		
Fy	+3170	-410	+1730	-4090	
Fz	+560	+20	-90		-490

S_h = 7800 psi

S_c = 15,000 psi

S_E = MAX. COMPUTED EXPANSION STRESS = 6350 psi AT POINT B

S_A = ALLOWABLE STRESS RANGE = 20,700 psi

THE M.W. KELLOGG CO | PIPING FLEXIBILITY AND STRESS ANALYSIS ORIGINAL DATA AND RESULTS | CALC. R.M.C. CHECKED H.W. DATE 11-23-53 | FORM A | CALC NO. 5.9

PLANE	M_x	M_y	M_z	F_x	F_y	F_z
	+ 14 27	0	+ 93	+ 75 92	+ 135 29	- 1 170 64
x	+s + 98 91	0	0	0	+s_b + 2 712 62	-s_a - 4 417 59
y	+u + 72 98	0	+q 0	+cq 0	+u_o + 494 67	-cu - 2 102 31
z	+v	+q		-cq	+cv	-v_o
Σ	+A_{xz} + 186 16	+A_{xy} 0	+A_{xz} + 93	+B_{xx} + 75 92	+B_{xy} + 3 342 58	+B_{xz} - 7 690 54
		+ 12 57	0	- 178 61	0	+ 951 01
x	+v +122 17	+q 0	-v_o	- 3 384 83	-cq 0	+cv + 6 688 82
y	+s + 63 46	0	-s_a	- 466 25	0	+s_b + 3 406 56
z	+u		-cu		+cq	+u_o
Σ	+A_{yy} +198 20	+A_{yz} 0	+B_{yx}	- 4 029 69	+B_{yy} 0	+B_{yz} + 11 046 39
		+ 14 27		+ 1 170 64	- 1 068 67	- 75 92
x	+u + 103 64	+u_o	+ 4 716 97	-cu	- 5 674 30	+cq 0
y	+v + 70 87	+cv	+ 1 885 17	-v_o	- 3 817 19	-cq 0
z	+s	+s_b		-s_a		
Σ	+A_{zz} + 188 78	+B_{zx}	+ 7 772 78	+B_{zy}	- 10 560 16	+B_{zz} - 75 92
			+ 98 670 68		- 87 692 13	- 19 808 72
x	+u_{oo}+v_{oo}	+389 559 08	-cu_o	-258 254 12	-cv_o	- 185 319 45
y	+s_{aa}+c^2v	+160 962 34	-cv_o	-116 354 15	-s_{ab}-c^2q	- 26 866 38
z	+s_{bb}+c^2u		-s_{ab}-c^2q		-cu_o	
Σ	+C_{xx}	+649 192 10	+C_{xy}	- 462 300 40	+C_{xz}	-231 994 55
				+ 83 147 59		- 11 093 69
x	+s_{bb}+c^2u	+385 996 67	-s_{ab}-c^2q	-118 033 63		
y	+u_{oo}+v_{oo}	+216 554 40	-cu_o	- 19 211 95		
z	+s_{aa}+c^2v		-cv_o			
Σ	+C_{yy}	+685 698 66	+C_{yz}	-148 339 27		
				+168 082 92		
x	+s_{aa}+c^2v			+636 191 25		
y	+s_{bb}+c^2u			+360 572 73		
z	+u_{oo}+v_{oo}					
Σ	+C_{zz}			+1164 846 90		

"STOP" SUMMATION - MEMBERS - 0'-C

THE M.W. KELLOGG CO | PIPING FLEXIBILITY AND STRESS ANALYSIS PLANE SUMMATION OF SHAPE COEFFICIENTS | CALC. R.M.C. CHECKED M.H. DATE 11-23-53 | FORM D-3 | CALC. NO. 5.9

equation form, the multiplication with the respective moments and forces and the proper summation of these products will yield $EI^*\theta_x$, $EI^*\theta_y$, $EI^*\theta_z$, $EI^*(\delta^*_x - \Delta_x)$, $EI^*(\delta^*_y - \Delta_y)$, $EI^*(\delta^*_z - \Delta_z)$ for the point in question where δ^*_x, δ^*_y, δ^*_z are the deflections with reference to the origin. Any extraneous movement at the terminal point must, of course, be included in the summation. In other words, the pipe line from the terminal to the point in question is treated as an independent line whose free-end deformations can be determined since the moments and forces are known.

