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TABLE A-4
NICKEL AND HIGH NICKEL ALLOYS

Spec. No.	UNS Alloy No.	Temper or Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Seamless Pipe and Tube								
B 161	N02200	Annealed	Ni	41	(1)(5)	55	15	1.00
	N02200	Annealed	Ni	41	(1)(6)	55	12	1.00
	N02200	Str. rel.	Ni	41	(1)	65	40	1.00
B 161	N02201	Annealed	Ni–LC	41	(1)(5)	50	12	1.00
	N02201	Annealed	Ni–LC	41	(1)(6)	50	10	1.00
	N02201	Str. Rel.	Ni–LC	41	(1)	60	30	1.00
B 163	N08800	Annealed	Ni–Cr–Fe	45	(1)(7)	75	30	1.00
	N08800	Annealed	Ni–Cr–Fe	45	(1)(2)(7)	75	30	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(1)	65	25	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(1)(2)	65	25	1.00
B 165	N04400	Annealed	Ni–Cu	42	(1)(5)	70	28	1.00
	N04400	Annealed	Ni–Cu	42	(1)(6)	70	25	1.00
	N04400	Str. rel.	Ni–Cu	42	(1)(2)(3)	85	35	1.00
B 167	N06600	H.F./Ann.	Ni–Cr–Fe	43	(1)(5)	80	30	1.00
	N06600	H.F./Ann.	Ni–Cr–Fe	43	(1)(2)(5)	75	30	1.00
	N06600	H.F./Ann.	Ni–Cr–Fe	43	(1)(6)	75	25	1.00
	N06600	H.F./Ann.	Ni–Cr–Fe	43	(1)(2)(6)	80	25	1.00
B 167	N06600	C.D./Ann.	Ni–Cr–Fe	43	(1)(5)	80	35	1.00
	N06600	C.D./Ann.	Ni–Cr–Fe	43	(1)(2)(5)	80	35	1.00
	N06600	C.D./Ann.	Ni–Cr–Fe	43	(1)(6)	80	30	1.00
	N06600	C.D./Ann.	Ni–Cr–Fe	43	(1)(2)(6)	80	30	1.00
B 407	N08800	C.D./Ann.	Ni–Cr–Fe	45	(7)	75	30	1.00
	N08800	C.D./Ann.	Ni–Cr–Fe	45	(2)(7)	75	30	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(7)	65	25	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(2)(7)	65	25	1.00
B 423	N08825	C.W./Ann.	Ni–Fe–Cr–Mo–Cu	45	(1)(7)	85	35	1.00
	N08825	C.W./Ann.	Ni–Fe–Cr–Mo–Cu	45	(1)(2)(7)	85	35	1.00
B 622	N06022	Sol. Ann.	Ni–Mo–Cr–LC	44	(1)(12)(13)	100	...	1.00
	N06022	Sol. Ann.	Ni–Mo–Cr–LC	44	(1)(2)(12)(13)	100	...	1.00
B 677	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–LC	45	(1)	87	...	1.00
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–LC	...	(1)	94	...	1.00
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–LC	...	(1)(2)	94	...	1.00
B 690	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(8)(13)	104	46	1.00
	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(2)(8)(13)	104	46	1.00

TABLE A-4
NICKEL AND HIGH NICKEL ALLOYS

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																			
−20 to 100	200	300	400	500	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	UNS Alloy No.	Spec. No.
																		Seamless Pipe and Tube	
10.0	10.0	10.0	10.0	10.0	10.0	...	...	...	...	...	...	...	...	...	...	...	...	N02200	B 161
8.0	8.0	8.0	8.0	8.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	N02200	
16.3	16.3	16.3	16.3	16.0	15.4	...	...	...	...	...	...	...	...	...	...	...	...	N02200	
8.0	7.7	7.5	7.5	7.5	7.5	7.5	7.4	7.3	7.2	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	N02200	B 161
6.7	6.4	6.3	6.2	6.2	6.2	6.2	6.2	6.0	5.9	5.8	4.5	3.7	3.0	2.4	2.0	1.5	1.2	N02200	
15.0	15.0	15.0	15.8	14.7	14.2	...	...	...	...	...	...	...	...	...	...	...	...	N02200	
18.7	18.7	17.9	17.2	16.7	16.3	16.1	15.9	15.7	15.5	15.3	15.1	14.9	14.7	14.5	13.0	9.8	6.6	N08800	B 163
18.7	18.7	18.7	18.7	18.7	18.7	18.6	18.6	18.5	18.5	18.3	18.2	17.9	17.6	17.0	13.0	9.8	6.6	N08800	
16.2	15.4	14.5	13.5	12.9	12.2	11.9	11.7	11.4	11.1	10.9	10.7	10.5	10.3	10.1	10.0	9.3	7.4	N08810	
16.2	16.2	16.2	16.2	16.0	16.0	16.0	15.7	15.4	15.3	15.1	14.8	14.6	14.4	13.7	11.6	9.3	7.4	N08810	
17.5	16.4	15.4	14.8	14.7	14.7	14.7	14.7	14.6	14.2	11.0	8.0	...	...	...	...	...	...	N04400	B 165
16.6	14.6	13.6	13.2	13.1	13.1	13.1	13.1	13.0	12.7	11.0	8.0	...	...	...	...	...	...	N04400	
21.2	21.2	21.2	21.1	21.0	...	...	...	...	...	...	...	...	...	...	...	...	...	N04400	
20.0	19.1	18.2	17.5	16.9	16.1	16.0	15.6	15.5	15.3	15.0	14.9	10.6	7.0	4.5	3.0	2.2	2.0	N06600	B 167
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	19.6	16.0	10.6	7.0	4.5	3.0	2.2	2.0	N06600	
16.7	15.3	14.5	14.0	13.6	13.2	13.1	13.0	12.9	12.7	12.3	11.8	10.6	7.0	4.5	3.0	2.2	2.0	N06600	
16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.7	16.5	15.9	15.9	7.0	4.5	3.0	2.2	2.0	N06600	
20.0	20.0	20.0	20.0	20.0	20.0	19.8	19.6	19.4	19.1	18.7	16.0	10.6	7.0	4.5	3.0	2.2	2.0	N06600	B 167
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	16.0	10.6	7.0	4.5	3.0	2.2	2.0	N06600	
20.0	19.1	18.2	17.5	16.9	16.1	16.0	15.6	15.5	15.3	15.0	14.9	10.6	7.0	4.5	3.0	2.2	2.0	N06600	
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	19.6	16.0	10.6	7.0	4.5	3.0	2.2	2.0	N06600	
18.7	18.7	17.9	17.2	16.7	16.3	16.1	15.9	15.7	15.5	15.3	15.1	14.9	14.7	14.5	13.0	9.8	6.6	N08800	B 407
18.7	18.7	18.7	18.7	18.7	18.7	18.6	18.6	18.5	18.5	18.3	18.2	17.9	17.6	17.0	13.0	9.8	6.6	N08800	
16.2	15.4	14.5	13.5	12.9	12.2	11.9	11.7	11.4	11.1	10.9	10.7	10.5	10.3	10.1	10.0	9.3	7.4	N08810	
16.2	16.2	16.2	16.2	16.0	16.0	16.0	15.7	15.4	15.3	15.1	14.8	14.6	14.4	13.7	11.6	9.3	7.4	N08810	
21.2	21.2	20.4	19.2	18.3	17.8	17.6	17.3	17.2	17.1	...	...	...	...	...	...	...	...	N08825	B 423
21.2	21.2	21.2	21.2	21.2	21.2	21.1	21.0	20.9	20.8	...	...	...	...	...	...	...	...	N08825	
25.0	25.0	24.5	22.7	21.2	20.1	19.6	19.2	18.9	18.6	...	...	...	...	...	...	...	...	N06022	B 622
25.0	25.0	24.8	23.9	23.2	22.7	22.6	22.4	22.3	22.2	...	...	...	...	...	...	...	...	N06022	
21.7	21.7	20.9	19.6	18.3	17.3	16.9	16.9	16.9	16.9	...	...	...	...	...	...	...	...	N08925	B 677
23.5	23.5	21.3	19.9	18.7	17.9	17.7	17.6	17.5	...	...	...	...	...	...	...	...	...	N08926	
23.5	23.5	22.9	21.8	20.8	20.0	19.6	19.3	19.2	...	...	...	...	...	...	...	...	...	N08926	
26.0	26.0	24.2	22.7	20.9	19.9	19.3	19.0	18.7	18.4	...	...	...	...	...	...	...	...	N08367	B 690
26.2	26.0	24.6	23.5	22.9	22.3	22.1	21.9	21.8	21.7	...	...	...	...	...	...	...	...	N08367	

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TABLE A-4
NICKEL AND HIGH NICKEL ALLOYS (CONT'D)

Spec. No.	UNS Alloy No.	Temper or Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Seamless Pipe and Tube (Cont'd)								
B 729	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)	80	35	1.00
	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)(2)	80	35	1.00
Welded Pipe and Tube								
B 464	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)	80	35	0.85
	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)(2)	80	35	0.85
B 468	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)	80	35	0.85
	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)(2)	80	35	0.85
B 619	N06022	Sol. Ann.	Ni–Mo–Cr–LC	44	(1)(12)	100	...	0.85
	N06022	Sol. Ann.	Ni–Mo–Cr–LC	44	(1)(2)(12)	100	...	0.85
B 626	N06022	Sol. Ann.	Ni–Mo–Cr–LC	44	(1)(12)	100	...	0.85
	N06022	Sol. Ann.	Ni–Mo–Cr–LC	44	(1)(2)(12)	100	...	0.85
B 673	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–LC	45	(1)	87	...	0.85
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–LC	...	(1)	94	...	0.85
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–LC	...	(1)(2)	94	...	0.85
B 674	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–LC	45	(1)	87	...	0.85
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–LC	...	(1)	94	...	0.85
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–LC	...	(1)(2)	94	...	0.85
B 675	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(8)(13)	104	46	0.85
	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(2)(8)(13)	104	46	0.85
B 676	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(8)(13)	104	46	0.85
	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(2)(8)(13)	104	46	0.85
B 804	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(8)(13)	95	45	0.85
	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(2)(8)(13)	95	45	0.85
Plate, Sheet, and Strip								
B 168	N06600	Annealed	Ni–Cr–Fe	43	(1)	80	35	1.00
	N06600	Annealed	Ni–Cr–Fe	43	(1)(2)	80	35	1.00
	N06600	Hot rolled	Ni–Cr–Fe	43	(1)(4)	85	35	1.00
	N06600	Hot rolled	Ni–Cr–Fe	43	(1)(2)(4)	85	35	1.00
B 409	N08800	Annealed	Ni–Cr–Fe	45	(4)(7)	75	30	1.00
	N08800	Annealed	Ni–Cr–Fe	45	(2)(4)(7)	75	30	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(4)(7)	65	25	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(2)(4)(7)	65	25	1.00

TABLE A-4
NICKEL AND HIGH NICKEL ALLOYS (CONT'D)

–20 to 100	200	300	400	500	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	UNS Alloy No.	Spec. No.
Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																			
Seamless Pipe and Tube (Cont'd)																			
20.0	20.0	19.8	18.7	18.2	17.7	17.5	17.3	17.1	16.8	...	...	...	...	...	...	...	...	N08020	B 729
20.0	20.0	19.8	19.4	19.3	19.3	19.2	19.2	19.2	19.1	...	...	...	...	...	...	...	...	N08020	
Welded Pipe and Tube																			
17.0	17.0	16.8	15.9	15.5	15.1	14.9	14.7	14.5	14.3	...	...	...	...	...	...	...	...	N08020	B 464
17.0	17.0	16.8	16.5	16.4	16.4	16.3	16.3	16.3	16.2	...	...	...	...	...	...	...	...	N08020	
17.0	17.0	16.8	15.9	15.5	15.1	14.9	14.7	14.5	14.3	...	...	...	...	...	...	...	...	N08020	B 468
17.0	17.0	16.8	16.5	16.4	16.4	16.3	16.3	16.3	16.2	...	...	...	...	...	...	...	...	N08020	
21.2	21.2	20.8	19.3	18.0	17.1	16.7	16.3	16.1	15.8	...	...	...	...	...	...	...	...	N06022	B 619
21.2	21.2	21.1	20.3	19.7	19.3	19.2	19.0	19.0	18.9	...	...	...	...	...	...	...	...	N06022	
21.2	21.2	20.8	19.3	18.0	17.1	16.7	16.3	16.1	15.8	...	...	...	...	...	...	...	...	N06022	B 626
21.2	21.2	21.1	20.3	19.7	19.3	19.2	19.0	19.0	18.9	...	...	...	...	...	...	...	...	N06022	
18.4	18.4	17.8	16.7	15.6	14.7	14.4	14.4	14.4	14.4	...	...	...	...	...	...	...	...	N08925	B 673
20.0	20.0	18.1	16.9	15.9	15.2	15.0	15.0	14.9	...	...	...	...	...	...	...	...	...	N08926	
20.0	20.0	19.5	18.5	17.7	17.0	16.7	16.4	16.3	...	...	...	...	...	...	...	...	...	N08926	
18.4	18.4	17.8	16.7	15.6	14.7	14.4	14.4	14.4	14.4	...	...	...	...	...	...	...	...	N08925	B674
20.0	20.0	18.1	16.9	15.9	15.2	15.0	15.0	14.9	...	...	...	...	...	...	...	...	...	N08926	
20.0	20.0	19.5	18.5	17.7	17.0	16.7	16.4	16.3	...	...	...	...	...	...	...	...	...	N08926	
22.1	22.1	20.6	19.3	17.8	16.9	16.4	16.2	15.9	15.6	...	...	...	...	...	...	...	...	N08367	B 675
22.1	22.1	20.9	20.0	19.5	19.0	18.8	18.6	18.5	18.4	...	...	...	...	...	...	...	...	N08367	
22.1	22.1	20.6	19.3	17.8	16.9	16.4	16.2	15.9	15.6	...	...	...	...	...	...	...	...	N08367	B 676
22.1	22.1	20.9	20.0	19.5	19.0	18.8	18.6	18.5	18.4	...	...	...	...	...	...	...	...	N08367	
20.2	20.2	19.1	18.2	17.3	16.6	16.1	15.8	15.6	15.3	...	...	...	...	...	...	...	...	N08367	B 804
20.2	20.2	19.1	18.2	17.8	17.3	17.2	17.0	16.9	16.8	...	...	...	...	...	...	...	...	N08367	
Plate, Sheet, and Strip																			
20.0	20.0	20.0	20.0	20.0	20.0	19.8	19.6	19.4	19.1	18.7	16.0	10.6	7.0	4.5	3.0	2.2	2.0	N06600	B 168
20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	20.0	16.0	10.6	7.0	4.5	3.0	2.2	2.0	N06600	
21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.1	21.0	20.4	20.2	19.6	19.3	14.5	10.3	7.2	5.8	5.5	N06600	
21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	21.2	14.5	10.3	7.2	5.8	5.5	N06600	
18.7	18.7	17.9	17.2	16.7	16.3	16.1	15.9	15.7	15.5	15.3	15.1	14.9	14.7	14.5	13.0	9.8	6.6	N08800	B 409
18.7	18.7	18.7	18.7	18.7	18.7	18.6	18.6	18.5	18.5	18.3	18.2	17.9	17.6	17.0	13.0	9.8	6.6	N08800	
16.2	15.4	14.5	13.5	12.9	12.2	11.9	11.7	11.4	11.1	10.9	10.7	10.5	10.3	10.1	10.0	9.3	7.4	N08810	
16.2	16.2	16.2	16.2	16.0	16.0	16.0	15.7	15.4	15.3	15.1	14.8	14.6	14.4	13.7	11.6	9.3	7.4	N08810	

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TABLE A-4
NICKEL AND HIGH NICKEL ALLOYS (CONT'D)

Spec. No.	UNS Alloy No.	Temper or Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Plate, Sheet, and Strip (Cont'd)								
B 424	N08825	Annealed	Ni–Fe–Cr–Mo–Cu	45	(1)(7)	85	35	1.00
	N08825	Annealed	Ni–Fe–Cr–Mo–Cu	45	(1)(2)(7)	85	35	1.00
B 463	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)	80	35	1.00
	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)(12)	80	35	1.00
B 575	N06022	Sol. Ann.	Ni–Mo–Cr–LC	44	(1)(12)	100	...	1.00
	N06022	Sol. Ann.	Ni–Mo–Cr–LC	44	(1)(2)(12)	100	...	1.00
B 625	N08925	Annealed	Ni–Fe–Cr–Mo–Cu–LC	45	(1)	87	...	1.00
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–LC	...	(1)	94	...	1.00
	N08926	Annealed	Ni–Fe–Cr–Mo–Cu–N–LC	...	(1)(2)	94	...	1.00
B 688	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(7)(9)(13)	104	46	1.00
	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(2)(7)(9)(13)	104	46	1.00
	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(7)(10)(13)	100	45	1.00
	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(2)(7)(10)(13)	100	45	1.00
	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(7)(11)(13)	95	45	1.00
	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(2)(7)(11)(13)	95	45	1.00
Bars, Rods, Shapes, and Forgings								
B 408	N08800	Annealed	Ni–Cr–Fe	45	(7)	75	30	1.00
	N08800	Annealed	Ni–Cr–Fe	45	(2)(7)	75	30	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(7)	65	25	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(2)(7)	65	25	1.00
B 425	N08825	Annealed	Ni–Fe–Cr–Mo–Cu	45	(1)(7)	85	35	1.00
	N08825	Annealed	Ni–Fe–Cr–Mo–Cu	45	(1)(2)(7)	85	35	1.00
B 462	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)	80	35	1.00
	N08020	Annealed	Ni–Fe–Cr–Mo–Cu–Cb	45	(1)(2)	80	35	1.00
B 473	N08020	Annealed	Cr–Ni–Fe–Mo–Cu–Cb	45	(1)	80	35	1.00
	N08020	Annealed	Cr–Ni–Fe–Mo–Cu–Cb	45	(1)(2)	80	35	1.00
B 564	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(8)(13)	95	45	1.00
	N08367	Annealed	Ni–Fe–Cr–Mo	45	(1)(2)(8)(13)	95	45	1.00
	N08800	Annealed	Ni–Cr–Fe	45	(1)	75	30	1.00
	N08800	Annealed	Ni–Cr–Fe	45	(1)(2)	75	30	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(1)	65	25	1.00
	N08810	Annealed	Ni–Cr–Fe	45	(1)(2)	65	25	1.00
B 574	N06022	Sol. Ann.	Ni–Mo–Cr–LC	44	(1)(12)	100	...	1.00
	N06022	Sol. Ann.	Ni–Mo–Cr–LC	44	(1)(2)(12)	100	...	1.00

TABLE A-4
NICKEL AND HIGH NICKEL ALLOYS (CONT'D)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding

−20 to 100	200	300	400	500	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	UNS Alloy No.	Spec. No.
																			Plate, Sheet, and Strip (Cont'd)
21.2	21.2	20.4	19.2	18.3	17.8	17.6	17.3	17.2	17.1	...	...	...	...	...	...	...	...	N08825	B 424
21.2	21.2	21.2	21.2	21.2	21.2	21.1	21.0	20.9	20.8	...	...	...	...	...	...	...	...	N08825	
20.0	20.0	19.8	18.7	18.2	17.5	17.4	17.3	17.0	16.8	...	...	...	...	...	...	...	...	N08020	B 463
20.0	20.0	19.8	19.4	19.3	19.2	19.2	19.2	19.1	19.1	...	...	...	...	...	...	...	...	N08020	
25.0	25.0	24.5	22.7	21.2	20.1	19.6	19.2	18.9	18.6	...	...	...	...	...	...	...	...	N06022	B 575
25.0	25.0	24.8	23.9	23.2	22.7	22.6	22.4	22.3	22.2	...	...	...	...	...	...	...	...	N06022	
21.7	21.7	20.9	19.6	18.3	17.3	16.9	16.9	16.9	16.9	...	...	...	...	...	...	...	...	N08925	B 625
23.5	23.5	21.3	19.9	18.7	17.9	17.7	17.6	17.5	...	...	...	...	...	...	...	...	...	N08926	
23.5	23.5	22.9	21.8	20.8	20.0	19.6	19.3	19.2	...	...	...	...	...	...	...	...	...	N08926	
26.0	26.0	24.2	22.7	20.9	19.9	19.3	19.0	18.7	18.4	...	...	...	...	...	...	...	...	N08367	B 688
26.0	26.0	24.6	23.5	22.9	22.3	22.1	21.9	21.8	21.7	...	...	...	...	...	...	...	...	N08367	
25.0	25.0	23.6	22.2	20.4	19.5	18.9	18.6	18.3	18.0	...	...	...	...	...	...	...	...	N08367	
25.0	25.0	23.6	22.6	22.0	21.9	21.3	21.1	21.0	20.9	...	...	...	...	...	...	...	...	N08367	
23.8	23.8	22.5	21.4	20.4	19.5	18.9	18.6	18.3	18.0	...	...	...	...	...	...	...	...	N08367	
23.8	23.8	22.5	21.4	20.9	20.4	20.2	20.0	19.9	19.8	...	...	...	...	...	...	...	...	N08367	
																			Bars, Rods, Shapes, and Forgings
18.7	18.7	17.9	17.2	16.7	16.3	16.1	15.9	15.7	15.5	15.3	15.1	14.9	14.7	14.5	13.0	9.8	6.6	N08800	B 408
18.7	18.7	18.7	18.7	18.7	18.7	18.6	18.6	18.5	18.5	18.3	18.2	17.9	17.6	17.0	13.0	9.8	6.6	N08800	
16.2	15.4	14.5	13.5	12.9	12.2	11.9	11.7	11.4	11.1	10.9	10.7	10.5	10.3	10.1	10.0	9.3	7.4	N08810	
16.2	16.2	16.2	16.2	16.0	16.0	16.0	15.7	15.4	15.3	15.1	14.8	14.6	14.4	13.7	11.6	9.3	7.4	N08810	
21.2	21.2	20.4	19.2	18.3	17.8	17.6	17.3	17.2	17.1	...	...	...	...	...	...	...	...	N08825	B 425
21.2	21.2	21.2	21.2	21.2	21.2	21.1	21.0	20.9	20.8	...	...	...	...	...	...	...	...	N08825	
20.0	20.0	19.8	18.7	18.2	17.7	17.5	17.3	17.1	16.8	...	...	...	...	...	...	...	...	N08020	B 462
20.0	20.0	19.8	19.4	19.3	19.3	19.2	19.2	19.2	19.1	...	...	...	...	...	...	...	...	N08020	
20.0	20.0	19.8	18.7	18.2	17.7	17.5	17.3	17.1	16.8	...	...	...	...	...	...	..	...	N08020	B 473
20.0	20.0	19.8	19.4	19.3	19.3	19.2	19.2	19.2	19.1	...	...	...	...	...	...	...	...	N08020	
23.8	23.8	22.5	21.4	20.4	19.5	18.9	18.6	18.3	18.0	...	...	...	...	...	...	...	...	N08367	B 564
23.8	23.8	22.5	21.4	20.9	20.4	20.2	20.0	19.9	19.8	...	...	...	...	...	...	...	...	N08367	
18.7	18.7	17.9	17.2	16.7	16.3	16.1	15.9	15.7	15.5	15.3	15.1	14.9	14.7	14.5	13.0	9.8	6.6	N08800	
18.7	18.7	18.7	18.7	18.7	18.7	18.6	18.6	18.5	18.5	18.3	18.2	17.9	17.6	17.0	13.0	9.8	6.6	N08800	
16.2	15.4	14.5	13.5	12.9	12.2	11.9	11.7	11.4	11.1	10.9	10.7	10.5	10.3	10.1	10.0	9.3	7.4	N08810	
16.2	16.2	16.2	16.2	16.0	16.0	16.0	15.7	15.4	15.3	15.1	14.8	14.6	14.4	13.7	11.6	9.3	7.4	N08810	
25.0	25.0	24.5	22.7	21.2	20.1	19.6	19.2	18.9	18.6	...	...	...	...	...	...	...	...	N06022	B 574
25.0	25.0	24.8	23.9	23.2	22.7	22.6	22.4	22.3	22.2	...	...	...	...	...	...	...	...	N06022	

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TABLE A-4
NICKEL AND HIGH NICKEL ALLOYS (CONT'D)

Spec. No.	UNS Alloy No.	Temper or Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Bars, Rods, Shapes, and Forgings (Cont'd)								
B 649	N08925	Annealed	Ni-Fe-Cr-Mo-Cu-LC	45	(1)	87	...	0.85
	N08926	Annealed	Ni-Fe-Cr-Mo-Cu-N-LC	...	(1)	94	...	1.00
	N08926	Annealed	Ni-Fe-Cr-Mo-Cu-N-LC	...	(1)(2)	94	...	1.00
B 691	N08367	Annealed	Ni-Fe-Cr-Mo	45	(1)(8)(13)	95	45	1.00
	N08367	Annealed	Ni-Fe-Cr-Mo	45	(1)(2)(8)(13)	95	45	1.00
Seamless Fittings								
B 366	N06022	Sol. Ann.	Ni-Mo-Cr-LC	44	(1)(12)(13)	100	...	1.00
	N06022	Sol. Ann.	Ni-Mo-Cr-LC	44	(1)(2)(12)(13)	100	...	1.00
	N08020	Annealed	Cr-Ni-Fe-Mo-Cu-Cb	45	(1)	80	35	...
	N08020	Annealed	Cr-Ni-Fe-Mo-Cu-Cb	45	(1)(2)	80	35	...
	N08367	Annealed	Ni-Fe-Cr-Mo	45	(1)(8)(13)	95	45	1.00
	N08367	Annealed	Ni-Fe-Cr-Mo	45	(1)(2)(8)(13)	95	45	1.00
B 366	N08926	Annealed	Ni-Fe-Cr-Mo-Cu-N-LC	...	(1)	94	...	1.00
	N08926	Annealed	Ni-Fe-Cr-Mo-Cu-N-LC	...	(1)(2)	94	...	1.00
B 462	N08367	Annealed	Ni-Fe-Cr-Mo	45	(1)(8)(13)	95	45	1.00
	N08367	Annealed	Ni-Fe-Cr-Mo	45	(1)(2)(8)(13)	95	45	1.00
Welded Fittings								
B 366	N06022	Sol. Ann.	Ni-Mo-Cr-LC	44	(1)(12)(13)	100	...	0.85
	N06022	Sol. Ann.	Ni-Mo-Cr-LC	44	(1)(2)(12)(13)	100	...	0.85
	N08020	Annealed	Cr-Ni-Fe-Mo-Cu-Cb	45	(1)	80	35	0.85
	N08020	Annealed	Cr-Ni-Fe-Mo-Cu-Cb	45	(1)(2)	80	35	0.85
B 366	N08925	Annealed	Ni-Fe-Cr-Mo-Cu-LC	45	(1)	87	...	0.85
	N08926	Annealed	Ni-Fe-Cr-Mo-Cu-N-LC	...	(1)	94	...	0.85
	N08926	Annealed	Ni-Fe-Cr-Mo-Cu-N-LC	...	(1)(2)	94	...	0.85

GENERAL NOTES:

(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME Boiler and Pressure Vessel Code applications, see related specifications in Section II of the ASME Code.

(b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.

(c) The P-Numbers indicated in this Table are identical to those adopted by the ASME Boiler and Pressure Vessel Code. Qualification of welding procedures, welders, and welding operators is required and shall comply with the ASME Boiler and Pressure Vessel Code, Section IX, except as modified by para. 127.5.

(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."

(e) The materials listed in this table shall not be used at design temperatures above those for which allowable stress values are given.

(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3.

(g) Pressure-temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this Table are for use in designing piping components which are not manufactured in accordance with referenced standards.

(h) The y coefficient = 0.4 except where Note (7) applies [see Table 104.1.2(A)].

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TABLE A-4
NICKEL AND HIGH NICKEL ALLOYS (CONT'D)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																			
-20 to 100	200	300	400	500	600	650	700	750	800	850	900	950	1000	1050	1100	1150	1200	UNS Alloy No.	Spec. No.
																			Bars, Rods, Shapes, and Forgings (Cont'd)
21.7	21.7	20.9	19.6	18.3	17.3	16.9	16.9	16.9	16.9	...	...	...	...	...	...	...	...	N08925	B 649
23.5	23.5	21.3	19.9	18.7	17.9	17.7	17.6	17.5	...	...	...	...	...	...	...	...	...	N08926	
23.5	23.5	22.9	21.8	20.8	20.0	19.6	19.3	19.2	...	...	...	...	...	...	...	...	...	N08926	
23.8	23.8	22.5	21.4	20.4	19.5	18.9	18.6	18.3	18.0	...	...	...	...	...	...	...	...	N08367	B 691
23.8	23.8	22.5	21.4	20.9	20.4	20.2	20.0	19.9	19.8	...	...	...	...	...	...	...	...	N08367	
																			Seamless Fittings
25.0	25.0	24.5	22.7	21.2	20.1	19.6	19.2	18.9	18.6	...	...	...	...	...	...	...	...	N06022	B 366
25.0	25.0	24.8	23.9	23.2	22.7	22.6	22.4	22.3	22.2	...	...	...	...	...	...	...	...	N06022	
20.0	20.0	19.8	18.7	18.2	17.5	17.4	17.3	17.0	16.8	...	...	...	...	...	...	...	...	N08020	
20.0	20.0	19.8	19.4	19.3	19.2	19.2	19.2	19.1	19.1	...	...	...	...	...	...	...	...	N08020	
23.8	23.8	22.5	21.4	20.4	19.5	18.9	18.6	18.3	18.0	...	...	...	...	...	...	...	...	N08367	
23.8	23.8	22.5	21.4	20.9	20.4	20.2	20.0	19.9	19.8	...	...	...	...	...	...	...	...	N08367	
23.5	23.5	21.3	19.9	18.7	17.9	17.7	17.6	17.5	...	...	...	...	...	...	...	...	...	N08926	B 366
23.5	23.5	22.9	21.8	20.8	20.0	19.6	19.3	19.2	...	...	...	...	...	...	...	...	...	N08926	
23.8	23.8	22.5	21.4	20.4	19.5	18.9	18.6	18.3	18.0	...	...	...	...	...	...	...	...	N08367	B 462
23.8	23.8	22.5	21.4	20.9	20.4	20.2	20.0	19.9	19.8	...	...	...	...	...	...	...	...	N08367	
																			Welded Fittings
21.2	21.2	20.8	19.3	18.0	17.1	16.7	16.3	16.1	15.8	...	...	...	...	...	...	...	...	N06022	B 366
21.2	21.2	21.1	20.3	19.7	19.3	19.2	19.0	19.0	18.9	...	...	...	...	...	...	...	...	N06022	
17.0	17.0	16.8	15.9	15.5	14.9	14.8	14.7	14.5	14.3	...	...	...	...	...	...	...	...	N08020	
17.0	17.0	16.8	16.5	16.4	16.4	16.3	16.3	16.3	16.2	...	...	...	...	...	...	...	...	N08020	
18.4	18.4	17.8	16.7	15.6	14.7	14.4	14.4	14.4	14.4	...	...	...	...	...	...	...	...	N08925	B 366
20.0	20.0	18.1	16.9	15.9	15.2	15.0	15.0	14.9	...	...	...	...	...	...	...	...	...	N08926	
20.0	20.0	19.5	18.5	17.7	17.0	16.7	16.4	16.3	...	...	...	...	...	...	...	...	...	N08926	

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGS. 100.1.2(A) AND (B).

(2) Due to the relatively low yield strengths of these materials, these higher allowable stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These stress values exceed 67% but do not exceed 90% of the yield strength at temperature. Use of these values may result in dimensional changes due to permanent strain. These values should not be used for flanges of gasketed joints or other applications where slight amounts ofdistortion can cause leakage or malfunction.

(3) The maximum temperature is limited to 500°F because harder temper adversely affects design stress in the creep rupture temperature range.

(4) These values may be used for plate material only.

(5) These values apply to sizes NPS 5 and smaller.

(6) These values apply to sizes larger than NPS 5.

(7) See Table 104.1.2(A) for *y* coefficient value.

(8) Heat treatment after forming or welding is neither required nor prohibited. However, if heat treatment is applied, the solution annealing treatment shall consist of heating to a minimum temperature of 2025°F and then quenching in water or rapidly cooling by other means.

(9) These values apply to thickness less than $^3/_{16}$ in.

(10) These values apply to thickness from $^3/_{16}$ in. up to and including $^3/_4$ in.

(11) These values apply to thickness more than $^3/_4$ in.

(12) All filler metal, including consumable insert material, shall comply with the requirements of Section IX of the ASME Boiler and Pressure Vessel Code.

(13) This material is one of the highest tensile strength materials approved for use in ASME pressure component applications and little fatigue data is available for it in the ASME database. Therefore, the designer shall consider this when calculating the allowable stress range for expansion stresses and provide appropriate design margins.

TABLE A-5
CAST IRON

Spec. No.	Class	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Gray Cast Iron					
A 48	20	(1)(2)(3)(4)	20	...	...
	25	(1)(2)(3)(4)	25	...	...
	30	(1)(2)(3)(4)	30	...	...
	35	(1)(2)(3)(4)	35	...	...
	40	(1)(2)(3)(4)	40	...	...
	45	(1)(2)(3)(4)	45	...	...
	50	(1)(2)(3)(4)	50	...	...
	55	(1)(2)(3)(4)	55	...	...
	60	(1)(2)(3)(4)	60	...	...
A 126	A	(3)(4)(7)	21	...	...
	B	(3)(4)(7)	31	...	...
	C	(3)(4)(7)	41	...	...
A 278	20	(2)(4)(5)	20	...	...
	25	(2)(4)(5)	25	...	...
	30	(2)(4)(5)	30	...	...
	35	(2)(4)(5)	35	...	...
	40	(2)(4)(5)	40	...	...
	45	(2)(4)(5)	45	...	...
	50	(2)(4)(5)	50	...	...
	55	(2)(4)(5)	55	...	...
	60	(2)(4)(5)	60	...	...
Ductile Cast Iron					
A 395	...	(6)(8)	60	40	0.80
A 536	60-42-10	(1)(8)	60	42	0.80
	70-50-05	(1)(8)	70	50	0.80

GENERAL NOTES:

(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME Boiler and Pressure Vessel Code applications, see related specifications in Section II of the ASME Code.

(b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.

(c) Cast iron components shall not be welded during fabrication or assembly as part of the piping system.

(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."

(e) The materials listed in this Table shall not be used at design temperatures above those for which allowable stress values are given.

(f) The tabulated stress values for ductile cast iron materials are $S \times F$ (material quality factor). Material quality factors are not applicable to other types of cast iron.

(g) Pressure-temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this Table are for use in designing piping components which are not manufactured in accordance with referenced standards.

(h) The y coefficient = 0.4 [see Table 104.1.2(A)].

TABLE A-5
CAST IRON

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding							
−20 to 400	450	500	600	650	−20 to 650	Class	Spec. No.
							Gray Cast Iron
2.0	...	...	...	...	...	20	A 48
2.5	...	...	...	...	...	25	
3.0	...	...	...	...	...	30	
3.5	...	...	...	...	...	35	
4.0	...	...	...	...	...	40	
4.5	...	...	...	...	...	45	
5.0	...	...	...	...	...	50	
5.5	...	...	...	...	...	55	
6.0	...	...	...	...	...	60	
2.0	...	...	...	...	...	A	A 126
3.0	...	...	...	...	...	B	
4.0	...	...	...	...	...	C	
2.0	2.0	...	...	...	...	20	A 278
2.5	2.5	...	...	...	...	25	
3.0	3.0	...	...	...	...	30	
3.5	3.5	...	...	...	...	35	
...	...	...	...	...	4.0	40	
...	...	...	...	...	4.5	45	
...	...	...	...	...	5.0	50	
...	...	...	...	...	5.5	55	
...	...	...	...	...	6.0	60	
							Ductile Cast Iron
...	...	...	...	...	9.6	...	A 395
...	...	...	...	...	4.8	60-42-10	A 536
...	...	...	...	...	5.6	70-50-05	

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR BOILER EXTERNAL PIPING — SEE FIGS. 100.1.2(A) AND (B).

(2) Material quality factors are not applicable to these materials.

(3) For saturated steam at 250 psi (406°F), the stress values given at 400°F may be used.

(4) For limitations on the use of this material, see para. 124.4.

(5) This material shall not be used where the design pressure exceeds 250 psig [1725 kPa(gage)] or where the design temperature exceeds 450°F (230°C).

(6) This material shall not be used for boiler external piping where the design pressure exceeds 350 psig [2415 kPa (gage)] or where the design temperature exceeds 450°F (230°C).

(7) Piping components conforming to either ASME B16.1 or ASME B16.4 may be used for boiler external piping, subject to all the requirements of the particular standard.

(8) For limitations on the use of this material, see para. 124.6.

TABLE A-6
COPPER AND COPPER ALLOYS

Spec No.	UNS Alloy No.	Temper or Condition	Size or Thickness, in.	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Seamless Pipe and Tube								
B 42	C10200, C12000, C12200	Annealed	...	31	(2)	30	9	1.00
	C10200, C12000, C12200	Drawn	$\frac{1}{8}$ to 2	31	(2)(4)	45	40	1.00
	C10200, C12000, C12200	Drawn	$2\frac{1}{2}$ to 12	31	(2)(4)	36	30	1.00
B 43	C23000	Annealed	...	31	(2)	40	12	1.00
B 68	C10200, C12000, C12200	Annealed	...	31	(1)	30	9	1.00
B 75	C10200, C12000	Annealed	...	31	(2)	30	9	1.00
	C10200, C12000	Light Drawn	...	31	(2)(4)	36	30	1.00
	C10200, C12000	Hard Drawn	...	31	(2)(4)	45	40	1.00
B 75	C12200, C14200	Annealed	...	31	(2)	30	9	1.00
	C12200, C14200	Light Drawn	...	31	(2)(4)	36	30	1.00
	C12200, C14200	Hard Drawn	...	31	(2)(4)	45	40	1.00
B 88	C10200, C12000, C12200	Annealed	...	31	(1)	30	9	1.00
	C10200, C12000, C12200	Drawn	...	31	(1)(4)	36	30	1.00
B 111	C10200, C12000	Light Drawn	...	31	(1)(3)	36	30	1.00
	C10200, C12000	Hard Drawn	...	31	(1)(3)	45	40	1.00
	C12200, C14200	Light Drawn	...	31	(1)(3)	36	30	1.00
	C12200, C14200	Hard Drawn	...	31	(1)(3)	45	40	1.00
B 111	C23000	Annealed	...	32	(1)	40	12	1.00
	C28000	Annealed	...	32	(2)	50	20	1.00
	C44300, C44400, C44500	Annealed	...	32	(2)	45	15	1.00
	C60800	Annealed	...	35	(1)	50	19	1.00
B 111	C68700	Annealed	...	32	(1)	50	18	1.00
	C70400	Annealed	...	34	(1)	38	12	1.00
	C70400	Light Drawn	...	34	(1)(4)	40	30	1.00

TABLE A-6
COPPER AND COPPER ALLOYS

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																	
−20 to 100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	UNS Alloy No.	Spec. No.
															Seamless Pipe and Tube	
6.0	5.1	4.8	4.8	4.7	4.0	3.0	...	...	...	...	...	...	...	...	C10200, C12000, C12200	B 42
11.3	11.3	11.3	11.3	11.0	10.3	4.3	...	...	...	...	...	...	...	...	C10200, C12000, C12200	
9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	C10200, C12000, C12200	
8.0	8.0	8.0	8.0	8.0	7.0	5.0	2.0	...	...	...	...	...	...	...	C23000	B 43
6.0	6.0	5.9	5.8	5.0	3.8	2.5	...	...	...	...	...	...	...	...	C10200, C12000, C12200	B 68
6.0	5.1	4.8	4.8	4.7	4.0	3.0	...	...	...	...	...	...	...	...	C10200, C12000	B 75
9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	C10200, C12000	
11.3	11.3	11.3	11.3	11.0	10.3	4.3	...	...	...	...	...	...	...	...	C10200, C12000	
6.0	5.1	4.8	4.8	4.7	4.0	3.0	...	...	...	...	...	...	...	...	C12200, C14200	B 75
9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	C12200, C14200	
11.3	11.3	11.3	11.3	11.0	10.3	4.3	...	...	...	...	...	...	...	...	C12200, C14200	
6.0	5.1	4.8	4.8	4.7	4.0	3.0	...	...	...	...	...	...	...	...	C10200, C12000, C12200	B 88
9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	C10200, C12000, C12200	
9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	C10200, C12000	B 111
11.3	11.3	11.3	11.3	11.0	10.3	4.3	...	...	...	...	...	...	...	...	C10200, C12000	
9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	C12200, C14200	
11.3	11.3	11.3	11.3	11.0	10.3	4.3	...	...	...	...	...	...	...	...	C12200, C14200	
8.0	8.0	8.0	8.0	8.0	7.0	5.0	2.0	...	...	...	...	...	...	...	C23000	B 111
12.5	12.5	12.5	12.5	12.5	10.8	5.3	...	...	...	...	...	...	...	...	C28000	
10.0	10.0	10.0	10.0	10.0	9.8	3.5	2.0	...	...	...	...	...	...	...	C44300, C44400, C44500	
12.5	12.4	12.2	11.9	11.6	10.0	6.0	4.0	2.0	...	...	...	...	...	...	C60800	
12.0	11.9	11.8	11.7	11.7	6.5	3.3	1.8	...	...	...	...	...	...	...	C68700	B 111
8.0	8.0	...	...	...	...	...	...	...	...	...	...	...	...	...	C70400	
10.0	10.0	...	...	...	...	...	...	...	...	...	...	...	...	...	C70400	

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TABLE A-6
COPPER AND COPPER ALLOYS (CONT'D)

Spec No.	UNS Alloy No.	Temper or Condition	Size or Thickness, in.	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Seamless Pipe and Tube (Cont'd)								
B 111	C70600	Annealed	...	34	(2)	40	15	1.00
	C71000	Annealed	...	34	(2)	45	16	1.00
	C71500	Annealed	...	34	(2)	52	18	1.00
B 280	C12200	Annealed	...	31	(1)	30	9	1.00
	C12200	Drawn	...	31	(1)(4)	36	30	1.00
B 302	C12000, C12200	Drawn	...	32	(1)(3)	36	30	1.00
B 315	C61300, C61400	Annealed	...	35	(1)	65	28	1.00
B 466	C70600	Annealed	...	34	(1)	38	13	1.00
	C71500	Annealed	...	34	(1)	50	18	1.00
Welded Pipe and Tube								
B 467	C70600	Annealed	4½ & under	34	(1)	40	15	0.85
	C70600	Annealed	Over 4½	34	(1)	38	13	0.85
	C71500	Annealed	4½ & under	34	(1)	50	20	0.85
	C71500	Annealed	Over 4½	34	(1)	45	15	0.85
B 608	C61300, C61400	Annealed	4 to 48	35	(1)(6)	70	30	0.85
Plate								
B 402	C70600	Annealed	2½ & under	34	(1)	40	15	1.00
	C71500	Annealed	2½ & under	34	(1)	50	20	1.00
	C71500	Annealed	Over 2½ to 5	34	(1)	45	18	1.00
Rod and Bar								
B 151	C71500	Annealed	Over 1	34	(1)	45	18	1.00
Die Forgings (Hot Pressed)								
B 283	C37700	As forged	1½ & under	...	(1)(3)	50	18	1.00
	C37700	As forged	Over 1½	...	(1)(3)	46	15	1.00

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TABLE A-6
COPPER AND COPPER ALLOYS (CONT'D)

-20 to 100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	UNS Alloy No.	Spec. No.
Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																
																Seamless Pipe and Tube (Cont'd)
10.0	9.7	9.5	9.3	9.0	8.7	8.5	8.2	8.0	7.0	6.0	...	...	...	...	C70600	B 111
10.7	10.6	10.5	10.4	10.3	10.1	9.9	9.6	9.3	8.9	8.4	7.7	7.0	...	...	C71000	
12.0	11.6	11.3	11.0	10.8	10.6	10.3	10.1	9.9	9.8	9.6	9.5	9.4	...	...	C71500	
6.0	5.1	4.8	4.8	4.7	4.0	3.0	...	...	...	...	...	...	...	...	C12200	B 280
9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	C12200	
9.0	9.0	9.0	9.0	8.7	8.5	8.2	...	...	...	...	...	...	...	...	C12000, C12200	B 302
16.2	16.2	16.2	16.2	16.2	16.2	15.9	15.3	14.7	...	...	...	...	...	...	C61300, C61400	B 315
8.7	8.4	8.3	8.0	7.8	7.7	7.6	7.5	7.3	7.0	6.0	...	...	...	...	C70600	B 466
12.0	11.6	11.3	11.0	10.8	10.6	10.3	10.1	9.9	9.8	9.6	...	...	...	...	C71500	
																Welded Pipe and Tube
8.5	8.2	8.1	7.9	7.6	7.4	7.2	7.1	6.3	5.7	4.3	...	...	...	...	C70600	B 467
7.4	7.1	7.1	6.8	6.6	6.5	6.5	6.4	6.2	5.7	4.3	...	...	...	...	C70600	
10.6	9.6	8.9	8.8	8.8	8.8	8.8	8.8	8.8	8.8	8.8	...	...	...	...	C71500	
8.5	8.2	8.0	7.8	7.7	7.5	7.3	7.1	7.0	6.9	6.8	...	...	...	...	C71500	
14.0	14.0	14.0	14.0	14.0	14.0	14.0	13.6	13.2	...	...	...	...	...	...	C61300, C61400	B 608
																Plate
10.1	9.7	9.5	9.3	9.0	8.7	8.5	8.2	8.0	7.0	6.0	...	...	...	...	C70600	B 402
12.5	11.3	10.5	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	10.4	C71500	
11.3	10.1	9.4	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	9.3	...	...	C71500	
																Rod and Bar
11.3	10.8	10.5	10.2	9.9	9.7	9.5	9.4	9.3	9.2	9.1	...	...	...	...	C71500	B 151
																Die Forgings (Hot Pressed)
12.0	11.3	10.9	...	...	...	...	...	...	...	...	...	...	...	...	C37700	B 283
10.0	9.5	9.1	...	...	...	...	...	...	...	...	...	...	...	...	C37700	

TABLE A-6
COPPER AND COPPER ALLOYS (CONT'D)

Spec No.	UNS Alloy No.	Temper or Condition	Size or Thickness, in.	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Castings								
B 61	C92200	As cast	...	...	...	34	16	0.80
B 62	C83600	As cast	...	...	...	30	14	0.80
B 148	C95200	As cast	...	35	(1)	65	25	0.80
	C95400	As cast	...	35	(1)(5)	75	30	0.80
B 584	C92200	As cast	...	...		34	16	0.80
	C93700	As cast	...	...	(3)	30	12	0.80
	C97600	As cast	...	...	(3)	40	17	0.80
Bolts, Nuts, and Studs								
B 150	C61400	HR50	$\frac{1}{2}$ & under	...	(1)(3)	80	50	1.00
	C61400	HR50	Over $\frac{1}{2}$ to 1	...	(1)(3)	75	35	1.00
	C61400	HR50	Over 2 to 3	...	(1)(3)	70	30	1.00

GENERAL NOTES:

(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME Boiler and Pressure Vessel Code applications, see related specifications in Section II of the ASME Code.

(b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.

(c) The P-Numbers listed in this Table are identical to those adopted by the ASME Boiler and Pressure Vessel Code, Qualification of welding procedures, welders, and welding operators is required and shall comply with the ASME Boiler and Pressure Vessel Code, Section IX, except as modified by para. 127.5.

(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."

(e) The materials listed in this Table shall not be used at design temperatures above those for which allowable stress values are given. However, for saturated steam at 250 psi (406°F), the allowable stress values given for 400°F may be used.

(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3.

(g) Pressure-temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this Table are for use in designing piping components which are not manufactured in accordance with referenced standards.

(h) For limitations on the use of copper and copper alloys for flammable liquids and gases, refer to paras. 122.7, 122.8, and 124.7.

(i) The y coefficient = 0.4 [see Table 104.1.2(A)].

TABLE A-6
COPPER AND COPPER ALLOYS (CONT'D)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding																
−20 to 100	150	200	250	300	350	400	450	500	550	600	650	700	750	800	UNS Alloy No.	Spec. No.
																Castings
6.8	6.8	6.8	6.8	6.8	6.8	6.6	6.2	5.8	4.0	...	...	...	...	...	C92200	B 61
6.0	6.0	6.0	6.0	5.8	5.7	5.5	5.4	...	...	...	...	...	...	...	C83600	B 62
12.6	12.6	11.9	11.6	11.4	11.4	11.4	11.4	11.4	...	...	...	...	...	...	C95200	B 148
15.0	15.0	15.0	15.0	15.0	14.5	13.9	12.8	11.1	...	...	...	...	...	...	C95400	
6.8	6.8	6.8	6.8	6.8	6.8	6.6	6.2	5.8	4.0	...	...	...	...	...	C92200	B 584
6.0	6.0	5.8	5.4	5.3	5.2	5.1	...	...	...	...	...	...	...	...	C93700	
6.0	5.8	5.6	5.5	5.4	...	...	...	...	...	...	...	...	...	...	C97600	
																Bolts, Nuts, and Studs
10.0	9.9	9.9	9.8	9.8	9.7	9.6	9.5	9.5	...	...	...	...	...	...	C61400	B 150
8.7	8.7	8.6	8.6	8.5	8.5	8.4	8.3	8.2	...	...	...	...	...	...	C61400	
8.0	8.0	7.9	7.9	7.8	7.8	7.7	7.6	7.5	...	...	...	...	...	...	C61400	

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGS. 100.1.2(A) and (B).

(2) This material may be used for Boiler External Piping provided that the nominal size does not exceed 3 in., and the design temperature does not exceed 406°F. This material shall not be used for blowoff piping. Where threaded brass or copper pipe is used for feed water piping, it shall have a wall thickness not less than that required for schedule 80 steel pipe of the same nominal size.

(3) Welding or brazing of this material is not permitted.

(4) When this material is used for welded or brazed construction, the allowable stress values used shall not exceed those given for the same material in the annealed condition.

(5) Castings which are welded or repair welded shall be heat treated at 1150°F–1200°F, followed by moving-air cooling. The required time at temperature is based on the cross section thicknesses as follows:

(a) 1½ hr for the first inch, or fraction thereof;

(b) ½ hr for each additional inch or fraction thereof.

(6) Welds must be made by an electric fusion welding process involving the addition of filler metal.

TABLE A-7
ALUMINUM AND ALUMINUM ALLOYS

Spec No.	UNS Alloy No.	Temper	Size or Thickness, in.	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Drawn Seamless Tube								
B 210	A93003	0	0.010 to 0.500	21	(1)	14	5	1.00
	A93003	H14	0.010 to 0.500	21	(1)(3)	20	17	1.00
	Alclad A93003	0	0.010 to 0.500	21	(1)(4)	13	4.5	1.00
	Alclad A93003	H14	0.010 to 0.500	21	(1)(3)(4)	19	16	1.00
B 210	A95050	0	0.018 to 0.500	21	(1)	18	6	1.00
	Alclad A95050	0	0.018 to 0.500	21	(1)(13)(23)	17	...	1.00
	A96061	T4	0.025 to 0.500	23	(1)(6)	30	16	1.00
	A96061	T6	0.025 to 0.500	23	(1)(6)	42	35	1.00
	A96061	T4, T6 welded	0.025 to 0.500	23	(1)(7)	24	...	1.00
Seamless Pipe and Seamless Extruded Tube								
B 241	A93003	0	All	21	(1)	14	5	1.00
	A93003	H18	Less than 1.000	21	(1)(3)	27	24	1.00
	A93003	H112	Note (20)	21	(1)(3)(20)	14	5	1.00
	Alclad A93003	0	All	21	(1)(4)	13	4.5	1.00
	Alclad A93003	H112	All	21	(1)(3)(4)	13	4.5	1.00
B 241	A95083	0	Up thru 5.000	25	(1)(8)	39	16	1.00
	A95083	H112	Up thru 5.000	25	(1)(8)	39	16	1.00
	A95454	0	Up thru 5.000	22	(1)	31	12	1.00
	A95454	H112	Up thru 5.000	22	(1)	31	12	1.00
B 241	A96061	T4	All	23	(1)(6)(9)	26	16	1.00
	A96061	T6	Under 1 in. dia	23	(1)(2)(5)	42	35	1.00
	A96061	T6	All	23	(1)(6)(9)	38	35	1.00
	A96061	T4, T6 welded	All	23	(1)(7)(9)	24	...	1.00
	A96063	T6	Note (10)	23	(1)(6)(10)	30	25	1.00
	A96063	T5, T6 welded	Note (10)	23	(1)(7)(10)	17	...	1.00
Drawn Seamless Condenser and Heat Exchanger Tube								
B 234	A93003	H14	0.010 to 0.200	21	(1)(2)	20	17	1.00
	Alclad A93003	H14	0.010 to 0.200	21	(1)(2)(4)	19	16	1.00
	A95454	H34	0.010 to 0.200	22	(1)(2)	39	29	1.00

TABLE A-7
ALUMINUM AND ALUMINUM ALLOYS

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding								
−20 to 100	150	200	250	300	350	400	UNS Alloy No.	Spec. No.
								Drawn Seamless Tube
3.4	3.4	3.4	3.0	2.4	1.8	1.4	A93003	B 210
5.0	5.0	5.0	4.9	4.3	3.0	2.4	A93003	
3.0	3.0	3.0	2.7	2.2	1.6	1.3	Alclad A93003	
4.5	4.5	4.5	4.4	3.9	2.7	2.1	Alclad A93003	
4.0	4.0	4.0	4.0	4.0	2.8	1.4	A95050	B210
3.3	3.3	3.3	3.3	3.3	2.5	1.3	Alclad A95050	
7.5	7.5	7.5	7.4	6.9	6.3	4.5	A96061	
10.5	10.5	10.5	9.9	8.4	6.3	4.5	A96061	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	
								Seamless Pipe and Seamless Extruded Tube
3.4	3.4	3.4	3.0	2.4	1.8	1.4	A93003	B 241
6.8	6.8	6.7	6.3	5.4	3.5	2.5	A93003	
3.4	3.4	3.4	3.0	2.4	1.8	1.4	A93003	
3.0	3.0	3.0	2.7	2.2	1.6	1.2	Alclad A93003	
3.0	3.0	3.0	2.7	2.2	1.6	1.2	Alclad A93003	
9.8	9.8	...	...	...	...	...	A95083	B 241
9.8	9.8	...	...	...	...	...	A95083	
7.8	7.8	7.8	7.4	5.5	4.1	3.0	A95454	
7.8	7.8	7.8	7.4	5.5	4.1	3.0	A95454	
6.5	6.5	6.5	6.4	6.0	5.8	4.5	A96061	B 241
10.5	10.5	10.5	9.9	8.4	6.3	4.5	A96061	
9.5	9.5	9.5	9.1	7.9	6.3	4.5	A96061	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	
7.5	7.5	7.4	6.8	5.0	3.4	2.0	A96063	
4.3	4.3	4.3	4.2	3.9	3.0	2.0	A96063	
								Drawn Seamless Condenser and Heat Exchanger Tube
5.0	5.0	5.0	4.9	4.3	3.0	2.4	A93003	B 234
4.5	4.5	4.5	4.4	3.9	2.7	2.1	Alclad A93003	
9.8	9.8	9.8	7.5	5.5	4.1	3.0	A95454	

TABLE A-7
ALUMINUM AND ALUMINUM ALLOYS (CONT'D)

Spec No.	UNS Alloy No.	Temper	Size or Thickness, in.	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Drawn Seamless Condenser and Heat Exchanger Tube (Cont'd)								
B 234	A96061	T4	0.025 to 0.200	23	(1)(6)	30	16	1.00
	A96061	T6	0.025 to 0.200	23	(1)(6)	42	35	1.00
	A96061	T4, T6 welded	0.025 to 0.200	23	(1)(7)	24	...	1.00
Arc-Welded Round Tube								
B 547	A93003	O	0.125 to 0.500	21	(1)(15)	14	5	1.00
	A93003	O	0.125 to 0.500	21	(1)(16)	14	5	0.85
	A93003	H112	0.250 to 0.400	21	(1)(14)(15)	17	10	1.00
	A93003	H112	0.250 to 0.400	21	(1)(14)(16)	17	10	0.85
B 547	Alclad A93003	O	0.125 to 0.499	21	(1)(4)(15)	13	4.5	1.00
	Alclad A93003	O	0.125 to 0.499	21	(1)(4)(16)	13	4.5	0.85
	Alclad A93003	H112	0.250 to 0.499	21	(1)(4)(14)(15)	16	9	1.00
	Alclad A93003	H112	0.250 to 0.499	21	(1)(4)(14)(16)	16	9	0.85
B 547	A95083	O	0.125 to 0.500	25	(1)(8)(15)	40	18	1.00
	A95083	O	0.125 to 0.500	25	(1)(8)(16)	40	18	0.85
B 547	A95454	O	0.125 to 0.500	22	(1)(15)	31	12	1.00
	A95454	O	0.125 to 0.500	22	(1)(16)	31	12	0.85
	A95454	H112	0.250 to 0.499	22	(1)(14)(15)	32	18	1.00
	A95454	H112	0.250 to 0.499	22	(1)(14)(16)	32	18	0.85
B 547	A96061	T4	0.125 to 0.249	23	(1)(7)(15)(17)	30	16	1.00
	A96061	T4	0.125 to 0.249	23	(1)(7)(16)(17)	30	16	0.85
	A96061	T451	0.250 to 0.500	23	(1)(7)(15)(17)	30	16	1.00
	A96061	T451	0.250 to 0.500	23	(1)(7)(16)(17)	30	16	0.85
B 547	A96061	T6	0.125 to 0.249	23	(1)(7)(15)(17)	42	35	1.00
	A96061	T6	0.125 to 0.249	23	(1)(7)(16)(17)	42	35	0.85
	A96061	T651	0.250 to 0.500	23	(1)(7)(15)(17)	42	35	1.00
	A96061	T651	0.250 to 0.500	23	(1)(7)(16)(17)	42	35	0.85

TABLE A-7
ALUMINUM AND ALUMINUM ALLOYS (CONT'D)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding								
−20 to 100	150	200	250	300	350	400	UNS Alloy No.	Spec. No.
					Drawn Seamless Condenser and Heat Exchanger Tube (Cont'd)			
7.5	7.5	7.5	7.4	6.9	6.3	4.5	A96061	B 234
10.5	10.5	10.5	9.9	8.4	6.3	4.5	A96061	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	
							Arc-Welded Round Tube	
3.4	3.4	3.4	3.0	2.4	1.8	1.4	A93003	B 547
2.9	2.9	2.9	2.6	2.0	1.5	1.2	A93003	
3.4	3.4	3.4	3.0	2.4	1.8	1.4	A93003	
2.9	2.9	2.9	2.6	2.0	1.5	1.2	A93003	
3.0	3.0	3.0	2.7	2.2	1.6	1.3	Alclad A93003	B 547
2.6	2.6	2.6	2.3	1.9	1.4	1.1	Alclad A93003	
3.0	3.0	3.0	2.7	2.2	1.6	1.3	Alclad A93003	
2.6	2.6	2.6	2.3	1.9	1.4	1.1	Alclad A93003	
10.0	10.0	...	...	...	...	...	A95083	B 547
8.5	8.5	...	...	...	...	...	A95083	
7.8	7.8	7.8	7.4	5.5	4.1	3.0	A95454	B 547
6.6	6.6	6.6	6.3	4.7	3.5	2.6	A95454	
7.8	7.8	7.8	7.4	5.5	4.1	3.0	A95454	
6.6	6.6	6.6	6.3	4.7	3.5	2.6	A95454	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	B 547
5.1	5.1	5.1	5.0	4.7	3.9	3.0	A96061	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	
5.1	5.1	5.1	5.0	4.7	3.9	3.0	A96061	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	B 547
5.1	5.1	5.1	5.0	4.7	3.9	3.0	A96061	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	
5.1	5.1	5.1	5.0	4.7	3.9	3.0	A96061	

TABLE A-7
ALUMINUM AND ALUMINUM ALLOYS (CONT'D)

Spec No.	UNS Alloy No.	Temper	Size or Thickness, in.	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Sheet and Plate								
B 209	A93003	O	0.051 to 3.000	21	(1)	14	5	1.00
	A93003	H112	0.250 to 0.499	21	(1)(3)	17	10	1.00
	A93003	H112	0.500 to 2.000	21	(1)(3)	15	6	1.00
B 209	Alclad A93003	O	0.051 to 0.499	21	(1)(4)	13	4.5	1.00
	Alclad A93003	O	0.500 to 3.000	21	(1)(18)	14	5	1.00
	Alclad A93003	H112	0.250 to 0.499	21	(1)(3)(4)	16	9	1.00
	Alclad A93003	H112	0.500 to 2.000	21	(1)(3)(19)	15	6	1.00
B 209	A95083	O	0.051 to 1.500	25	(1)(8)	40	18	1.00
	A95454	O	0.051 to 3.000	22	(1)	31	12	1.00
	A95454	H112	0.250 to 0.499	22	(1)(3)	32	18	1.00
	A95454	H112	0.500 to 3.000	22	(1)(3)	31	12	1.00
B 209	A96061	T4	0.051 to 0.249	23	(1)(6)(9)	30	16	1.00
	A96061	T451	0.250 to 3.000	23	(1)(6)(9)	30	16	1.00
	A96061	T4 welded	0.051 to 0.249	23	(1)(7)(9)	24	...	1.00
	A96061	T451 welded	0.250 to 3.000	23	(1)(7)(9)	24	...	1.00
B 209	A96061	T6	0.051 to 0.249	23	(1)(6)(9)	42	35	1.00
	A96061	T651	0.250 to 4.000	23	(1)(6)(9)	42	35	1.00
	A96061	T651	4.001 to 6.000	23	(1)(6)(9)	40	35	1.00
	A96061	T6 welded	0.051 to 0.249	23	(1)(7)(9)	24	...	1.00
	A96061	T651 welded	0.250 to 6.000	23	(1)(7)(9)	24	...	1.00
Die and Hand Forgings								
B 247	A93003	H112	Up thru 4.000	21	(1)(11)	14	5	1.00
	A93003	H112 welded	Up thru 4.000	21	(1)(7)(11)	14	5	1.00
B 247	A95083	H111	Up thru 4.000	25	(1)(6)(8)	39	16	1.00
	A95083	H112	Up thru 4.000	25	(1)(6)(8)	39	16	1.00
	A95083	H111, H112 welded	Up thru 4.000	25	(1)(7)(8)	38	16	1.00
B 247	A96061	T6	Up thru 4.000	23	(1)(6)(11)	38	35	1.00
	A96061	T6	Up thru 4.000	23	(1)(6)(12)	37	33	1.00
	A96061	T6	4.001 to 8.000	23	(1)(6)(12)	35	32	1.00
	A96061	T6 welded	Up thru 8.000	23	(1)(7)	24	...	1.00

TABLE A-7
ALUMINUM AND ALUMINUM ALLOYS (CONT'D)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding								
−20 to 100	150	200	250	300	350	400	UNS Alloy No.	Spec. No.
								Sheet and Plate
3.4	3.4	3.4	3.0	2.4	1.8	1.4	A93003	B 209
4.3	4.3	4.3	4.0	3.6	3.0	2.4	A93003	
3.8	3.8	3.7	3.2	2.4	1.8	1.4	A93003	
3.0	3.0	3.0	2.7	2.2	1.6	1.3	Alclad A93003	B 209
3.0	3.0	3.0	2.7	2.2	1.6	1.3	Alclad A93003	
3.8	3.8	3.8	3.6	3.3	2.7	2.1	Alclad A93003	
3.4	3.4	3.4	2.9	2.2	1.6	1.3	Alclad A93003	
10.0	10.0	...	...	...	...	...	A95083	B 209
7.8	7.8	7.8	7.4	5.5	4.1	3.0	A95454	
8.0	8.0	8.0	8.0	5.5	4.1	3.0	A95454	
7.8	7.8	7.8	7.4	5.5	4.1	3.0	A95454	
7.5	7.5	7.5	7.4	6.9	6.3	4.5	A96061	B 209
7.5	7.5	7.5	7.4	6.9	6.3	4.5	A96061	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	
10.5	10.5	10.5	9.9	8.4	6.3	4.5	A96061	B 209
10.5	10.5	10.5	9.9	8.4	6.3	4.5	A96061	
10.0	10.0	10.0	9.6	8.2	6.3	4.4	A96061	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	
								Die and Hand Forgings
3.4	3.4	3.4	3.0	2.4	1.8	1.4	A93003	B 247
3.4	3.4	3.4	3.0	2.4	1.8	1.4	A93003	
9.8	9.8	...	...	...	...	...	A95083	B 247
9.8	9.8	...	...	...	...	...	A95083	
9.5	9.5	...	...	...	...	...	A95083	
9.5	9.5	9.5	9.1	7.9	6.3	4.5	A96061	B 247
9.3	9.3	9.3	8.8	7.7	6.3	4.5	A96061	
8.8	8.8	8.8	8.4	7.4	6.1	4.5	A96061	
6.0	6.0	6.0	5.9	5.5	4.6	3.5	A96061	

TABLE A-7
ALUMINUM AND ALUMINUM ALLOYS (CONT'D)

Spec No.	UNS Alloy No.	Temper	Size or Thickness, in.	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Rods, Bars, and Shapes								
B 221	A91060	-O	All	21	(1)(21)(22)	8.5	2.5	1.00
		-H112	All	21	(1)(3)(21)(22)	8.5	2.5	1.00
B 221	A91100	-O	All	21	(1)(21)(22)	11	3	1.00
		-H112	All	21	(1)(3)(21)(22)	11	3	1.00
B 221	A93003	-O	All	21	(1)(21)(22)	14	5	1.00
		-H112	All	21	(1)(3)(21)(22)	14	5	1.00
B 221	A92024	-T3	Up thru 0.249	...	(1)(2)(9)(21)(22)	57	42	1.00
			0.250–0.749	...	(1)(2)(9)(21)(22)	60	44	1.00
			0.750–1.499	...	(1)(2)(9)(21)(22)	65	46	1.00
			1.500 and over	...	(1)(2)(9)(21)(22)	68	48	1.00
B 221	A95083	-O	Up thru 5.000	25	(1)(8)(21)(22)	39	16	1.00
		-H111	Up thru 5.000	25	(1)(3)(8)(21)(22)	40	24	1.00
		-H112	Up thru 5.000	25	(1)(3)(8)(21)(22)	39	16	1.00
B 221	A95086	-H112	Up thru 5.000	25	(1)(2)(8)(21)(22)	35	14	1.00
B 221	A95154	-O	All	22	(1)(8)(21)(22)	30	11	1.00
		-H112	All	22	(1)(3)(8)(21)(22)	30	11	1.00
B 221	A95454	-O	Up thru 5.000	22	(1)(21)(22)	31	12	1.00
		-H111	Up thru 5.000	22	(1)(3)(21)(22)	33	19	1.00
		-H112	Up thru 5.000	22	(1)(3)(21)(22)	31	12	1.00
B 221	A95456	-O	Up thru 5.000	25	(1)(8)(21)(22)	41	19	1.00
		-H111	Up thru 5.000	25	(1)(3)(8)(21)(22)	42	26	1.00
		-H112	Up thru 5.000	25	(1)(3)(8)(21)(22)	41	19	1.00
B 221	A96061	-T4	All	23	(1)(2)(9)(21)(22)	26	16	1.00
		-T6	All	23	(1)(2)(9)(21)(22)	38	35	1.00
		-T4 Wld.	All	23	(1)(7)(9)(21)(22)	24	...	1.00
		-T6 Wld.	All	23	(1)(7)(9)(21)(22)	24	...	1.00

TABLE A-7
ALUMINUM AND ALUMINUM ALLOYS (CONT'D)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding								
−20 to 100	150	200	250	300	350	400	UNS Alloy No.	Spec. No.
								Rods, Bars, and Shapes
1.7	1.7	1.6	1.5	1.3	1.1	0.80	A91060	B 221
1.7	1.7	1.6	1.5	1.3	1.1	0.80		
2.0	2.0	2.0	2.0	1.8	1.4	1.0	A91100	B 221
2.0	2.0	2.0	2.0	1.8	1.4	1.0		
3.4	3.4	3.4	3.0	2.4	1.8	1.4	A93003	B 221
3.4	3.4	3.4	3.0	2.4	1.8	1.4		
14.3	14.3	14.3	12.6	9.5	6.0	4.2	A92024	B 221
15.0	15.0	15.0	13.2	10.0	6.3	4.4		
16.3	16.3	16.3	14.3	10.8	6.8	4.7		
17.0	17.0	17.0	15.0	11.3	7.1	5.0		
9.8	9.8	...	...	...	...	...	A95083	B 221
10.0	10.0	...	...	...	...	...		
9.8	9.8	...	...	...	...	...		
8.8	8.8	...	...	...	...	...	A95086	B 221
7.5	7.5	...	...	...	...	...	A95154	B 221
7.5	7.5	...	...	...	...	...		
7.8	7.8	7.8	7.4	5.5	4.1	3.0	A95454	B 221
8.3	8.3	8.3	7.5	5.5	4.1	3.0		
7.8	7.8	7.8	7.4	5.5	4.1	3.0		
10.3	10.3	...	...	...	...	...	A95456	B 221
10.5	10.5	...	...	...	...	...		
10.3	10.3	...	...	...	...	...		
6.5	6.5	6.5	6.4	6.0	5.8	4.5	A96061	B 221
9.5	9.5	9.5	9.1	7.9	6.3	4.5		
6.0	6.0	6.0	5.9	5.5	4.6	3.5		
6.0	6.0	6.0	5.9	5.5	4.6	3.5		

TABLE A-7
ALUMINUM AND ALUMINUM ALLOYS (CONT'D)

Spec No.	UNS Alloy No.	Temper	Size or Thickness, in.	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Rods, Bars, and Shapes (Cont'd)								
B 221	A96063	-T1	Up thru 0.500	23	(1)(2)(21)(22)	17	9	1.00
			0.501–1.000	23	(1)(2)(21)(22)	16	8	1.00
		-T5	Up thru 0.500	23	(1)(2)(21)(22)	22	16	1.00
			0.501–1.000	23	(1)(2)(21)(22)	21	15	1.00
		-T6	Up thru 1.000	23	(1)(2)(21)(22)	30	25	1.00
		-T5, -T6 Wld.	Up thru 1.000	23	(1)(7)(21)(22)	17	...	1.00
Castings								
B 26	A24430	F	...	...	(1)(2)	17	6	0.80
	A03560	T6	...	...	(1)(2)	30	20	0.80
	A03560	T71	...	...	(1)(2)	25	18	0.80

GENERAL NOTES:

(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME Boiler and Pressure Vessel Code applications, see related specifications in Section II of the ASME Code.

(b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.

(c) The P-Numbers listed in this Table are identical to those adopted by the ASME Boiler and Pressure Vessel Code. Qualification of welding procedures, welders, and welding operators is required and shall comply with the ASME Boiler and Pressure Vessel Code, Section IX, except as modified by para. 127.5.

(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."

(e) The materials listed in this Table shall not be used at design temperatures above those for which allowable stress values are given.

(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3.

(g) Pressure-temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this Table are for use in designing piping components which are not manufactured in accordance with referenced standards.

(h) Aluminum and aluminum alloys shall not be used for flammable fluids within the boiler plant structure (see para. 122.7).

(i) The y coefficient = 0.4 [see Table 104.1.2(A)].

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGS. 100.1.2(A) and (B).

(2) These allowable stress values are not applicable when either welding or thermal cutting is employed.

(3) These allowable stress values are not applicable when either welding or thermal cutting is employed. In such cases, the corresponding stress values for the O temper shall be used.

(4) These allowable stress values are 90% of those for the corresponding core material.

(5) These allowable stress values apply only to seamless pipe smaller than NPS 1 which is extruded and then drawn.

(6) These allowable stress values are not applicable when either welding or thermal cutting is employed. In such cases, the corresponding stress values for the welded condition shall be used.

TABLE A-7
ALUMINUM AND ALUMINUM ALLOYS (CONT'D)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding

-20 to 100	150	200	250	300	350	400	UNS Alloy No.	Spec. No.
							Rods, Bars, and Shapes (Cont'd)	
4.3	4.3	4.3	4.2	4.2	3.4	2.0	A96063	B 221
4.0	4.0	4.0	4.0	4.0	3.4	2.0		
5.5	5.5	5.4	5.1	4.6	3.4	2.0		
5.3	5.3	5.1	4.9	4.3	3.4	2.0		
7.5	7.5	7.4	6.8	5.0	3.4	2.0		
4.3	4.3	4.3	4.2	3.9	3.0	2.0		
								Castings
3.2	3.2	3.2	3.0	2.8	2.5	2.2	A24430	B 26
6.0	6.0	6.0	5.0	...	...	...	A03560	
5.0	5.0	5.0	4.9	4.3	3.3	1.9	A03560	

NOTES (CONT'D):

(7) The strength of a reduced-section tensile specimen is required to qualify welding procedures. Refer to the ASME Boiler and Pressure Vessel Code, Section IX, QW-150.

(8) Refer to the ASME Boiler and Pressure Vessel Code, Section VIII, Part UNF, NF-13(b) regarding stress corrosion.

(9) For stress relieved tempers (T351, T3510, T3511,T451, T4510, T4511,T651, T6510, and T6511) stress values for the material in the basic temper shall be used.

(10) These allowable stress values apply to all thicknesses of and sizes of seamless pipe. They also apply to seamless extruded tube in thicknesses up to and including 1.000 in.

(11) These allowable stress values are for die forgings.

(12) These allowable stress values are for hand forgings.

(13) For temperatures up to 300°F, these allowable stress values are 83% of those for the corresponding core material. At temperatures of 350°F and 400°F, these allowable stress values are 90% of those for the corresponding core material.

(14) These allowable stress values are for the tempers listed in the welded condition and are identical to those for the 0 temper.

(15) These allowable stress values are based on 100% radiography of the longitudinal weld in accordance with ASTM B 547, para. 11.

(16) These allowable stress values are based on spot radiography of the longitudinal weld in accordance with ASTM B 547, para. 11.

(17) These allowable stress values are for the heat treated tempers listed in the welded condition.

(18) The tension test specimen from plate which is not less than 0.500 in. thick is machined from the core and does not include the cladding alloy. Therefore, the allowable stress values for thicknesses less than 0.500 in. shall be used.

(19) The tension test specimen from plate which is not less than 0.500 in thick is machined from the core and does not include the cladding alloy. Therefore, these allowable stress values are 90% of those for the core material of the same thickness.

(20) The allowable stress values for seamless pipe in sizes NPS 1 and larger are as follows:

100 °F	3.5 ksi
150 °F	3.5 ksi
200 °F	3.4 ksi

(21) Stress values in restricted shear such as dowel bolts, or similar construction in which the shearing member is so restricted that the section under consideration would fail without reduction of areas shall be 0.80 times the values in the above Table.

(22) Stress values in bearing shall be 1.60 times the values in the above Table.

(23) ASTM B 210 does not include this alloy/grade of material.

TABLE A-8
TEMPERATURES 1200°F AND ABOVE

Spec. No.	Type or Grade	UNS Alloy No.	Temper	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi
Seamless Pipe and Tube								
A 213	TP304H	S30409	...	18Cr–8Ni	8	...	75	30
	TP310H	S31009	...	25Cr–20Ni	8	(2)(4)	75	30
	TP316H	S31609	...	16Cr–12Ni–2Mo	8	...	75	30
A 213	TP321H	S32109	...	18Cr–10Ni–Ti	8	...	75	30
	TP347H	S34709	...	18Cr–10Ni–Cb	8	...	75	30
	TP348H	S34809	...	18Cr–10Ni–Cb	8	...	75	30
A 312	TP304H	S30409	...	18Cr–8Ni	8	...	75	30
	TP310H	S31009	...	25Cr–20Ni	8	(2)(4)	75	30
	TP316H	S31609	...	16Cr–12Ni–2Mo	8	...	75	30
A 312	TP321H	S32109	...	18Cr–10Ni-Ti	8	...	75	30
	TP347H	S34709	...	18Cr–10Ni–Cb	8	...	75	30
	TP348H	S34809	...	18Cr–10Ni–Cb	8	...	75	30
A 376	TP304H	S30409	...	18Cr–8Ni	8	...	75	30
	TP316H	S31609	...	16Cr–12Ni–2Mo	8	...	75	30
	TP321H	S32109	...	18Cr–10Ni–Ti	8	...	75	30
	TP347H	S34709	...	18Cr–10Ni–Cb	8	...	75	30
A 430	FP304H	S30409	...	18Cr–8Ni	8	...	70	30
	FP316H	S31609	...	16Cr–12Ni–2Mo	8	...	70	30
	FP321H	S32109	...	18Cr–10Ni–Ti	8	...	70	30
	FP347H	S34709	...	18Cr–10Ni–Cb	8	...	70	30
B 163	...	N08800	Annealed	Ni–Cr–Fe	45	(1)	75	30
	...	N08810	Annealed	Ni–Cr–Fe	45	(1)	65	25
B 407	...	N08800	C.D./Ann.	Ni–Cr–Fe	45	...	75	30
	...	N08810	Annealed	Ni–Cr–Fe	45	...	65	25
Welded Pipe and Tube — Without Filler Metal								
A 249	TP304H	S30409	...	18Cr–8Ni	8	...	75	35
	TP310H	S31009	...	25Cr–20Ni	8	(1)(2)(4)	75	35
	TP316H	S31609	...	16Cr–12Ni–2Mo	8	...	75	35

TABLE A-8
TEMPERATURES 1200°F AND ABOVE

E or *F*	1200	1250	1300	1350	1400	1450	1500	Type or Grade	Spec. No.
	Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding								
								Seamless Pipe and Tube	
1.00	6.1	4.7	3.7	2.9	2.3	1.8	1.4	TP304H	A 213
1.00	4.0	3.0	2.2	1.7	1.3	0.97	0.75	TP310H	
1.00	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316H	
1.00	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321H	A 213
1.00	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP347H	
1.00	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP348H	
1.00	6.1	4.7	3.7	2.9	2.3	1.8	1.4	TP304H	A 312
1.00	4.0	3.0	2.2	1.7	1.3	0.97	0.75	TP310H	
1.00	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316H	
1.00	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321H	A 312
1.00	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP347H	
1.00	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP348H	
1.00	6.1	4.7	3.7	2.9	2.3	1.8	1.4	TP304	A 376
1.00	7.4	5.5	4.1	3.1	2.3	1.7	1.3	TP316H	
1.00	5.4	4.1	3.2	2.5	1.9	1.5	1.1	TP321H	
1.00	7.9	5.9	4.4	3.2	2.5	1.8	1.3	TP347H	
1.00	6.1	4.7	3.7	2.9	2.3	1.8	1.4	FP304H	A 430
1.00	7.4	5.5	4.1	3.1	2.3	1.7	1.3	FP316H	
1.00	5.4	4.1	3.2	2.5	1.9	1.5	1.1	FP321H	
1.00	7.9	5.9	4.4	3.2	2.5	1.8	1.3	FP347H	
1.00	6.6	4.2	2.0	1.6	1.1	1.0	0.80	N08800	B 163
1.00	7.4	5.9	4.7	3.8	3.0	2.4	1.9	N08810	
1.00	6.6	4.2	2.0	1.6	1.1	1.0	0.80	N08800	B 407
1.00	7.4	5.9	4.7	3.8	3.0	2.4	1.9	N08810	
								Welded Pipe and Tube — Without Filler Metal	
0.85	5.2	4.0	3.2	2.5	2.0	1.6	1.2	TP304H	A 249
0.85	3.4	2.6	1.9	1.4	1.1	0.82	0.64	TP310H	
0.85	6.3	4.7	3.5	2.6	1.9	1.5	1.1	TP316H	

TABLE A-8
TEMPERATURES 1200°F AND ABOVE (CONT'D)

Spec. No.	Type or Grade	UNS Alloy No.	Temper	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi
Welded Pipe and Tube — Without Filler Metal (Cont'd)								
A 249	TP321H	S32109	...	18Cr–10Ni–Ti	8	...	75	35
	TP347H	S34709	...	18Cr–10Ni–Cb	8	...	75	35
	TP348H	S34809	...	18Cr–10Ni–Cb	8	...	75	35
A 312	TP304H	S30409	...	18Cr–8Ni	8	...	75	30
	TP310H	S31009	...	25Cr–20Ni	8	(2)(4)	75	30
	TP316H	S31609	...	16Cr–12Ni–2Mo	8	...	75	30
A 312	TP321H	S32109	...	18Cr–10Ni–Ti	8	...	75	30
	TP347H	S32709	...	18Cr–10Ni–Cb	8	...	75	30
Plate								
A 240	304	S30400	...	18Cr–8Ni	8	(2)(3)	75	30
	310S	S31008	...	25Cr–20Ni	8	(2)(3)(4)	75	30
	316	S31600	...	16Cr–12Ni–2Mo	8	(2)(3)	75	30
	316L	S31603	...	16Cr–12Ni–2Mo	8	(1)	70	25
A 240	321	S32100	...	18Cr–10Ni–Ti	8	(2)(3)	75	30
	347	S34700	...	18Cr–10Ni–Cb	8	(2)(3)	75	30
	348	S34800	...	18Cr–10Ni–Cb	8	(1)(2)(3)	75	30
B 409	...	N08800	Annealed	Ni–Cr–Fe	45	(3)	75	30
	...	N08810	Annealed	Ni–Cr–Fe	45	(3)	65	25
Bars, Rods, and Shapes								
B 408	...	N08800	Annealed	Ni–Cr–Fe	45	...	75	30
	...	N08810	Annealed	Ni–Cr–Fe	45	...	65	25
Forgings								
A 182	F304H	S30409	...	18Cr–8Ni	8	...	75	30
	F310H	S31009	...	25Cr–20Ni	8	(1)(2)(4)	75	30
	F316H	S31609	...	16Cr–12Ni–2Mo	8	...	75	30
A 182	F321H	S32109	...	18Cr–10Ni–Ti	8	...	75	30
	F347H	S34709	...	18Cr–10Ni–Cb	8	...	75	30
	F348H	S34809	...	18Cr–10Ni–Cb	8	...	75	30

TABLE A-8
TEMPERATURES 1200°F AND ABOVE (CONT'D)

E or F	Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding 1200	1250	1300	1350	1400	1450	1500	Type or Grade	Spec. No.
									Welded Pipe and Tube — Without Filler Metal (Cont'd)
0.85	4.6	3.5	2.7	2.1	1.6	1.3	1.0	TP321H	A 249
0.85	6.7	5.0	3.7	2.7	2.1	1.6	1.1	TP347H	
0.85	6.7	5.0	3.7	2.7	2.1	1.6	1.1	TP348H	
0.85	5.2	4.0	3.2	2.5	2.0	1.6	1.2	TP304H	A 312
0.85	3.4	2.6	1.9	1.4	1.1	0.82	0.64	TP310H	
0.85	6.3	4.7	3.5	2.6	1.9	1.5	1.1	TP316H	
0.85	4.6	3.5	2.7	2.1	1.6	1.3	1.0	TP321H	A 312
0.85	6.7	5.0	3.7	2.7	2.1	1.6	1.1	TP347H	
									Plate
1.00	6.1	4.7	3.7	2.9	2.3	1.8	1.4	304	A 240
1.00	2.5	1.5	0.80	0.50	0.40	0.30	0.20	310S	
1.00	7.4	5.5	4.1	3.1	2.3	1.7	1.3	316	
1.00	6.4	4.7	3.5	2.5	1.8	1.3	1.0	316L	
1.00	3.6	2.6	1.7	1.1	0.80	0.50	0.30	321	A 240
1.00	4.4	3.3	2.2	1.5	1.2	0.90	0.80	347	
1.00	4.4	3.3	2.2	1.5	1.2	0.90	0.80	348	
1.00	6.6	4.2	2.0	1.6	1.1	1.0	0.80	N08800	B 409
1.00	7.4	5.9	4.7	3.8	3.0	2.4	1.9	N08810	
									Bars, Rods, and Shapes
1.00	6.6	4.2	2.0	1.6	1.1	1.0	0.80	N08800	B 408
1.00	7.4	5.9	4.7	3.8	3.0	2.4	1.9	N08810	
									Forgings
1.00	6.1	4.7	3.7	2.9	2.3	1.8	1.4	F304H	A 182
1.00	4.0	3.0	2.2	1.7	1.3	0.97	0.75	F310H	
1.00	7.4	5.5	4.1	3.1	2.3	1.7	1.3	F316H	
1.00	5.4	4.1	3.2	2.5	1.9	1.5	1.1	F321H	A 182
1.00	7.9	5.9	4.4	3.2	2.5	1.8	1.3	F347H	
1.00	7.9	5.9	4.4	3.2	2.5	1.8	1.3	F348H	

TABLE A-8
TEMPERATURES 1200°F AND ABOVE (CONT'D)

Spec. No.	Type or Grade	UNS Alloy No.	Temper	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi
Forgings (Cont'd)								
B 564	...	N08800	Annealed	Ni–Cr–Fe	45	...	75	30
	...	N08810	Annealed	Ni–Cr–Fe	45	...	65	25
Fittings (Seamless and Welded)								
A 403	WP304H	S30409	...	18Cr–8Ni	8	(1)	75	30
	WP316H	S31609	...	16Cr–12Ni–2Mo	8	(1)	75	30
	WP321H	S32109	...	18Cr–10Ni–Ti	8	(1)	75	30
	WP347H	S34709	...	18Cr–10Ni–Cb	8	(1)	75	30
	WP348H	S34809	...	18Cr–10Ni–Cb	8	(1)	75	30

GENERAL NOTES:

(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME Boiler and Pressure Vessel Code applications, see related specifications in Section II of the ASME Code.