For the next point for which the deflections are required the same procedure is repeated with the shape coefficients summed from the first to the second point. This part of the pipe line is now considered as an independent line for which the terminal deformations are those calculated for the previous point.

Since

$$\delta^*_x = \delta_x - z\theta_y + y\theta_z$$
$$\delta^*_y = \delta_y - x\theta_z + z\theta_x$$
$$\delta^*_z = \delta_z - y\theta_x + x\theta_y$$

the actual deflections, δ_x, δ_y, δ_z, can be computed.

A deflection calculation is conveniently made on Form G. The summations of shape coefficients from the terminal to the point in question are entered under the columns for the respective moments and forces, skipping a line between each row. The equa-

+53.75 Fyc

MXA	MZA	MYA	MYA	MZA	MZA	FXA	FXA	FYA	FYA	FZA	FZA	MZC	FYC	FZO	CONSTANTS
+.93		0		+188.78		+7772.78		-10560.16		-75.92		+188.78	-10560.16	-75.92	-EI θxc
+3342.58		0		-10560.16		-462300.40		+685698.66		-148339.27		-10560.16	+685698.66	-148339.27	-EI(δxc-Xc θzc)
+31.39		0		+6371.33		+262331.33		-356405.40		-2562.30		+6371.33	-356405.40	-2562.30	-EI Xc θzc
Σ +3373.97		0		-4188.83		-199969.07		+329293.26		-150901.57		-4188.83	+329293.26	-150901.57	-EI δzc
												+53.75 (-4188.83) =			
												-141,373.01			
												+329,293.26			
												Fyc COEFFICIENT = +187,920.25			

THE M.W. KELLOGG CO | PIPING FLEXIBILITY AND STRESS ANALYSIS | CALC. N.S. CHECKED H.W. DATE 4-17-52 | FORM J CALC. NO. 5.9

CONVERSION TO CODE RULES	POINT	0'	1	2	3	4	5	6	7
	x	+78.75	-1.06	-6.18	-4.25	-6.51	-6.00	0	0
$\frac{E_c}{E_h}$ = 1.27753	y	+80.75	+1.50	0	0	0	0	0	-6.00
	z	+17.25	-1.06	-6.18	-1.76	0	+6.00	+8.50	+6.00
$S_E = \frac{E_c}{E_h} \cdot S'_E$	F_x	+962.89	→	→	→	→	→	→	→
	F_y	+3170.65	→	→	→	→	→	→	→
S_E = PSI	F_z	+564.36	→	→	→	→	→	→	→
$\frac{R_c}{R'} = \frac{E_c}{E_h} \cdot C$ OR	M_x	-25666	-16544	-20752	-40347	-45927	→	-26903	+48
	$+F_y \cdot z$	+54699	-3361	-19595	-5580	0	+19024	+26951	+19024
$\frac{R_c}{R'} = \frac{E_c}{E_h} \frac{S'_E - S_h}{S'_E}$	$-F_z \cdot y$	-45572	-847	0	0	0	0	0	+3386
	M_x	-16544	-20752	-40347	-45927	-45927	-26903	+48	+22458
	M_y	-11639	+16194	+16617	+19080	+18376	+14702	+5539	-2646
WHICHEVER IS GREATER	$+F_z \cdot x$	+44443	-598	-3488	-2399	-3674	-3386	0	0
$\frac{R_s}{R'} = 0$	$-F_x \cdot z$	-16610	+1021	+5951	+1695	0	-5777	-8185	-5777
$\frac{R_h}{R'} = (1-\frac{2}{3}C)$	M_y	+16199	+16617	+19080	+18376	+14702	+5539	-2646	-8423
	M_z	+136912	-35024	-30219	-10624	+2851	+23492	+42516	→
$\frac{R_h}{R'} = 1$	$+F_z \cdot y$	+77753	+1944	0	0	0	0	0	-5777
	$-F_y \cdot x$	-249689	+3361	+19595	+13475	+20641	+19024	0	0
R' = CALCULATED REACTIONS BASED ON HOT MODULUS, E_H	M_z	-35024	-30219	-10624	+2851	+23492	+42516	+42516	+36739
	SIN α								
	COS α								
x | y | z	PLANE								
M'_x | M'_y | M'_z	M_b								
M'_z | $+M'_x$ | $+M'_y$	x COS α								
$-M'_y$ | $-M'_z$ | $-M'_x$	x SIN α								
Σ | Σ | Σ	M'_b								
$+M'_z$ | $+M'_x$ | $+M'_y$	x SIN α								
$+M'_y$ | $+M'_z$ | $+M'_x$	x COS α								
Σ | Σ | Σ	M_t								
PIPE | Z	f = 12/Z								
13.625 | 168.8	β								
	$S_b = f\beta M_b$								
	$S'_b = f\beta M'_b$								
	$2S_t = fM_t$								
	$S_b^2 + S'^2_b + 4S_t^2$								
$\sqrt{S_b^2 + S'^2_b + 4S_t^2} = S_E$									