(b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.

(c) The P-Numbers listed in this Table are identical to those adopted by the ASME Boiler and Pressure Vessel Code. Qualification of welding procedures, welders, and welding operators is required and shall comply with the ASME Boiler and Pressure Vessel Code, Section IX, except as modified by para. 127.5.

(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."

(e) The materials listed in this Table shall not be used at design temperatures above those for which allowable stress values are given.

(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3.

(g) Pressure-temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this Table are for use in designing piping components which are not manufactured in accordance with referenced standards.

(h) All the materials listed are classified as austenitic [see Table 104.1.2(A)].

TABLE A-8
TEMPERATURES 1200°F AND ABOVE (CONT'D)

E or F	Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding							Type or Grade	Spec. No.
	1200	1250	1300	1350	1400	1450	1500		
								Forgings (Cont'd)	
1.00	6.6	4.2	2.0	1.6	1.1	1.0	0.80	N08800	B 564
1.00	7.4	5.9	4.7	3.8	3.0	2.4	1.9	N08810	
								Fittings (Seamless and Welded)	
1.00	6.1	4.7	3.7	2.9	2.3	1.8	1.4	WP304H	A 403
1.00	7.4	5.5	4.1	3.1	2.3	1.7	1.3	WP316H	
1.00	5.4	4.1	3.2	2.5	1.9	1.5	1.1	WP321H	
1.00	7.9	5.9	4.4	3.2	2.5	1.8	1.3	WP347H	
1.00	7.9	5.9	4.4	3.2	2.5	1.8	1.3	WP348H	

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGS. 100.1.2(A) and (B).

(2) These allowable stress values shall be used only if the carbon content of the material is 0.04% or higher.

(3) These allowable stress values tabulated shall be used only if the material is heat treated by heating to a minimum temperature of 1900°F and quenching in water or rapidly cooling by other means.

(4) These allowable stress values shall be used only when the grain size of the material is ASTM No. 6 or coarser.

TABLE A-9
TITANIUM AND TITANIUM ALLOYS

Spec No.	Grade	Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Seamless Pipe and Tube								
B 337	1	Annealed	Ti	51	(1)	35	25	1.00
	2	Annealed	Ti	51	(1)	50	40	1.00
	3	Annealed	Ti	52	(1)	65	55	1.00
	7	Annealed	Ti–Pd	51	(1)	50	40	1.00
	12	Annealed	Ti–Mo–Ni	52	(1)	70	50	1.00
B 338	1	Annealed	Ti	51	(1)	35	25	1.00
	2	Annealed	Ti	51	(1)	50	40	1.00
	3	Annealed	Ti	52	(1)	65	55	1.00
	7	Annealed	Ti–Pd	51	(1)	50	40	1.00
	12	Annealed	Ti–Mo–Ni	52	(1)	70	50	1.00
Welded Pipe and Tube								
B 337	1	Annealed	Ti	51	(1)(2)	35	25	0.85
	2	Annealed	Ti	51	(1)(2)	50	40	0.85
	3	Annealed	Ti	52	(1)(2)	65	55	0.85
	7	Annealed	Ti–Pd	51	(1)(2)	50	40	0.85
	12	Annealed	Ti–Mo–Ni	52	(1)(2)	70	50	0.85
B 338	1	Annealed	Ti	51	(1)(2)	35	25	0.85
	2	Annealed	Ti	51	(1)(2)	50	40	0.85
	3	Annealed	Ti	52	(1)(2)	65	55	0.85
	7	Annealed	Ti–Pd	51	(1)(2)	50	40	0.85
	12	Annealed	Ti–Mo–Ni	52	(1)(2)	70	50	0.85
Plate, Sheet, and Strip								
B 265	1	Annealed	Ti	51	(1)	35	25	1.00
	2	Annealed	Ti	51	(1)	50	40	1.00
	3	Annealed	Ti	52	(1)	65	55	1.00
	7	Annealed	Ti–Pd	51	(1)	50	40	1.00
	12	Annealed	Ti–Mo–Ni	52	(1)	70	50	1.00

TABLE A-9
TITANIUM AND TITANIUM ALLOYS

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding												
−20 to 100	150	200	250	300	350	400	450	500	550	600	Grade	Spec. No.
											Seamless Pipe and Tube	
8.8	8.1	7.3	6.5	5.8	5.2	4.8	4.5	4.1	3.6	3.1	1	B 337
12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7	2	
16.3	15.6	14.3	13.0	11.7	10.4	9.3	8.3	7.5	6.7	6.0	3	
12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7	7	
17.5	17.5	16.4	15.2	14.2	13.3	12.5	11.9	11.4	11.1	10.8	12	
8.8	8.1	7.3	6.5	5.8	5.2	4.8	4.5	4.1	3.6	3.1	1	B 338
12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7	2	
16.3	15.6	14.3	13.0	11.7	10.4	9.3	8.3	7.5	6.7	6.0	3	
12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7	7	
17.5	17.5	16.4	15.2	14.2	13.3	12.5	11.9	11.4	11.1	10.8	12	
											Welded Pipe and Tube	
7.5	6.9	6.2	5.5	4.9	4.4	4.1	3.8	3.5	3.1	2.6	1	B 337
10.6	10.2	9.3	8.4	7.7	7.1	6.5	6.1	5.6	5.3	4.8	2	
13.8	13.3	12.1	11.1	10.0	8.8	7.9	7.1	6.4	5.7	5.1	3	
10.6	10.2	9.3	8.4	7.7	7.1	6.5	6.1	5.6	5.3	4.8	7	
14.9	14.9	13.9	12.9	12.1	11.3	10.6	10.1	9.7	9.4	9.2	12	
7.5	6.9	6.2	5.5	4.9	4.4	4.1	3.8	3.5	3.1	2.6	1	B 338
10.6	10.2	9.3	8.4	7.7	7.1	6.5	6.1	5.6	5.3	4.8	2	
13.8	13.3	12.1	11.1	10.0	8.8	7.9	7.1	6.4	5.7	5.1	3	
10.6	10.2	9.3	8.4	7.7	7.1	6.5	6.1	5.6	5.3	4.8	7	
14.9	14.9	13.9	12.9	12.1	11.3	10.6	10.1	9.7	9.4	9.2	12	
											Plate, Sheet, and Strip	
8.8	8.1	7.3	6.5	5.8	5.2	4.8	4.5	4.1	3.6	3.1	1	B 265
12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7	2	
16.3	15.6	14.3	13.0	11.7	10.4	9.3	8.3	7.5	6.7	6.0	3	
12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7	7	
17.5	17.5	16.4	15.2	14.2	13.3	12.5	11.9	11.4	11.1	10.8	12	

TABLE A-9
TITANIUM AND TITANIUM ALLOYS (CONT'D)

Spec No.	Grade	Condition	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	E or F
Forgings								
B 381	F1	Annealed	Ti	51	(1)	35	25	1.00
	F2	Annealed	Ti	51	(1)	50	40	1.00
	F3	Annealed	Ti	52	(1)	65	55	1.00
	F7	Annealed	Ti–Pd	51	(1)	50	40	1.00
	F12	Annealed	Ti–Mo–Ni	52	(1)	70	50	1.00
Bars and Billets								
B 348	1	Annealed	Ti	51	(1)	35	25	1.00
	2	Annealed	Ti	51	(1)	50	40	1.00
	3	Annealed	Ti	52	(1)	65	55	1.00
	7	Annealed	Ti–Pd	51	(1)	50	40	1.00
	12	Annealed	Ti–Mo–Ni	52	(1)	70	50	1.00
Castings								
B 367	C-2	As-cast	Ti	50	(1)(3)	50	40	0.80

GENERAL NOTES:
(a) The tabulated specifications are ANSI/ASTM or ASTM. For ASME Boiler and Pressure Vessel Code applications, see related specifications in Section II of the ASME Code.
(b) The stress values in this Table may be interpolated to determine values for intermediate temperatures.
(c) The P-Numbers listed in this Table are identical to those adopted by the ASME Boiler and Pressure Vessel Code. Qualification of welding procedures, welders, and welding operators is required and shall comply with the ASME Boiler and Pressure Vessel Code, Section IX, except as modified by para. 127.5.
(d) Tensile strengths and allowable stresses shown in "ksi" are "thousands of pounds per square inch."
(e) The materials listed in this Table shall not be used at design temperatures above those for which allowable stress values are given.
(f) The tabulated stress values are $S \times E$ (weld joint efficiency factor) or $S \times F$ (material quality factor), as applicable. Weld joint efficiency factors are shown in Table 102.4.3.
(g) Pressure-temperature ratings of piping components, as published in standards referenced in this Code, may be used for components meeting the requirements of those standards. The allowable stress values given in this Table are for use in designing piping components which are not manufactured in accordance with referenced standards.
(h) The y coefficient = 0.4 [see Table 104.1.2(A)].

TABLE A-9
TITANIUM AND TITANIUM ALLOYS (CONT'D)

Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature, °F, Not Exceeding												
−20 to 100	150	200	250	300	350	400	450	500	550	600	Grade	Spec. No.
												Forgings
8.8	8.1	7.3	6.5	5.8	5.2	4.8	4.5	4.1	3.6	3.1	F1	B 381
12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7	F2	
16.3	15.6	14.3	13.0	11.7	10.4	9.3	8.3	7.5	6.7	6.0	F3	
12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7	F7	
17.5	17.5	16.4	15.2	14.2	13.3	12.5	11.9	11.4	11.1	10.8	F12	
												Bars and Billets
8.8	8.1	7.3	6.5	5.8	5.2	4.8	4.5	4.1	3.6	3.1	1	B 348
12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7	2	
16.3	15.6	14.3	13.0	11.7	10.4	9.3	8.3	7.5	6.7	6.0	3	
12.5	12.0	10.9	9.9	9.0	8.4	7.7	7.2	6.6	6.2	5.7	7	
17.5	17.5	16.4	15.2	14.2	13.3	12.5	11.9	11.4	11.1	10.8	12	
												Castings
10.0	9.1	8.2	7.4	7.0	6.2	...	...	...	...	...	C-2	B 367

NOTES:

(1) THIS MATERIAL IS NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE FIGS. 100.1.2(A) and (B).

(2) Filler metal shall not be used in the manufacture of welded pipe or tubing.

(3) Welding of this material is not permitted.

APPENDIX B

Begins on Next Page

01

TABLE B-1
THERMAL EXPANSION DATA

A = Mean Coefficient of Thermal Expansion, 10^{-6}in./in./°F
B = Linear Thermal Expansion, in./100 ft

} In Going From 70°F to Indicated Temperature [Note (1)]

Material	Coef-ficient	Temperature Range 70°F to																
		−325	−150	−50	70	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
Group 1 carbon and low alloy steels [Note (2)]	*A*	5.5	5.9	6.2	6.4	6.7	6.9	7.1	7.3	7.4	7.6	7.8	7.9	8.1	8.2	8.3	8.4	8.4
	B	−2.6	−1.6	−0.9	0	1.0	1.9	2.8	3.7	4.7	5.7	6.8	7.9	9.0	10.1	11.3	12.4	14.7
Group 2 low alloy steels [Note (3)]	*A*	6.0	6.5	6.7	7.0	7.3	7.4	7.6	7.7	7.8	7.9	8.1	8.1	8.2	8.3	8.4	8.4	8.5
	B	−2.9	−1.7	−1.0	0	1.1	2.1	3.0	4.0	5.0	6.0	7.1	8.1	9.2	10.3	11.4	12.4	14.8
5Cr–1Mo steels	*A*	5.6	6.0	6.2	6.4	6.7	6.9	7.0	7.1	7.2	7.3	7.3	7.4	7.5	7.6	7.6	7.7	7.8
	B	−2.7	−1.6	−0.9	0	1.1	1.9	2.8	3.6	4.6	5.5	6.4	7.4	8.4	9.4	10.4	11.4	12.4
9Cr–1Mo steels	*A*	5.0	5.4	5.6	5.8	6.0	6.2	6.3	6.4	6.5	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.2
	B	−2.4	−1.4	−0.8	0	0.9	1.7	2.5	3.3	4.1	5.0	5.9	6.8	7.7	8.7	9.6	10.6	11.6
Straight chromium stainless steels																		
12Cr to 13Cr steels	*A*	5.1	5.5	5.7	5.9	6.2	6.3	6.4	6.5	6.5	6.6	6.7	6.7	6.8	6.8	6.9	6.9	7.0
	B	−2.4	−1.5	−0.8	0	1.0	1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.6	8.4	9.3	10.2	10.6
15Cr to 17Cr steels	*A*	4.5	4.9	5.1	5.3	5.5	5.7	5.8	5.9	6.0	6.1	6.1	6.2	6.3	6.4	6.4	6.5	6.6
	B	−2.1	−1.3	−0.7	0	0.9	1.6	2.3	3.0	3.8	4.6	5.3	6.2	7.0	7.9	8.7	9.6	10.0
27Cr steels	*A*	4.3	4.7	4.9	5.0	5.2	5.2	5.3	5.4	5.4	5.5	5.6	5.7	5.7	5.8	5.9	5.9	6.0
	B	−2.0	−1.2	−0.7	0	0.8	1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.4	7.2	7.9	8.8	9.6
Austenitic stainless steels (304, 305, 316, 317, 321, 347, 348 19-9DL, XM-15, etc.)	*A*	7.5	8.0	8.2	8.5	8.9	9.2	9.5	9.7	9.8	10.0	10.1	10.2	10.3	10.5	10.6	10.7	10.8
	B	−3.6	−2.1	−1.2	0	1.4	2.5	3.7	5.0	6.3	7.5	8.8	10.2	11.5	12.9	14.3	15.7	17.2
Other austenitic stainless steels (309, 310, 315, XM-19, etc.)	*A*	7.1	7.6	7.8	8.2	8.5	8.8	8.9	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9	10.1
	B	−3.4	−2.0	−1.1	0	1.3	2.4	3.5	4.7	5.8	7.0	8.2	9.5	10.7	12.0	13.3	14.7	16.0
Gray cast iron	*A*	...	...	...	...	5.8	5.9	6.1	6.3	6.5	6.7	6.8	7.0	7.2	...	...	...	...
	B	...	...	...	0	0.9	1.6	2.4	3.2	4.1	5.0	6.0	7.0	8.0	...	...	...	...
Ductile cast iron		...	4.9	5.3	5.7	6.0	6.3	6.5	6.9	7.0	7.1	7.3	7.4	7.5	...	...	...	...
	B	...	−1.3	−0.8	0	0.9	1.7	2.6	3.5	4.4	5.4	6.4	7.4	8.4	...	...	...	...

(continued)

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TABLE B-1
THERMAL EXPANSION DATA (CONT'D)

A = Mean Coefficient of Thermal Expansion, 10^{-6}in./in./°F
B = Linear Thermal Expansion, in./100 ft

} In Going From 70°F to Indicated Temperature [Note (1)]

Material	Coefficient	Temperature Range 70°F to −325	−150	−50	70	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
Monel (67Ni–30Cu) N04400	*A*	5.8	6.8	7.2	7.7	8.1	8.3	8.5	8.7	8.8	8.9	8.9	9.0	9.1	9.1	9.2	9.2	9.3
	B	−2.7	−1.8	−1.0	0	1.3	2.3	3.4	4.5	5.6	6.7	7.8	8.9	10.1	11.3	12.4	13.6	14.8
Nickel alloys N02200 and N02201	*A*	5.6	6.4	6.7	7.0	7.3	7.5	7.7	7.9	8.1	8.2	8.3	8.4	8.5	8.6	8.7	8.8	8.9
	B	−2.7	−1.7	−1.0	0	1.2	2.1	3.1	4.1	5.1	6.2	7.2	8.4	9.5	10.6	11.8	13.0	14.2
Nickel alloy N06600	*A*	5.5	6.1	6.4	6.8	7.1	7.3	7.5	7.6	7.8	7.9	8.1	8.2	8.3	8.4	8.6	8.7	8.9
	B	−2.6	−1.6	−0.9	0	1.1	2.0	3.0	3.9	5.0	6.0	7.1	8.1	9.3	10.4	11.6	12.9	14.2
Nickel alloys N08800 and N08810	*A*	5.9	6.9	7.4	7.9	8.3	8.6	8.8	8.9	9.0	9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8
	B	−2.8	−1.7	−1.1	0	1.3	2.4	3.5	4.6	5.7	6.9	8.1	9.3	10.5	11.7	13.0	14.3	15.7
Nickel alloy N08825	*A*	...	...	7.2	7.5	7.7	7.9	8.0	8.1	8.2	8.3	8.4	8.5	8.6	...	...	...	...
	B	...	...	−1.0	0	1.2	2.2	3.2	4.2	5.2	6.3	7.4	8.5	9.6	...	...	...	...
Copper alloys C1XXXX series	*A*	7.7	8.7	9.0	9.3	9.6	9.7	9.8	9.9	10.0	...	...	...	...	...	...	...	...
	B	−3.7	−2.3	−1.3	0	1.5	2.7	3.9	5.1	6.1	...	...	...	...	...	...	...	...
Bronze alloys	*A*	8.4	8.8	9.2	9.6	10.0	10.1	10.2	10.3	10.4	10.5	10.6	10.7	10.8	10.9	11.0	...	...
	B	−4.0	−2.3	−1.3	0	1.6	2.8	4.1	5.3	6.6	8.0	9.3	10.7	12.1	13.5	14.9	...	...
Brass alloys	*A*	8.2	8.5	9.0	9.3	9.8	10.0	10.2	10.5	10.7	10.9	11.2	11.4	11.6	11.9	12.1	...	...
	B	−3.9	−2.2	−1.3	0	1.5	2.8	4.1	5.4	6.8	8.3	9.8	11.4	13.0	14.7	16.4	...	...
Copper–nickel (70Cu–30Ni)	*A*	6.7	7.4	7.8	8.2	8.5	8.7	8.9	9.1	9.2	9.3	...	...	...	...	...	...	...
	B	−3.2	−2.0	−1.1	0	1.3	2.4	3.5	4.7	5.9	7.0	...	...	...	...	...	...	...
Aluminum alloys	*A*	9.9	10.9	11.6	12.3	13.0	13.3	13.6	13.9	14.2	...	...	...	...	...	...	...	...
	B	−4.7	−2.9	−1.7	0	2.0	3.7	5.4	7.2	9.0	...	...	...	...	...	...	...	...
Titanium alloys (Grades 1, 2, 3, 7, and 12)	*A*	...	...	4.5	4.6	4.7	4.8	4.8	4.9	4.9	5.0	5.1	...	...	...	...	...	...
	B	...	...	−0.6	0	0.7	1.3	1.9	2.5	3.1	3.8	4.4	...	...	...	...	...	...

(continued)

01 **TABLE B-1 (CONT'D)**

NOTES:
(1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.
(2) Group 1 alloys (by nominal composition):

Carbon steels (C, C–Si, C–Mn, and C–Mn–Si)	
C–½Mo	½Ni–½Mo–V
½Cr–⅕Mo–V	½Ni–½Cr–¼Mo–V
½Cr–¼Mo–Si	¾Ni–½Mo–Cr–V
½Cr–½Mo	¾Ni–½Mo–⅓Cr–v
½Cr–½Ni–¼Mo	¾Ni–½Cu–Mo
¾Cr–½Ni–Cu	¾Ni–½Cr–½Mo–V
¾Cr–¾Ni–Cu–Al	¾Ni–1Mo–¾Cr
1Cr–⅕Mo	1Ni–½Cr–½Mo
1Cr–⅕Mo–Si	1¼Ni–1Cr–½Mo
1Cr–½Mo	1¾Ni–¾Cr–¼Mo
1Cr–½Mo–V	2Ni–¾Cr–¼Mo
1¼Cr–½Mo	2Ni–¾Cr–⅓Mo
1¼Cr–½Mo–Si	2½Ni
1¾Cr–½Mo–Cu	3½Ni
2Cr–½Mo	3½Ni–1¾Cr–½Mo–V
2¼Cr–1Mo	
3Cr–1Mo	

(3) Group 2 alloys (by nominal composition):

M–V
Mn–¼Mo
Mn–½Mo
Mn–½Mo–¼Ni
Mn–½Mo–½Ni
Mn–½Mo–¾Ni

01

TABLE B-1 (SI)
THERMAL EXPANSION DATA

A = Mean Coefficient of Thermal Expansion, 10^{-6} mm/mm/°C
B = Linear Thermal Expansion, mm/m
} in Going From 20°C to Indicated Temperature [Note (1)]

Material	Coef-ficient	Temperature Range 20°C to −200	−100	−50	20	50	75	100	125	150	175	200	225	250	275
Group 1 carbon and low Alloy steels [Note (2)]	*A*	9.9	10.7	11.1	11.6	11.8	11.9	12.1	12.2	12.4	12.5	12.7	12.8	13.0	13.2
	B	−2.2	−1.3	−0.8	0	0.4	0.7	1.0	1.3	1.6	1.9	2.3	2.6	3.0	3.4
Group 2 low alloy steels [Note (3)]	*A*	10.8	11.7	12.0	12.5	12.7	12.9	13.1	13.3	13.4	13.5	13.6	13.7	13.8	13.9
	B	−2.4	−1.4	−0.8	0	0.4	0.7	1.0	1.4	1.7	2.1	2.5	2.8	3.2	3.6
5Cr–1Mo steels	*A*	10.1	10.8	11.2	11.6	11.8	12.0	12.1	12.2	12.4	12.5	12.6	12.6	12.7	12.7
	B	−2.2	−1.3	−0.8	0	0.4	0.7	1.0	1.3	1.6	1.9	2.3	2.6	2.9	3.3
9Cr–1Mo steels	*A*	9.0	9.8	10.1	10.4	10.6	10.7	10.8	10.9	11.1	11.2	11.3	11.4	11.5	11.6
	B	−2.0	−1.2	−0.7	0	0.3	0.6	0.9	1.1	1.4	1.7	2.0	2.3	2.6	3.0
Straight chromium stainless steels															
12Cr to 13Cr steels	*A*	9.1	9.9	10.2	10.7	10.8	11.0	11.1	11.2	11.3	11.4	11.5	11.6	11.7	11.7
	B	−2.0	−1.2	−0.7	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
15Cr to 17Cr steels	*A*	8.1	8.8	9.1	9.6	9.7	9.8	9.9	10.0	10.2	10.3	10.3	10.4	10.5	10.6
	B	−1.8	−1.1	−0.6	0	0.3	0.5	0.8	1.1	1.3	1.6	1.9	2.1	2.4	2.7
27Cr steels	*A*	7.7	8.5	8.7	9.0	9.1	9.2	9.3	9.4	9.4	9.5	9.5	9.6	9.7	9.7
	B	−1.7	−1.0	−0.6	0	0.3	0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	2.5
Austenitic stainless steels (304, (305, 316, 317, 321, 347, 348 19-9DL XM-15, etc.)	*A*	13.5	14.3	14.7	15.3	15.6	15.9	16.1	16.4	16.6	16.8	17.0	17.2	17.3	17.5
	B	−3.0	−1.7	−1.0	0	0.5	0.9	1.3	1.7	2.2	2.6	3.1	3.5	4.0	4.5
Other austenitic stainless steels (309, 310, 315, XM-19, etc.)	*A*	12.8	13.6	14.1	14.7	14.9	15.1	15.4	15.6	15.8	16.0	16.1	16.2	16.3	16.4
	B	−2.8	−1.6	−1.0	0	0.4	0.8	1.2	1.6	2.1	2.5	2.9	3.3	3.8	4.2
Gray cast iron	*A*	...	...	...	9.8	10.1	10.2	10.4	10.5	10.7	10.8	11.0	11.1	11.2	11.4
	B	...	...	...	0	0.3	0.6	0.8	1.1	1.4	1.7	2.0	2.3	2.6	2.9
Ductile cast iron	*A*	...	8.8	9.5	10.3	10.6	10.8	10.9	11.1	11.3	11.4	11.7	12.0	12.2	12.3
	B	...	−1.1	−0.7	0	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.5	2.8	3.1
Monel (67Ni–30Cu) N04400	*A*	10.4	12.2	13.0	13.8	14.1	14.4	14.7	14.9	15.0	15.2	15.3	15.4	15.6	15.7
	B	−2.3	−1.5	−0.9	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.2	3.6	4.0
Nickel alloys N02200 and N02201	*A*	10.1	11.5	12.0	12.7	12.9	13.1	13.3	13.5	13.6	13.8	13.9	14.0	14.2	14.3
	B	−2.2	−1.4	−0.8	0	0.4	0.7	1.1	1.4	1.8	2.1	2.5	2.9	3.3	3.6
Nickel alloy N06600	*A*	9.9	10.8	11.5	12.2	12.5	12.7	12.8	13.1	13.2	13.3	13.5	13.6	13.7	13.8
	B	−2.2	−1.3	−0.8	0	0.4	0.7	1.0	1.4	1.7	2.1	2.4	2.8	3.2	3.5
Nickel alloys N08800 and N08810	*A*	10.6	12.5	13.3	14.3	14.6	14.9	15.1	15.3	15.5	15.7	15.8	15.9	16.0	16.1
	B	−2.3	−1.5	−0.9	0	0.4	0.8	1.2	1.6	2.0	2.4	2.8	3.3	3.7	4.1
Nickel alloy N08825	*A*	...	...	12.9	13.5	13.6	13.8	13.9	14.0	14.1	14.2	14.4	14.4	14.5	14.6
	B	...	...	−0.9	0	0.4	0.8	1.1	1.5	1.8	2.2	2.6	3.0	3.3	3.7

(continued)

TABLE B-1 (SI) THERMAL EXPANSION DATA 01

A = Mean Coefficient of Thermal Expansion, 10^{-6}mm/mm/°C
B = Linear Thermal Expansion, mm/m
} in Going From 20°C to Indicated Temperature [Note (1)]

Temperature Range 20°C to

300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
13.3	13.5	13.6	13.7	13.8	13.9	14.1	14.2	14.3	14.4	14.6	14.7	14.8	14.9	15.0	15.0	15.1	15.1	15.2	...	...
3.7	4.1	4.5	4.9	5.2	5.6	6.1	6.5	6.9	7.3	7.7	8.1	8.6	9.0	9.4	9.8	10.2	10.7	11.1	...	...
14.0	14.1	14.2	14.3	14.4	14.5	14.6	14.6	14.7	14.8	14.8	14.9	14.9	15.0	15.1	15.1	15.2	...	...	...	...
3.9	4.3	4.7	5.1	5.5	5.9	6.3	6.7	7.1	7.5	7.9	8.3	8.7	9.1	9.5	9.9	10.3	...	...	...	...
12.8	12.9	13.0	13.1	13.1	13.2	13.2	13.3	13.4	13.5	13.5	13.6	13.6	13.7	13.8	13.8	13.9	...	...	...	...
3.6	3.9	4.3	4.6	5.0	5.3	5.7	6.1	6.4	6.8	7.2	7.5	7.9	8.3	8.7	9.1	9.4	...	...	...	...
11.7	11.8	11.8	11.9	12.0	12.1	12.2	12.2	12.3	12.4	12.5	12.6	12.6	12.7	12.8	12.8	12.9	...	...	...	...
3.3	3.6	3.9	4.2	4.6	4.9	5.2	5.6	5.9	6.3	6.6	7.0	7.3	7.7	8.1	8.4	8.8	...	...	...	...
11.7	11.8	11.8	11.9	11.9	12.0	12.1	12.1	12.2	12.2	12.2	12.3	12.3	12.4	12.4	12.4	12.5	...	...	...	...
3.3	3.6	3.9	4.2	4.5	4.9	5.2	5.5	5.8	6.2	6.5	6.8	7.2	7.5	7.8	8.1	8.5	...	...	...	...
10.7	10.8	10.8	10.9	11.0	11.0	11.1	11.2	11.3	11.3	11.4	11.4	11.5	11.6	11.6	11.7	11.7	...	...	...	...
3.0	3.3	3.6	3.9	4.2	4.5	4.8	5.1	5.4	5.7	6.0	6.3	6.7	7.0	7.3	7.6	8.0	...	...	...	...
9.8	9.8	9.9	9.9	10.0	10.0	10.1	10.2	10.2	10.3	10.3	10.4	10.4	10.5	10.6	10.6	10.7	...	...	...	...
2.7	3.0	3.3	3.5	3.8	4.1	4.3	4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.7	7.0	7.3	...	...	...	...
17.6	17.7	17.9	18.0	18.1	18.2	18.3	18.3	18.5	18.5	18.6	18.7	18.8	18.9	19.0	19.1	19.2	...	...	...	...
4.9	5.4	5.9	6.4	6.9	7.4	7.8	8.3	8.9	9.4	9.9	10.4	10.9	11.4	12.0	12.5	13.0	...	...	...	...
16.5	16.5	16.7	16.7	16.8	16.9	17.0	17.1	17.2	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9	...	...	...	...
4.6	5.0	5.5	5.9	6.4	6.8	7.3	7.8	8.2	8.7	9.2	9.7	10.1	10.6	11.1	11.6	12.2	...	...	...	...
11.5	11.7	11.8	12.0	12.1	12.3	12.4	12.6	12.7	12.9	13.0	...	...	...	...	...	...	...	...	...	...
3.2	3.6	3.9	4.2	4.6	5.0	5.3	5.7	6.1	6.5	6.9	...	...	...	...	...	...	...	...	...	...
12.5	12.7	12.7	12.9	13.0	13.1	13.1	13.2	13.3	13.5	13.6	...	...	...	...	...	...	...	...	...	...
3.5	3.9	4.2	4.6	4.9	5.3	5.7	6.0	6.4	6.8	7.2	...	...	...	...	...	...	...	...	...	...
15.8	15.9	16.0	16.0	16.1	16.1	16.2	16.2	16.2	16.3	16.3	16.3	16.4	16.4	16.5	16.5	16.5	16.6	16.6	16.7	16.7
4.4	4.9	5.3	5.7	6.1	6.5	7.0	7.4	7.8	8.2	8.6	9.1	9.5	9.9	10.4	10.8	11.2	11.7	12.1	12.6	13.0
14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.0	15.1	15.2	15.3	15.4	15.5	15.6	15.7	15.8	15.8	15.9	16.0	16.1	16.2
4.0	4.4	4.8	5.2	5.6	6.0	6.4	6.8	7.3	7.7	8.1	8.5	9.0	9.4	9.9	10.3	10.8	11.2	11.7	12.2	12.6
13.9	14.0	14.1	14.2	14.4	14.5	14.6	14.7	14.8	14.9	15.0	15.0	15.2	15.3	15.4	15.6	15.7	15.8	15.9	16.1	16.2
3.9	4.3	4.7	5.1	5.5	5.9	6.3	6.7	7.1	7.5	7.9	8.4	8.8	9.3	9.7	10.2	10.6	11.1	11.6	12.1	12.7
16.2	16.3	16.3	16.4	16.5	16.6	16.7	16.7	16.8	16.9	17.0	17.1	17.1	17.2	17.3	17.4	17.5	17.6	17.7	17.8	17.9
4.5	5.0	5.4	5.8	6.3	6.7	7.2	7.6	8.1	8.5	9.0	9.5	9.9	10.4	10.9	11.4	11.9	12.4	12.9	13.4	14.0
14.7	14.8	14.9	15.0	15.1	15.1	15.2	15.3	15.4	15.5	15.6	...	...	...	...	...	...	...	...	...	...
4.1	4.5	4.9	5.3	5.7	6.1	6.5	7.0	7.4	7.8	8.3	...	...	...	...	...	...	...	...	...	...

(continued)

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TABLE B-1 (SI)
THERMAL EXPANSION DATA (CONT'D)

A = Mean Coefficient of Thermal Expansion, 10^{-6} mm/mm/°C } in Going From 20°C to Indicated Temperature [Note (1)]

B = Linear Thermal Expansion, mm/m

Material	Coef-ficient	Temperature Range 20°C to -200	-100	-50	20	50	75	100	125	150	175	200	225	250	275
Copper alloys C1XXXX series	A	13.9	15.7	16.2	16.8	17.0	17.1	17.3	17.4	17.5	17.6	17.7	17.8	17.9	18.0
	B	−3.1	−1.9	−1.1	0	0.5	0.9	1.4	1.8	2.3	2.7	3.2	3.7	4.1	4.6
Bronze alloys	A	15.1	15.8	16.4	17.2	17.6	17.9	18.1	18.2	18.3	18.3	18.4	18.5	18.5	18.6
	B	−3.3	−1.9	−1.1	0	0.5	1.0	1.4	1.9	2.4	2.8	3.3	3.8	4.3	4.8
Brass alloys	A	14.7	15.4	16.0	16.8	17.2	17.4	17.6	17.8	18.0	18.2	18.4	18.6	18.8	19.0
	B	−3.2	−1.9	−1.1	0	0.5	1.0	1.4	1.9	2.3	2.8	3.3	3.8	4.3	4.8
Copper–nickel (70Cu–30Ni)	A	11.9	13.4	14.0	14.7	14.9	15.2	15.4	15.5	15.7	15.9	16.1	16.2	16.3	16.4
	B	−2.6	−1.6	−1.0	0	0.4	0.8	1.2	1.6	2.0	2.5	2.9	3.3	3.7	4.2
Aluminum alloys	A	18.0	19.7	20.8	22.1	22.6	23.0	23.4	23.7	23.9	24.2	24.5	24.7	24.9	25.2
	B	−4.0	−2.4	−1.5	0	0.7	1.3	1.9	2.5	3.1	3.7	4.4	5.1	5.7	6.4
Titanium alloys (Grades 1, 2, 3, 7, and 12)	A	...	...	8.2	8.3	8.4	8.4	8.5	8.5	8.6	8.6	8.6	8.7	8.7	8.8
	B	...	...	−0.6	0	0.3	0.5	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.2

NOTES:

(1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.

(2) Group 1 alloys (by nominal composition):

Carbon steels
(C, C–Si, C–Mn, and C–Mn–Si)
C–½Mo
½Cr–⅕Mo–V
½Cr–¼Mo–Si
½Cr–½Mo
½Cr–½Ni–¼Mo
¾Cr–½Ni–Cu
¾Cr–¾Ni–Cu–Al
1Cr–⅕Mo
1Cr–⅕Mo–Si
1Cr–½Mo
1Cr–½Mo–V
1¼Cr–½Mo
1¼Cr–½Mo–Si
1¾Cr–½Mo–Cu
2Cr–½Mo
2¼Cr–1Mo
3Cr–1Mo

½Ni–½Mo–V
½Ni–½Cr–¼Mo–V
¾Ni–½Mo–Cr–V
¾Ni–½Mo–⅓Cr–V
¾Ni–½Cu–Mo
¾Ni–½Cr–½Mo–V
¾Ni–1Mo–¾Cr
1Ni–½Cr–½Mo
1¼Ni–1Cr–½Mo
1¾Ni–¾Cr–¼Mo
2Ni–¾Cr–¼Mo
2Ni–¾Cr–⅓Mo
2½Ni
3½Ni
3½Ni–1¾Cr–½Mo–V

(3) Group 2 alloys (by nominal composition):

M–V
Mn–¼Mo
Mn–½Mo
Mn–½Mo–¼Ni
Mn–½Mo–½Ni
Mn–½Mo–¾Ni

TABLE B-1 (SI) THERMAL EXPANSION DATA (CONT'D) 01

A = Mean Coefficient of Thermal Expansion, 10^{-6} mm/mm/°C
B = Linear Thermal Expansion, mm/m
in Going From 20°C to Indicated Temperature [Note (1)]

Temperature Range 20°C to

300	325	350	375	400	425	450	475	500	525	550	575	600	625	650	675	700	725	750	775	800
18.0	18.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
5.1	5.5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
18.7	18.8	18.9	19.0	19.0	19.1	19.2	19.3	19.4	19.4	19.5	19.6	19.7	19.7	19.8	...	...	...	...	...	...
5.2	5.7	6.2	6.7	7.2	7.7	8.3	8.8	9.3	9.8	10.3	10.9	11.4	11.9	12.5	...	...	...	...	...	...
19.2	19.3	19.5	19.7	19.9	20.1	20.3	20.5	20.7	20.8	21.0	21.2	21.4	21.6	21.8	...	...	...	...	...	...
5.4	5.9	6.4	7.0	7.6	8.1	8.7	9.3	9.9	10.5	11.1	11.8	12.4	13.1	13.7	...	...	...	...	...	...
16.5	16.5	16.6	16.6	16.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
4.6	5.0	5.5	5.9	6.3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
25.5	25.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
7.1	7.8	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
8.8	8.9	8.9	9.0	9.0	9.1	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2.5	2.7	2.9	3.2	3.4	3.7	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...

APPENDIX C

Begins on Next Page

TABLE C-1
MODULI OF ELASTICITY FOR FERROUS MATERIAL

Material	E = Modulus of Elasticity, psi (Multiply Tabulated Values by 10^6) [Note (1)]															
	Temperature, °F															
	−100	70	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400	1500
Carbon steels with carbon content 0.30% or less	30.2	29.5	28.8	28.3	27.7	27.3	26.7	25.5	24.2	22.4	20.4	18.0	...	...	...	...
Carbon steels with carbon content above 0.30%	30.0	29.3	28.6	28.1	27.5	27.1	26.5	25.3	24.0	22.3	20.2	17.9	15.4	...	...	...
Carbon-moly steels	29.9	29.2	28.5	28.0	27.4	27.0	26.4	25.3	23.9	22.2	20.1	17.8	15.3	...	...	...
Nickel steels	28.5	27.8	27.1	26.7	26.1	25.7	25.2	24.6	23.9	23.2	22.4	21.5	20.4	19.2	17.7	...
Chromium steels:																
½Cr through 2Cr	30.4	29.7	29.0	28.5	27.9	27.5	26.9	26.3	25.5	24.8	23.9	23.0	21.8	20.5	18.9	...
2¼Cr through 3Cr	31.4	30.6	29.8	29.4	28.8	28.3	27.7	27.1	26.3	25.6	24.6	23.7	22.5	21.1	19.4	...
5Cr through 9Cr	31.7	30.9	30.1	29.7	29.0	28.6	28.0	27.3	26.1	24.7	22.7	20.4	18.2	15.5	12.7	...
Austenitic stainless steels: Type 304—18Cr–8Ni Type 310—25Cr–20Ni Type 316—16Cr–12Ni–2Mo Type 321—18Cr–10Ni–Ti Type 347—18Cr–10Ni–Cb Type 309—23Cr–12Ni	29.1	28.3	27.6	27.0	26.5	25.8	25.3	24.8	24.1	23.5	22.8	22.1	21.2	20.2	19.2	18.1
Straight chromium stainless steels (12Cr, 17Cr, 27Cr)	30.1	29.2	28.5	27.9	27.3	26.7	26.1	25.6	24.7	23.2	21.5	19.1	16.6	...	...	...
Gray cast iron	...	13.4	13.2	12.9	12.6	12.2	11.7	11.0	10.2	...	...	...	...	...	...	...

NOTE:
(1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.

01 TABLE C-1 (SI)
MODULI OF ELASTICITY FOR FERROUS MATERIAL

Material	E = Modulus of Elasticity, GPa [Note (1)]																	
	Temperature, °C																	
	–75	20	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
Carbon steels with carbon content 0.30% or less	208	203	201	198	195	191	189	185	179	172	162	150	136	122	107	...	...	...
Carbon steels with carbon content above 0.30%	207	202	200	197	194	190	188	184	178	171	161	149	135	121	106	...	...	...
Carbon-moly steels	206	201	199	196	193	189	187	183	177	170	160	149	135	121	106	...	...	...
Nickel steels	196	192	190	187	184	180	178	174	169	162	153	141	128	115	101	...	...	...
Chromium steels:																		
½Cr through 2Cr	210	205	204	201	197	193	190	186	181	176	170	160	148	133	...	...	...	...
2¼Cr through 3Cr	216	211	210	207	203	199	195	191	187	182	175	165	153	137	...	...	...	...
5Cr through 9Cr	219	213	212	209	205	201	197	193	189	185	181	176	171	164	156	147	138	...
Austenitic stainless steels:																		
Type 304—18Cr–8Ni Type 310—25Cr–20Ni Type 316—16Cr–12Ni–2Mo Type 321—18Cr–10Ni–Ti Type 347—18Cr–10Ni–Cb Type 309—23Cr–12Ni	201	195	194	192	188	184	180	176	172	168	164	160	156	152	146	140	134	127
Straight chromium stainless steels (12Cr, 17Cr, 27Cr)	208	201	200	198	194	190	186	181	178	174	167	156	144	130	113	...	...	...
Gray cast iron	...	92	92	91	89	87	85	82	78	73	67	...	...	...	...	...	...	...

NOTE:
(1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.

TABLE C-2 01
MODULI OF ELASTICITY FOR NONFERROUS MATERIAL

Materials	E = Modulus of Elasticity, psi (Multiply Tabulated Values by 10^6) [Note (1)]												
	Temperature, °F												
	−100	70	200	300	400	500	600	700	800	900	1000	1100	1200
High Nickel Alloys													
N02200 (200) N02201 (201)	30.9	30.0	29.3	28.8	28.5	28.1	27.8	27.3	26.7	26.1	25.5	25.1	24.5
N04400 (400)	26.8	26.0	25.4	25.0	24.7	24.3	24.1	23.7	23.1	22.6	22.1	21.7	21.2
N06002 (X)	29.4	28.5	27.8	27.4	27.1	26.6	26.4	25.9	25.4	24.8	24.2	23.7	23.2
N06600 (600)	31.9	31.0	30.2	29.9	29.5	29.0	28.7	28.2	27.6	27.0	26.4	25.9	25.3
N06625 (625)	30.9	30.0	29.3	28.8	28.5	28.1	27.8	27.3	26.7	26.1	25.5	25.1	24.5
N08800 (800) (2) N08810 (800H) (2)	29.4	28.5	27.8	27.4	27.1	26.6	26.4	25.9	25.4	24.8	24.2	23.8	23.2
N10001 (B)	32.0	31.1	30.3	29.9	29.5	29.1	28.8	28.3	27.7	27.1	26.4	26.0	25.3
N06007 (G)	28.6	27.8	27.1	26.7	26.4	26.0	25.7	25.3	24.7	24.2	23.6	23.2	22.7
N06455 (C-4)	30.6	29.8	29.1	28.6	28.3	27.9	27.6	27.1	26.5	25.9	25.3	24.9	24.3
N08320 (20 Mod)	28.6	27.8	27.1	26.7	26.4	26.0	25.7	25.3	24.7	24.2	23.6	23.2	22.7
N10276 (C276)	30.6	29.8	29.1	28.6	28.3	27.9	27.6	27.1	26.5	25.9	25.3	24.9	24.3
N10665 (B-2)	32.3	31.4	30.6	30.1	29.8	29.3	29.0	28.6	27.9	27.3	26.7	26.2	25.6
Aluminum and Aluminum Alloys													
A24430 (B443) A91060 (1060) A91100 (1100) A93003 (3003) A93004 (3034) A96061 (6061) A96063 (6063)	10.5	10.0	9.6	9.2	8.7	8.1	...	...	...	...	...	...	...
A95052 (5052) A95154 (5154) A95454 (5454) A95652 (5652)	10.7	10.2	9.7	9.4	8.9	8.3	...	...	...	...	...	...	...
A03560 (356) A95083 (5083) A95086 (5086) A95456 (5456)	10.8	10.3	9.8	9.5	9.0	8.3	...	...	...	...	...	...	...
Copper and Copper Alloys													
C83600 C92200	14.4	14.0	13.7	13.4	13.2	12.9	12.5	12.0	...	...	...	...	...
C46400 C65500 C95200 C95400	15.4	15.0	14.6	14.4	14.1	13.8	13.4	12.8	...	...	...	...	...

(continued)

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TABLE C-2
MODULI OF ELASTICITY FOR NONFERROUS MATERIAL (CONT'D)

Materials	E = Modulus of Elasticity, psi (Multiply Tabulated Values by 10^6 [Note (1)] Temperature, °F: −100	70	200	300	400	500	600	700	800	900	1000	1100	1200
Copper and Copper Alloys (Cont'd)													
C11000	16.5	16.0	15.6	15.4	15.0	14.7	14.2	13.7	...	...	...	...	...
C10200, C12000, C12200, C12500, C14200, C23000, C61400	17.5	17.0	16.6	16.3	16.0	15.6	15.1	14.5	...	...	...	...	...
C70600	18.5	18.0	17.6	17.3	16.9	16.6	16.0	15.4	...	...	...	...	...
C97600	19.6	19.0	18.5	18.2	17.9	17.5	16.9	16.2	...	...	...	...	...
C71000	20.6	20.0	19.5	19.2	18.8	18.4	17.8	17.1	...	...	...	...	...
C71500	22.7	22.0	21.5	21.1	20.7	20.2	19.6	18.8	...	...	...	...	...
Unalloyed Titanium													
Grades 1, 2, 3, 7, and 12	...	15.5	15.0	14.6	14.0	13.3	12.6	11.9	11.2	...	...	...	...

NOTES:
(1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.
(2) For N08800 and N08810, use the following E values above 1200°F: at 1300°F, $E = 22.7$; at 1400°F, $E = 21.9$; at 1500°F, $E = 21.2 \times 10^6$ psi.

TABLE C-2 (SI) 01
MODULI OF ELASTICITY FOR NONFERROUS MATERIAL

Materials	E = Modulus of Elasticity, GPa [Note (1)] — Temperature, °C																	
	−75	20	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
High Nickel Alloys																		
N02200 (200) N02201 (201)	214	207	205	202	199	197	194	191	189	186	183	180	176	172	169	164	161	156
N04400 (400)	185	179	178	175	173	170	168	166	164	161	158	156	153	149	146	142	139	135
N06002 (X)	203	197	195	192	189	187	184	182	179	177	174	171	167	163	160	156	153	148
N06600 (600)	221	214	212	209	206	203	200	198	195	192	189	186	182	178	174	170	166	161
N06625 (625)	214	207	205	202	199	197	194	191	189	186	183	180	176	172	169	164	161	156
N08800 (800) N08810 (800H)	203	197	195	192	189	187	184	182	179	177	174	171	167	163	160	156	153	148
N10001 (B)	222	214	213	210	207	204	201	198	196	193	190	186	182	178	175	170	167	161
N06007 (G)	198	192	190	187	185	182	180	177	175	172	169	167	163	159	156	152	149	144
N06455 (C-4)	212	205	204	201	198	195	193	190	188	185	182	179	175	171	167	163	160	155
N08320 (20Mod)	198	192	190	187	185	182	180	177	175	172	169	167	163	159	156	152	149	144
N10276 (C-276)	212	205	204	201	198	195	193	190	188	185	182	179	175	171	167	163	160	155
N10665 (B-2)	224	217	215	212	209	206	203	200	198	195	191	188	184	180	176	172	168	163
Aluminum and Aluminum Alloys																		
A24430 (B443) A91060 (1060) A91100 (1100) A93003 (3003) A93004 (3034) A96061 (6061) A96063 (6063)	72	69	68	66	63	61	57	52	46	...	...	...	...	...	...	...	...	...
A95052 (5052) A95154 (5154) A95454 (5454) A95652 (5652)	74	70	69	67	65	62	58	53	47	...	...	...	...	...	...	...	...	...
A03560 (356) A95083 (5083) A95086 (5086) A95456 (5456)	74	71	70	68	65	62	58	54	47	...	...	...	...	...	...	...	...	...
Copper and Copper Alloys																		
C83600 C92200	99	97	96	94	93	91	89	87	84	81	...	...	...	...	...	...	...	...
C46400 C65500 C95200 C95400	107	103	102	101	99	98	96	93	90	86	...	...	...	...	...	...	...	...

(continued)

01

TABLE C-2 (SI)
MODULI OF ELASTICITY FOR NONFERROUS MATERIAL (CONT'D)

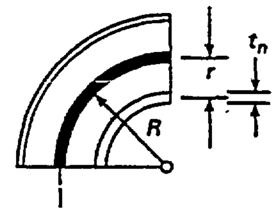
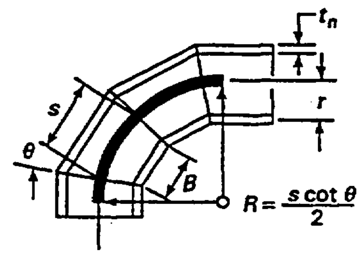
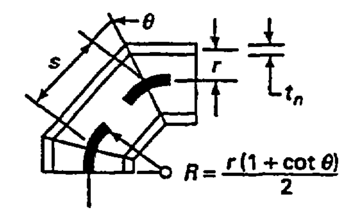
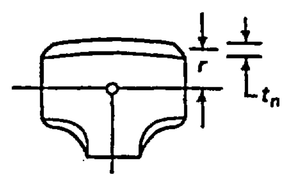
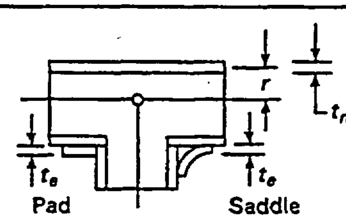
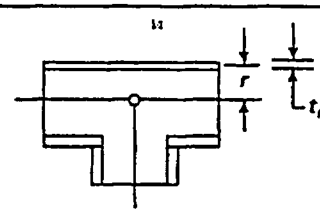
	E = Modulus of Elasticity, GPa [Note (1)]																	
	Temperature, °C																	
Materials	−75	20	50	100	150	200	250	300	350	400	450	500	550	600	650	700	750	800
Copper and Copper Alloys (Cont'd)																		
C11000	114	110	109	108	106	104	102	99	96	92	...	...	...	...	...	...	...	...
C10200, C12000, C12200, C12500, C14200, C23000, C61400	121	117	116	115	113	111	108	106	102	98	...	...	...	...	...	...	...	...
C70600, C97600, C71000, C71500	128	124	123	121	119	117	115	112	108	104	...	...	...	...	...	...	...	...
Unalloyed Titanium																		
Grades 1, 2, 3, 7, and 12	...	107	106	103	100	97	92	88	84	79	75	71	...	...	...	...	...	...

NOTE:
(1) These data are for information and it is not to be implied that materials are suitable for all the temperature ranges shown.

APPENDIX D

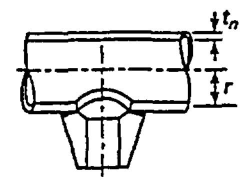
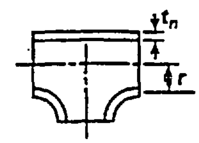
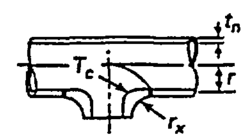
Begins on Next Page

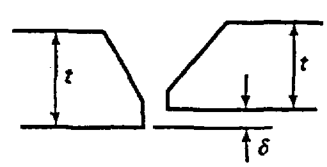
TABLE D-1
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS

Description	Flexibility Characteristic h	Flexibility Factor k	Stress Intensification Factor i	Sketch
Welding elbow or pipe bend [Notes (1), (2), (3), (9), (13)]	$\frac{t_n R}{r^2}$	$\frac{1.65}{h}$	$\frac{0.9}{h^{2/3}}$	
Closely spaced miter bend [Notes (1), (2), (3), (13)] $s < r(1 + \tan\theta)$ $B \geq 6\ t_n$ $\theta \leq 22\frac{1}{2}$ deg.	$\frac{s t_n \cot\theta}{2r^2}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Widely spaced miter bend [Notes (1), (2), (4), (13)] $s \geq r(1 + \tan\theta)$ $\theta \leq 22\frac{1}{2}$ deg.	$\frac{t_n(1 + \cot\theta)}{2r}$	$\frac{1.52}{h^{5/6}}$	$\frac{0.9}{h^{2/3}}$	
Welding tee per ASME B16.9 [Notes (1), (2), (10)]	$\frac{4.4 t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Reinforced fabricated tee [Notes (1), (2), (5), (10)]	$\frac{\left(t_n + \frac{t_e}{2}\right)^{5/2}}{r(t_n)^{3/2}}$	1	$\frac{0.9}{h^{2/3}}$	
Unreinforced fabricated tee [Notes (1), (2), (10)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

(continued)

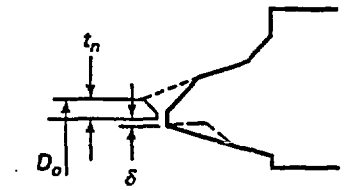
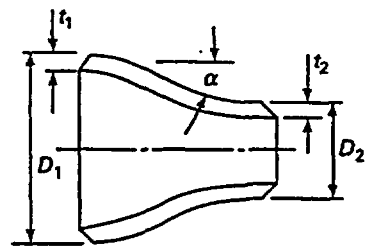
TABLE D-1
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS (CONT'D)

Description	Flexibility Characteristic h	Flexibility Factor k	Stress Intensification Factor i	Sketch
Branch welded-on fitting (integrally reinforced) per MSS SP-97 [Notes (1), (2)]	$\frac{3.3 t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Extruded outlet meeting the requirements of para. 104.3.1(G) [Notes (1), (2)]	$\frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	
Welded-in contour insert with $r_x \geq D_{ob}/8$ $T_c \geq 1.5\ t_n$ [Notes (1), (2)]	$4.4\ \frac{t_n}{r}$	1	$\frac{0.9}{h^{2/3}}$	

Description	Flexibility Factor k	Stress Intensification Factor i	Sketch
Branch connection [Notes (1), (6)]	1	For checking branch end $1.5\left(\frac{R_m}{t_{nh}}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{t_{nb}}{t_{nh}}\right)\left(\frac{r'_m}{r_p}\right)$	See Fig. D-1
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.13$	1	1.0 [Note (12)]	
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/8$ in., and δ_{avg}/t = any value	1	1.9 max. or $[0.9 + 2.7(\delta_{avg}/t)]$, but not less than 1.0 [Note (12)]	
Butt weld [Note (1)] $t \geq 0.237$ in., $\delta_{max} \leq 1/16$ in., and $\delta_{avg}/t \leq 0.33$	1		
Fillet welds	1	2.1; or 1.3 for fillet welds as defined in Note (11)	See Figs. 127.4.4(A), 127.4.4(B), and 127.4.4(C)

(continued)

TABLE D-1
FLEXIBILITY AND STRESS INTENSIFICATION FACTORS (CONT'D)

Description	Flexibility Factor k	Stress Intensification Factor i	Sketch
Tapered transition per para. 127.4.2(B) and ASME B16.25 [Note (1)]	1	1.9 max. or $1.3 + 0.0036\frac{D_o}{t_n} + 3.6\frac{\delta}{t_n}$	
Concentric reducer per ASME B16.9 [Note (7)]	1	2.0 max. or $0.5 + 0.01\alpha\left(\frac{D_2}{t_2}\right)^{1/2}$	
Threaded pipe joint, or threaded flange	1	2.3	...
Corrugated straight pipe, or corrugated or creased bend [Note (8)]	5	2.5	...

NOTES:

(1) The following nomenclature applies to Table D-1:

- B = length of miter segment at crotch, in. (mm)
- D_o = outside diameter, in.
- D_{ob} = outside diameter of branch, in. (mm)
- R = bend radius of elbow or pipe bend, in. (mm)
- r = mean radius of pipe, in. (mm) (matching pipe for tees)
- r_x = external crotch radius of welded-in contour inserts, in. (mm)
- s = miter spacing at center line, in. (mm)
- T_c = crotch thickness of welded-in contour inserts, in. (mm)
- t_n = nominal wall thickness of pipe, in. (mm) (matching pipe for tees)
- t_r = reinforcement pad or saddle thickness, in. (mm)
- α = reducer cone angle, deg.
- δ = mismatch, in. (mm)
- θ = one-half angle between adjacent miter axes, deg.

(2) The flexibility factors k and stress intensification factors i in Table D-1 apply to bending in any plane for fittings and shall in no case be taken less than unity. Both factors apply over the effective arc length (shown by heavy center lines in the sketches) for curved and miter elbows, and to the intersection point for tees. The values of k and i can be read directly from Chart D-1 by entering with the characteristic h computed from the formulas given.

(3) Where flanges are attached to one or both ends, the values of k and i in Table D-1 shall be multiplied by the factor c given below, which can be read directly from Chart D-2, entering with the computed h: one end flanged, $c = h^{1/6}$; both ends flanged, $c = h^{1/3}$.

(4) Also includes single miter joints.

(5) When $t_r > 1.5t_n$, $h = 4.05t_n/r$.

TABLE D-1 (CONT'D)

NOTES (CONT'D):

(6) The equation applies only if the following conditions are met.
  (*a*) The reinforcement area requirements of para. 104.3 are met.
  (*b*) The axis of the branch pipe is normal to the surface of run pipe wall.
  (*c*) For branch connections in a pipe, the arc distance measured between the centers of adjacent branches along the surface of the run pipe is not less than three times the sum of their inside radii in the longitudinal direction or is not less than two times the sum of their radii along the circumference of the run pipe.
  (*d*) The inside corner radius r_1 (see Fig. D-1) is between 10% and 50% of t_{nh}.
  (*e*) The outer radius r_2 (see Fig. D-1) is not less than the larger of $T_b/2$, $(T_b + y)/2$ [shown in Fig. D-1 sketch (c)], or $t_{nh}/2$.
  (*f*) The outer radius r_3 (see Fig. D-1) is not less than the larger of:
    (1) $0.002\theta d_o$;
    (2) $2(\sin\theta)^3$ times the offset for the configurations shown in Fig. D-1 sketches (a) and (b).
  (*g*) $R_m/t_{nh} \leq 50$ and $rt_m/R_m \leq 0.5$.

(7) The equation applies only if the following conditions are met:
  (*a*) Cone angle α does not exceed 60 deg., and the reducer is concentric.
  (*b*) The larger of D_1/t_1 and D_2/t_2 does not exceed 100.
  (*c*) The wall thickness is not less than t_1 throughout the body of the reducer, except in and immediately adjacent to the cylindrical portion on the small end, where the thickness shall not be less than t_2.

(8) Factors shown apply to bending; flexibility factor for torsion equals 0.9.

(9) The designer is cautioned that cast butt welding elbows may have considerably heavier walls than those of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(10) The stress intensification factors in the Table were obtained from tests on full size outlet connections. For less than full size outlets, the full size values should be used until more applicable values are developed.

(11) A stress intensification factor of 1.3 may be used for socket weld fitting if toe weld blends smoothly with no undercut in pipe wall as shown in the concave, unequal leg fillet weld of Fig. 127.4.4(A).

(12) The stress intensification factors apply to girth butt welds between two items for which the wall thicknesses are between $0.875t$ and $1.10t$ for an axial distance of $\sqrt{D_o t}$. D_o and t are nominal outside diameter and nominal wall thickness, respectively. δ_{avg} is the average mismatch or offset.

(13) In large diameter thin-wall elbows and bends, pressure can significantly affect magnitudes of k and i. Values from the table may be corrected by dividing k by

$$\left[1 + 6\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{7/3}\left(\frac{R}{r}\right)^{1/3}\right]$$

and dividing i by

$$\left[1 + 3.25\left(\frac{P}{E_c}\right)\left(\frac{r}{t_n}\right)^{5/2}\left(\frac{R}{r}\right)^{2/3}\right]$$

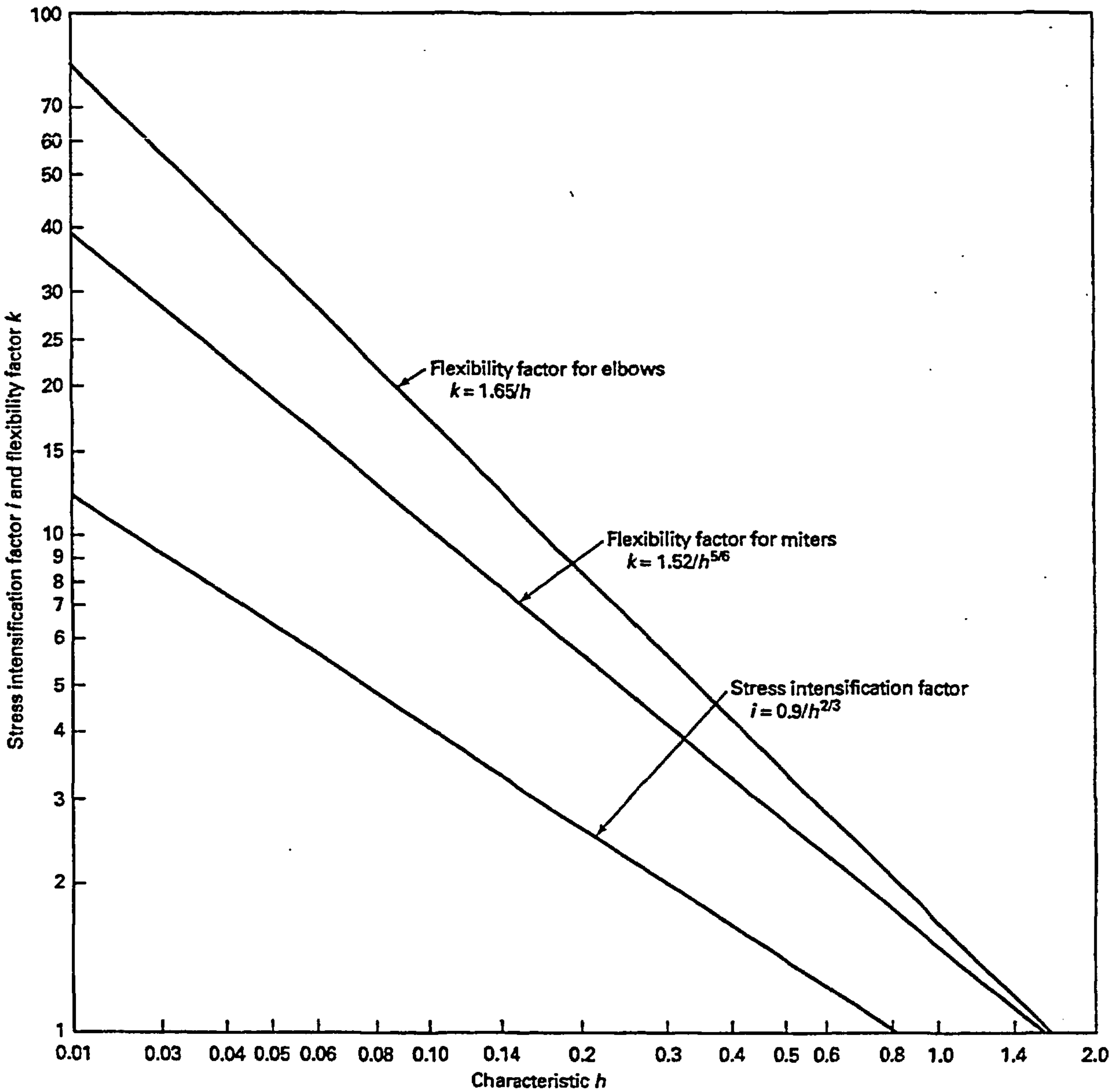


CHART D-1 FLEXIBILITY FACTOR k AND STRESS INTENSIFICATION FACTOR i

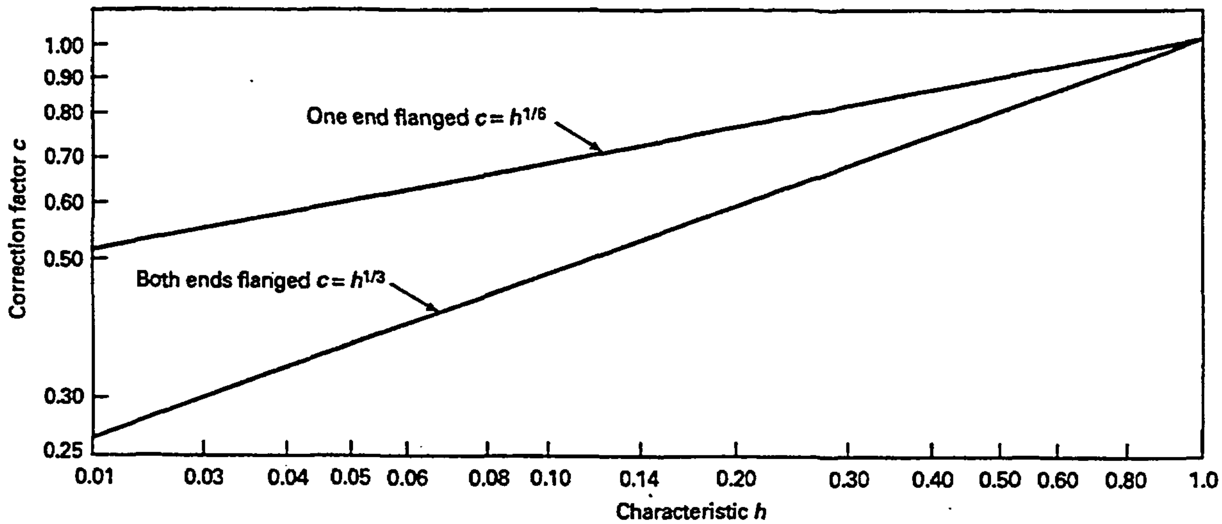
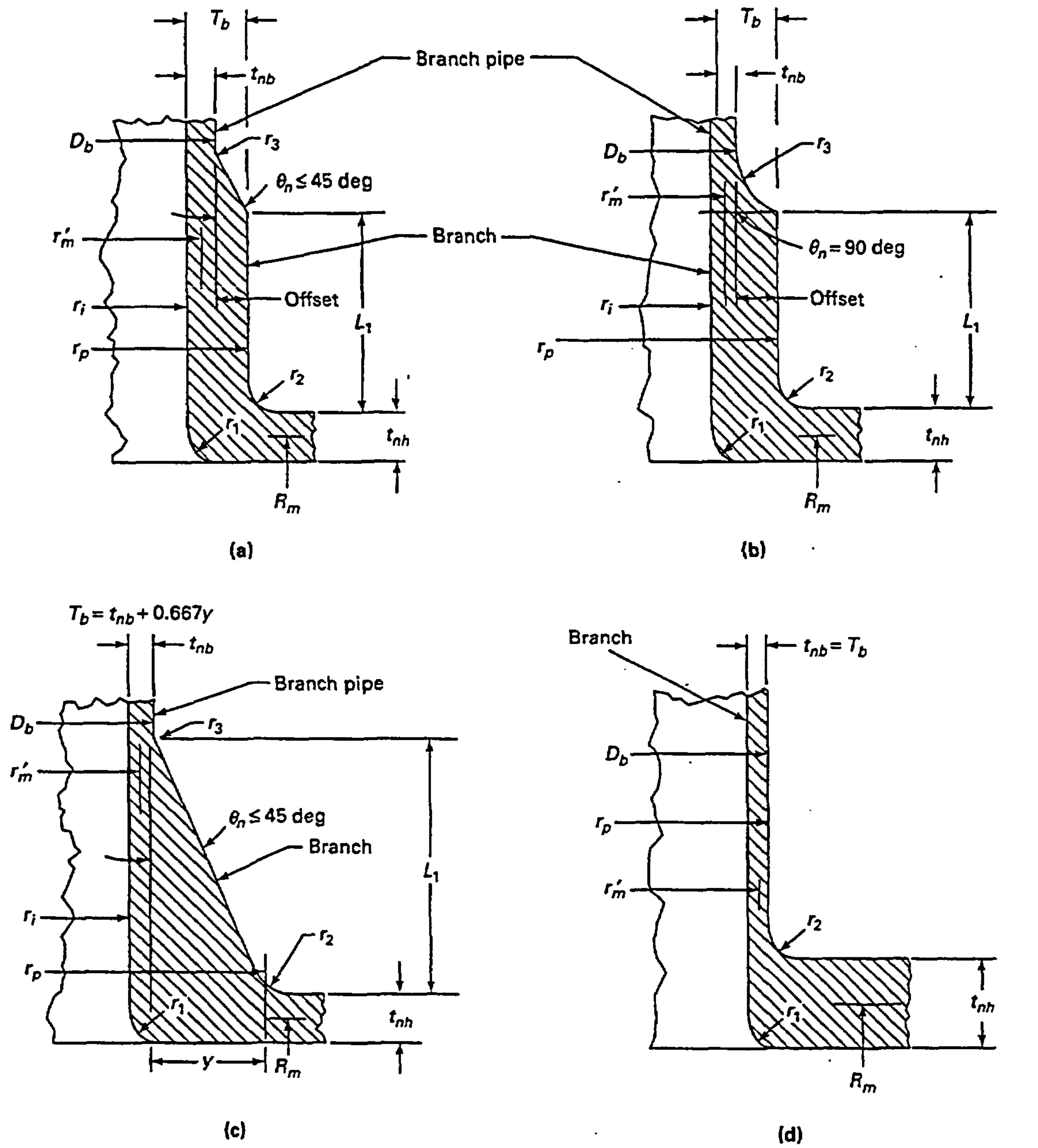


CHART D-2 CORRECTION FACTOR c



D_b = outside diameter of branch pipe, in. (mm)
L_1 = height of nozzle, in. (mm)
R_m = mean radius of run pipe, in. (mm)
T_b = effective thickness of branch reinforcement, in. (mm)
r_1 = inside radius of branch, in. (mm)
r'_m = mean radius of branch pipe, in. (mm)
r_1, r_2, r_3 = transition radii of branch reinforcement, in. (mm)
r_p = outside radius of branch reinforcement, in. (mm)
t_{nb} = nominal thickness of branch pipes, in. (mm)
t_{nh} = nominal thickness of run pipe, in. (mm)
θ_n = transition angle of branch reinforcement, deg

FIG. D-1 BRANCH CONNECTION DIMENSIONS

APPENDIX F
REFERENCED STANDARDS[1]
ASME B31.1-2001, POWER PIPING

Specific editions of standards incorporated in this Code by reference are shown in this issue of Appendix F. It is not practical to refer to a specific edition of each standard throughout the Code text, but instead, the specific edition reference dates are shown here. Appendix F will be revised at intervals as needed and issued. The names and addresses of the sponsoring organizations are also shown in this issue.

American National Standards

B1.20.3-1976 (R81)
B16.18-1984 (R94)
B18.2.1-1981 (R92)
B18.2.4.6M-1979 (R90)
B18.22M-1981
B18.22.1-1965 (R81)
Z223.1-1996

ASTM Specifications [Note (2)]

A 36-89
A 47-84 (R89)
A 48-83
A 53-90A

A 105-87a
A 106-90
A 125-81
A 126-84
A 134-89a
A 135-89a
A 139-89b
A 178-90
A 179-90
A 181-87
A 182-90
A 192-90
A 193-90
A 194-88a
A 197-87
A 199-89

A 210-90
A 211-75 (R85)
A 213-90
A 214-90
A 216-89
A 217-89

ASTM Specifications [Note (2)] (Cont'd)

A 226-90
A 229-83
A 234-90a
A 240-89b
A 242-89
A 249-90
A 254-90
A 268-90a
A 276-89a
A 278-85
A 283-87
A 285-82 (R87)
A 299-82 (R87)

A 307-90
A 312-89a
A 320-90
A 322-90
A 333-88a
A 335-89a
A 350-89a
A 351-89b
A 354-90
A 358-88a
A 369-89
A 376-88
A 377-89
A 387-90
A 389-89
A 395-88

A 403-89
A 409-95a
A 420-90a
A 426-89
A 430-88
A 437-88

ASTM Specifications [Note (2)] (Cont'd)

A 449-93
A 450-89
A 451-80 (R85)
A 452-88
A 453-88a
A 479-89

A 515-82 (R87)
A 516-86
A 530-89
A 564-89
A 575-86a
A 576-90
A 587-89a

A 671-85
A 672-89a
A 691-85a

A 714-89a

B 26-88
B 32-89
B 42-89
B 43-88
B 61-86
B 62-86
B 68-86
B 75-86
B 88-88a

B 108-87
B 111-88
B 148-90a
B 150-86
B 151-94

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REFERENCED STANDARDS (CONT'D)

ASTM Specifications [Note (2)] (Cont'd)

B 161-87
B 163-89
B 165-87
B 167-90
B 168-90

B 209-89
B 210-88
B 221-88
B 234-88
B 241-88
B 247-88
B 251-88
B 265-89
B 280-86
B 283-89

B 302-87
B 315-86
B 337-83
B 338-83
B 348-83
B 361-88
B 366-93
B 367-83
B 381-83

B 402-86
B 407-88
B 408-87
B 409-87
B 423-90
B 424-87
B 425-90
B 462-89
B 463-84
B 464-89
B 466-86
B 467-88
B 468-89
B 473-87

B 547-88
B 564-88
B 584-98A

B 608-88
B 625-93
B 649-93
B 673-91
B 674-91
B 677-91

B 729-87

ASTM Standard Test Methods

D 323-99

E 125-63 (R85)
E 186-91
E 280-93
E 446-91

MSS Standard Practices

SP-6-96
SP-9-97
SP-25-98
SP-42-90
SP-43-91
SP-45-98
SP-51-91
SP-53-95
SP-54-95
SP-55-96
SP-58-93
SP-61-92
SP-67-95
SP-69-96
SP-75-98
SP-79-92
SP-80-97
SP-89-98
SP-93-87
SP-94-92
SP-97-95
SP-105-96

AWS Specifications

A3.0-94
QC1-88

API Specifications

5L, 38th Edition, 1990

ASME Codes and Standards

Boiler and Pressure Vessel Code, 1992 Edition, including Addenda
B1.1-1989
B1.13M-1995
B1.20.1-1983 (R92)
(ANSI/ASME B1.20.1)
B16.1-1989
(ASME/ANSI B16.1)
B16.3-1992
B16.4-1992

ASME Codes and Standards (Cont'd)

B16.5-1988
(ASME/ANSI B16.5)
B16.9-1993
B16.10-1992
B16.11-1991
B16.14-1991
B16.15-1985 (R94)
(ANSI/ASME B16.15)
B16.20-1993
B16.21-1992
B16.24-1991
B16.25-1992
B16.28-1994
B16.34-1996
B16.42-1987
(ASME/ANSI B16.42)
B16.47-1990
B16.48-1997
B18.2.2-1987 (R93)
(ASME/ANSI B18.2.2)
B18.2.3.5M-1979 (R95)
B18.2.3.6M-1979 (R95)
B18.21.1-1994
B31.3-1996
B31.4-1992
B31.8-1995
B36.10M-1996
B36.19M-1985 (R94)
(ANSI/ASME B36.19M)
TDP-1-1985

ASNT Specifications

CP-189-95
SNT-TC-1A (1992)

AWWA and ANSI/AWWA Standards

C-110/A21.10-87
C-111/A21.11-90
C-115/A21.15-88
C-150/A21.50-91
C-151/A21.51-91

C-200-91
C-207-86
C-208-89

C-300-89
C-301-84
C-302-87

REFERENCED STANDARDS (CONT'D)

AWWA and ANSI/AWWA Standards (Cont'd)	National Fire Codes	PFI Standard
	NFPA 8503-92	ES-16-94
C-400-86	NFPA 1963-93	
C-500-86		
C-504-87		
C-600-87		
C-606-87		

NOTES:

(1) The issue date shown immediately following the hyphen after the number of the standard (e.g., B1.1-1989, A 36-89, SP-6-90) is the effective date of issue (edition) of the standard. B18.2.2-1987 (R93) designates specification reaffirmed without change in 1993.

(2) For boiler external piping material application, see para. 123.2.2.

Specifications and standards of the following organizations, appear in this Appendix:

ANSI American National Standards Institute
11 W 42nd Street
New York, NY 10036
Phone: 212 642-4900

API American Petroleum Institute
1220 L Street, NW
Washington, DC 20005
Phone: 202 682-8000

ASME The American Society of Mechanical Engineers
Three Park Avenue
New York, NY 10016-5990

ASME Order Department
22 Law Drive
Box 2300
Fairfield, NJ 07007-2300
Phone: 201 882-1167
800-THE-ASME (US & Canada)
Fax: 201 882-1717, 5155

ASNT American Society of Nondestructive Testing
1711 Arlingate Lane
PO Box 28518
Columbus, OH 43228-0518
Phone: 614 274-6003

ASTM American Society for Testing and Materials
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959
Phone: 610 832-9585
Fax: 610 832-9555

AWS American Welding Society
550 NW LeJeune Road
PO Box 351040
Miami, FL 33135
Phone: 305 443-9353

AWWA American Water Works Association
6666 W. Quincy Avenue
Denver, CO 80235
Phone: 303 794-7711

MSS Manufacturers Standardization Society of the Valve and Fittings Industry, Inc.
127 Park Street, NE
Vienna, VA 22180
Phone: 703 281-6613

NFPA National Fire Protection Association
1 Batterymarch Park
PO Box 9101
Quincy, MA 02269-9101
Phone: 617 770-3000
Fax: 617 770-0700

PFI Pipe Fabrication Institute
PO Box 173
Springdale, PA 15144
Phone: 412 274-4722

PPI Plastic Pipe Institute
1275 K Street, NW
Suite 400
Washington, DC 20005
Phone: 202 371-5200
Fax: 202 371-1022

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APPENDIX G
NOMENCLATURE

This Appendix is a compilation of the nomenclature used within this Code. Included are the term definitions and units that can be uniformly applied. These terms are also defined at a convenient location within the Code. When used elsewhere within the Code, definitions given here shall be understood to apply.

		Units		References	
Symbol	Definition	US	SI	Paragraph	Table/Fig./App.
A	Corrosion, erosion, and mechanical allowances (including threading, grooving)	in.	mm	104.1.2(A)[Eqs.(3), (3A), (4), (4A)] 104.4.1(B) 104.5.2(B) 104.5.3(A) 104.3.1	...
Area available for reinforcement:					
A_1	in run pipe	in.^{2}	mm^2	104.3.1(D.2)	104.3.1(D) 104.3.1(G)
A_2	in branch pipe	in.^{2}	mm^2	104.3.1(D.2)	104.3.1(D) 104.3.1(G)
A_3	by deposited metal beyond outside diameter of run and branch and for fillet weld attachments of rings, pads, and saddles	in.^{2}	mm^2	104.3.1(d.2)	104.3.1(D)
A_4	by reinforcing ring, pad, or integral reinforcement	in.^{2}	mm^2	104.3.1(D.2)	104.3.1(D) 104.3.1(G)
A_5	in saddle on right angle connection	in.^{2}	mm^2	104.3.1(D.2)	104.3.1(D)
A_7	Required reinforcement area	in.^{2}	mm^2	104.3.1(D.2)	104.3.1(D) 104.3.1(G)
b	Subscript referring to branch	...	...	104.3.1(D.2)	104.3.1(D)
c	Flanged elbow correction factor	...	...	...	Table D-1 Chart D-2
C	Cold-spring factor	...	...	119.10.1[Eqs. (9), (10)]	...
C_x	Size of fillet weld for socket welding components other than flanges	in.	mm	...	127.4.4(C)
d	Inside diameter of pipe	in.	mm	104.1.2(A)[Eqs. (3A), (4A)]	...
d_1	Inside center line longitudinal direction of the finished branch opening in the run of the pipe	in.	mm	...	104.3.1(D)
d_2	Half-width of reinforcement zone	in.	mm	104.3.1(D.2)	104.3.1(D)
d_5	Diameter of finished opening	in.	mm	104.4.1(C)	...
d_6	Inside or pitch diameter of gasket	in.	mm	104.5.3(A)	...
d_b	Corroded internal diameter of branch pipe	in.	mm	104.3.1(G.4)	104.3.1(G)

NOMENCLATURE (CONT'D)

Symbol	Definition	Units US	Units SI	References Paragraph	References Table/Fig./App.
d_c	Corroded internal diameter of extruded outlet	in.	mm	104.3.1(G.4)	104.3.1(G)
d_n	Nominal inside diameter of pipe	in.	mm	102.3.2(D)	...
d_r	Corroded internal diameter of run	in.	mm	104.3.1(G.4)	104.3.1(G)
D	Nominal pipe size	in.	mm	119.7.1(A.3)	...
D_n	Nominal outside diameter of pipe	in.	mm	102.3.2(D)	...
D_o	Outside diameter of pipe	in.	mm	102.3.2(D) 104.1.2(A)[Eqs. (3), (4)] 104.3.1(D.2) 104.8.1[Eqs. (11a), (11b)] 104.8.2[Eqs. (12a), (12b)]	App. D
D_{ob}	Outside diameter of branch	in.	mm	...	App. D
E	Weld joint efficiency factor	...	...	104.1.2(A)[Eqs (3), (3A), (4), (4A)] 104.4.1(B)	102.4.3 App. A Notes to Tables A-1 thru A-4 and A-7
E	Young's modulus of elasticity (used with subscripts)	psi	MPa	119.6.2 119.6.4 119.10.1[Eqs. (9), (10)]	App. C
F	Casting quality factor	...	...	104.1.2(A)	App. A Notes to Tables A-1 thru A-7
f	Stress range reduction factor	...	...	102.3.2(C) 104.8.3[Eqs. (13a), (13b)]	102.3.2(C)
h	Subscript referring to run or header	...	...	104.3.1(D.2)	104.3.1(D)
h	Flexibility characteristic, to compute i, k	...	...	...	App. D
h_o	Height of extruded lip	in.	mm	104.3.1(G.4)	104.3.1(G)
i	Stress intensification factor	...	...	104.8.1[Eqs. (11a), (11b)] 104.8.2[Eqs. (12a), (12b)] 104.8.3[Eqs. (13a), (13b)]	App. D
k	Factor for Occasional Loads	...	...	104.8.2[Eqs. (12a), (12b)]	...
k	Flexibility factor	...	...	...	App. D

NOMENCLATURE (CONT'D)

Symbol	Definition	Units US	Units SI	References Paragraph	References Table/Fig./App.
L	Developed length of line axis	ft	m	119.7.1(a.3)	...
L_4	Altitude of reinforcing zone outside run pipe	in.	mm	104.3.1(D.2)	104.3.1(D)
L_8	Altitude of reinforcing zone for extruded outlet	in.	mm	104.3.1(G.4)	104.3.1(G)
M	Moment of bending or torsional force (used with subscripts to define applications as shown in referenced paragraphs)	in.-lb, ft-lb	N-mm	104.8.1[Eqs. (11a), (11b)] 104.8.2[Eqs. (12a), (12b)] 104.8.3[Eqs. (13a), (13b)] 104.8.4	104.8.4
MAWP	Maximum Allowable Working Pressure	psi	kPa	100.2	...
MSOP	Maximum sustained operating pressure	psi	kPa	101.2.2 102.2.3 122.1.1(B) 122.1.2(A)	...
N	Equivalent full temperature cycles	...	...	102.3.2(C)[Eq. (2)]	102.3.2(C)
N_n	Number of cycles of lesser temperature change, $n = 1, 2, \ldots$	...	...	102.3.2(C)[Eq. (2)]	...
N_E	Number of cycles of full temperature change	...	...	102.3.2(C)[Eq. (2)]	...
NPS	Nominal pipe size	in.	...	General	...
P	Internal design gage pressure of pipe, component	psi	kPa	101.2.2 102.3.2(D) 104.1.2(A)[Eqs. (3), (3A), (4), (4A)] 104.4.1(B) 104.5.1(A) 104.5.2(B) 104.5.3(A)[Eq. (7)] 104.8.1[Eqs. (11a), (11b)] 122.1.2(A) 122.1.3(A) 122.1.4(B) 122.1.6(B)	...
r	ratio of partial T to maximum T (used with subscripts)	...	...	102.3.2(C)[Eq. (2)]	...
r	Mean radius of pipe using nominal wall t_n	in.	mm	104.3.3	App. D
r_1	Half width of reinforcement zone	in.	mm	104.3.1(G.4)	104.3.1(G)
r_b	Branch mean cross-sectional radius	in.	mm	104.8.4	...
r_o	Radius of curvature of external curved portion	in.	mm	104.3.1(G.4)	104.3.1(G)
r_x	External crotch radius of welded-in contour inserts	in.	mm	...	App. D
R	Reaction moment in fexibility analysis (used with subscripts)	in.-lb, ft-lb	N-mm	119.10.1[Eqs. (9), (10)]	...