THE M.W.KELLOGG CO. | PIPING FLEXIBILITY AND STRESS ANALYSIS MOMENTS AND STRESSES | CALC. N.S. CHECKED A.M.C. DATE 4-19-52 | FORM F-1 CALC. NO. 5.5

CONVERSION TO CODE RULES	POINT	8	9	10	11	C	O	A	B
	x	0	0	0	-6.00	-15.00	-33.75	-14.00	-14.00
$\frac{E_c}{E_h}$ = 1.27753	y	-70.25	-6.00	0	0	0	0	+8.00	+8.00
	z	0	-6.00	-16.75	-6.00	0	0	+5.50	-5.50
$S_E = \frac{E_c}{E_h} \cdot S_t$	F_x	+962.89	→	→	→	→	→	-800.52	+1763.41
	F_y	+3170.65	→	→	→	→	-915.98	+812.90	-1728.89
S_E = 6347 PSI	F_z	+564.36	→	→	→	→	→	-24.58	+94.49
$\frac{R_c}{R'} = \frac{E_c}{E_h} \cdot C$ OR	M_x	+22458	+62104	+46466	-6642	-25666	→	-10605	-15061
$\frac{R_c}{R'}, \frac{E_c}{E_h}\frac{S_t - S_h}{S_t}$	$+F_y \cdot z$	0	-19024	-53108	-19024	0	0	+4471	+9509
WHICHEVER IS GREATER	$-F_z \cdot y$	+39646	+3386	0	0	0	0	+197	-756
$\frac{R_c}{R'} = 0$	M'_x	+62104	+46466	-6642	-25666	-25666	-25666	-5937	-6308
	M_y	-8423	→	-2646	+13482	+15873	+7408	-3893	-7746
	$+F_z \cdot x$	0	0	0	-3386	-8465	-19047	+344	-1323
	$-F_x \cdot z$	0	+5777	+16128	+5777	0	0	+4403	+9699
$\frac{R_h}{R'} = (1 - \frac{2}{3}C)$	M_y	-8423	-2646	+13482	+15873	+7408	-11639	+854	+630
	M_z	+36739	-30904	-36681	→	-17657	+29903	-8472	+7460
$\frac{R_h}{R'} = 1$	$+F_x \cdot y$	-67643	-5777	0	0	0	0	-6404	+14107
	$-F_y \cdot x$	0	0	0	+19024	+47560	-30919	+11381	-27204
R' = CALCULATED REACTIONS BASED ON HOT MODULUS, E_h	M'_z	-30904	-36681	-36681	-17657	+29903	-1011	-3495	-2637
	SIN α	0							
	COS α	1.00							

x	y	z	PLANE	x								
M'_x	M'_y	M'_z	M_b	62104								
M'_z	$+M'_x$	$+M'_y$	x COS α	30904								
$-M'_y$	$-M'_z$	$-M'_x$	x SIN α	0								
Σ	Σ	Σ	M'_b	30904								
$+M'_z$	$+M'_x$	$+M'_y$	x SIN α	0								
$+M'_y$	$+M'_z$	$+M'_x$	x COS α	8423								
Σ	Σ	Σ	M_t	8423								
PIPE	Z	f = 12/Z		07109								
13.625	168.8	β		1.00								
		$S_b = f\beta M_b$		4415								
		$S'_b = f\beta M'_b$		2197								
		$2S_t = fM_t$		599								
		$S_b^2 + S'^2_b + 4S_t^2$		29.68 x 10⁶								
$\sqrt{S_b^2 + S'^2_b + 4S_t^2} = S_E$				4968								