NOMENCLATURE (CONT'D)

Symbol	Definition	Units		References	
		US	SI	Paragraph	Table/Fig./App.
R	Center line radius of elbow or bend, and effective "radius" of miter bends	in.	mm	104.3.3(C.3.1)	App. D
s	Miter spacing pipe center line	in.	mm	104.3.3(C.3.1)	App. D
S	Basic material allowable stress	psi	MPa	102.3.1(A) 121.1.2(A) 122.1.3(A)	App. A Notes to Tables A-1 thru A-7
S_a	Bolt design stress at atmospheric temperature	psi	kPa	104.5.1(A)	...
S_b	Bolt design stress at design temperature	psi	kPa	104.5.1(A)	...
S_c	Basic material allowable stress at minimum (cold) temperature	psi	MPa	102.3.2(C)[Eq. (1)]	...
S_f	Allowable stress for flange material or pipe	psi	kPa	104.5.1(A)	...
S_h	Basic material allowable stress at maximum (hot) temperature	psi	MPa	102.3.2(C) 102.3.2(D) 104.8.1[Eq. (11a)] 104.8.2[Eqs. (12a), (12b)] 119.10.1	...
S_{lp}	Longitudinal pressure stress	psi	MPa	102.3.2(D) 104.8	...
S_A	Allowable stress range for expansion stress	psi	MPa	102.3.2(C)[Eq. (1)] 104.8.3[Eqs. (13a), (13b)]	...
S_E	Computed thermal expansion stress range	psi	MPa	104.8.3[Eqs. (13a), (13b)] 119.10.1[Eq. (10)]	...
SE	Allowable stress (including weld joint efficiency factor)	psi	MPa	102.3.1(A) 104.1.2(A)[Eqs. (3), (3A), (4), (4A)] 104.4.1(B) 104.5.2(B)[Eq. (6)] 104.5.3(A)[Eq. (7)]	App. A
SF	Allowable stress (including casting quality factor)	psi	MPa	104.1.2(A)	...
S_L	Longitudinal stress due to pressure, weight, and other sustained loads	psi	kPa	102.3.2(D) 104.8.1[Eqs. (11A), (11B)]	...
t	Pressure design thickness pipe, components (used with subscripts)	in.	mm	104.1.2(A)[Eqs. (3), (3A), (4), (4A)] 104.3.1(D.2) 104.3.1(G.4) 104.3.3(C.3.1)	

NOMENCLATURE (CONT'D)

Symbol	Definition	Units US	Units SI	References Paragraph	References Table/Fig./App.
				104.3.3(C.3.2) 104.4.1(B) 104.5.2(B) 104.5.3(A)[Eq. (7)] 104.8.1 104.8.4(C) 127.4.8(B) 132.4.2(E)	104.3.1(G) 104.5.3 127.4.8(D)
t_b	Required thickness of branch pipe	in.	mm	104.3.1(G.4)	104.3.1(G)
t_c	Throat thickness of cover fillet weld, branch conn.	in.	mm	127.4.8(B) 132.4.2(E)	127.4.8(D)
t_e	Effective branch wall thickness	in.	mm	104.8.4(C)	...
t_h	Required thickness of header or run	in.	mm	104.3.1(G)	104.3.1(D) 104.3.1(G)
t_m	Minimum required thickness of component, including allowances (c) for mechanical joining, corrosion, etc. (used with subscripts), viz., t_{mb}=minimum thickness of branch t_{mh}=minimum thickness of header	in.	mm	104.1.2(A)[Eqs. (3), (3A), (4), (4A)] 104.3.1(D.2) 104.3.1(G) 104.3.1(G.4) 104.3.3(C.3.1) 104.3.3(C.3.2) 104.4.1(B) 104.5.2(B)[Eq. (6)] 104.5.3(A)	127.4.2 104.3.1(D) 104.3.1(G)
t_n	Nominal wall thickness of component (used with subscripts), viz., t_{nb}=nominal wall thickness of branch t_{nh}=nominal wall thickness of header t_{nr}=nominal thickness of reinforcement	in.	mm	102.3.2(D) 104.3.3 104.8.1 104.8.4 127.4.8(B) 132.4.2(E)	127.4.4(B), (C) 127.4.8(D) App. D
t_p	Pressure design thickness	in.	mm	104.5.3(A)[Eq. (7)]	...
t_r	Thickness of reinforcing pad or saddle	in.	mm	104.3.1(D.2) 127.4.8(B)	104.3.1(D) 127.4.8(D) Table D
t_s	Wall thickness of segment or miter	in.	mm	104.3.3(C.3)	App. D
t_w	Weld thickness	in.	mm	104.3.1(C.2)	127.4.8(F)
T	Pipe wall thickness (measured or minimum, in accordance with purchase specification used with or without subscripts), viz., T_b=thickness of branch T_h=thickness of header, etc	in.	mm	104.3.1(D.2) 104.3.1(G.4)	104.3.1(D) 104.3.1(G) App. D
T_c	Crotch thickness of welded-in contour inserts	in.	mm	...	App. D

NOMENCLATURE (CONT'D)

Symbol	Definition	Units		References	
		US	SI	Paragraph	Table/Fig./App.
T_o	Corroded finished thickness extruded outlet	in.	mm	104.3.1(G.4)	104.3.1(G)
U	Anchor distance (length of straight line joining anchors)	ft	m	119.7.1(A.3)	...
$x_{min.}$	Size of fillet weld for slip-on and socket welding flanges or socket wall for socket welds	in.	mm	...	127.4.4(B)
y	A coefficient having values given in Table 104.1.2(A)	...	...	104.1.2[Eqs. (3), (3A), (4), (4A)]	104.1.2(A)
Y	Resultant of movement to be absorbed by pipelines	...	...	119.7.1(A.3)	...
Z	Section modulus of pipe	$in.^3$	mm^3	104.8.1[Eqs. (11a), (11b)] 104.8.2[Eqs. (12a), (12b)] 104.8.3[Eqs. (13a), (13b)]	104.8.4(C)
α	Angle between axes of branch and run	deg	deg	104.3.1(D.2)	104.3.1(D)
α	Reducer cone angle	deg	deg	...	Table D-1
β	Length of segment at crotch	in.	mm	...	App. D
δ	Mismatch or offset	in.	mm	127.3.1(C)	App. D
ΔT	Range of temperature change	°F	°C	102.3.2(C)	...
θ	Angle of miter cut	deg	deg	104.3.3	App. D
$\geq$	Equal to or greater than	...	...	...	...
$\leq$	Equal to or less than	...	...	...	...

APPENDIX H
PREPARATION OF TECHNICAL INQUIRIES

H-1 INTRODUCTION

The ASME B31 Committee, Code for Pressure Piping, will consider written requests for interpretations and revisions of the Code rules, and develop new rules if dictated by technical development. The Committee's activities in this regard are limited strictly to interpretations of the rules or to the consideration of revisions to the present rules on the basis of new data or technology. The Introduction to this Code states "It is the owner's responsibility to determine which Code Section is applicable to a piping installation." The Committee will not respond to inquiries requesting assignment of a Code Section to a piping installation. As a matter of published policy, ASME does not approve, certify, rate, or endorse any item, construction, proprietary device, or activity, and, accordingly, inquiries requiring such consideration will be returned. Moreover, ASME does not act as a consultant on specific engineering problems or on the general application or understanding of the Code rules. If, based on the inquiry information submitted, it is the opinion of the Committee that the inquirer should seek professional assistance, the inquiry will be returned with the recommendation that such assistance be obtained.

Inquiries that do not provide the information needed for the Committee's full understanding will be returned.

H-2 REQUIREMENTS

Inquiries shall be limited strictly to interpretations of the rules or to the consideration of revisions to the present rules on the basis of new data or technology. Inquiries shall meet the following requirements:

(a) Scope. Involve a single rule or closely related rules in the scope of the Code. An inquiry letter concerning unrelated subjects will be returned.

(b) Background. State the purpose of the inquiry, which may be either to obtain an interpretation of Code rules, or to propose consideration of a revision to the present rules. Provide concisely the information needed for the Committee's understanding of the inquiry, being sure to include reference to the applicable Code Section, Edition, Addenda, paragraphs, figures, and tables. If sketches are provided, they shall be limited to the scope of the inquiry.

(c) Inquiry Structure

(1) Proposed Question(s). The inquiry shall be stated in a condensed and precise question format, omitting superfluous background information, and, where appropriate, composed in such a way that "yes" or "no" (perhaps with provisos) would be an acceptable reply. The inquiry statement should be technically and editorially correct.

(2) Proposed Reply(ies). Provide a proposed reply stating what it is believed that the Code requires. If in the inquirer's opinion, a revision to the Code is needed, recommended wording shall be provided in addition to information justifying the change.

H-3 SUBMITTAL

Inquiries should be submitted in typewritten form; however, legible handwritten inquiries will be considered. They shall include the name and mailing address of the inquirer, and be mailed to the following address:

Secretary
ASME B31 Committee
Three Park Avenue
New York, NY 10016-5990

APPENDIX J
QUALITY CONTROL REQUIREMENTS FOR BOILER EXTERNAL PIPING (BEP)

FOREWORD

This Appendix contains the quality control requirements for boiler external piping. The following is that portion of Appendix A-300 Quality Control System of the ASME Boiler and Pressure Vessel Code, Section I, which is applicable to BEP.

J-1.0 QUALITY CONTROL SYSTEM

J-1.1 General

J-1.1.1 Quality Control System. The Manufacturer or assembler shall have and maintain a quality control system which will establish that all Code requirements, including material, design, fabrication, examination (by the Manufacturer), and inspection of boilers and boiler parts (by the Authorized Inspector), will be met. Provided that Code requirements are suitably identified, the system may include provisions for satisfying any requirements by the Manufacturer or user which exceed minimum Code requirements and may include provisions for quality control of non-Code work. In such systems, the Manufacturer may make changes in parts of the system which do not affect the Code requirements without securing acceptance by the Authorized Inspector. Before implementation, revisions to quality control systems of Manufacturers and assemblers of safety and safety relief valves shall have been found acceptable to an ASME designee if such revisions affect Code requirements.

The system that the Manufacturer or assembler uses to meet the requirements of this Section must be one suitable for his own circumstances. The necessary scope and detail of the system shall depend on the complexity of the work performed and on the size and complexity of the Manufacturer's (or assembler's) organization. A written description of the system the Manufacturer or assembler will use to produce a Code item shall be available for review. Depending upon the circumstances, the description may be brief or voluminous.

The written description may contain information of proprietary nature relating to the Manufacturer's (or assembler's) processes. Therefore, the Code does not require any distribution of this information, except for the Authorized Inspector or ASME designee.

It is intended that information learned about the system in connection with evaluation will be treated as confidential and that all loaned descriptions will be returned to the Manufacturer upon completion of the evaluation.

J-1.2 Outline of Features to Be Included in the Written Description of the Quality Control System

The following is a guide to some of the features which should be covered in the written description of the quality control system and which is equally applicable to both shop and field work.

J-1.2.1 Authority and Responsibility. The authority and responsibility of those in charge of the quality control system shall be clearly established. Persons performing quality control functions shall have sufficient and well-defined responsibility, the authority, and the organizational freedom to identify quality control problems and to initiate, recommend, and provide solutions.

J-1.2.2 Organization. An organization chart showing the relationship between management and engineering, purchasing, manufacturing, field assembling, inspection, and quality control is required to reflect the actual organization. The purpose of this chart is to identify and associate the various organizational groups with the particular function for which they are responsible. The Code does not intend to encroach on the Manufacturer's right to establish, and from time to time to alter, whatever form of organization the Manufacturer considers appropriate for its Code work.

J-1.2.3 Drawings, Design Calculations, and Specification Control. The Manufacturer's or assembler's quality control system shall provide procedures which will assure that the latest applicable drawings, design

calculations, specifications, and instructions, required by the Code, as well as authorized changes, are used for manufacture, assembly, examination, inspection, and testing.

J-1.2.4 Material Control. The Manufacturer or assembler shall include a system of receiving control which will insure that the material received is properly identified and has documentation, including required material certifications or material test reports, to satisfy Code requirements as ordered. The material control system shall insure that only the intended material is used in Code construction.

J-1.2.5 Examination and Inspection Program. The Manufacturer's quality control system shall describe the fabrication operations, including examinations, sufficiently to permit the Authorized Inspector to determine at what stages specific inspections are to be performed.

J-1.2.6 Correction of Nonconformities. There shall be a system agreed upon with the Authorized Inspector for correction of nonconformities. A nonconformity is any condition which does not comply with the applicable rules of this Section. Nonconformities must be corrected or eliminated in some way before the completed component can be considered to comply with this Section.

J-1.2.7 Welding. The quality control system shall include provisions for indicating that welding conforms to requirements of Section IX as supplemented by this Section.

J-1.2.8 Nondestructive Examination. The quality control system shall include provisions for identifying nondestructive examination procedures the Manufacturer will apply to conform with requirements of this Section.

J-1.2.9 Heat Treatment. The quality control system shall provide controls to assure that heat treatments as required by the rules of this Section are applied. Means shall be indicated by which the Authorized Inspector can satisfy himself that these Code heat treatment requirements are met. This may be by review of furnace time – temperature records or by other methods as appropriate.

J-1.2.10 Calibration of Measurement and Test Equipment. The Manufacturer or assembler shall have a system for the calibration of examination, measuring, and test equipment used in fulfillment of requirements of this Section.

J-1.2.11 Records Retention. The Manufacturer or assembler shall have a system for the maintenance of radiographs and Manufacturers' Data Reports as required by this Section.

J-1.2.12 Sample Forms. The forms used in the quality control system and any detailed procedures for their use shall be available for review. The written description shall make necessary references to these forms.

J-1.2.13 Inspection of Boilers and Boiler Parts

J-1.2.13.1 Inspection of boilers and boiler parts shall be by the Authorized Inspector described in PG-91.

J-1.2.13.2 The written description of the quality control system shall include reference to the Authorized Inspector.

J-1.2.13.2.1 The Manufacturer (or assembler) shall make available to the Authorized Inspector at the Manufacturer's plant (or construction site) a current copy of the written description or the applicable quality control system.

J-1.2.13.2.2 The Manufacturer's quality control system shall provide for the Authorized Inspector at the Manufacturer's plant to have access to all drawings, calculations, specifications, procedures, process sheets, repair procedures, records, test results, and any other documents as necessary for the Inspector to perform his duties in accordance with this Section. The Manufacturer may provide such access either to his own files of such documents or by providing copies to the Inspector.

J-1.2.14 Inspection of Safety and Safety Relief Valves

J-1.2.14.1 Inspection of safety and safety relief valves shall be by designated representative of the ASME, as described in PG-73.3.

J-1.2.14.2 The written description of the quality control system shall include reference to the ASME designee.

J-1.2.14.2.1 The valve Manufacturer (or assembler) shall make available to the ASME designee at the Manufacturer's plant a current copy of the written description of the applicable quality control system.

J-1.2.14.2.2 The valve Manufacturer's (or assembler's) quality control system shall provide for the ASME designee to have access to all drawings, calculations, specifications, procedures, process sheets, repair procedures, records, test results, and any other documents as necessary for the designee to perform his duties in accordance with this Section. The Manufacturer may provide such access either to his own files of such documents or by providing copies to the designee.

NONMANDATORY APPENDIX II[1]
RULES FOR THE DESIGN OF SAFETY VALVE INSTALLATIONS

FOREWORD

ASME B31.1 contains rules governing the design, fabrication, materials, erection, and examination of power piping systems. Experience over the years has demonstrated that these rules may be reasonably applied to safety valve installations. Nevertheless, instances have occurred wherein the design of safety valve installations may not have properly and fully applied the ASME B31.1 rules. Accordingly, this nonmandatory Appendix to ASME B31.1 has been prepared to illustrate and clarify the application of ASME B31.1 rules to safety valve installations. To this end, Appendix II presents the designer with design guidelines and alternative design methods.

II-1.0 SCOPE AND DEFINITION

II-1.1 Scope

The scope of Appendix II is confined to the design of the safety valve installations as defined in para. 1.2 of this Appendix. The loads acting at the safety valve station will affect the bending moments and stresses in the complete piping system, out to its anchors and/or extremities, and it is the designer's responsibility to consider these loads. Appendix II, however, deals primarily with the safety valve installation, and not the complete piping system.

The design of the safety valve installation requires that careful attention be paid to:

(1) all loads acting on the system;

(2) the forces and bending moments in the piping and piping components resulting from the loads;

(3) the loading and stress criteria; and

(4) general design practices.

All components in the safety valve installation must be given consideration, including the complete piping system, the connection to the main header, the safety valve, valve and pipe flanges, the downstream discharge or vent piping, and the system supports. The scope of this Appendix is intended to cover all loads on all components. It is assumed that the safety valve complies with the requirements of American National Standards prescribed by ASME B31.1 for structural integrity.

This Appendix has application to either safety, relief, or safety-relief valve installations. For convenience, however, the overpressure protection device is generally referred to as a safety valve. The loads associated with relief or safety-relief valve operation may differ significantly from those of safety valve operation, but otherwise the rules contained herein are equally applicable to each type of valve installation. See para. II-1.2 for definition.

This Appendix provides analytic and nomenclature definition figures to assist the designer, and is not intended to provide actual design layout (drains, drip pans, suspension, air gaps, flanges, weld ends, and other design details are not shown). Sample problems have been provided at the end of the text to assist the designer in application of the rules in this Appendix.

II-1.2 Definitions (Valve Descriptions Follow the Definitions Given in Section I of the ASME Boiler and Pressure Vessel Code)

Safety Valve: an automatic pressure relieving device actuated by the static pressure upstream of the valve and characterized by full opening pop action. It is used for gas or vapor service.

Relief Valve: an automatic pressure relieving device actuated by the static pressure upstream of the valve which opens further with the increase in pressure over the opening pressure. It is used primarily for liquid service.

Safety Relief Valve: an automatic pressure actuated relieving device suitable for use either as a safety valve or relief valve, depending on application.

Power-Actuated Pressure Relieving Valve: a relieving device whose movements to open or close are fully controlled by a source of power (electricity, air, steam,

[1] Nonmandatory Appendices are identified by a Roman numeral; mandatory Appendices are identified by a letter. Therefore, Roman numeral I is not used in order to avoid confusion with the letter I.

or hydraulic). The valve may discharge to atmosphere or to a container at lower pressure. The discharge capacity may be affected by the downstream conditions, and such effects shall be taken into account. If the power-actuated pressure relieving valves are also positioned in response to other control signals, the control impulse to prevent overpressure shall be responsive only to pressure and shall override any other control function.

Open Discharge Installation: an installation where the fluid is discharged directly to the atmosphere or to a vent pipe that is uncoupled from the safety valve. Figure II-1-2(A) shows a typical open discharge installation with an elbow installed at the valve discharge to direct the flow into a vent pipe. The values for l and m on Fig. II-1-2(A) are upper limits for which the rules for open discharge systems may be used. l shall be limited to a value less than or equal to $4D_o$; m shall be limited to a value less than or equal to $6D_o$ where D_o is the outside diameter of the discharge pipe. Open discharge systems which do not conform to these limits shall be evaluated by the designer for the applicability of these rules.

Closed Discharge Installation: an installation where the effluent is carried to a distant spot by a discharge pipe which is connected directly to the safety valve. Figure II-1-2(B) shows a typical closed discharge system.

Safety Valve Installation: the safety valve installation is defined as that portion of the system shown on Figs. II-1-2(A) and II-1-2(B). It includes the run pipe, branch connection, the inlet pipe, the valve, the discharge piping, and the vent pipe. Also included are the components used to support the system for all static and dynamic loads.

II-2.0 LOADS

II-2.1 Thermal Expansion

Loads acting on the components in the safety valve installation and the displacements at various points due to thermal expansion of the piping shall be determined by analyzing the complete piping system out to its anchors, in accordance with procedures in para. 119.

II-2.1.1 Installations with Open Discharge. For safety valve installations with open discharge, there will be no thermal expansion loads acting on the discharge elbow, the valve, or the valve inlet other than that from restraint to thermal expansion as described below. Restraint to thermal expansion can sometimes occur due to drain lines, or when structural supports are provided to carry the reaction forces associated with safety valve lift. Examples of such structural supports are shown in Fig. II-6-1 sketch (b). When such restraints exist, the thermal expansion loads and stresses shall be calculated and effects evaluated.

II-2.1.2 Installations with Closed Discharge. Loads due to thermal expansion and back pressure of a safety valve installation with a closed discharge can be high enough to cause malfunction of the valve, excessive leakage of the valve or flange, or overstress of other components. The loads due to thermal expansion shall be evaluated for all significant temperature combinations, including the cases where the discharge piping is hot following safety valve operation.

II-2.2 Pressure

Pressure loads acting on the safety valve installation are important from two main considerations. The first consideration is that the pressure acting on the walls of the safety valve installation can cause membrane stresses which could result in rupture of the pressure retaining parts. The second consideration is that the pressure effects associated with discharge can cause high loads acting on the system which create bending moments throughout the piping system. These pressure effects are covered in para. II-2.3.

All parts of the safety valve installation must be designed to withstand the design pressures without exceeding the Code allowable stresses. The branch connection, the inlet pipe, and the inlet flanges shall be designed for the same design pressure as that of the run pipe. The design pressure of the discharge system will depend on the safety valve rating and on the configuration of the discharge piping. The open discharge installation and the closed discharge installation present somewhat different problems in the determination of design pressures, and these problems are discussed in the paragraphs below.

II-2.2.1 Design Pressure and Velocity for Open Discharge Installation Discharge Elbows and Vent Pipes. There are several methods available to the designer for determining the design pressure and velocity in the discharge elbow and vent pipe. It is the responsibility of the designer to assure himself that the method used yields conservative results. A method for determining the design pressures and velocities in the discharge elbow and vent pipe for open discharge

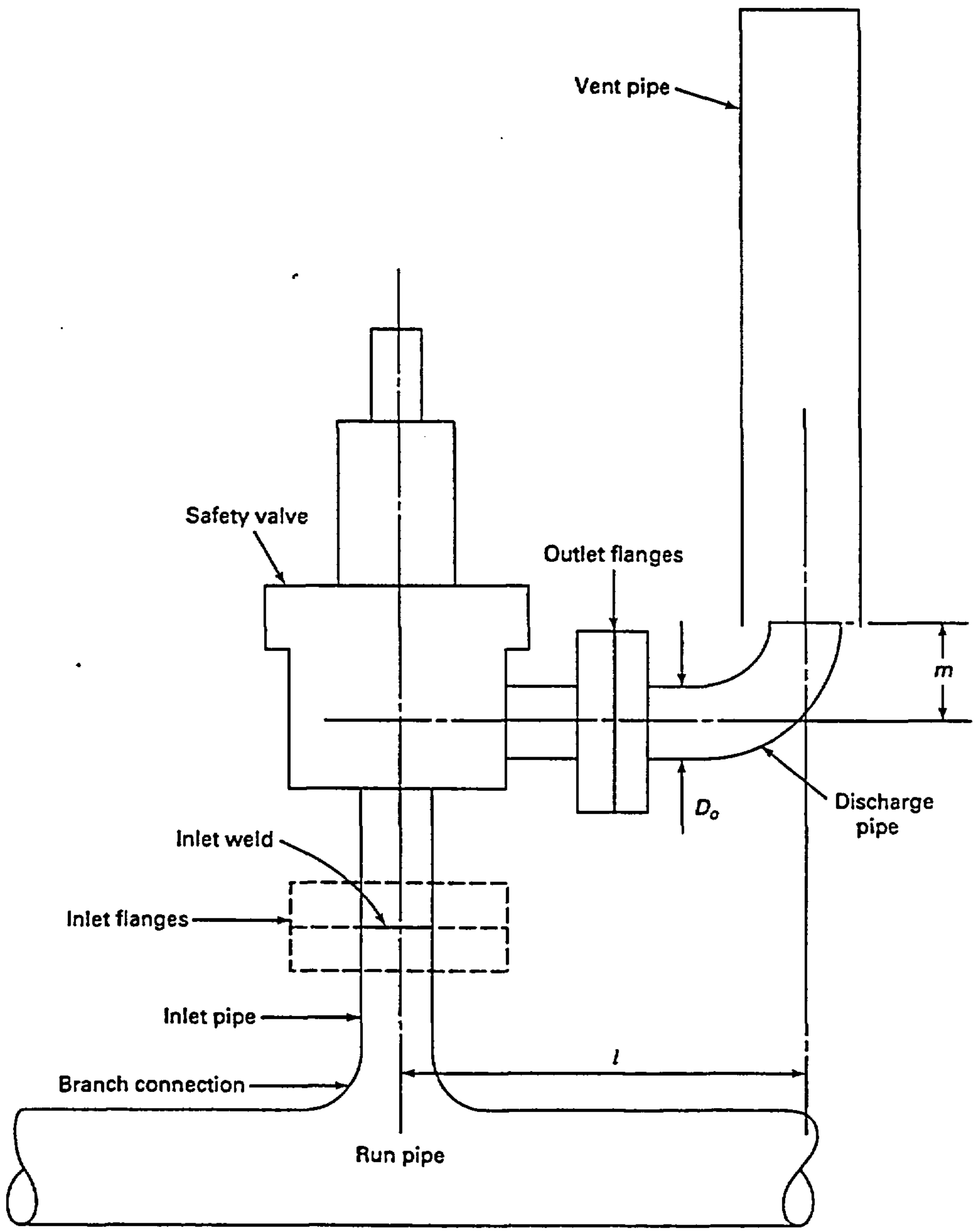


FIG. II-1-2(A) SAFETY VALVE INSTALLATION (OPEN DISCHARGE SYSTEM)

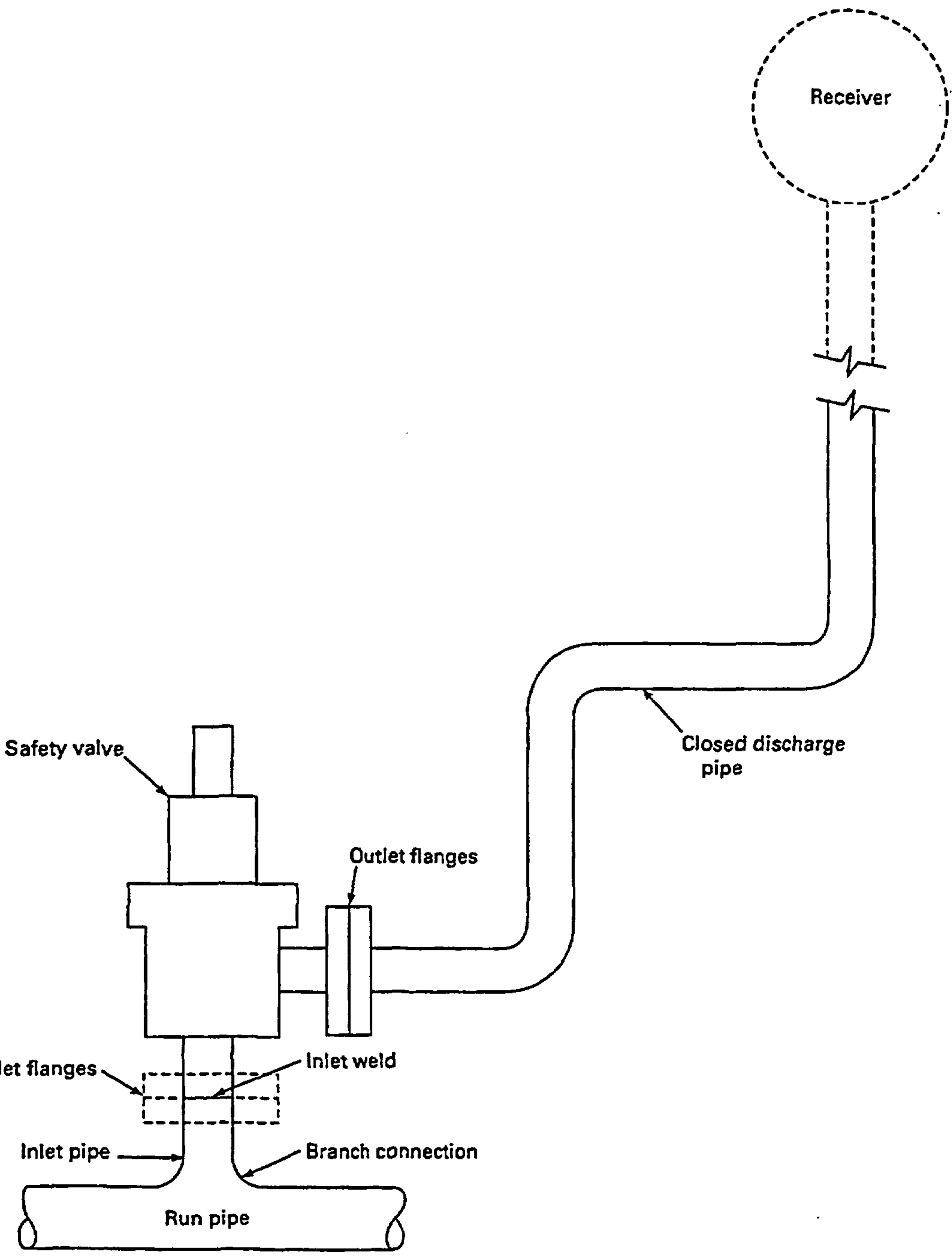


FIG. II-1-2(B) SAFETY VALVE INSTALLATION (CLOSED DISCHARGE SYSTEM)

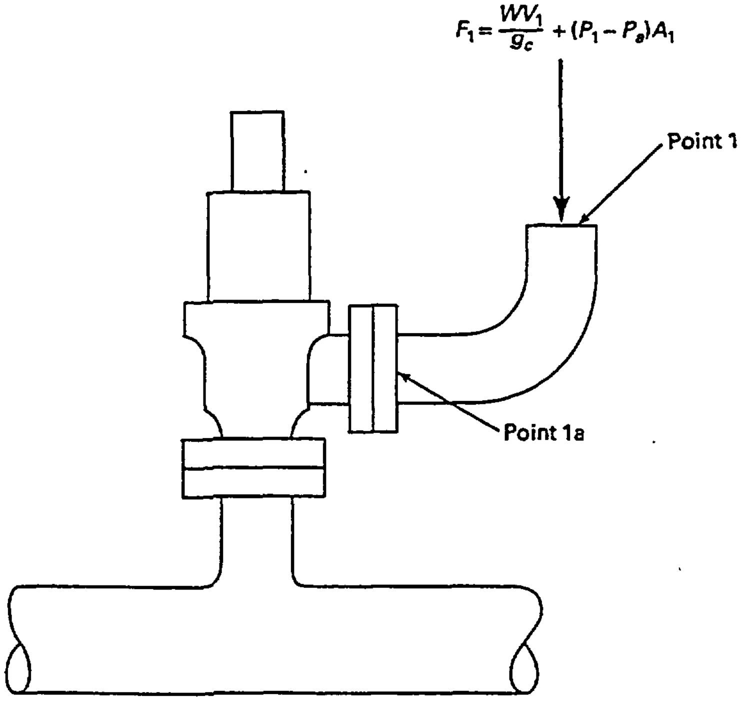


FIG. II-2-1

installation is shown below and illustrated in the sample problem.

First, calculate the design pressure and velocity for the discharge elbow.

(1) Determine the pressure P_1 that exists at the discharge elbow outlet (Fig. II-2-1).

$$P_1 = \frac{W}{A_1}\frac{(b-1)}{b}\sqrt{\frac{2(h_o - a)J}{g_c\,(2b-1)}}$$

(2) Determine the velocity V_1 that exists at the discharge elbow outlet (Fig. II-2-1).

$$V_1 = \sqrt{\frac{2g_cJ(h_o - a)}{(2b-1)}}$$

where

W = actual mass flow rate, lbm/sec
A_1 = discharge elbow area, in.^{2}
h_o = stagnation enthalpy at the safety valve inlet, Btu/lbm
J = 778.16 ft-lbf/Btu
g_c = gravitational constant
= 32.2 lbm-ft/lbf-sec^2
P_1 = pressure, psia (lbf/in.^{2}, absolute)
V_1 = ft/sec

TABLE II-2.2.1

Steam Condition	a, Btu/lbm	b
Wet steam, < 90% quality	291	11
Saturated steam, ≥ 90% quality, 15 psia ≤ P_1 ≤ 1000 psia	823	4.33
Superheated steam, ≥ 90% quality, 1000 psia < P_1 ≤ 2000 psia[1]	831	4.33

NOTE:
(1) This method may be used as an approximation for pressures > 2000 psi, but an alternate method should be used for verification.

Common values of a and b are listed in Table II-2.2.1.

(3) Determine the safety valve outlet pressure P_{1a} at the inlet to the discharge elbow (Fig. II-2-1).

(3.1) Determine the length to diameter ratio (dimensionless) for the pipe sections in the discharge elbow (L/D).

$$L/D = \frac{L_{max.}}{D}$$

(3.2) Determine a Darcy-Weisbach friction factor f to be used. (For steam, a value of 0.013 can be used as a good estimate since f will vary slightly in turbulent pipe flow.)

(3.3) Determine a specific heat ratio (for superheated steam, $k = 1.3$ can be used as an estimate — for saturated steam, $k = 1.1$).

(3.4) Calculate:

$$f\left(\frac{L_{max.}}{D}\right)$$

(3.5) Enter Chart II-1 with value of

$$f\left(\frac{L_{max.}}{D}\right)$$

and determine P/P^*.

(3.6) $P_{1a} = P_1\ (P/P^*)$

(3.7) P_{1a} is the maximum operating pressure of the discharge elbow.

Secondly, determine the design pressure and velocity for the vent pipe.

(1) Determine the pressure P_3 that exists at the vent pipe outlet (Fig. II-2-2).

$$P_3 = P_1\left(\frac{A_1}{A_3}\right)$$

(2) Determine the velocity V_3 that exists at the vent pipe outlet (Fig. II-2-2).

$$V_3 = V_1$$

(3) Repeat Steps (3.1) to (3.7) in the calculation of the discharge elbow maximum operating pressure to determine the maximum operating pressure of the vent pipe.

(4) Determine the velocity V_2 and pressure P_2 that exists at the inlet to the vent pipe (Fig. II-2-2).

(4.1) Enter Chart II-1[2] with value of

$$f\left(\frac{L_{max.}}{D}\right)$$

from Step (3.4) and determine value of V/V^* and P/P^*.

(4.2) Calculate V_2

$$V_2 = V_3\ (V/V^*)$$

(4.3) P_2, $P_2 = P_3\ (P/P^*)$. This is the highest pressure the vent stack will see and should be used in calculating vent pipe blow back (see para. II-2.3.1.2).

II-2.2.2 Pressure for Closed Discharge Installations. The pressures in a closed discharge pipe during steady state flow may be determined by the methods described in para. II-2.2.1. However, when a safety valve discharge is connected to a relatively long run of pipe and is suddenly opened, there is a period of transient flow until the steady state discharge condition is reached. During this transient period, the pressure and flow will not be uniform. When the safety valve is initially opened, the discharge pipe may be filled with air. If the safety valve is on a steam system, the steam discharge from the valve must purge the air from the pipe before steady state steam flow is established and, as the pressure builds up at the valve outlet flange and waves start to travel down the discharge pipe, the pressure wave initially emanating from the valve will steepen as it propagates, and it may steepen into a shock wave before it reaches the exit. Because of this, it is recommended that the design pressure of the closed discharge pipe be greater than the steady state operating pressure by a factor of at least 2.

II-2.3 Reaction Forces From Valve Discharge

It is the responsibility of the piping system designer to determine the reaction forces associated with valve discharge. These forces can create bending moments at various points in the piping system so high as to cause catastrophic failure of the pressure boundary parts. Since the magnitude of the forces may differ substantially, depending on the type of discharge system, each system type is discussed in the paragraphs below.

II-2.3.1 Reaction Forces With Open Discharge Systems

II-2.3.1.1 Discharge Elbow. The reaction force F due to steady state flow following the opening of the safety valve includes both momentum and pressure effects. The reaction force applied is shown in Fig. II-2-1, and may be computed by the following equation.

[2] Chart II-1 may be extended to other values of $f\ (L_{max.}/D)$ by use of the Keenan and Kaye Gas Tables for Fanno lines. The Darcy-Weisbach friction factor is used in Chart II-1, whereas the Gas Tables use the Fanning factor which is one-fourth the value of the Darcy-Weisbach factor.

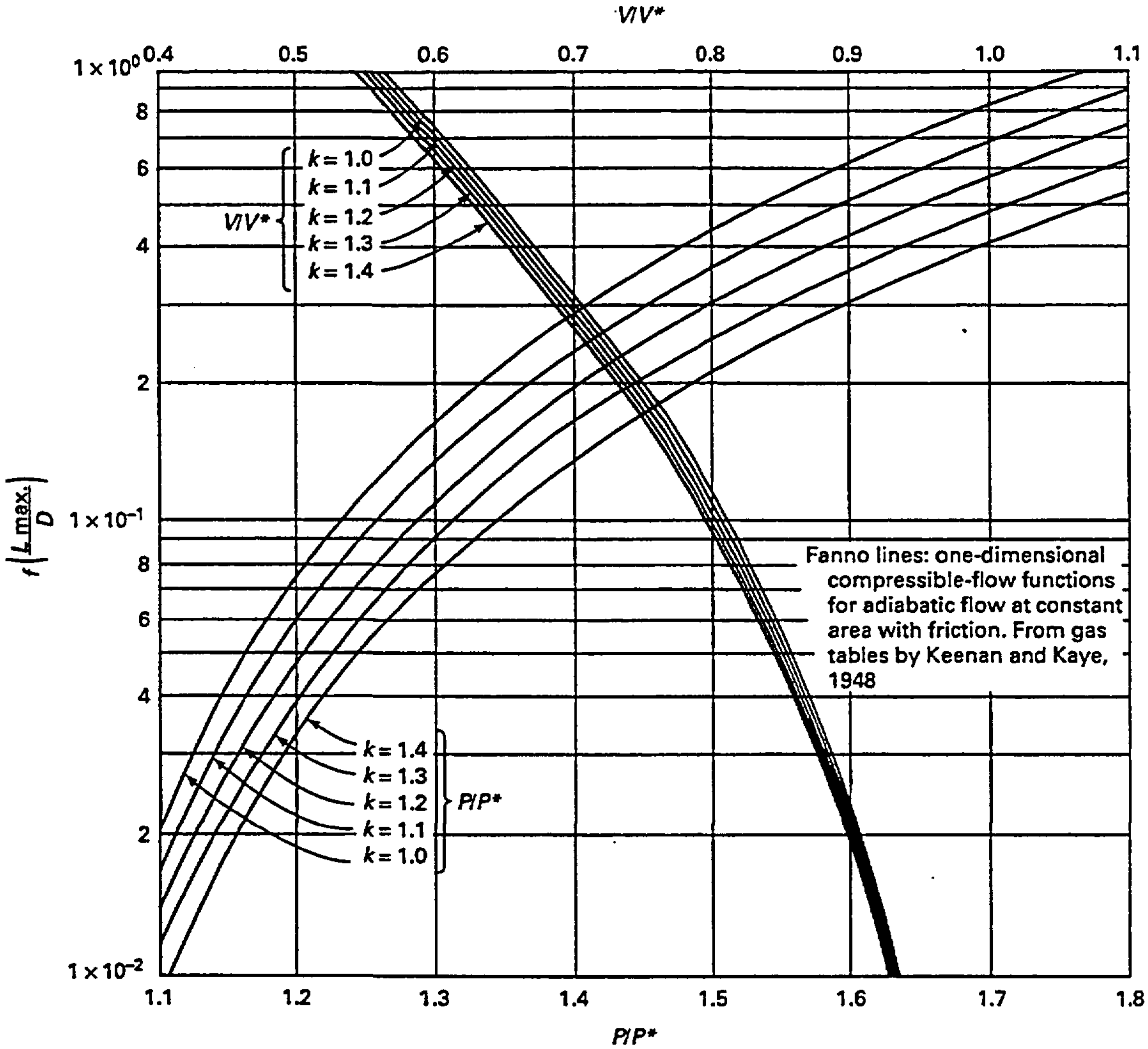


CHART II-1

$$F_1 = \frac{W}{g_c} V_1 + (P_1 - P_a) A_1$$

where

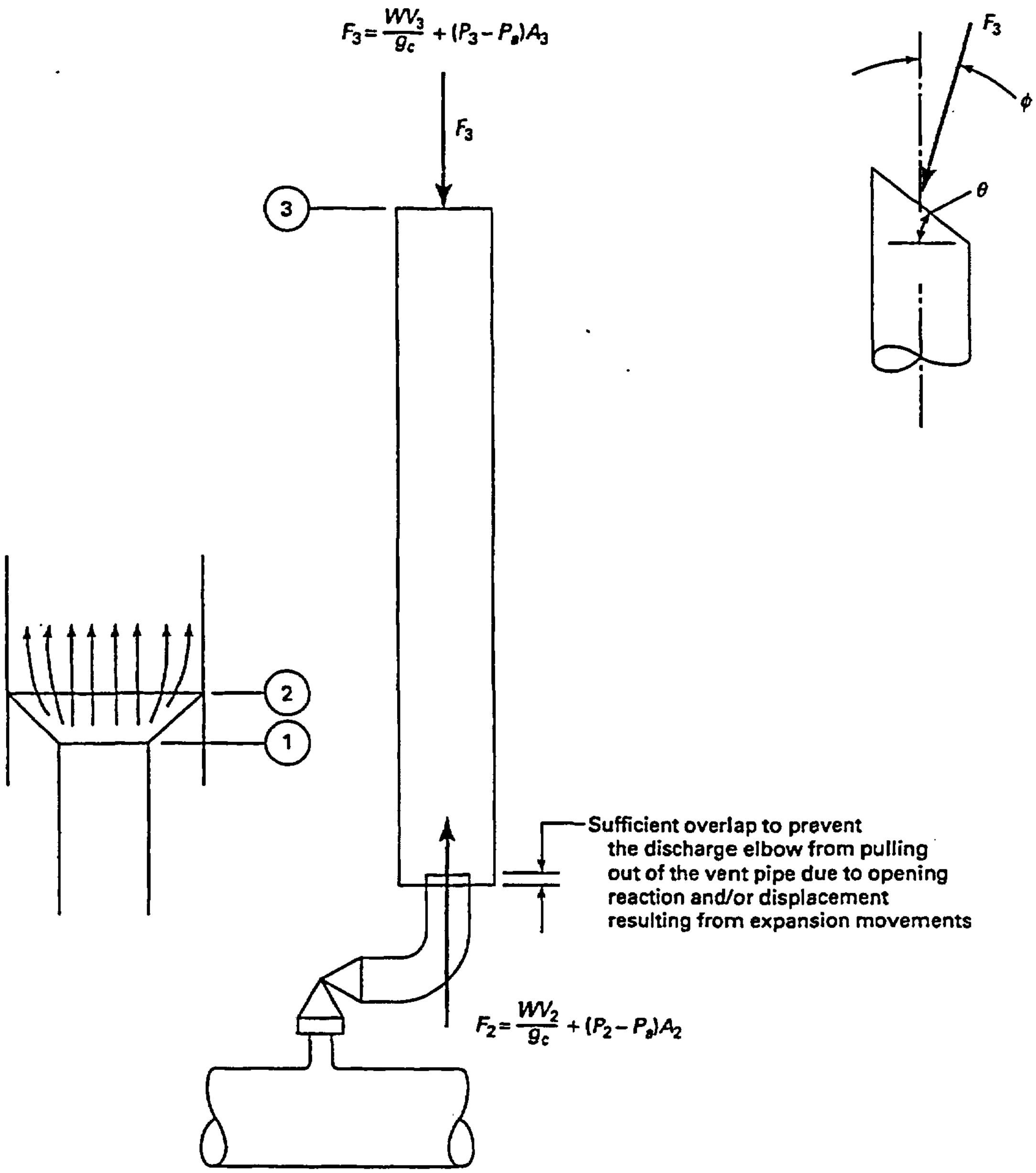
F_1 = reaction force, lbf at Point 1
W = mass flow rate, (relieving capacity stamped on the valve × 1.11), lbm/sec
g_c = gravitational constant
= 32.2 lbm-ft/lbf-sec^2
V_1 = exit velocity at Point 1, ft/sec
P_1 = static pressure at Point 1, psia
A_1 = exit flow area at Point 1, in.^{2}
P_a = atmospheric pressure, psia

To insure consideration of the effects of the suddenly applied load F, a dynamic load factor DLF should be applied (see para. II-3.5.1.3).

The methods for calculating the velocities and pressures at the exit point of the discharge elbow are the same as those discussed in para. II-2.2 of this Appendix.

II-2.3.1.2 Vent Pipe. Figure II-2-2 shows the external forces resulting from a safety valve discharge, which act on the vent pipe. The methods for calculating F_2 and F_3 are the same as those previously described. The vent pipe anchor and restraint system must be capable of taking the moments caused by these two forces, and also be capable of sustaining the unbalanced forces in the vertical and horizontal directions.

A bevel of the vent pipe will result in a flow that is not vertical. The equations shown are based on vertical flow. To take account for the effect of a bevel at the exit, the exit force will act at an angle ϕ, with



$F_3 = \frac{WV_3}{g_c} + (P_3 - P_a)A_3$
F_3
3
F_3
ϕ
θ
2
1
Sufficient overlap to prevent the discharge elbow from pulling out of the vent pipe due to opening reaction and/or displacement resulting from expansion movements
$F_2 = \frac{WV_2}{g_c} + (P_2 - P_a)A_2$

FIG. II-2-2

the axis of the vent pipe discharge which is a function of the bevel angle θ. The beveled top of the vent deflects the jet approximately 30 deg off the vertical for a 60 deg bevel, and this will introduce a horizontal component force on the vent pipe systems.

The terms in the equations shown on Fig. II-2-2 are the same as those defined in para. II-2.3.1. above.

The vent pipe must be sized so that no steam is blown back at the vent line entrance. The criteria which may be used as a guide to prevent this condition are listed below.

$$\frac{W(V_1 - V_2)}{g_c} > (P_2 - P_a)A_2 - (P_1 - P_a)A_1$$

P_a = standard atmospheric pressure, psia
W = mass flow rate, lbm/sec
V = velocity, ft/sec
P_1, P_2 = local absolute pressure, psia
A = area, in.^{2}
g_c = gravitational constant = 32.2 lbm-ft/lbf-sec^2

The inequality states that the momentum at Point 1 has to be greater than the momentum at Point 2 in order that air is educted into the vent pipe. If the momentum at Point 1 equalled the momentum at Point 2, no air would be educted into the vent pipe. If the momentum at Point 1 was less than the momentum at Point 2, steam would "blow back" from the vent pipe.

The educting effect of the vent pipe is especially important for indoor installation of safety valves. The steam being vented from the upper body during safety valve operation will be removed from the area through the vent pipe. For that reason, the fluid momentum at 1 should exceed the fluid momentum at 2, not just be equal.

If this inequality is satisfied, "blow back" will not occur. The pressures and velocities are those calculated in para. II-2.2.1.

II-2.3.2 Reaction Forces with Closed Discharge Systems. When safety valves discharge a closed piping system, the forces acting on the piping system under steady state flow will be self-equilibrated, and do not create significant bending moments on the piping system. The large steady state force will act only at the point of discharge, and the magnitude of this force may be determined as described for open discharge systems.

Relief valves discharging into an enclosed piping system create momentary unbalanced forces which act on the piping system during the first few milliseconds following relief valve lift. The pressure waves traveling through the piping system following the rapid opening of the safety valve will cause bending moments in the safety valve discharge piping and throughout the remainder of the piping system. In such a case, the designer must compute the magnitude of the loads, and perform appropriate evaluation of their effects.

II-2.4 Other Mechanical Loads

Other design mechanical loads that must be considered by the piping designer include the following:

II-2.4.1 Interaction loads on the pipe run when more than one valve opens.

II-2.4.2 Loads due to earthquake and/or piping system vibration (see para. II-3.4).

II-3.0 BENDING MOMENT COMPUTATIONS

II-3.1 General

One of the most important considerations related to the mechanical design and analysis of safety valve installation is the identification and calculation of the moments at critical points in the installation. If the bending moments are not properly calculated, it will not be possible to meet the loading and stress criteria contained in ASME B31.1. As a minimum, the following loads, previously discussed in para. II-2.0 of this Appendix, should be considered in determining these moments:

(1) thermal expansion
(2) dead weight
(3) earthquake
(4) reaction force from valve discharge
(5) other mechanical loads

The analysis of the safety valve installation should include all critical sections, such as intersection points, elbows, transition sections, etc., and any related piping, vessels, and their supports which may interact with the safety valve installation. It is often most appropriate to model the safety valve installation and its related piping as a lumped mass system joined by straight or curved elements.

II-3.2 Thermal Expansion Analysis

There are many standard and acceptable methods for determination of moments due to thermal expansion of the piping installation. The thermal expansion analysis must comply with the requirements in para. 119. The

safety valve installation often presents a special problem in that there may be a variety of operational modes to consider where each mode represents a different combination of temperatures in various sections of the piping system. The design condition shall be selected so that none of the operational modes represents a condition that gives thermal expansion bending moments greater than the design condition.

The design of the safety valve installation should consider the differential thermal growth and expansion loads, as well as the local effects of reinforcing and supports. The design should also consider the differential thermal growth and expansion loads existing after any combination of safety valves (one valve to all valves) operates, raising the temperature of the discharge piping.

II-3.3 Dead Weight Analysis

The methods used for determination of bending moments due to dead weight in a safety valve installation are not different from the methods used in any other piping installation. If the support system meets the requirements in para. 121, the bending moments due to dead weight may be assumed to be 1500Z (in.-lb) where Z is the section modulus (in.^{3}) of the pipe or fitting being considered. However, bending moments due to dead weight are easily determined and should always be calculated in systems where stresses exceed 90% of the allowable stress limits in meeting the requirements of Eqs. (11) and (12) of para. 104.8.

II-3.4 Earthquake Analysis

Seismic loads must be known in order to calculate bending moments at critical points in the safety valve installation. If a design specification exists, it should stipulate if the piping system must be designed for earthquake. If so, it should specify the magnitude of the earthquake, the plant conditions under which the earthquake is assumed to occur, and the type earthquake analysis to be used (equivalent static or dynamic). If a design specification does not exist, it is the responsibility of the designer to determine what consideration must be given to earthquake analysis. It is beyond the scope of this Appendix to provide rules for calculating moments due to earthquake. The literature contains satisfactory references for determining moments by use of static seismic coefficients and how to perform more sophisticated dynamic analyses of the piping system using inputs in such form as time histories of displacement, velocity, and acceleration or response spectra where displacement, velocity, or acceleration is presented as a function of frequency.

Two types of seismic bending moments occur. One type is due to inertia effects and the other type is due to seismic motions of pipe anchors and other attachments. As will be shown later, the moments due to inertia effects must be considered in Eq. (12), para. 104.8, in the kS_h category. Moments due to seismic motions of the attachments may be combined with thermal expansion stress and considered in Eq. (13), para. 104.8 in the S_A category. For this reason, it may sometimes be justified for the designer to consider the moments separately; otherwise both sets of moments would have to be included in the kS_h category.

II-3.5 Analysis for Reaction Forces due to Valve Discharge

II-3.5.1 Open Discharge Systems

II-3.5.1.1 The moments due to valve reaction forces may be calculated by simply multiplying the force, calculated as described in para. II-2.3.1.1, times the distance from the point in the piping system being analyzed, times a suitable dynamic load factor. In no case shall the reaction moment used in para. II-4.2 at the branch connection below the valve be taken at less than the product of

$$(DLF)\,(F_1)\,(D)$$

where

F_1 = force calculated per para. II-2.3.1.1
D = nominal O.D. of inlet pipe
DLF = dynamic load factor (see para. II-3.5.1.3)

Reaction force and resultant moment effects on the header, supports, and nozzles for each valve or combination of valves blowing shall be considered.

II-3.5.1.2 Multiple Valve Arrangements. Reaction force and moment effects on the run pipe, header, supports, vessel, and connecting nozzles for each valve blowing, and when appropriate, for combinations of valves blowing should be considered. In multiple valve arrangements, each valve will open at a different time, and since all valves may not be required to open during an overpressure transient, several possible combinations of forces can exist. It may be desirable to vary the direction of discharge of several safety valves on the same header to reduce the maximum possible forces when all valves are blowing.

II-3.5.1.3 Dynamic Amplification of Reaction Forces. In a piping system acted upon by time varying loads, the internal forces and moments are generally greater than those produced under static application of

the load. This amplification is often expressed as the dynamic load factor *DLF* and is defined as the maximum ratio of the dynamic deflection at any time to the deflection which would have resulted from the static application of the load. For structures having essentially one degree-of-freedom and a single load application, the *DLF* value will range between one and two depending on the time-history of the applied load and the natural frequency of the structure. If the run pipe is rigidly supported, the safety valve installation can be idealized as a one degree-of-freedom system and the time-history of the applied loads can often be assumed to be a single ramp function between the no-load and steady state condition. In this case the *DLF* may be determined in the following manner.

(1) Calculate the safety valve installation period T using the following equation and Fig. II-3-1.

$$T = 0.1846 \sqrt{\frac{Wh^3}{EI}}.$$

where

T = safety valve installation period, sec
W = weight of safety valve, installation piping, flanges, attachments, etc., lb
h = distance from run pipe to center line of outlet piping, in.
E = Young's modulus of inlet pipe, lb/in.^{2}, at design temperature
I = moment of inertia of inlet pipe, in.^{4}

(2) Calculate ratio of safety valve opening time to installation period (t_o/T) where t_o is the time the safety valve takes to go from fully closed to fully open, sec, and T is determined in (1) above.

(3) Enter Fig. II-3-2 with the ratio of safety valve opening time to installation period and read the *DLF* from the ordinate. The *DLF* shall never be taken less than 1.1.

If a less conservative *DLF* is used, the *DLF* shall be determined by calculation or test.

II-3.5.1.4 Valve Cycling. Often, safety valves are full lift, pop-type valves, and are essentially full-flow devices, with no capability for flow modulation. In actual pressure transients, the steam flow required to prevent overpressure is a varying quantity, from zero to the full rated capacity of the safety valves. As a result, the valves may be required to open and close a number of times during the transient. Since each opening and closing produces a reaction force, consideration should be given to the effects of multiple valve operations on the piping system, including supports.

II-3.5.1.5 Time-History Analysis. The reaction force effects are dynamic in nature. A time-history dynamic solution, incorporating a multidegree of freedom lumped mass model solved for the transient hydraulic forces is considered to be more accurate than the form of analysis presented in this Appendix.

II-3.5.2 Closed Discharge Systems. Closed discharge systems do not easily lend themselves to simplified analysis techniques. The discussions on pressure in para. II-2.2.2 and on forces in para. II-2.3.2 indicate that a time-history analysis of the piping system may be required to achieve realistic values of moments.

II-3.5.3 Water Seals. To reduce the problem of steam or gas leakage through the safety valve seats, the valve inlet piping may be shaped to form a water seal below each valve seat. If the valves are required to open to prevent overpressure, the water from the seal is discharged ahead of the steam as the valve disk lifts. The subsequent flow of water and steam through the discharge piping produces a significant pressure and momentum transient. Each straight run of discharge piping experiences a resulting force cycle as the water mass moves from one end of the run to the other.

For most plants which employ water seals, only the first cycle of each occurrence has a force transient based on water in the seal. The remaining cycles of each occurrence would be based on steam occupying the seal piping, and the transient forces would be reduced in magnitude.

II-4.0 LOADING CRITERIA AND STRESS COMPUTATION

II-4.1

All critical points in the safety valve installation shall meet the following loading criteria.

$$S_{lp} + S_{SL} \leq S_h \quad (1)$$

$$S_{lp} + S_{SL} + S_{OL} \leq kS_h \quad (2)$$

$$S_{lp} + S_{SL} + S_E \leq S_A + S_h \quad (3)$$

where

S_{lp} = longitudinal pressure stress
S_{SL} = bending stresses due to sustained loads, such as dead weight

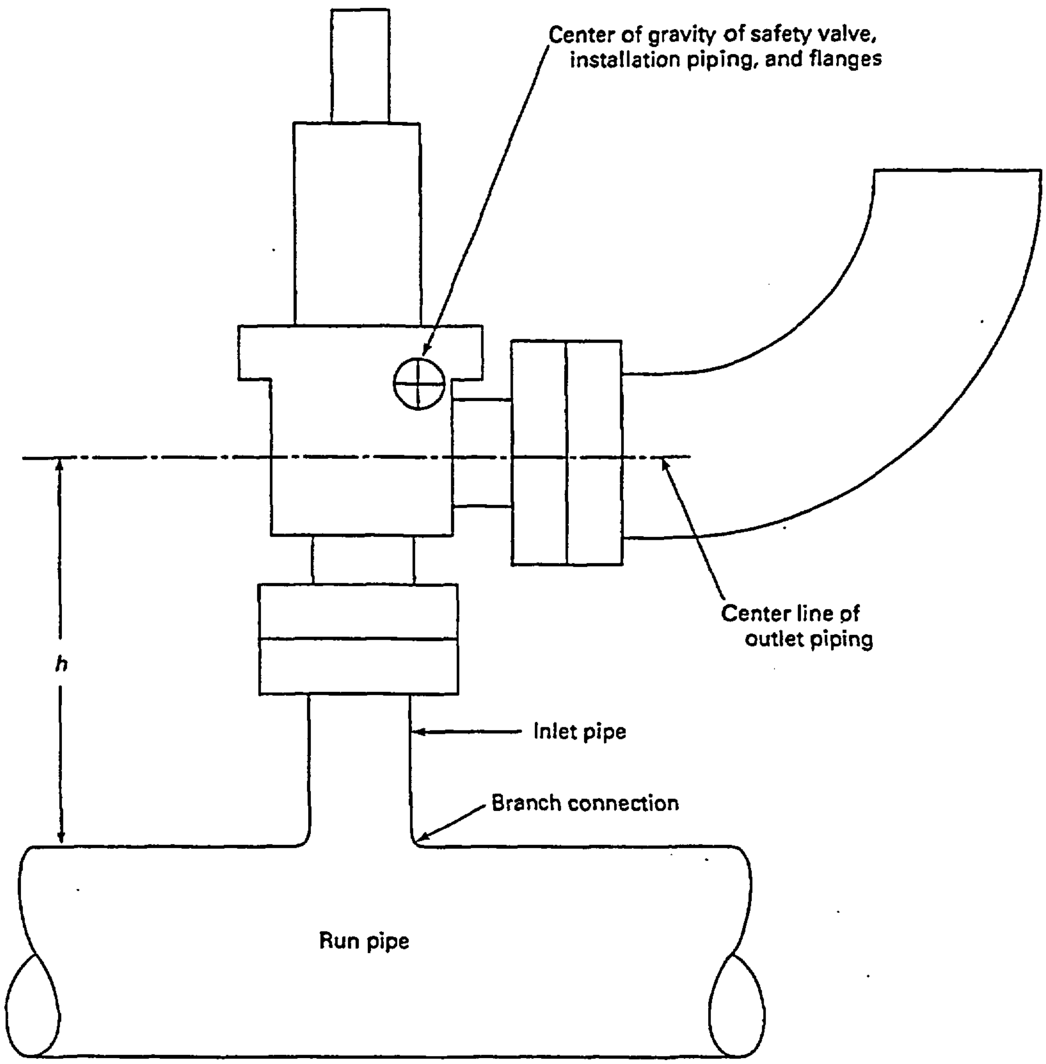


FIG. II-3-1 SAFETY VALVE INSTALLATION (OPEN DISCHARGE SYSTEM)

S_{OL} = bending stresses due to occasional loads, such as earthquake, reaction from safety valve discharge and impact loads

S_E = bending stresses due to thermal expansion

S_h, k, and S_A are as defined in ASME B31.1

The three loading criteria defined above are represented by Eqs. (11) and (12) in para. 104.8.

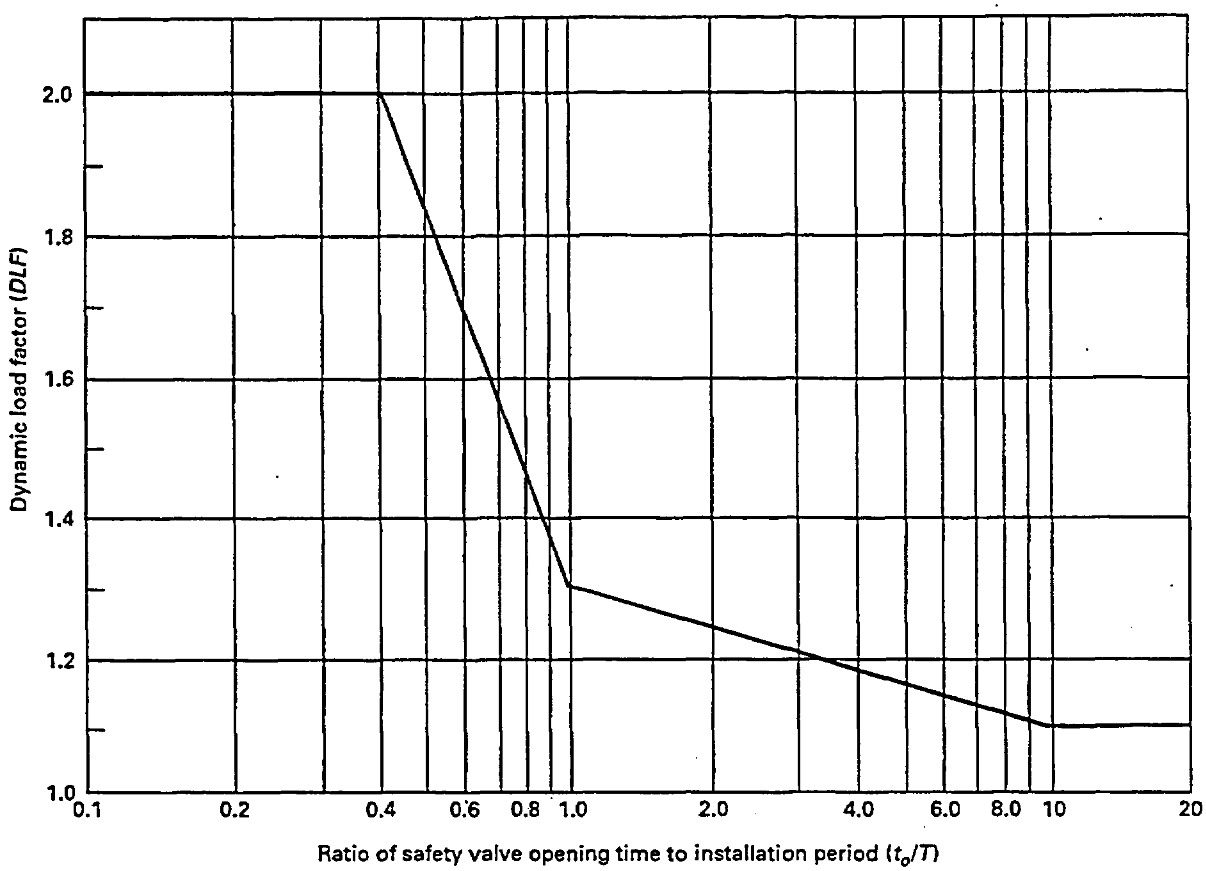
II-4.2 Stress Calculations

II-4.2.1 Pressure Stresses. The Code does not require determination of the pressure stresses that could cause failure of the pressure containing membrane. Instead, the Code provides rules to insure that sufficient wall thickness is provided to prevent failures due to pressure. It is not necessary to repeat these rules in this Appendix; however, some of the more important are listed below for reference.

(1) All pipe (plus other components) must satisfy the minimum required wall thickness of Eq. (3) of para. 104.1.2. In addition, wall thickness must be adequate to satisfy Eqs. (11) and (12) in para. 104.8. These two equations may govern determination of wall thickness in low pressure systems.

(2) No minimum wall thickness calculations are needed for components purchased to approved standards in Table 126.1.

(3) Pipe bends must meet the requirements of (1) above *after* bending.



GENERAL NOTE: This figure is based on curves from *Introduction to Structural Dynamics*, J. M. Biggs, McGraw-Hill Book Co., 1964.

FIG. II-3-2 DYNAMIC LOAD FACTORS FOR OPEN DISCHARGE SYSTEM
This Figure Is Based on Curves From *Introduction to Structural Dynamics*, J. M. Biggs, McGraw-Hill Book Co., 1964

(4) Branch connections which do not meet the requirements of (2) above must meet the area replacement requirements of para. 104.3.

II-4.2.2 Pressure Plus Bending Stresses. In order to guard against membrane failures (catastrophic), prevent fatigue (leak) failures, and to assure shakedown, the equations in para. 104.8 must be satisfied. These equations apply to all components in the safety valve installation and will not be repeated here. However, some additional explanation of these equations in regard to the very critical points upstream of the safety valve are in the paragraphs below.

II-4.2.2.1 Additive Stresses at Branch Connection. For purposes of Eqs. (11), (12), and (13) in para. 104.8 the section modulus and moments for application to branch connections, such as safety valve inlet pipes, are:

(1) For branch connections the Z should be the effective section modulus for the branch as defined in para. 104.8.

Thus,

$$Z = Z_b = \pi r_b^2 t_s \text{ (effective section modulus)}$$

where

r_b = mean branch cross-sectional radius, in.
t_s = lesser of t_r and it_b where
t_r = nominal thickness of run pipe
i = the branch connection stress intensification factor

t_b = nominal thickness of branch pipe

(2) Moment terms shall be defined as follows:

$$M_B = \sqrt{M_{x3}^2 + M_{y3}^2 + M_{z3}^2}$$

where M_B, M_{x3}, M_{y3}, and M_{z3} are defined in para. 104.8.

(3) Where the D_o/t_n of the branch connection differs from the D_o/t_n header or run, the larger of the two D_o/t_n values should be used in the first term of Eqs. (11) and (12) where D_o and t_n are defined in paras. 104.1 and 104.8, respectively.

II-4.2.2.2 Additive Stresses in Inlet Pipe. Equations (11), (12), and (13) in para. 104.8 may be applied to the inlet pipe in the same manner as described above for the branch connection, except that the values for D_o/t_n and Z should be for the inlet pipe and the stress intensification factor used will be different. It should be noted that the values D_o, t_n, and Z should be taken from a point on the inlet pipe such that D_o/t_n will have a maximum and Z a minimum value for the inlet pipe.

II-4.2.3 Analysis of Flange. It is important that the moments from the various loading conditions described in para. II-4.2.2 do not overload the flanges on the safety valve inlet and outlet. One method of doing this is to convert the moments into an equivalent pressure that is then added to the internal pressure. The sum of these two pressures P_{FD} would be acceptable if either of the following criteria are met.

(1) P_{FD} does not exceed the ASME B16.5 flange rating.

(2) S_H, S_R, and S_T should be less than the yield stress at design temperature, where S_H, S_R, and S_T are as defined in 2-7 of ASME Section VIII, Division 1 with these exceptions.

(A) P_{FD} should be used in the ASME Section VIII, Division 1 equations instead of the design pressure.

(B) S_H should include the longitudinal pressure stress at the flange hub.

II-4.2.4 Analysis of Valve. The allowable forces and moments which the piping system may place on the safety valves must be determined from the valve manufacturer. In some cases, the valve flanges are limiting rather than the valve body.

II-5.0 DESIGN CONSIDERATIONS

II-5.1 General

The design of safety valve installations shall be in accordance with para. 104 except that consideration be given to the rules provided in the following subparagraphs. These rules are particularly concerned with that portion of the piping system attached to and between the safety valve and the run pipe, header, or vessel which the valve services and includes the branch connection to the run pipe, header, or vessel.

II-5.2 Geometry

II-5.2.1 Locations of Safety Valve Installations. Safety valve installations should be located at least eight pipe diameters (based on I.D.) downstream from any bend in a high velocity steam line to help prevent sonic vibrations. This distance should be increased if the direction of the change of the steam flow is from vertical upwards to horizontal in such a manner as to increase density of the flow in the area directly beneath the station nozzles. Similarly, safety valve installation should not be located closer than eight pipe diameters (based on I.D.) either upstream or downstream from fittings.

II-5.2.2 Spacing of Safety Valve Installation. Spacing of safety valve installations must meet the requirements in Note (6)(c), Appendix D, Table D-1.

II-5.3 Types of Valves and Installations

II-5.3.1 Installations With Single Outlet Valves. Locate unsupported valves as close to the run pipe or header as is physically possible to minimize reaction moment effects.

Orientation of valve outlet should preferably be parallel to the longitudinal axis of the run pipe or header.

Angular discharge elbows oriented to minimize the reaction force moment shall have a straight pipe of at least one pipe diameter provided on the end of the elbow to assure that the reaction force is developed at the desired angle. Cut the discharge pipe square with the center line. Fabrication tolerances, realistic field erection tolerances, and reaction force angle tolerances must be considered when evaluating the magnitude of the reaction moment.

The length of unsupported discharge piping between the valve outlet and the first outlet elbow [Fig. II-1-2(A), distance *l*] should be as short as practical to minimize reaction moment effects.

II-5.3.2 Installations with Double Outlet Valves. Double outlet valves with symmetrical tail-pipes and vent stacks will eliminate the bending moment in the nozzle and the run pipe or header providing there is equal and steady flow from each outlet. If equal flow cannot be guaranteed, the bending moment due to the unbalanced flow must be considered. Thrust loads must also be considered.

II-5.3.3 Multiple Installations. The effects of the discharge of multiple safety valves on the same header shall be such as to tend to balance one another for all modes of operation.

II-5.4 Installation Branch Connections

Standard branch connections shall as a minimum meet the requirements of para. 104.3. It should be noted that branch connections on headers frequently do not have sufficient reinforcement when used as a connection for a safety valve. It may be necessary to provide additional reinforcing (weld deposit buildup) or special headers that will satisfactorily withstand the reaction moments applied.

Material used for the branch connection and its reinforcement shall be the same or of higher strength than that of the run pipe or header.

It is strongly recommended that branch connections intersect the run pipe or header normal to the surface of the run pipe or header at $\alpha = 90$ deg, where α is defined as the angle between the longitudinal axis of the branch connection and the normal surface of the run pipe or header. Branch connections that intersect the run pipe or headers at angles,

$$90 \text{ deg} > \alpha \geq 45 \text{ deg}$$

should be avoided. Branch connections should not in any case intersect the run pipe or header at angles,

$$\alpha < 45 \text{ deg}$$

II-5.5 Water in Installation Piping

II-5.5.1 Drainage of Discharge Piping. Drains shall be provided so that condensed leakage, rain, or other water sources will not collect on the discharge side of the valve and adversely affect the reaction force. Safety valves are generally provided with drain plugs that can be used for a drain connection. Discharge piping shall be sloped and provided with adequate drains if low points are unavoidable in the layout.

II-5.5.2 Water Seals. Where water seals are used ahead of the safety valve, the total water volume in the seals shall be minimized. To minimize forces due to slug flow or water seal excursion, the number of changes of direction and the lengths of straight runs of installation piping shall be limited. The use of short radius elbows is also discouraged; the pressure differential across the cross section is a function of the elbow radius.

II-5.6 Discharge Stacks

If telescopic or uncoupled discharge stacks, or equivalent arrangements, are used then care should be taken to insure that forces on the stack are not transmitted to the valve discharge elbow. Stack clearances shall be checked for interference from thermal expansion, earthquake displacements, etc. Discharge stacks shall be supported adequately for the forces resulting from valve discharge so that the stack is not deflected, allowing steam to escape in the vicinity of the valve. In addition, the deflection of the safety valve discharge nozzle (elbow) and the associated piping system when subjected to the reaction force of the blowing valve shall be calculated. This deflection shall be considered in the design of the discharge stacks slip-joint to assure that the discharge nozzle remains in the stack, preventing steam from escaping in the vicinity of the valve.

To prevent blowback of discharging steam from inlet end of vent stack, consider the use of an antiblowback device that still permits thermal movements of header.

II-5.7 Support Design

Supports provided for safety valves and the associated piping require analysis to determine their role in restraint as well as support. These analyses shall consider at least the following effects:

(A) differential thermal expansion of the associated piping, headers, and vessels;

(B) dynamic response characteristics of the support in relation to the equipment being supported and the structure to which it is attached, during seismic events and valve operation. Maximum relative motions of various portions of the building and structures to which supports are attached resulting from seismic excitation must be considered in selecting, locating, and analyzing support systems.

(C) capability of the support to provide or not provide torsional rigidity, per the support design requirements.

II-5.7.1 Pipe Supports. Where necessary, it is recommended that the support near the valve discharge be connected to the run pipe, header, or vessel rather than to adjacent structures in order to minimize differential thermal expansion and seismic interactions.

Each straight leg of discharge piping should have a support to take the force along that leg. If the support is not on the leg itself, it should be as near as possible on an adjacent leg.

When a large portion of the system lies in a plane, the piping if possible should be supported normal to that plane even though static calculations do not identify a direct force requiring restraint in that direction. Dynamic analyses of these systems have shown that out-of-plane motions can occur.

II-5.7.2 Snubbers. Snubbers are often used to provide a support or a stop against a rapidly applied load, such as the reaction force of a blowing valve or the pressure-momentum transient in a closed piping system. Since snubbers generally displace a small distance before becoming rigid, the displacement must be considered in the analysis. In addition, if the load is applied to the snubber for a relatively long time, the snubber performance characteristics shall be reviewed to assure that the snubber will not permit motion during the time period of interest, or the additional displacement must be considered in the analysis. The snubber performance shall also be reviewed for response to repetitive load applications caused by the safety valve cycling open and closed several times during a pressure transient.

II-5.8 Silencer Installation

Silencers are occasionally installed on safety valve discharges to dissipate the noise generated by the sonic velocity attained by the fluid flowing through the valve.

Silencers must be properly sized to avoid excessive backpressure on the safety valve causing improper valve action or reducing relieving capacity.

Safety valve discharge piping, silencers, and vent stacks shall be properly supported to avoid excessive loading on the valve discharge flange.

II-6.0 SAMPLE DESIGNS

Examples of various safety valve installations that a designer may encounter in practice are presented in Figs. II-1-2(A) and II-6-1.

II-7.0 SAMPLE PROBLEM (SEE FIGS. II-7-1 AND II-7-2)

II-7.1 Procedure

(1) Determine pressure and velocity at discharge elbow exit.

(2) Calculate maximum operating pressure for discharge exit.

(3) Calculate reaction force at discharge elbow exit.

(4) Calculate bending moments of Points (1) and (2) from reaction force and seismic motion.

(5) Determine stress intensification factors at Points (1) and (2).

(6) Calculate predicted stresses at Points (1) and (2) and compare with allowable stress.

(7) Calculate maximum operating pressure for vent pipe.

(8) Check for blowback.

(9) Calculate forces and moments on vent pipe.

(1) Pressure and Velocity at Discharge Elbow Exit (Para. II-2.2.1)

$$P_1 = \frac{W}{A_1}\frac{(b-1)}{b}\sqrt{\frac{2(h_o - a)J}{g_c(2b-1)}}$$

$$V_1 = \sqrt{\frac{2g_c\,J(h_o - a)}{(2b-1)}}$$

W = flow rate
= 116.38 lbm/sec

A_1 = 50.03 in.^{2}

h_o = stagnation enthalpy for steam at 925 psia, 1000°F
= 1507.3 Btu/lbm

a = 823 Btu/lbm for $15 \le P_1 \le 1000$ psia and $h_o \le 1600$ Btu/lbm

b = 4.33 for $15 \le P_1 \le 1000$ psia and $h_o \le 1600$ Btu/lbm

J = 778 ft-lbf/Btu

g_c = 32.2 lbm-ft/lbf-sec^2

P_1 = 118 psia

V_1 = 2116 ft/sec

(2) Discharge Elbow Maximum Operating Pressure

L/D for 8 in. Class 150 ASME weld neck flange

$$= \frac{4\text{ in.}}{7.981\text{ in.}} = 0.5$$

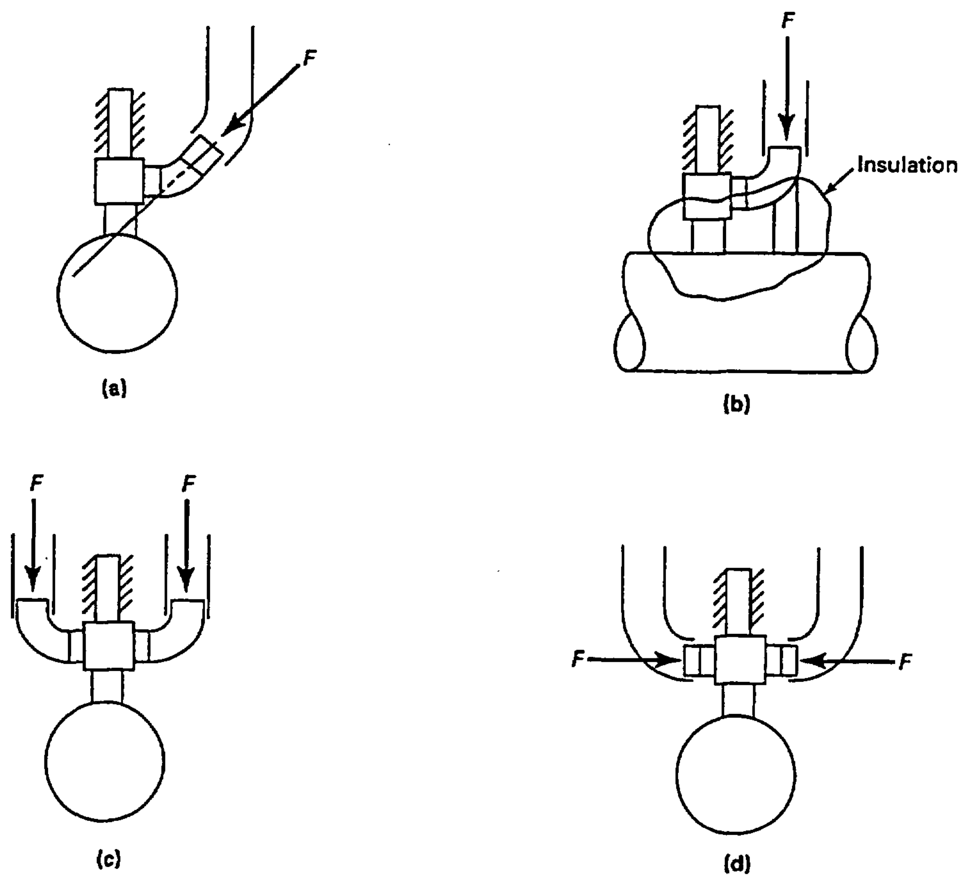


FIG. II-6-1

L/D for 8 in. SCH 40 short radius elbow = 30

L/D for 12 in. of 8 in. SCH 40 pipe

$$= \frac{12 \text{ in.}}{7.981 \text{ in.}} = 1.5$$

$$\Sigma\left(\frac{L}{D}\right) = \left(\frac{L_{max.}}{D}\right) = 32.0$$

$f = 0.013$

$k = 1.3$

$$f\left(\frac{L_{max.}}{D}\right) = 0.416$$

From Chart II-1, $P/P^* = 1.647$.

$$P_{1a} = P_1 (P/P^*) = 194 \text{ psia}$$

(3) Reaction Force at Discharge Elbow Exit. Reaction force,

$$F_1 = \frac{WV_1}{g_c} + (P_1 - P_a) A_1$$

$W = 116.38$ lbm/sec
$V_1 = 2116$ ft/sec
$g_c = 32.2$ lbm-ft/lbf-sec^2
$P_1 = 118$ psia
$A_1 = 50.03$ in.^{2}
$P_a = 15$ psia

relief valve set pressure = 910 psig
steam temperature = 1000°F
orifice size = 11.05 in.^{2} (Q orifice)
actual flow capacity of valve
at 10% accumulation = 418,950 lbm/hr
valve inlet I.D. = 6 in.
valve outlet I.D. = 8 in.
valve discharge elbow = 8 in. SCH 40
valve vent pipe = 12 in. SCH 30
seismic coefficient = 1.5*g*
nozzle material = ASTM A 335 P22 2$^1/_4$Cr–1Mo
allowable stress at 1000°F = 7800 psi
valve weight = 800 lb
valve rise time = 0.040 sec

Determine stresses at Points (1) and (2) due to seismic and relief valve discharge loads only.

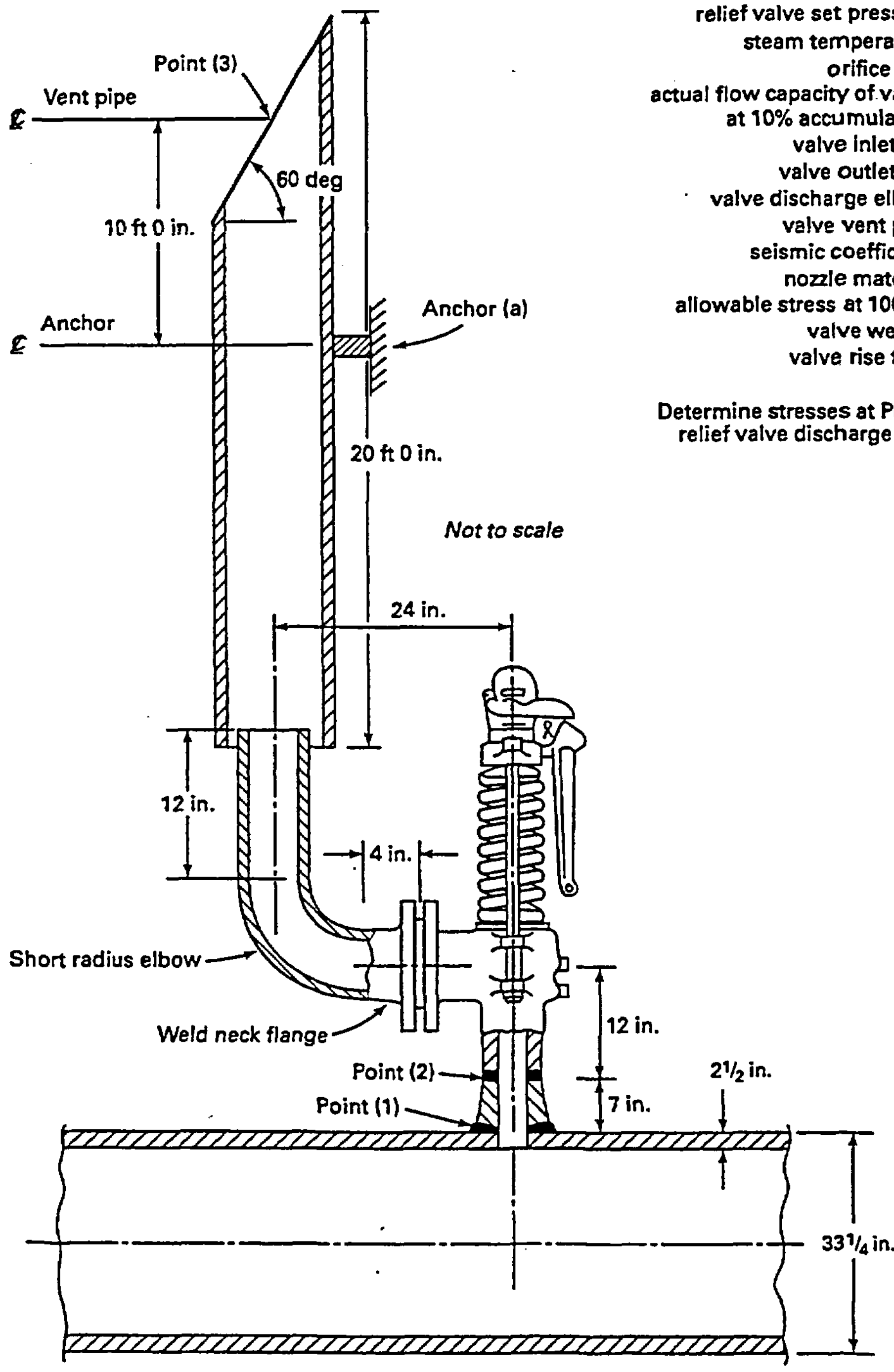


FIG. II-7-1

$$i = 1.5\left(\frac{R_m}{T_r}\right)^{2/3}\left(\frac{r'_m}{R_m}\right)^{1/2}\left(\frac{T'_b}{T_r}\right)\left(\frac{r'_m}{r_p}\right)$$

R_m, T_r, r'_m, T'_b, and r_p are shown in sketch below:

$$i_{(1)} = 1.5\left(\frac{15.375}{2.5}\right)^{2/3}\left(\frac{4.25}{15.375}\right)^{1/2}\left(\frac{2.5}{2.5}\right)\left(\frac{4.25}{5.5}\right)$$

$$i_{(1)} = 2.05$$

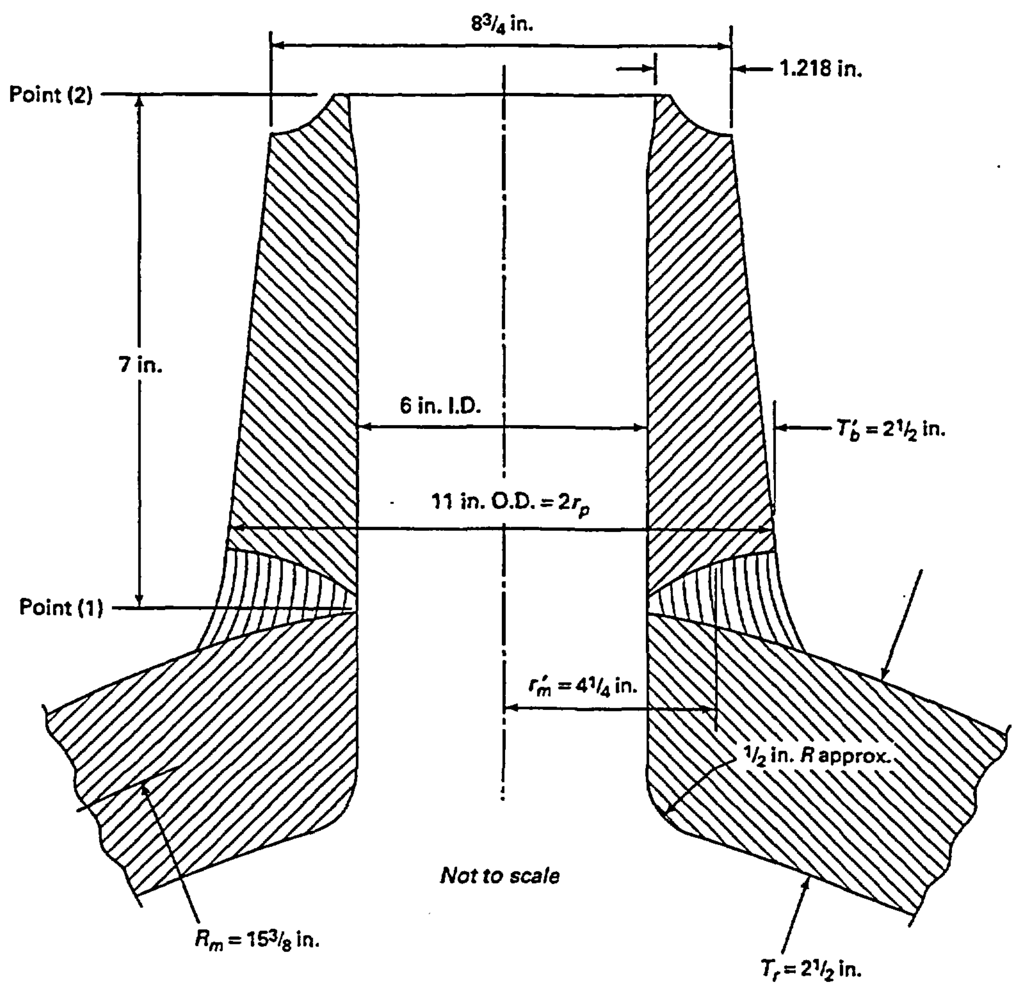


FIG. II-7-2

$$(P_1 - P_a) = 118 - 15$$
$$= 103 \text{ psig}$$
$$WV_1/g_c = 7648 \text{ lbf}$$
$$(P_1 - P_a)A_1 = 5153 \text{ lbf}$$
$$F_1 = 12{,}801 \text{ lbf}$$

(4) Bending Moments at Points (1) and (2)

(A) Bending Moment at Points (1) and (2) due to Reaction at Point (1):

$$M_{1(1)} = M_{1(2)}$$
$$= F_1 \times L \times DLF$$
$$L = \text{moment arm}$$
$$= 24 \text{ in.}$$

DLF = dynamic load factor

To determine DLF, first determine the safety valve installation period T:

$$T = 0.1846 \sqrt{\frac{Wh^3}{EI}}$$

where

W = weight of valve
= 800 lb
h = distance from run pipe to center line of outlet piping
= 19 in.
E = Young's modulus of inlet pipe at design temperature
= 23×10^6 psi
I = moment of inertia of inlet pipe
= $\frac{\pi}{64}(D_o^4 - D_i^4)$
Use average O.D. and I.D. to determine I.
D_o = 9.875 in. avg.; D_i = 6 in. avg.
= 403.2 in.^{4}
T = 0.00449 sec

For a valve rise time of 0.040 sec = t_o, the ratio t_o/T is 8.9. From Fig. II-3-2, DLF = 1.11.