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"A" BRANCH

CONVERSION TO CODE RULES	POINT	A	15	14	13	12	0		
	x	-14.00	0	+1.25	+11.50	+1.25	0		
$\frac{E_c}{E_h}$ =	y	+8.00	-6.75	-1.25	0	0	0		
	z	+5.50	0	0	0	-1.25	-4.25		
$S_E = \frac{E_c}{E_h} \cdot S_t$	F_x	-800.52	→	→	→	→	→		
	F_y	+812.91	→	→	→	→	→		
S_E = PSI	F_z	-24.58	→	→	→	→	→		
$\frac{R_c}{R'} = \frac{E_c}{E_h} \cdot C$ OR	M_x	-10605	-5937	-6103	-6134	→	-7150		
$\frac{R_c}{R'}, \frac{E_c}{E_h}\frac{S_t - S_h}{S_t}$	$+F_y \cdot z$	+4471	0	0	0	-1016	-3455		
WHICHEVER IS GREATER	$-F_z \cdot y$	+197	-166	-31	0	0	0		
$\frac{R_c}{R'} =$	M'_x	-5937	-6103	-6134	-6134	-7150	-10605		
	M_y	-3893	+854	→	+823	+540	-492		
	$+F_z \cdot x$	+344	0	-31	-283	-31	0		
	$-F_x \cdot z$	+4403	0	0	0	-1001	-3403		
$\frac{R_h}{R'} = (1 - \frac{2}{3}C)$	M_y	+854	+854	+823	+540	-492	-3894		
	M_z	-8472	-3495	+1909	+1894	-7454	-8470		
$\frac{R_h}{R'} =$	$+F_x \cdot y$	-6404	+5409	+1001	0	0	0		
	$-F_y \cdot x$	+11381	0	-1016	-9348	-1016	0		
R' = CALCULATED REACTIONS BASED ON HOT MODULUS, E_h	M'_z	-3495	+1909	+1894	-7454	-8470	-8470		
	SIN α						1		
	COS α						0		

x	y	z	PLANE	x								
M'_x	M'_y	M'_z	M_b								-10605	
M'_z	$+M'_x$	$+M'_y$	x COS α								0	
$-M'_y$	$-M'_z$	$-M'_x$	x SIN α								+3894	
Σ	Σ	Σ	M'_b								+3894	
$+M'_z$	$+M'_x$	$+M'_y$	x SIN α								-8470	
$+M'_y$	$+M'_z$	$+M'_x$	x COS α								0	
Σ	Σ	Σ	M_t								-8470	
PIPE	Z	f = 12/Z									.14670	
10.50	81.8	β									1.00	
		$S_b = f\beta M_b$									1556	
		$S'_b = f\beta M'_b$									571	
		$2S_t = fM_t$									1243	
		$S_b^2 + S'^2_b + 4S_t^2$									4.29 x 10⁶	
$\sqrt{S_b^2 + S'^2_b + 4S_t^2} = S_E$											2072	

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tions are completely written out. The moments and forces are entered at the heads of the columns, and the products of these and the shape coefficients are placed in the blank lines. Extraneous movements or carry-overs from previous points are listed at the extreme left and the products at the right of the sheet performed. The thermal expansion constants are computed in accordance with formulas given on the form. A summation horizontally produces the indicated sum ($EI^*\theta_x$, $EI^*\delta_x$ for example) from which rotations in radians and deflections in feet are found.