Using F_1 = 12,801 lbf, L = 24 in., and DLF = 1.11.

$$M_{1(1)} = M_{1(2)} = 341{,}018 \text{ in.-lb}$$

(B) Bending Moments at Points (1) and (2) due to Seismic Loading

Seismic force,

$$F_S = \text{mass} \times \text{acceleration}$$

$$= \left[\frac{800 \text{ lbm}}{32.2 \text{ lbm-ft/lbf-sec}^2}\right] \times 1.5(32.2 \text{ ft/sec}^2)$$

$$= 1200 \text{ lbf}$$

Moment arm for Point (1) = 19 in.

$$M_{S(1)} = 1200 \text{ lbf } (19 \text{ in.}) = 22{,}800 \text{ in.-lb}$$

Moment arm for Point (2) = 12 in.

$$M_{S(2)} = 1200 \text{ lbf } (12 \text{ in.}) = 14{,}400 \text{ in.-lb}$$

(C) Combined Bending Moments at Points (1) and (2)

$$M_{(1)} = M_{1(1)} + M_{S(1)} = 363{,}819 \text{ in.-lb}$$

$$M_{(2)} = M_{1(2)} + M_{S(2)} = 355{,}419 \text{ in.-lb}$$

(5) Stress Intensification Factors at Points (1) and (2)

(A) At Point (1), Branch Connection

$$i_{(1)} = 2.05$$

(B) Stress Intensification Factors at Point (2), Buttweld

$$i_{(2)} = 1.0$$

(6) Predicted Stresses at Points (1) and (2)

(A) Predicted Stresses at Point (1), Branch Connection

$$\text{Predicted stress} = \frac{PD_o}{4t_n}$$

$$\frac{D_o}{t_n} \text{ for run pipe} = \frac{33.25 \text{ in.}}{2.5 \text{ in.}} = 13.3$$

$$\frac{D_o}{t_n} \text{ for branch pipe} = \frac{11 \text{ in.}}{2.5 \text{ in.}} = 4.4$$

Use larger value with P = 910 psig.

$$\text{Pressure stress}_{(1)} = 3030 \text{ psi}$$

$$\text{Flexure stress}_{(1)} = \frac{0.75 i M_{(1)}}{Z_{(1)}}$$

$$Z_{(1)} = \pi r_b^2 t_s$$

$$t_S = \text{lesser of } t_r \text{ or } (i)\, t_b$$

$$t_R = 2.5 \text{ in.}; (i)\, t_b = (2.05)\, 2.5 \text{ in.}$$

$$t_S = 2.5 \text{ in.}$$

$$r_b = 4.25 \text{ in.}$$

$$Z_{(1)} = 142 \text{ in.}^3$$

$i_{(1)} = 2.05;\ M_{(1)} = 363{,}819$ in.-lb

$$\text{Flexure stress}_{(1)} = 3939 \text{ psi}$$
$$\text{Combined stress}_{(1)} = \text{pressure stress}_{(1)} + \text{flexure stress}_{(1)} = 6969 \text{ psi}$$

(B) Predicted Stresses at Point (2), Buttweld

$$\text{Pressure stress} = \frac{P\,D_o}{4\,t_n}$$
$$P = 910 \text{ psig}$$
$$D_o = 8.75 \text{ in.}$$
$$t_n = 1.218 \text{ in.}$$
$$\text{Pressure stress}_{(2)} = 1635 \text{ psi}$$
$$\text{Flexure stress}_{(2)} = \frac{0.75\,i\,M_{(2)}}{Z_{(2)}}$$
$$Z_{(2)} = \frac{\pi}{32}\,\frac{D_o^4 - D_i^4}{D_o}$$
$$D_o = 8.75 \text{ in.}$$
$$D_i = 6 \text{ in.}$$
$$Z_{(2)} = 51.1 \text{ in.}^3$$
$$i_{(2)} = 1.0$$
$$M_{(2)} = 355{,}419 \text{ in.-lb}$$
$$\text{Flexure stress}_{(2)} = 6955 \text{ psi}$$

(Note that $0.75i$ is set equal to 1.0 whenever $0.75i$ is less than 1.0, as in this case.)

$$\text{Combined stress}_{(2)} = \text{pressure stress}_{(2)} + \text{flexure stress}_{(2)} = 8590 \text{ psi}$$

(C) Comparison of Predicted Stress with Allowable Stress. Allowable stress of nozzle material at 1000°F is

$$S_h = 7800 \text{ psi}$$
$$k = 1.2$$
$$kS_h = 9360 \text{ psi}$$
$$\text{Combined stress}_{(1)} = 6969 \text{ psi}$$
$$\text{Combined stress}_{(2)} = 8590 \text{ psi}$$

(7) Calculate the Maximum Operating Pressure for Vent Pipe

$$P_3 = P_1\left(\frac{A_1}{A_3}\right) = 118 \text{ psia}\left(\frac{50.03 \text{ in.}^2}{114.80 \text{ in.}^2}\right)$$
$$= 51.4 \text{ psia}$$

L/D for 20 ft 0 in. of 12 in. SCH 30 pipe = 19.85.

$$\Sigma(L/D) = \left(\frac{L_{max.}}{D}\right) = 19.85$$
$$f = 0.013$$
$$k = 1.3$$
$$f\left(\frac{L_{max.}}{D}\right) = 0.258$$

From Chart II-1, $P/P^* = 1.506$.

$$P_2 = P_3\,(P/P^*) = 77.4 \text{ psia}$$

(8) Check for Blowback From Vent Pipe. Calculate the velocity V_2 that exists at the inlet to the vent pipe (para. II-2.2.1.4).

$$f\left(\frac{L_{max.}}{D}\right) = 0.258 \text{ from Step (7)}$$
$$V_3 = V_1 = 2116 \text{ ft/sec}$$

From Chart II-1, $V/V^* = 0.7120$.

$$V_2 = V_3\,(V/V^*) = 1507 \text{ ft/sec}$$

Check the inequality from para. II-2.3.1.2.

$$\frac{W\,(V_1 - V_2)}{g_c} > (P_2 - P_a)\,A_2 - (P_1 - P_a)\,A_1$$

$$\frac{116.38\,(2116 - 1507)}{32.2} > (77.4 - 14.7)(114.8) - (118 - 14.7)(50.03)$$

$$2201 > 2030$$

The inequality has been satisfied but the designer may require a design margin that would make 14 in. SCH 30 more acceptable. If a larger vent pipe is chosen, then the vent pipe analysis would have to be repeated for the 14 in. SCH 30 pipe.

(9) Calculate Forces and Moments on Vent Pipe Anchor (a)

$$F_2 = \frac{WV_2}{g_c} + (P_2 - P_a)\,A_2$$

$$= \frac{(116.38)(1507)}{32.2} + (77.4 - 14.7)\,(114.8)$$

$$= 5447 + 7198.0 = 12{,}645 \text{ lbf}$$

$$F_3 = \frac{(116.38)(2116)}{32.2} + (51.4 - 14.7)(114.8)$$

$$= 7648 + 4213 = 11{,}861 \text{ lbf}$$

Assume a 30 deg jet deflection angle for vent pipe outlet.

Vertical component of F_3

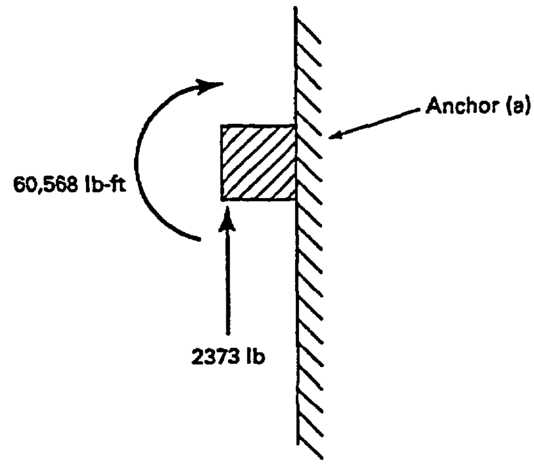


FIG. II-7-3

$$F_{3V} = F_3 \cos 30 \text{ deg} = 10{,}272 \text{ lbf}$$

Horizontal component of F_3

$$F_{3H} = F_3 \sin 30 \text{ deg} = 5931 \text{ lbf}$$

Net imbalance on the vent pipe in the vertical direction is

$$F_2 - F_{3V} = 2373 \text{ lbf}$$

Moment on vent pipe anchor

$$\Sigma M = (F_2 - F_{3V})\,\frac{D_o}{2} + F_{3H} \times [\text{distance from (a) to point 3}]$$

$$= (2373)\left(\frac{1.06}{2}\right) + (5931)(10.0)$$

$$= 60{,}568 \text{ ft-lb}$$

The vent pipe anchor would then be designed for the loads shown in Fig. II-7-3 for safety valve operation.

Conclusion

Branch connection stresses at Points (1) and (2) due to seismic and relief valve discharge are within 1.2 S_h. Blowback will not occur with the 12 in. standard weight vent pipe. The vent pipe anchor loads have been identified.

NONMANDATORY APPENDIX III[1]
RULES FOR NONMETALLIC PIPING

FOREWORD

ASME B31.1 contains rules governing the design, fabrication, materials, erection, and examination of power piping systems. Experience in the application of nonmetallic materials for piping systems has shown that a number of considerations exist for the use of these materials that are not addressed in the current body of the Code. In order to address these, the requirements and recommendations for the use of nonmetallic piping (except in paras. 105.3, 108.4, 116, and 118) have been separately assembled in this nonmandatory Appendix.

III-1.0 SCOPE AND DEFINITION

III-1.1 General

III-1.1.1 This Appendix provides minimum requirements for the design, materials, fabrication, erection, testing, examination, and inspection of nonmetallic piping within the jurisdiction of the ASME B31.1 Power Piping Code. All references to the Code or to Code paragraphs in this Appendix are to the Section B31.1 Power Piping Code. In this Appendix, nonmetallic piping shall be limited to plastic and elastomerbased piping materials, with or without fabric or fibrous material added for pressure reinforcement.

III-1.1.2 Standards and specifications incorporated in this Appendix are listed in Table III-4.1.1. The effective date of these documents shall correspond to the date of this Appendix.

III-1.1.3 The provisions in Chapters I through VI and in Appendices A through F are requirements of this Appendix only when specifically referenced herein.

[1] Nonmandatory Appendices are identified by a Roman numeral; mandatory Appendices are identified by a letter. Therefore, Roman numeral I is not used in order to avoid confusion with the letter I.

III-1.2 Scope

III-1.2.1 All applicable requirements of para. 100.1 and the limitations of para. 105.3 shall be met in addition to those in this Appendix.

III-1.2.2 Use of this Appendix is limited to:

(A) water service;

(B) nonflammable and nontoxic liquid, dry material, and slurry systems;

(C) reinforced thermosetting resin pipe in buried flammable and combustible liquid service systems [refer to para. 122.7.3(F)]; and

(D) polyethylene pipe in buried flammable and combustible liquid and gas service. Refer to paras. 122.7.3(F) and 122.8.1(G).

III-1.2.3 Nonmetallic piping systems shall not be installed in a confined space where toxic gases could be produced and accumulate, either from combustion of the piping materials or from exposure to flame or elevated temperatures from fire.

III-1.3 Definitions and Abbreviations

III-1.3.1 Terms and definitions relating to plastic and other nonmetallic piping materials shall be in accordance with ASTM D 883. The following terms and definitions are in addition to those provided in the ASTM standard.

adhesive: a material designed to join two other component materials together by surface attachment (bonding)

adhesive joint: a bonded joint made using an adhesive on the surfaces to be joined

bonder: one who performs a manual or semiautomatic bonding operation

bonding operator: one who operates a machine or automatic bonding equipment

bonding procedure: the detailed methods and practices involved in the production of a bonded joint

Bonding Procedure Specification (BPS): the document that lists the parameters to be used in the construction

of bonded joints in accordance with the requirements of this Code

butt-and-wrapped joint: a joint made by applying plies of reinforcement saturated with resin to the surfaces to be joined

chopped roving: a collection of noncontinuous glass strands gathered without mechanical twist. Each strand is made up of glass filaments bonded together with a finish or size for application by chopper gun

chopped strand mat: a collection of randomly oriented glass fiber strands, chopped or swirled together with a binder in the form of a blanket

continuous roving: a collection of continuous glass strands wound into a cylindrical package without mechanical twist

curing agent: a reactive material which when combined with a resin material reacts or polymerizes (cross-links) with the resin; also referred to as a hardener

diluent: a reactive modifying material, usually liquid, which reduces the concentration of a resin material to facilitate handling characteristics and improve wetting

fire retardant resin: a specially compounded material combined with a resin material designed to reduce or eliminate the tendency to burn

flexibilizer: a modifying liquid material added to a resinous mixture designed to allow the finished component the ability to be flexed or less rigid and more prone to bending

grout: a heavily filled paste material used to fill crevices and transitions between piping components

heat fusion joint: a joint made by heating the surfaces to be joined and pressing them together so they fuse and become essentially one piece

hot gas welded joint: a joint made by simultaneously heating a filler material and the surfaces to be joined with a stream of hot air or hot inert gas until the materials soften, after which the surfaces to be joined are pressed together and welded with the molten filler material

liner: a coating or layer of material constructed as, applied to, or inserted within the inside surface of a piping component intended to protect the structure from chemical attack, to inhibit erosion, or to prevent leakage under strain

seal weld: the addition of material external to a joint by welding or bonding for the purpose of enhancing leak tightness

solvent cement joint: a joint using a solvent cement to soften the surfaces to be joined, after which the joining surfaces are pressed together and become essentially one piece as the solvent evaporates

stiffness factor: the measurement of a pipe's ability to resist deflection as determined in accordance with ASTM D 2412

thixatropic agent: a material added to resin to impart high static shear strength (viscosity) and low dynamic shear strength

ultraviolet absorber: a material which when combined in a resin mixture will selectively absorb ultraviolet radiation

woven roving: a heavy glass fiber fabric reinforcing material made by the weaving of glass fiber roving

III-1.3.2 Abbreviations used in this Appendix denote materials and terms as follows:

Abbreviation	Term
ABS[2]	Acrylonitrile-butadiene-styrene
AP	Polyacetal
CP	Chlorinated polyether
CPVC[2]	Chlorinated poly (vinyl chloride)
DS	Design stress
FEP[2]	Perfluoro (ethylene propylene)
HDB	Hydrostatic design basis
HDS	Hydrostatic design stress
PA[2]	Polyamide (nylon)
PB	Polybutylene
PE[2]	Polyethylene
PFA	Poly (perfluoroalkoxy)
POP	Poly (phenylene oxide)
PP[2]	Polypropylene
PPS	Polyphenylene
PR	Pressure rated
PTFE[2]	Polytetrafluoroethylene
PVC[2]	Poly (vinyl chloride)
PVDC	Poly (vinylidene chloride)
PVDF	Poly(vinylidene fluoride)
RTR	Reinforced thermosetting resin
SDR	Standard dimensional ratio

[2] Abbreviations in accordance with ASTM D 1600.

III-2.0 DESIGN

III-2.1 Conditions and Criteria

III-2.1.1 General

(A) The Design Conditions of para. 101 shall apply for the design of nonmetallic piping systems.

(B) The design of nonmetallic piping systems must ensure the adequacy of material and its manufacture, considering at least the following:

(B.1) tensile, compressive, flexural, shear strength, and modulus of elasticity at design temperature (long-term and short-term);

(B.2) creep characteristics for the service conditions;

(B.3) design stress and its basis;

(B.4) coefficient of thermal expansion;

(B.5) ductility and plasticity;

(B.6) impact and thermal shock properties;

(B.7) temperature limits for the service;

(B.8) transition temperatures: melting and vaporization;

(B.9) toxicity of the material or of the gases produced by its combustion or exposure to elevated temperatures;

(B.10) porosity and permeability;

(B.11) test methods;

(B.12) methods of making joints and their efficiency;

(B.13) deterioration in the service environment;

(B.14) the effects on unprotected piping from external heat sources (particularly solar radiation).

III-2.1.2 Pressure-Temperature Ratings for Components

(A) Components having specific pressure-temperature ratings have been established in the standards listed in Table III-4.1.1. Other components may be used in accordance with para. III-2.1.2(B).

(A.1) Except as qualified in paras. III-2.1.3, the ratings of Tables III-4.2.1, III-4.2.2, and III-4.2.3 are the limiting values for allowable stresses at temperature in this Appendix.

(A.2) The application of pressures exceeding the pressure-temperature ratings of valves is not permitted. Valves shall be selected for operation within the limits defined in para III-2.1.2(C)

(B) Components Not Having Specific Ratings

(B.1) Pipe and other piping components for which allowable stresses have been developed in accordance with para. III-2.1.3, but which do not have specific pressure-temperature ratings, shall be rated by the rules for pressure design in para. III-2.2 within the range of temperatures for which stresses are listed in Tables III-4.2.1, III-4.2.2, and III-4.2.3.

(B.2) Custom-molded pipe and other piping components that do not have allowable stresses or pressure-temperature ratings shall be qualified for pressure design as required in para. III-2.2.9.

(C) Allowances for Pressure and Temperature Variations. Allowances for variations of pressure, or temperature, or both, above design conditions are not permitted. The most severe conditions of coincident pressure and temperature shall be used to determine the design conditions.

(D) Considerations for Local Conditions. Where two services that operate at different pressure-temperature conditions are connected, the valve segregating the two services shall be rated for the most severe service conditions. Other requirements of para. 102.2.5 must be considered where applicable.

III-2.1.3 Allowable Stresses and Other Stress Limits

(A) General. Tables III-4.2.1, III-4.2.2, and III-4.2.3 list recommended maximum allowable stresses in the form of hydrostatic design stresses (HDS), allowable design stresses (DS), and the hydrostatic design basis (HDB), which may be used in design calculations except where modified by other provisions of this Appendix. The use of hydrostatic design stresses for calculations other than pressure design has not been established. The basis for determining allowable stresses and pressures is outlined in para. III-2.1.3(B). The allowable stresses are grouped by materials and listed for stated temperatures. Where sufficient data have been provided, straight-line interpolation between temperatures is permissible. The materials listed are available from one or more manufacturers and may be obtained with maximum allowable stresses varying from those listed in Tables III-4.2.1, III-4.2.2, and III-4.2.3. These materials and values are acceptable for use where they have been established in accordance with (B) below and para. III-2.2.9.

(B) Basis for Allowable Stresses for Internal Pressure

(B.1) Thermoplastics. A method of determining hydrostatic design stress (HDS) and pressure rating (PR) is described in ASTM D 2837. Hydrostatic design stresses are provided in Table III-4.2.1 for those materials and temperatures for which sufficient data have been compiled to substantiate a determination of stress. Data on these materials at other temperatures, and on other materials, are being developed. Pending publication of additional data, the limitations in para. III-2.1.2(B) shall be observed.

(B.2) Reinforced Thermosetting Resin (Laminated). For laminated piping components, the design stresses

(DS) are listed in Table III-4.2.2. These typically are based on one-tenth of the minimum tensile strengths specified in Table 1 of ASTM C 582.

(B.3) Reinforced Thermosetting Resin (Filament Wound and Centrifugally Cast). For filament wound and centrifugally cast piping components, hydrostatic design basis (HDB) values are listed in Table III-4.2.3. These values may be obtained by procedures in ASTM D 2992. HDS may be obtained by multiplying the HDB by a service (design) factor[3] selected for the application, in accordance with procedures described in ASTM D 2992, within the following limits.

(B.3.1) When using the cyclic HDB from Table III-4.2.3, the service (design) factor shall not exceed 1.0.

(B.3.2) When using the static HDB from Table III-4.2.3, the service (design) factor shall not exceed 0.5.

III-2.1.4 Limits of Calculated Stresses due to Sustained Loads

(A) Internal Pressure Stresses. The limits for stress due to internal pressure are provided in para. III-2.2.2.

(B) External Pressure Stresses. Stresses due to uniform external pressures shall be considered safe when the wall thickness of the component, and means of stiffening, have been established in accordance with para. III-2.2.9.

(C) External Loading Stresses. Design of reinforced thermosetting resin (RTR) and thermoplastic piping under external loading shall be based on the results of the parallel plate loading test in ASTM D 2412. The allowable deflection for RTR and thermoplastic pipe shall be 5% of the pipe diameter. Where other nonmetallic piping is intended for use under conditions of external loading, it shall be subject to a crushing or three-edge bearing test, in accordance with ASTM C 14 or C 301, and the allowable load shall be 25% of the minimum value obtained.

III-2.1.5 Limits of Calculated Stresses due to Occasional Loads

(A) Operation. The total stress produced by pressure, live and dead loads, and by occasional loads, such as wind or earthquake, shall not exceed the considerations and recommendations in para. III-2.5. Wind and earthquake forces need not be considered as acting concurrently.

(B) Test. Stresses due to test conditions are not subject to the limitations in (A) above. It is not necessary to consider other occasional loads, such as wind and earthquake, as occurring concurrently with test loads.

III-2.1.6 Allowances

(A) Erosion, Corrosion, Threading, and Grooving. In determining the minimum required thickness of a piping component, allowances shall be included for erosion and for thread depth or groove depth.

(B) Mechanical Strength. When necessary, pipe wall thicknesses shall be increased to prevent overstress, damage, collapse, or buckling due to superimposed loads from supports, ice formation, backfill, or other causes. Where increasing thickness will cause excessive local stress, or is otherwise impractical, the required strength may be obtained through the use of additional supports, braces, or other means without an increased wall thickness. Particular consideration should be given to the mechanical strength of a small branch connected to large piping or to equipment.

III-2.2 Pressure Design of Piping Components

III-2.2.1 Criteria for Pressure Design. The design of piping components shall consider the effects of pressure and temperature in accordance with para. III-2.1.2, and provide for allowances in accordance with para. III-2.1.6. In addition, the design shall be checked for adequacy of mechanical strength under other applicable loadings as required in paras. III-2.1.4 and III-2.1.5.

(A) The required minimum wall thickness of straight sections of pipe t_m shall be determined in accordance with Eq. (1).

$$t_m = t + c \tag{1}$$

where

t_m = minimum required thickness, in.

t = pressure design thickness, in., as calculated in para. III-2.2.2 for internal pressure, or in accordance with para. III-2.2.3 for external pressure

c = the sum of the mechanical allowances (thread or groove depth), plus erosion and/or corrosion allowance, and the manufacturer's minus tolerance for product wall thickness, in. For threaded components, the nominal thread depth shall apply. For machined surfaces or grooves where a tolerance is not specified, the tolerance shall be assumed to be 0.02 in., in addition to the specified depth of the thread or groove.

[3] The service (design) factor should be selected by the designer after evaluating fully the service conditions and the engineering properties of the specific material under consideration. Aside from the limits in paras. III-2.1.3.(B.3.1) and (B.3.2), it is not the intent of the Code to specify service (design) factors.

III-2.2.2 Straight Pipe Under Internal Pressure

(A) The internal pressure design thickness t shall not be less than that calculated by the following equations.

(A.1) Thermoplastic Pipe

$$t = \frac{D}{2S_a/P + 1} \qquad (2)$$

(A.2) Reinforced Thermosetting Resin (Laminated)

$$t = \frac{D}{2S_b/P + 1} \qquad (3)$$

(A.3) Reinforced Thermosetting Resin (Filament Wound and Centrifugally Cast)

$$t = \frac{D}{2S_c F/P + 1} \qquad (4)$$

where

D = outside diameter of pipe, in.
F = service design factor in accordance with para. III-2.1.3(B.3)
P = internal design gage pressure, psi
S_a = hydrostatic design stress from Table III-4.2.1
S_b = design stress from Table III-4.2.2
S_c = hydrostatic design basis from Table III-4.2.3

(B) The internal pressure design thickness t in (A.1) and (A.2) above shall not include any thickness of pipe wall reinforced with less than 30% (by weight) of reinforcing fibers, or added liner thickness.

III-2.2.3 Straight Pipe Under External Pressure

(A) Thermoplastic Pipe. The external pressure design thickness t shall be qualified as required by para. III-2.2.9

(B) Reinforced Thermosetting Resin Pipe

(B.1) Above Ground. For determining design pressure thickness for straight pipe under external pressure, the procedures outlined in ASTM D 2924 shall be followed. A safety factor of at least 4 shall be used.

(B.2) Below Ground. For determining design pressure thickness for straight pipe under external pressure in a buried condition, the procedures outlined in AWWA C-950, Appendix A, Sections A-2.5 and A-2.6 shall be followed.

(C) Metallic Pipe Lined With Nonmetals

(C.1) The external pressure design thickness for the base (outer) material shall be determined in accordance with para. 104.1.3.

(C.2) The external pressure design thickness t for the lining material shall be qualified as required by para. III-2.2.9.

III-2.2.4 Curved and Mitered Segments of Pipe

(A) Pipe Bends. The minimum required thickness t_m of a pipe bend after bending shall be determined as for straight pipe in accordance with para. III-2.2.1.

(B) Elbows. Manufactured elbows not in accordance with para. III-2.1.2 shall meet the requirements of para. III-2.2.9.

(C) Mitered Bends. Mitered bend sections shall meet the requirements of para. III-2.2.9.

III-2.2.5 Branch Connections

(A) General. A pipe having a branch connection is weakened by the opening that must be made in it, and unless the wall thickness of the pipe is sufficiently in excess of that required to sustain the pressure, it is necessary to provide added reinforcement. The amount of reinforcement required shall be in accordance with the requirements of para. III-2.2.9 except as provided in (B) and (C) below.

(B) Branch Connections Using Fittings. A branch connection shall be considered to have adequate strength to sustain the internal and external pressure which will be applied to it if a fitting (a tee, lateral, or cross) is utilized in accordance with para. III-2.1.2(A).

(C) Additional Considerations. The requirements of (A) and (B) above are designed to assure satisfactory performance of a branch connection subjected only to internal or external pressure. The designer shall also consider the following:

(C.1) external forces and moments which may be applied to a branch connection by thermal expansion and contraction, by dead and live loads, by vibration or pulsating pressure, or by movement of piping terminals, supports, and anchors;

(C.2) adequate flexibility shall be provided in branch piping to accommodate movements of the run piping;

(C.3) ribs, gussets, or clamps may be used for pressure-strengthening a branch connection in lieu of the reinforcement required by (A) above if the adequacy of the design is established in accordance with para. III-2.2.9.

III-2.2.6 Closures. Closures in piping systems, such as those provided for temporary or future lateral or end-point branches, shall be made using fittings, flanges, or parts in accordance with paras. III-2.2.7 and III-2.2.9.

III-2.2.7 Pressure Design of Flanges

(A) General

(A.1) Nonmetallic flanges that are rated in accordance with published ASTM standards listed in Table III-4.1.1 shall be considered suitable for use within the limitations specified in this Appendix. Alternatively,

flanges shall be in accordance with para. 103, or may be designed in conformance with the requirements of para. III-2.2.7 or III-2.2.9.

(A.2) Flanges for use with ring type gaskets may be designed in accordance with Section VIII, Division 1, Appendix 2 of the ASME Boiler and Pressure Vessel Code, except that the allowable stresses for nonmetallic componens shall govern. All nomenclature shall be as defined in the ASME Code except the following:

P = design gage pressure

S_a = bolt design stress at atmospheric temperature. (Bolt design stresses shall not exceed those in Appendix A.)

S_b = bolt design stress at design temperature. (Bolt design stresses shall not exceed those in Appendix A.)

S_f = allowable stress for flange material from Para. III-4.2

(A.3) The flange design rules in (A.2) above are not applicable for designs employing full-face gaskets that extend beyond the bolts or where flanges are in solid contact beyond the bolts. The forces and reactions in such a joint differ from those joints employing ring type gaskets, and the flanges should be designed in accordance with Section VIII, Division 1, Appendix Y of the ASME Boiler and Pressure Vessel Code. (Note that the plastic flange sealing surface may be more irregular than the sealing surface of a steel flange. For this reason, thicker and softer gaskets may be required for plastic flanges.)

(B) Blind Flanges. Blind flanges shall be in accordance with para. 103, or alternatively, may be designed in accordance with para. 104.5.2, except that the allowable stress for nonmetallic components shall be taken from the data in para. III-4.2. Otherwise, the design of blind flanges shall meet the requirements of para. III-2.2.9.

III-2.2.8 Reducers. Reducers not in compliance with para. 103 shall meet the requirements of para. III-2.2.9.

III-2.2.9 Design of Other Components

(A) Listed Components. Other pressure-retaining components manufactured in accordance with standards listed in Table III-4.1.1 may be utilized in accordance with para. III-2.1.2.

(B) Unlisted Components and Products. For pressure-retaining components and piping products not in accordance with the standards and specifications in Table III-4.1.1, and for proprietary components and joints for which the rules in paras. III-2.2.1 through III-2.2.8 do not apply, pressure design shall be based on calculations consistent with the design criteria of the Code. This must be substantiated by one or more of the following, with consideration given to applicable dynamic effects, such as vibration and cyclic operation, the effects of thermal expansion or contraction, and the load effects of impact and thermal shock:

(B.1) extensive successful service experience under comparable design conditions with similarly proportioned components or piping elements made of the same or like material;

(B.2) performance tests under design conditions, including applicable dynamic and creep effects, continued for a time period sufficient to determine the acceptability of the component or piping element for its design life;

(B.3) for either (B.1) or (B.2) above, reasonable interpolations between sizes and pressure classes and reasonable analogies among related materials are permitted.

III-2.3 Selection of Piping Components

III-2.3.1 General. Nonmetallic pipe, tubing, fittings, and miscellaneous items conforming to the standards and specifications listed in Table III-4.1.1 shall be used within the limitations of para. III-4.0 of this Appendix.

III-2.4 Selection of Piping Joints

III-2.4.1 General. Joints shall be suitable for the pressure-temperature design conditions and shall be selected giving consideration to joint tightness and mechanical strength under those conditions (including external loadings), the materials of construction, the nature of the fluid service, and the limitations of paras. III-2.4.2 through III-2.4.7.

III-2.4.2 Bonded Joints

(A) General Limitations. Unless limited elsewhere in para. III-2.4.2, joints made by bonding in accordance with para. III-5.1, and examined in accordance with para. III-6.2, may be used within other limitations on materials and piping components in this Appendix.

(B) Specific Limitations

(B.1) Fillet Joints. Fillet bonded joints may be used in hot gas welded joints, only, if in conformance with the requirements of para. III-5.1.3(A).

(B.2) Butt-and-Wrapped Joints. Butt-and-wrapped joints in RTR piping shall be made with sufficient strength to withstand pressure and external loadings.

III-2.4.3 Flanged Joints

(A) General Limitations. Unless limited elsewhere in

para. III-2.4.3, flanged joints may be used, considering the requirements for materials in para. III-3.0, and for piping components in para. III-2.3, within the following limitations.

(A.1) Joints With Flanges of Different Ratings. Where flanges of different ratings are bolted together, the rating of the joint shall be that of the lower rated flange. Bolting torque shall be limited so that excessive loads will not be imposed on the lower rated flange in obtaining a tight joint.

(A.2) Metallic to Nonmetallic Flanged Joints. Where metallic and nonmetallic flanges are to be joined, both should be flat-faced. Full-faced gaskets are preferred. If full-faced gaskets are not used, bolting torque shall be limited so that the nonmetallic flange is not overloaded.

III-2.4.4 Expanded or Rolled Joints. Expanded or rolled joints are not permitted in nonmetallic piping systems.

III-2.4.5 Threaded Joints

(A) General Limitations

(A.1) Threaded joints may be used within the requirements for materials in para. III-3.0, and on piping components in para. III-2.3, within the following limitations.

(A.2) Threaded joints shall be avoided in any service where severe erosion or cyclic loading may occur, unless the joint has been specifically designed for these conditions.

(A.3) Where threaded joints are designed to be seal welded, thread sealing compound shall not be used.

(A.4) Layout of piping should minimize reaction loads on threaded joints, giving special consideration to stresses due to thermal expansion and the operation of valves.

(A.5) Metallic-to-nonmetallic and dissimilar nonmetallic threaded joints are not permitted in piping 2½ in. NPS, and larger.

(A.6) Threaded joints are not permitted at design temperatures above 150°F.

(B) Specific Limitations

(B.1) Thermoplastic Resin Piping. Threaded joints in thermoplastic piping shall conform to the following requirements.

(B.1.1) The pipe wall shall be at least Schedule 80 thickness.

(B.1.2) Pipe threads shall conform to ASME B1.20.1 NPT. Threaded fittings shall be compatible with that standard.

(B.1.3) A suitable thread lubricant and sealant shall be specified.

(B.1.4) Threaded piping joints are not permitted in polyolefin materials[4] because of creep characteristics that must be considered.

(B.2) Thermosetting Resin Piping. Threaded joints in thermosetting resin piping shall conform to the following requirements.

(B.2.1) Threads shall be factory cut or molded on pipe ends and in matching fittings, with allowance for thread depth in accordance with para. III-2.2.1(A).

(B.2.2) Threading of plain ends of piping is not permitted except where such male threads are limited to the function of forming a mechanical lock with matching female threads during bonding.

(B.2.3) Factory cut or molded threaded nipples, couplings, or adapters bonded to plain end components, may be used where necessary to provide connections to threaded metallic piping.

III-2.4.6 Caulked Joints. In liquid service, bell and spigot and other caulked joints shall be used within the pressure-temperature limitations of the joints and the components. Provisions shall be made to prevent disengagement of the joints at bends and dead ends and to support lateral reactions produced by branch connections or other causes.

III-2.4.7 Proprietary Joints. Metal coupling, mechanical, gland and other proprietary joints may be used within the limitations on materials in para. III-3.0, on components in para. III-2.3, and the following.

(A) Adequate provisions shall be made to prevent the separation of joints under internal pressure, temperature and external loads.

(B) Prior to acceptance for use, a prototype joint shall be subjected to performance tests to determine the safety of the joint under test conditions simulating all expected fluid service conditions.

III-2.5 Expansion and Flexibility

III-2.5.1 General Concepts

(A) Elastic Behavior. The concept of piping strain imposed by the restraint of thermal expansion or contraction, and by external movements, applies in principle to nonmetals. Nevertheless, the assumption that stresses can be predicted from these strains in a nonmetallic piping system, based on the linear elastic characteristics of the material, is generally not valid. The variation in elastic characteristics between otherwise similar material types, between source manufacturers, and between batch

[4] The polyolefin group of materials includes polyethylene, polypropylene, and polybutylene.

lots of the same source material, can at times be significant. If a method of flexibility analysis that assumes elastic behavior is used, the designer must be able to demonstrate its validity for the system and must establish conservative limits for the computed stresses.

(B) Overstrained Behavior. Stresses cannot be considered proportional to displacement strains in nonmetallic piping systems where an excessive level of strain may be produced in a localized area of the system, and in which elastic behavior of the piping material is uncertain. (See unbalanced systems in para. 119.3 of the Code.) Overstrain must be minimized by effective system routing in order to avoid the necessity of a requirement for special joints or expansion devices for accommodating excessive displacements.

(C) Progressive Failure. In thermoplastics and some thermosetting resins, displacement strains are not likely to produce immediate failure of piping but may produce unacceptable distortion. Thermoplastics, particularly, are prone to progressive deformation that may occur upon repeated thermal cycling or under prolonged exposure to elevated temperature.

(D) Brittle Failure. In brittle thermosetting resins, the materials are essentially rigid in behavior and may readily develop high-displacement stresses, to the point of sudden breakage or fracture, under moderate levels of strain.

III-2.5.2 Properties for Flexibility Analysis

(A) Thermal Expansion Data. Table III-4.3.1 of this Appendix lists coefficients of thermal expansion for several nonmetallic materials. More precise values in some instances may be obtained from the manufacturers of these materials. If these values are to be used in stress analysis, the thermal displacements shall be determined as indicated in para. 119.

(B) Modulus of Elasticity. Table III-4.3.2 lists representative data on the tensile modulus of elasticity E for several nonmetals. More precise values in some instances may be obtained from the materials manufacturer. (Note that the modulus may vary with the geometrical orientation of a test sample for filler-reinforced, filament-wound, or impregnated nonmetallic materials.) For materials and temperatures not listed, refer to an authoritative source, such as publications of the National Bureau of Standards.

(C) Poisson's Ratio. For nonmetals, Poisson's ratio will vary widely, depending upon materials and temperature. For that reason formulas used in linear elastic stress analysis can be used only if the manufacturer has test data to substantiate the use of a specific Poisson's ratio for that application.

(D) Dimensions. The nominal thickness and outside diameters of pipe and fittings shall be used in flexibility calculations.

III-2.5.3 Analysis

(A) Formal stress analysis is not required for systems that:

(A.1) are duplicates, or replacements without significant change, of successfully operating installations; or

(A.2) can readily be judged adequate by comparison with previously analyzed systems; or

(A.3) are routed with a conservative margin of inherent flexibility, or employ joining methods or expansion joint devices, or a combination of these methods, in accordance with applicable manufacturer's instruction.

(B) A substantiating stress analysis is required for a system not meeting the above criteria. The designer may demonstrate that adequate flexibility exists by employing a simplified, approximate, or comprehensive stress analysis, using a method that can be shown to be valid for the specific case. If essentially elastic behavior can be demonstrated for a piping system [see para. III-2.5.1(A)], the methods outlined in para. 119 may be applicable.

(C) Special attention shall be given to movement (displacement or rotation) of the piping with respect to supports and points of close clearance. Movements of a run at the junction of a small branch shall be considered in determining the need for flexibility in the branch.

III-2.5.4 Flexibility

(A) Piping systems shall have sufficient flexibility to prevent the effects of thermal expansion or contraction, the movement of pipe supports or terminal points, or pressure elongation from causing:

(A.1) failure of piping or supports from overstrain or fatigue;

(A.2) leakage at joints; or

(A.3) unacceptable stresses or distortion in the piping or in connected equipment.

(B) Where nonmetallic piping and components are used, piping systems must be designed and routed so that flexural stresses resulting from displacements due to expansion, contraction and other causes are minimized. This concept requires special attention for supports and restraints, the terminal connections, and for the techniques outlined in para. 119.5.1. Further infor-

mation on the design of thermoplastic piping can be found in PPI Technical Report TR-21.

III-2.6 Design of Pipe Supporting Elements

III-2.6.1 General. In addition to the other applicable requirements of paras. 120 and 121, supports, guides, and anchors shall be selected and applied to comply with the requirements of para. III-2.5, and the following.

(A) Support or restraint loads shall be transmitted to piping attachment or bearing points in a manner that will preclude pipe wall deformation or damage. Padding or other isolation material should be installed in support or restraint clearance spaces for added protection.

(B) Valves and in-line components shall be independently supported to prevent the imposition of high load effects on the piping or adjacent supports.

(C) Nonmetallic piping should be guarded where such systems are exposed to casual damage from traffic or other work activities.

(D) A manufacturer's recommendations for support shall be considered.

III-2.6.2 Thermoplastic and RTR Piping. Supports shall be spaced to avoid excessive displacement at design temperature and within the design life of the piping system. Decreases in the modulus of elasticity, with increasing temperature, and creep of the material, with time, shall be considered where applicable. The coefficient of thermal expansion of most plastic materials is high and must be considered in the design and location of supports and restraints.

III-2.7 Burial of RTR Pipe

III-2.7.1 Design. The design procedures of ANSI/AWWA C-950, Appendix A shall apply. A minimum pipe stiffness shall meet the requirements in Table 6 of ANSI/AWWA C-950. The minimum stiffness ($F/\Delta y$) shall be determined at 5% deflection using the apparatus and procedures of ASTM D 2412.

III-2.7.2 Installation. The pipe manufacturer's recommendations shall be equal to or more stringent than those described in ASTM D 3839 for RTR pipe or ASTM D 2774 for thermoplastic pipe. The manufacturer's recommendations should be followed.

III-3.0 MATERIALS

III-3.1 General Requirements

Paragraph III-3.0 provides limitations and qualifications for materials based on their inherent properties. The use of these materials in piping may also be subject to requirements and limitations in other parts of the Code.

III-3.2 Materials and Specifications

III-3.2.1 Listed Materials. Listed materials used in pressure containing piping shall have basic allowable stresses and other design limits as covered in para. III-2.1.

III-3.2.2 Unlisted Materials. Unlisted materials used in pressure containing piping shall have basic allowable stresses and other design limits determined in accordance with para. III-2.1, or on a more conservative basis.

III-3.2.3 Unknown Materials. Materials of an unknown specification or standard shall not be used.

III-3.2.4 Reclaimed Materials. Reclaimed piping components may be used provided they are properly identified as conforming to a listed specification and otherwise meet the requirements of this Appendix. Sufficient cleaning and examination shall be performed to determine that the components are acceptable for the intended service, considering at least the following:

(A.1) minimum available wall thickness;

(A.2) extent of any imperfections;

(A.3) possible loss of strength;

(A.4) chemical absorption.