Consideration must be given to intervening actions (branches or stops) between the end point and the point in question. In Sample Calculation 5.10 the deflections have been calculated for the piping shown in Sample Calculation 5.9. The rotations and deflections at point O are calculated twice; by summation from end A, and again from point O'. This provides a useful check when points from different branches are computed. From point A to O there are no intervening stops so that the calculation proceeds as described in the preceding paragraph. Between O' and O there is a stop at point C; the moment and forces due to this must be dropped out at C. It is a useful check to note that the δ_y at point C and the δ_z at point O are zero because of the stops.

5.18 Symmetrical Pipe Lines

One way of reducing the labor involved in flexibility calculations is to take advantage of symmetry. The procedure varies somewhat with the system; nevertheless, the following examples will illustrate the general approach. It should be noted that symmetry must be complete, that is, the pipe size, temperature, and material must be the same for corresponding branches. Also, the coordinate origin must be located on the center line of symmetry.

Consider first a single plane system such as that shown in Fig. 5.12. Because of symmetry, no bending or rotation occurs in the common branch O'–O. Thus the moments and forces for the A branch can be obtained by considering line OA only, assuming member O'–O infinitely stiff.

Next consider a multiplane system as shown in Fig. 5.13. Due to symmetry, the only deformations of the common branch O'–O occur in the x-plane. Thus, M_y, M_z, and F_x are zero for line O'–O. If the shape coefficients for this branch are computed in the x-plane, only s, s_a, s_b, s_{ab}, s_{aa}, and s_{bb} apply and their values are doubled in order to account for the loading from the two branches. In other words, the common branch may be considered split in two,

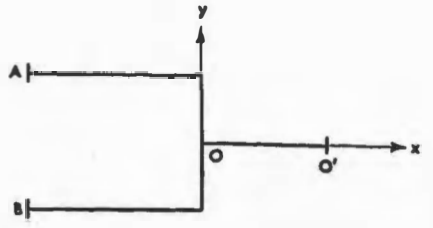

FIG. 5.12 Single-plane symmetrical system: three points of fixation.

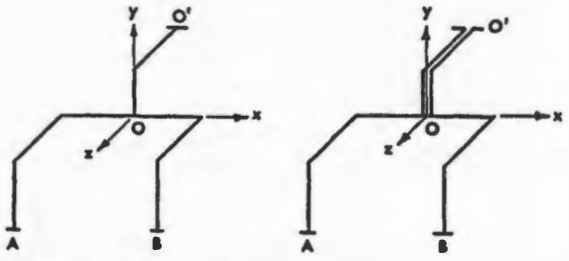

FIG. 5.13 Multiplane symmetrical system: three points of fixation.

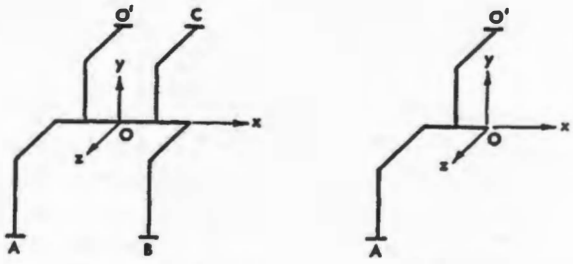

FIG. 5.14 Multiplane symmetrical system: four points of fixation.

each having half the moment of inertia of the pipe, and consequently a Q-value of 2. Accordingly, the problem can be solved with six equations for line O'–O–A, using the aforementioned six coefficients for branch O'–O and all the coefficients for branch O–A.

In Fig. 5.14, the rotations θ_y and θ_z and the translation δ_x are zero at point O. The system can be solved by setting up the following nine equations:

$$\theta_{xA} \quad \theta_{yA} \quad \theta_{zA} \quad \delta_{xA} \quad \delta_{yA} \quad \delta_{zA} \quad \theta_{yO} \quad \theta_{zO} \quad \delta_{xO}$$

5.19 Inversion Procedures

As previously stated, the General Analytical Method can be applied to the flexibility analysis of any type of piping configuration. However, the number of simultaneous equations necessary to solve the problem increases as the degree of complexity of the system increases, i.e. as the number of points of fixation of the system increases. Furthermore, the time required to solve a set of simul-