III-3.3 Temperature Limitations

The designer shall determine that materials which meet other requirements of this Appendix are suitable for the fluid service throughout the operating temperature range of the systems in which the materials will be used.

III-3.3.1 Upper Temperature Limitations

(A) The maximum design temperature for a listed material shall not exceed maximum temperatures listed in Tables III-4.2.1, III-4.2.2, or III-4.2.3, as applicable, except as provided in para. III-2.1.3(A).

(B) An unlisted material acceptable under para. III-3.2.2 shall have upper temperature limits established in accordance with para. III-2.1.2.

III-3.3.2 Lower Temperature Limitations

(A) The minimum design temperature for a listed material shall not be lower than the minimum temperatures listed in Tables III-4.2.1 and III-4.2.2, as applicable, except as provided in para. III-2.1.3(A).

(B) An unlisted material acceptable under para. III-3.2.2 shall have lower temperature limits established in accordance with the manufacturer's recommendation but in no case less than −20°F.

III-3.4 Fluid Service Limitations

III-3.4.1 General Limitations. The use of nonmetallic piping materials and components, under the scope of this Appendix, shall be limited to those services and conditions stated in para. III-1.2.2. In addition:

(A) nonmetallic materials shall not be used under severe cyclic conditions unless it can be demonstrated that the materials are suitable for the intended service in accordance with para. III-2.2.9;

(B) these materials shall be appropriately protected against transient or operating temperatures and pressures beyond design limits, and shall be adequately protected against mechanical damage;

(C) limitations on the use or application of materials in this Appendix apply to pressure containing parts. They do not apply to the use of materials for supports, linings, gaskets, or packing.

III-3.4.2 Specific Material Limitations

(A) Thermoplastics shall be installed and protected against elevated temperatures.

(B) Thermosetting and fiber-reinforced thermosetting resins shall be limited to the services stated in para. III-1.2.3 and shall be installed and protected against mechanical damage, vibration, and excessive cyclic strain in service.

III-3.4.3 Miscellaneous Materials: Joining and Auxiliary Materials. When selecting materials, such as cements, solvents, packing, and O-rings for making or sealing joints, the designer shall consider their suitability for the fluid service.

III-3.5 Piping Component Requirements

III-3.5.1 Dimensions of Piping Components

(A) Listed Piping Components. Dimensions of listed piping components, including tolerances, shall conform to the applicable piping component specification or standard listed in Table III-4.1.1.

(B) Unlisted Piping Components. Dimensions of unlisted piping components, including tolerances, shall conform to those of comparable listed piping components insofar as practical. In all cases, dimensions shall be such as to provide strength and performance equivalent to listed piping components and shall meet the requirements of para. III-2.2.9.

(C) Threads. Dimensions of piping connection threads not covered by a governing component specification or standard shall conform to para. III-2.4.5.

III-4.0 SPECIFICATIONS AND STANDARD DATA

III-4.1 Material Specifications and Standards

III-4.1.1 Standard Piping Components. Dimensions of standard piping components shall comply with the standards and specifications listed in Table III-4.1.1, in accordance with the requirements of para. III-2.1.2(A). Abbreviations used in this Appendix and in Table III-4.1.1 are listed in para. III-1.3.2.

III-4.1.2 Nonstandard Piping Components. Where nonstandard piping components are designed in accordance with para. III-2.2, adherence to dimensional standards of ANSI and ASME is strongly recommended where practical.

III-4.1.3 Reference Documents

(A) The documents listed in Table III-4.1.1 may contain references to codes, standards, or specifications not listed in the Table. Such unlisted codes, standards, or specifications are to be used only in the context of the listed documents in which they appear.

(B) Where documents listed in Table III-4.1.1 contain design rules that are in conflict with this Appendix, the design rules of this Appendix shall govern.

(C) The fabrication, assembly, examination, inspection, and testing requirements of Parts 5 and 6 of this Appendix apply to the construction of piping systems. These requirements are not applicable to the manufacture of material or components listed in Table III-4.1.1, unless specifically stated.

III-4.2 Stress and Temperature Limits

Tables III-4.2.1, III-4.2.2, and III-4.2.3 provide listings of the stress and recommended temperature limits for the following, in accordance with paras. III-2.1.3(A) and (B).

III-4.2.1 Thermoplastic Piping Components. Table III-4.2.1 provides hydrostatic design stresses (HDS) and recommended temperature limits for thermoplastic piping components.

TABLE III-4.1.1
NONMETALLIC MATERIAL AND PRODUCT STANDARDS

Standard or Specification	Designation[1,2]
Nonmetallic Fittings	
Threaded Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Sch 80	ASTM D 2464-90
Poly(Vinyl Chloride) PVC Plastic Pipe Fittings, Schedule 40	ASTM D 2466-90a
Socket-Type Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80	ASTM D 2467-90
Acrylonitrile-Butadiene-Styrene ABS Plastic Pipe Fittings, Schedule 40	ASTM D 2468-89
Thermoplastic Gas Pressure Pipe, Tubing, and Fittings	ASTM D 2513-90b
Reinforced Epoxy Resin Gas Pressure Pipe and Fittings	ASTM D 2517 (R1987)
Plastic Insert Fittings for Polyethylene (PE) Plastic Pipe	ASTM D 2609-90
Socket-Type Polyethylene Fittings for Outside Diameter-Controlled Polyethylene Pipe and Tubing	ASTM D 2683-90
Chlorinated Poly(Vinyl Chloride) CPVC Plastic Hot and Cold Water Distribution Systems	ASTM D 2846-90
Butt Heat Fusion Polyethylene (PE) Plastic Fittings for Polyethylene (PE) Plastic Pipe and Tubing	ASTM D 3261-90
Polybutylene (PB) Plastic Hot-Cold-Water Distribution Systems	ASTM D 3309-89a
Reinforced Thermosetting Resin (RTR) Flanges	ASTM D 4024-87
Threaded Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80	ASTM F 437-89a
Socket-Type Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 40	ASTM F 438-89a
Socket-Type Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80	ASTM F 439-89
Nonmetallic Pipe and Tube Products	
Polyethylene Line Pipe	API 15LE (1987)
Thermoplastic Line Pipe (PVC and CPVC)	API 15LP (1987)
Low Pressure Fiberglass Line Pipe	API 15LR (1986)
Concrete Sewer, Storm Drain, and Culvert Pipe	ASTM C 14-82
Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe, Sch 40 and 80	ASTM D 1527-77 (1989)
Poly(Vinyl Chloride) (PVC) Plastic Pipe, Sch 40, 80 and 120	ASTM D 1785-89
Polyethylene (PE) Plastic Pipe, Schedule 40	ASTM D 2104-89
Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter	ASTM D 2239-89
Poly(Vinyl Chloride) (PVC) Pressure-Rated Pipe (SDR Series)	ASTM D 2241-89
Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe (SDR-PR)	ASTM D2282-89
Machine-Made Reinforced Thermosetting-Resin Pipe	ASTM D 2310-80 (1986)
Polyethylene (PE) Plastic Pipe, Sch 40 and 80, Based on Outside Diameter	ASTM D 2447-89
Thermoplastic Gas Pressure Pipe, Tubing, and Fittings	ASTM D 2513-86A
Reinforced Epoxy Resin Gas Pressure Pipe and Fittings	ASTM D 2517 (R1987)
Polybutylene (PB) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter	ASTM D 2662-89
Polybutylene (PB) Plastic Tubing	ASTM D 2666-89
Joints for IPS PVC Pipe Using Solvent Cement	ASTM D 2672-89
Polyethylene (PE) Plastic Tubing	ASTM D 2737-89
Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Hot- and Cold-Water Distribution System	ASTM D 2846-90
Filament-Wound "Fiberglass" (Glass-Fiber Reinforced Thermosetting-Resin) Pipe	ASTM D 2996-88
Centrifugally Cast Reinforced Thermosetting Resin Pipe	ASTM D 2997-90
Polybutylene (PB) Plastic Pipe (SDR-PR) Based on Outside Diameter	ASTM D 3000-89
Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Controlled Outside Diameter	ASTM D 3035-89a
PB Plastic Hot-Water Distribution Systems	ASTM D 3309-89a
Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe, Schedules 40 and 80	ASTM F 441-89
Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe, (SDR-PR)	ASTM F 442-87
PVC Pressure Pipe, 4-inch through 12-inch, for Water	*AWWA C 900
AWWA Standarda for Glass-Fiber-Reinforced Thermosetting-Resin Pressure Pipe	*AWWA C 950-88
Miscellaneous	
Standard Methods of Testing Vitrified Clay Pipe	ASTM C 301-87
Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion Resistant Equipment	ASTM C 582-87
Standard Definitions of Terms Relating to Plastics	ASTM D 297-81

TABLE III-4.1.1 (CONT'D)
NONMETALLIC MATERIAL AND PRODUCT STANDARDS (CONT'D)

Standard or Specification	Designation[1,2]
Miscellaneous (Cont'd)	
Standard Abbreviations of Terms Relating to Plastics	ASTM D 1600-90
Threads 60° (Stub) for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe	*ASTM D 1694-91
Solvent Cements for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe and Fittings	ASTM D 2235-88
External Loading Properties of Plastic Pipe by Parallel-Plate Loading	ASTM D 2412-87
Solvent Cements for Poly(Vinyl Chloride) (PVC) Plastic Pipe and Fittings	ASTM D 2564-88
Heat-Joining Polyolefin Pipe and Fitting	ASTM D 2657-90
Obtaining Hydrostatic Design Basis for Thermoplastic Pipe Materials	ASTM D 2837-90
Making Solvent-Cemented Joints With Poly (Vinyl Chloride) (PVC) Pipe and Fittings	ASTM D 2855-90
Standard Test Method For External Pressure Resistance of Reinforced Thermosetting Resin Pipe	ASTM D 2924-86
Obtaining Hydrostatic or Pressure Design Basis for "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe and Fittings	*ASTM D 2992-87
Joints for Plastic Pressure Pipes Using Flexible Elastomeric Seals	ASTM D 3139-89
Underground Installation of "Fiberglass" (Glass-Fiber Reinforced Thermosetting Resin) Pipe	ASTM D 3839-89
Design and Construction of Nonmetallic Enveloped Gaskets for Corrosive Service	ASTM F 336-87
Solvent Cements for Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe and Fittings	ASTM F 493-89
Plastic Pipe Institute (PPI) Technical Report Thermal Expansion and Contraction of Plastic Pipe	PPI TR21-88

NOTES:

(1) An asterisk (*) preceding the designation indicates that the standard has been approved as an American National Standard by the American National Standards Institute.

(2) Numbers in parentheses are reapproval dates.

III-4.2.2 Laminated Reinforced Thermosetting Resin Piping Components. Table III-4.2.2 provides design stresses (DS) and recommended temperature limits for laminated reinforced thermosetting resin piping components.

III-4.2.3 Machine-Made Reinforced Thermosetting Resin Pipe. Table III-4.2.3 provides hydrostatic design bases (HDB) at a temperature level of 73°F for machine-made reinforced thermosetting resin pipe.

III-4.2.4 Notes for Tables III-4.2.1, III-4.2.2, and III-4.2.3. Notations may be identified in the body of Tables 4.2.1, 4.2.2, and 4.2.3 relative to the information, as applicable, in Notes (1) through (10) that follow Table III-4.2.3.

III-4.3 Standard Data

The following data are available and are acceptable for design purposes at the present time. It should be noted for all properties that individual compounds may vary from the values shown. Manufacturers should be consulted for specific values that may be applicable for their products.

III-4.3.1 See Table III-4.3.1 Thermal Expansion Coefficients, Nonmetals.

III-4.3.2 See Table III-4.3.2 Modulus of Elasticity, Nonmetals.

III-5.0 FABRICATION, ASSEMBLY, AND ERECTION

III-5.1 Bonding Plastic Joints

III-5.1.1 General

(A) Bonded joints which conform to para. III-5.0 may be used in accordance with para. III-2.4.2.

(B) Production joints shall be made only in accordance with a written Bonding Procedure Specification (BPS) that has been qualified in accordance with para. III-5.1.2.

(C) Production joints shall be made only by qualified bonders or bonding operators who have satisfactorily passed a performance qualification test that has been performed in accordance with a written BPS in accordance with para. III-5.1.2.

(D) Qualification in one BPS does not qualify a

TABLE III-4.2.1
HYDROSTATIC DESIGN STRESSES (HDS) AND RECOMMENDED TEMPERATURE LIMITS FOR THERMOPLASTIC PIPING COMPONENTS

ASTM Spec. No.	Material	Recommended Temperature Limits[1,2,3] Minimum,[4] °F	Maximum,[5] °F	Hydrostatic Design Stress at 73°F,[6] ksi	100°F, ksi	180°F, ksi
D 1527, D 2282, D 2513	ABS1210	0	180	1.0	0.8	...
	ABS1316	0	160	1.6	1.25	...
	ABS2112	0	180	1.25	1.0	...
...	AP	0	170	...	...	...
...	CP	0	210	0.8	...	...
D 2846, F 441, F 442	CPVC4120	0	200	2.0	1.6	0.5
...	PA	−20	180	...	...	...
D 2513, D 2662, D 2666, D 3000, D 3309	PB2110	0	210	1.0	0.8	0.5
D 2104, D 2239, D 2447, D 2513, D 2737, D 3035	PE2306	−30	140	0.63	0.4	...
	PE3306	−30	140	0.63	0.5	...
	PE3406	−30	140	0.63	0.5	0.25
	PE3408	−30	140	0.80	...	...
...	POP2125	30	210	...	...	...
...	PP	30	210	...	...	...
D 1785, D 2241, D 2513, D 2672	PVC1120	0	140	2.0	1.6	...
	PVC1220	0	150	2.0	1.6	...
	PVC2110	0	130	1.0	0.8	...
	PVC2112	0	130	1.25	1.0	...
	PVC2116	0	150	1.6	1.25	...
	PVC2120	0	150	2.0	1.6	...
...	PVDC	40	160	...	...	...
...	PVDF	0	275	...	...	...

Notes for this Table follow below Table III-4.2.3

bonder or bonding operator for any other bonding procedure.

(E) Bonding materials which have deteriorated by exposure to air or prolonged storage or which will not spread smoothly shall not be used.

(F) Longitudinal joints are not within the scope of para. III-5.1.

(G) Joint Identification. Each qualified bonder and bonding operator shall be assigned an identification symbol. Unless otherwise specified in the engineering design, each pressure containing bond or adjacent area shall be stenciled or otherwise suitably marked with the identification symbol of the bonder or bonding operator. Identification stamping shall not be used and

TABLE III-4.2.2
DESIGN STRESSES (DS) AND RECOMMENDED TEMPERATURE LIMITS FOR LAMINATED REINFORCED THERMOSETTING RESIN PIPING COMPONENTS

ASTM Spec. No.	Type	Resin	Reinforcing	Recommended Temperature Limits[3] Minimum, °F	Maximum, °F	Thickness, in.	Design Stress,[7] ksi
C 582	I	Polyester	Glass fiber	−20	180	1/8–3/16	0.9
						1/4	1.2
						5/16	1.35
						3/8 & up	1.5
...	...	Furan	Carbon	−20	180	...	...
...	...	Furan	Glass fiber	−20	180	...	...
C 582	II	Epoxy	Glass fiber	−20	180	1/8–3/16	0.9
						1/4	1.2
						5/16	1.35
						3/8 & up	1.5

Notes for this Table follow below Table III-4.2.3

any marking paint or ink shall not be detrimental to the piping material. In lieu of marking the bond, appropriate records shall be filed.

III-5.1.2 Qualification

(A) Qualification of the BPS to be used, and of the performance of bonders and bonding operators, is required. Bonding Procedure Specifications shall specify, for both the bonding operation and qualification testing requirements, all required materials, including material storage requirements; the fixtures and tools required, including the care of tools; and the temperature requirements for all operations, including the methods required for temperature measurement.

(B) Bonding Responsibility. An employer of bonding personnel is responsible for the bonding done by members of his organization and, except as provided in (C) below, shall conduct the required performance qualification tests to qualify the bonding procedure specifications and the bonders or bonding operators.

(C) Qualification by Others

(C.1) Bonding Procedure Specification (BPS). The piping system erector shall be responsible for qualifying a BPS that personnel of his organization will use. Subject to the specific approval of the designer, a BPS qualified by others may be used if the following conditions apply.

(C.1.1) The designer accepts that the proposed qualified BPS has been prepared and executed by a responsible recognized organization with expertise in the field of bonding.

(C.1.2) The designer accepts both the BPS and Procedure Qualification Record (PQR) by signature as his own.

(C.1.3) The piping erector has at least one bonder, currently employed, who has satisfactorily passed a performance qualification test using the proposed qualified BPS.

(C.2) Bonding Performance Qualification. A piping erector shall not accept a performance qualification test made by a bonder or bonding operator for another piping erector without the designer's specific approval. If approval is given, acceptance is limited to performance qualification tests on piping using the same or an equivalent BPS. The piping erector accepting such performance qualification tests shall obtain a copy of the PQR from the previous erector, showing the name of the piping erector by whom bonders or bonding operators were qualified, the dates of such qualification, and the date the bonder or bonding operator last assembled pressure piping under the previous performance qualification.

(D) Qualification tests for the bonding procedure and operator performance shall comply with the requirements of the BPS and the following.

(D.1) A test assembly shall be fabricated in accordance with the bonding procedure specification. The test assembly shall consist of at least one pipe-to-pipe joint and one pipe-to-fitting joint. The size of the pipe used for the test assembly shall be as follows.

TABLE III-4.2.3
HYDROSTATIC DESIGN BASIS (HDB) FOR MACHINE-MADE REINFORCED THERMOSETTING RESIN PIPE

ASTM Spec. No. and Type	Grade	Class	Material Designation ASTM D 2310	HDB Stress[8] at 73°F[9,10] Cyclic,[11] ksi	Static,[12] ksi
D 2517 filament wound	Glass fiber reinforced epoxy resin	No liner	RTRP-11AD	5.0	...
			RTRP-11AW	...	16.0
D 2996 filament wound	Glass fiber reinforced epoxy resin	No liner	RTRP-11AD	5.0	...
			RTRP-11AW	...	16.0
		Epoxy resin liner, reinforced	RTRP-11FE	6.3	...
			RTRP-11FD	5.0	...
	Glass fiber reinforced polyester resin	Polyester resin liner, reinforced	RTRP-12EC	4.0	...
			RTRP-12ED	5.0	...
			RTRP-12EU	...	12.5
		No liner	RTRP-12AD	5.0	...
			RTRP-12AU	...	12.5
D 2997 centrifugally cast	Glass fiber reinforced polyester resin	Polyester resin liner, nonreinforced	RTRP-22BT	...	10.0
			RTRP-22BU	...	12.5
		Epoxy resin liner, nonreinforced	RTRP-21CT	...	10.0
			RTRP-21CU	...	12.5

NOTES TO TABLES III-4.2.1, III-4.2.2, AND III-4.2.3:

(1) These recommended limits are for low pressure applications with water and other fluids that do not significantly affect the properties of the thermoplastic material. In conservative practice, the upper temperature limits may be reduced at higher pressures depending on the required service and expected life. Lower temperature limits are affected more by the environment, safeguarding, and installation conditions than by strength.

(2) Because of low thermal conductivity, temperature gradients through the piping component wall may be substantial. Tabulated limits apply where more than half the wall thickness is at or below the stated temperature.

(3) These recommended limits apply only to listed materials. Manufacturers should be consulted for temperature limits on specific types and kinds of materials not listed.

(4) Minimum for installation.

(5) Maximum for operation.

(6) Use these hydrostatic design stress values at all lower temperatures.

(7) The design stress (DS) values apply only in the temperature range of −20°F through 180°F.

(8) A service (design) factor must be applied to these HDB values to obtain the HDS.

(9) These HDB values apply only at 73°F.

(10) Recommended temperature limits for these materials are shown in Table III-4.2.2.

(11) When using the cyclic design basis, the service factor shall not exceed 1.0.

(12) When using the static design basis, the service factor shall not exceed 0.5.

(D.1.1) When the largest size to be joined (within the BPS) is 4 in. NPS or smaller, the test assembly shall be the same NPS as the largest size to be joined.

(D.1.2) When the largest size to be joined within the BPS is greater than 4 in. NPS, the test assembly shall be made of piping components either 4 in. NPS or a minimum of 25% of the NPS of the largest piping component to be joined, whichever is larger.

(D.2) The test assembly shall be subjected to one of the following qualification test operations.

(D.2.1) When the test assembly has been cured, it shall be subjected to a hydrostatic pressure test of the

TABLE III-4.3.1
THERMAL EXPANSION COEFFICIENTS, NONMETALS

Material Description	Mean Coefficients[1] in./in., °F	Range, °F
Thermoplastics		
Acetal AP2012	2	...
Acrylonitrile-butadiene-styrene		
ABS 1208	60	...
ABS 1210	55	45–55
ABS 1316	52	...
ABS 2112	60	...
Chlorinated poly (vinyl chloride)		
CPVC 4120	30	...
Polybutylene PB 2110	72	...
Polyether, chlorinated	45	...
Polyethylene		
PE 2306	90	70–100
PE 3306	90	70–120
PE 3406	90	70–120
PE 3408	90	70–120
Polyphenylene POP 2125	30	...
Polypropylene		
PP1110	48	33–67
PP1208	43	...
PP2105	40	...
Poly (vinyl chloride)		
PVC1120	30	23–373
PVC1220	35	34–40
PVC2110	50	...
PVC2112	45	...
PVC2116	40	37–45
PVC2120	30	...
Vinylidine fluoride	85	...
Vinylidine/vinyl chloride	100	...
Reinforced Thermosetting Resins		
Glass-epoxy, centrifugally cast	9–13	...
Glass-polyester, centrifugally cast	9–15	...
Glass-polyester, filament-wound	9–11	...
Glass-polyester, hand lay-up	12–15	...
Glass-epoxy, filament-wound	9–13	...
Other Nonmetallic Materials		
Hard rubber (Buna N)	40	...

NOTE:
(1) Divide table values by 10^6.

TABLE III-4.3.2
MODULUS OF ELASTICITY, NONMETALS

Material Description	E,[1] ksi (73.4°F)
Thermoplastics	
Acetal	410
ABS, Type 1210	300
ABS, Type 1316	340*
PVC, Type 1120	410
PVC, Type 1220	410
PVC, Type 2110	340*
PVC, Type 2116	360
Chlorinated PVC	420*
Chlorinated Polyether	160*
PE, Type 2306	120
PE, Type 3306	130
PE, Type 3406	130
PE, Type 3408	130
Polypropylene	120*
Polypropylene (vinylidene/chloride)	100*
Poly(vinylidene fluoride)	194*
Poly(tetrafluoroethylene)	57*
Poly(fluorinated ethylenepropylene)	67*
Poly(perfluoroalkoxy)	100*
Thermosetting Resins, Axially Reinforced	
Epoxy-glass, centrifugally cast	1200–1900
Epoxy-glass, filament-wound	1100–2000
Polyester-glass, centrifugally cast	1200–1900
Polyester-glass, filament-wound	1100–2000
Polyester-glass, hand lay-up	800–1000
Other	
Hard rubber (Buna N)	300

NOTE:

(1) The modulus of elasticity values for thermosetting resin pipe are given in the longitudinal direction; different values may apply in the circumferential or hoop direction. The modulus of elasticity values for thermoplastic resin pipe are temperature-dependent and stress-time related. Values noted with an asterisk (*) have not been confirmed by industry-accepted standards. In all cases for materials listed in this Table, manufacturers may be consulted for specific product information.

maximum of either 150 psig or 1.5 times an equivalent allowable pressure which shall be calculated using the least nominal wall thickness and outside diameter of the pipe in the test assembly. This pressure shall be determined using the equation in para. III-2.2.2(A) for the test material. The test shall be conducted so that the joint is loaded in both the circumferential and longitudinal directions. Joints shall not leak or separate when tested.

(D.2.2) When a test assembly is joined by heat fusion, the fusion joints may be tested by cutting a minimum of three coupons containing the joint and bending the strips using a procedure which shall be defined in the BPS. As a minimum requirement, the test strips shall not break when bent a minimum of 90 deg, at ambient temperature, over an inside bend radius of 1.5 times the nominal diameter of the tested pipe.

(E) Performance Requalification

(E.1) Renewal of a bonding performance qualification is required when:

(E.1.1) a bonder or bonding operator has not used

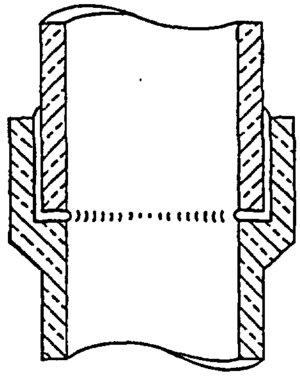
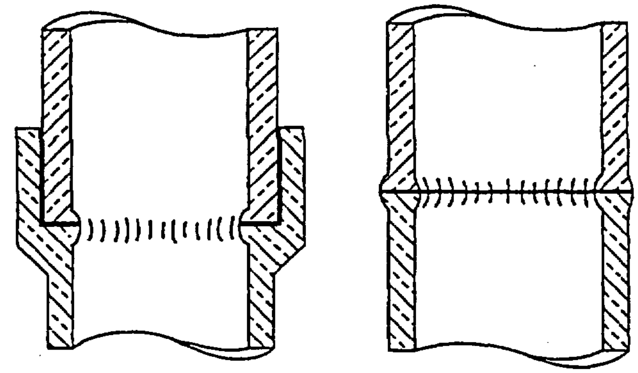


FIG. III-5.1.3(A)



Socket Joint Butt Joint

FIG. III-5.1.3(B)

the specific bonding process for a period of time greater than 6 months, or a specific maximum period of time otherwise permitted in the BPS for the work;

(E.1.2) there is a specific reason to question a bonder or bonding operator's ability to make bonds that meet the BPS.

(E.2) Renewal of a bonding performance qualification for a specific bonding process may be made in only a single test assembly.

(F) Qualification Records. An erector using bonders, or bonder operators, shall maintain a record of the procedures used and of operators employed by him who are qualified in these procedures.

III-5.1.3 Thermoplastic Joints

(A) Solvent-Cemented Joints

(A.1) Preparation. PVC and CPVC surfaces to be cemented shall be cleaned by wiping with a clean cloth moistened with acetone or methylethyl ketone. Cleaning for ABS shall conform to ASTM D 2235. Cuts shall be free of burrs and circumferential cuts shall be as square as those obtained by the use of a saw with a miter box or a square-end sawing vise. A slight interference fit between the pipe and a fitting socket is preferred, and the diametral clearance between a pipe and the entrance of a mating socket shall not exceed 0.04 in. This fit shall be checked before solvent cementing.

(A.2) Procedure. Joints shall be made in accordance with a qualified BPS. ASTM D 2855 provides a suitable basis for such a procedure. Solvent cements for PVC, CPVC, and ABS shall conform to ASTM D 2564, D 2846, and D 2235, respectively. Cement shall be applied to both joint surfaces. The amount of cement shall be sufficient to produce a small continuous fillet of cement at the outer limits of the joints. See Fig. III-5.1.3(A)

(A.3) Branch Connections. For branch connections not using a tee, a manufactured full reinforcement saddle with an integral branch socket shall be solvent cemented to the run pipe over its entire contact surface.

(A.4) Limitations on Imperfections. Imperfections exceeding the following limitations are considered defects and shall be repaired and reexamined in accordance with para. III-5.1.5:

(A.4.A) protrusion of dried cement exceeding 50% of pipe wall thickness into the bore of the pipe; or

(A.4.B) unfilled or unbonded areas in a joint as indicated by the lack or interruption of the continuous fillet noted in (A.2) above.

(B) Heat Fusion Joints

(B.1) Preparation. Surfaces to be heat fused together shall be cleaned of any foreign material. Cuts shall be free of burrs, and circumferential cuts shall be as square as those obtained by the use of a saw with a miter box or a square-end sawing vise.

(B.2) Procedure. Joints shall be made in accordance with a qualified BPS. The general procedures in ASTM D 2657, Technique I-Socket Fusion, II-Butt Fusion, and III-Saddle Fusion provide a suitable basis for such a procedure. Both surfaces to be joined shall be uniformly heated to produce a continuous homogeneous bond between them. This will produce a small continuous fillet of fused material at the outer limits of the joints. See Fig. III-5.1.3(B).

(B.3) Branch Connections. Branch connections shall be made only with the use of molded fittings in sizes that are commercially available.

(B.4) Limitations on Imperfections. Imperfections exceeding the following limitations are considered defects and shall be repaired and reexamined in accordance with para. III-5.1.5:

(B.4.A) protrusion of fused material exceeding 25% of the pipe wall thickness into the bore of the pipe; or

01 *(B.4.B)* unfilled or unbonded areas in a joint as indicated by the lack or interruption of the continuous fillet noted in (B.2) above.

III-5.1.4 Thermosetting Resin Joints

(A) Preparation. Cutting of pipe and preparation of bonding surfaces shall be done, as recommended by the manufacturer, without chipping or cracking of the cut ends; particularly, the inner surface of centrifugally cast pipe. Pipe may be preheated, if necessary, to comply with the above requirements. Cuts shall be free of burrs, and circumferential cuts shall be as square as required by the purchaser's specifications or the recommendations of the manufacturer, whichever requires the closer squareness. For branch connections, holes in the run pipe may be made with a hole saw. Mold release agent and any other material which may interfere with adhesion shall be removed from surfaces to be bonded.

(B) Joining Procedures

(B.1) Socket and Spigot Joints. Joints shall be made in accordance with a qualified BPS based on the manufacturer's recommended procedure. Application of adhesive to the surfaces to be joined, and assembly of those surfaces shall produce a continuous bond between them. Cut ends of the pipe and edges of the laminate fabric shall be sealed to prevent fluid penetration of the pipe wall or the laminate material.

(B.2) Butt-and-Wrap Joints. Joints shall be made in accordance with a qualified BPS. The general procedures in ASTM C 582 Contact-Molded Reinforced Thermosetting Plastic (RTP) Laminates for Corrosion Resistant Equipment provide a suitable basis for the development of such a procedure. Application of plies of reinforcement, saturated with catalyzed resin, to the surfaces to be joined shall produce a continuous structure with the surfaces. Cut ends shall be sealed as required in (B.1) above.

(C) Branch Connections. Branch connections shall be made using a manufactured tee fitting or a full reinforcement saddle having suitable provisions for joining as in (B) above. The cut edges of any hole in the run pipe shall be sealed with adhesive at the time the saddle is bonded to the run pipe.

(D) Limitations on Imperfections. Imperfections exceeding the following limitations are considered defects and shall be repaired and reexamined in accordance with para. III-5.1.5:

(D.1) protrusion of adhesive exceeding 25% of pipe wall thickness into the bore at the bottom of a socket, or inside a branch connection; or

(D.2) unfilled or unbonded areas in the joint.

III-5.1.5 Repair of Defects. Defective material, joints and other workmanship in piping which fail to meet the requirements of paras. III-3.0 and III-5.0, and of the engineering design, shall be repaired or replaced. Limitations on imperfections, and the method and extent of the required examination of repairs and replacements, shall be the same as for the original work.

III-5.2 Bending

III-5.2.1 Pipe Bending. Flattening of a bend is defined as the difference between the maximum and minimum outside diameters, at any cross section, expressed as a percentage of the nominal outside diameter. Flattening shall not exceed 8% for pipe exposed to internal pressure. For pipe under external pressure, flattening shall not exceed 3%. The thickness after bending shall not be less than that required in para. III-2.2.4(A).

III-5.2.2 Bending Methods. Pipe may be bent by any suitable hot or cold method permissible by radii limitations and material characteristics of the pipe being bent. Hot bending shall be done within a temperature range consistent with material characteristics, end-use requirements, and the pipe manufacturer's recommendations.

III-5.3 Component Forming

Piping components may be formed by any suitable hot or cold method permissible by the characteristics of the material being formed. Forming shall be done within a temperature range consistent with the material characteristics, end-use requirements, and the component manufacturer's recommendations. The thickness after forming shall not be less than that required by the engineering design.

III-5.4 Assembly and Erection

III-5.4.1 General. The assembly and erection of nonmetallic piping systems shall comply with the requirements of para. 135 of the Code and para. III-5.0 of this Appendix. In addition:

(A) when assembling nonmetallic flanges, flat washers shall be used under all bolt heads and nuts. The specified maximum bolt torque shall not be exceeded.

(B) full circumference wrenches shall be used to tighten threaded pipe joints. Tools and other devices used to hold or apply forces to the pipe shall be such that pipe surfaces are not scored or deeply scratched. For thermosetting resin piping, threads shall be coated

with sufficient adhesive to cover the threads and completely fill the clearance between the pipe and fittings.

III-6.0 EXAMINATION, INSPECTION, AND TESTING

III-6.1 General

The general requirements of Chapter VI with regard to visual examination and leak testing are basically applicable to nonmetallic piping systems.

III-6.2 Examination and Inspection

III-6.2.1 Visual Examination

(A) Visual examination is observation of the portion of components, joints, and other piping elements that are or can be exposed to view before, during, or after manufacture, fabrication, assembly, erection, inspection, or testing.

(B) Visual examination shall be performed in accordance with Article 9, Section V of the ASME Boiler and Pressure Vessel Code.

III-6.2.2 Examination Required

(A) Piping shall be examined at least to the extent required herein, or to any greater extent specified in the engineering design.

(A.1) Visually examine at least 5% of fabrication. For bonds (joints) each bonder or bonding operator's work shall be represented and shall include each type of bond for each bonder or bonding operator.

(A.2) Visually examine 100% of fabrication for bonds, other than circumferential bonds, and other than those in components made to material specifications recognized in this Code.

(A.3) Perform a random visual examination of the assembly of threaded, bolted, and other joints to satisfy the inspector that these conform to the requirements of para. III-5.4.1

(A.4) Perform a random visual examination during erection of piping, including checking of alignment and supports.

(A.5) Examine erected piping for evidence of damage that would require repair or replacement and for other deviations from the design.

(B) The inspector shall be assured, by examination of certifications, records, or other evidence that the materials and components are of the specified grades and that they have received the required examination and testing.

III-6.2.3 Extent of Required Examination. When visual examination reveals a defect requiring repair:

(A) two additional examinations of the same type shall be made of the same kind of item (if of a bond, others by the same bonder or bonding operator); and

(B) if the additional items examined as required by (A) above are acceptable, the item requiring repair shall be replaced or repaired and reexamined to meet the requirements of the Code, and all items represented by this additional examination shall be accepted; or

(C) if either of the items examined as required by (A) above reveals a defect, two additional items shall be examined; and

(D) if the additional items examined as required by (C) above are acceptable, the items requiring repair shall be replaced or repaired and reexamined to meet the requirements of the Code, and all items represented by this additional examination shall be accepted; or

(E) if either of the additional items examined as required by (C) above reveals a defect, all comparable items shall be replaced or they shall be fully examined, and all items requiring repair shall be repaired and reexamined to meet the requirements of the Code.

III-6.3 Pressure Tests

Leak tests, when specified shall be performed in accordance with para. 137.

NONMANDATORY APPENDIX IV[1]
CORROSION CONTROL FOR ASME B31.1 POWER PIPING SYSTEMS

FOREWORD

Present Code rules apply to the design, materials, fabrication, erection, tests, and inspection of new piping systems normally termed "new construction."

This nonmandatory Appendix contains guidelines that are applicable to existing operating piping systems contained in the scope of ASME B31.1, as well as "new construction."

Minimum requirements for corrosion control of power piping systems are outlined herein. It is recognized that many sound, although perhaps diverse, corrosion control programs exist. The philosophy used has been to establish minimum requirements. Users are encouraged to augment these guidelines to suit their particular needs and to offer constructive criticism to the Committee on this Appendix.

IV-1.0 GENERAL

IV-1.1

External and internal corrosion should be prevented or controlled consistent with design requirements and the environment in which the system is located.

IV-1.2

Application of corrosion control requires a significant amount of competent judgment. NACE[2] RP-01-69, Recommended Practice-Control of External Corrosion on Underground or Submerged Metallic Piping Systems, and RP-01-75, Recommended Practice-Control of Internal Corrosion in Steam Pipelines and Piping Systems, provide a guide for establishing the minimum requirements for control of corrosion of underground or submerged metallic piping systems. In addition, ASME B31G, Manual for Determining the Remaining Strength of Corroded Pipelines [3] may provide additional guidance.

IV-1.3

The following minimum requirements and procedures should be provided for protection of all piping systems containing hazardous liquids or gases and other piping as specified by the owner against internal, external, and atmospheric corrosion.

IV-2.0 EXTERNAL CORROSION CONTROL FOR BURIED OR SUBMERGED PIPELINES

IV-2.1 General

IV-2.1.1 Means to prevent or mitigate external corrosion of buried or submerged piping systems should be considered in the initial design, unless it can be demonstrated by tests, investigations, or experience in the area of installation that a detrimental corrosive environment does not exist.

IV-2.1.2 A means for control of external corrosion of buried or submerged pipe and components may be accomplished through application of an effective protective coating or wrapping. This method of corrosion control can be supplemented with cathodic protection such as sacrificial anodes, rectifier-ground bed units, and suitable drainage bonds in stray current areas. Materials should be selected with due regard to the type of supplemental corrosion protection employed.

IV-2.2 Protective Coating

IV-2.2.1 Protective coatings applied for the purpose of external corrosion should:

(A) be applied on a properly prepared surface;

(B) mitigate corrosion;

(C) have sufficient adhesion to the metal surface and be free of voids so as to effectively resist underfilm migration of moisture;

(D) be sufficiently ductile to resist cracking;

(E) have sufficient strength to resist damage due to handling and soil stress;

[1] Nonmandatory Appendices are identified by a Roman numeral; mandatory Appendices are identified by a letter. Therefore, Roman numeral I is not used in order to avoid confusion with the letter I.

[2] NACE: National Association of Corrosion Engineers, P.O. Box 1499, Houston, Texas 77001

(F) be impact resistant.

IV-2.2.2 Coatings should have low moisture absorption characteristics and provide high electrical resistance. Properly compounded concrete coatings may be used.

IV-2.2.3 Pipe coatings should be inspected visually with a holiday detector and thickness gage prior to backfilling the excavation. Any bare spots, thin areas, holidays, or other damage to the coating should be repaired and reexamined prior to backfilling.

IV-2.2.4 Precautions should be taken to minimize pipe coating damage during installation if coated pipe is installed by boring, driving, or similar method.

IV-2.2.5 Pipe coatings should be protected from damage resulting from adverse ditch conditions or damage from supporting blocks. Only fine grain backfill is permitted in contact with the coating. This fine grain layer should be continuous and of sufficient thickness to prevent coating damage from larger articles in the backfill.

IV-2.2.6 The backfilling operation should be carefully controlled to prevent damage to pipe coatings.

IV-2.3 Cathodic Protection System

IV-2.3.1 Unless it can be demonstrated by investigation, tests, or experience that cathodic protection is not needed, a cathodic protection system should be installed for all new buried carbon steel, alloy, ductile iron, cast iron, aluminum or other metallic piping.

IV-2.3.2 All cathodic protection systems should comply with one or more of the criteria contained in Section 6 of the latest issue of the NACE Standard RP-01-69.

IV-2.3.3 Cathodic protection current should be controlled so as to prevent damage to the protective coating, pipe, or components.

IV-2.4 Electrical Isolation

IV-2.4.1 Buried or submerged coated and uncoated piping systems should be electrically isolated at all interconnections with neighboring systems except where arrangements are made for mutual cathodic protection or where underground metallic structures are electrically interconnected and cathodically protected as a unit. Electrical isolation of dissimilar metals, i.e., steel pipe connected to aluminum tanks, should be provided.

IV-2.4.2 Grounding of all piping systems, where required, should be in accordance with IEEE[3] Standard 142 or acceptable alternate standards.

IV-2.4.3 The electrical continuity of all buried or submerged metallic piping systems is recommended for proper station grounding, and to facilitate the installation of cathodic protection. Continuity across all mechanical joints should be achieved by electrical bonding.

IV-2.4.4 Where piping systems are located in near electrical transmission tower footings, ground cables, ground rods, or in other areas where fault currents or unusual risk of lightning may be anticipated, piping should be provided with protection against damage which may result from fault currents or lightning. Protective measures should also be taken at insulating devices where used.

IV-2.4.5 If a pipe culvert or sleeve is used, the encased pipe should be independently supported outside each end of the sleeve and electrically insulated throughout the length of the section.

IV-2.5 Electrical Interference

IV-2.5.1 The possibility of external corrosion induced by stray electrical currents in the earth is recognized. These stray currents are generated by sources independent of the piping system, and are more predominant in highly industrialized areas, mining regions, and locales containing high voltage, direct current, electrical power ground beds. Neighbor company pipeline cathodic protection systems are also a common source of stray earth currents.

IV-2.5.2 The protection of the piping system against stray current induced corrosion should be provided by metallic bonds, increased electrical cathodic protection, supplemental protective coatings, or insulating flanges.

IV-2.5.3 Each cathodic protection system provided for the plant piping should be designed and installed so as to minimize any adverse effects on adjacent underground metallic structures.

IV-3.0 INTERNAL CORROSION CONTROL

IV-3.1

Internal corrosion might occur during operation. A liquid or gas which will corrode the internal surfaces of piping should not be transported unless its corrosive

[3] IEEE: Institute of Electrical and Electronics Engineers, 445 Hose Lane, P.O. Box 1331, Piscataway, NJ 08855

effects have been investigated. The piping material and any lining should be selected to be compatible with the flowing fluid to minimize corrosion, in accordance with NACE Standard RP-01-75.

IV-3.2 Inhibitors

If inhibitors are used to control internal corrosion, sufficient coupon samples or other types of monitoring techniques should be utilized to determine adequately the effectiveness of the inhibitors.

IV-3.3 Linings

If linings are used to prevent corrosion, they should meet the quality specifications established by the design engineer. They should be inspected in accordance with industry recommended practices. All base material and weld metal surfaces should be covered with the lining to at least the thickness specified by the designer.

IV-3.4 Precautions at Hydrotesting

Equipment fabricated from austenitic (300 series) and ferritic (400 series) stainless steels and requiring hydrostatic testing should be tested with deionized water, high purity steam condensate, or potable water, in decreasing order of preference.

NOTE: Potable water in this context follows U.S. practice, with 250 parts per million maximum chloride content, sanitized with chlorine or ozone.

After testing is completed, equipment should be thoroughly drained with all high point vents open during draining, and dried by air blowing, swabbing, or other appropriate means. If immediate draining and drying are not possible, hydrotest water should be circulated in the piping for at least one hour daily to reduce the possibility of pitting and microbiologically influenced corrosion.

IV-4.0 EXTERNAL CORROSION CONTROL FOR PIPING EXPOSED TO THE ATMOSPHERE

IV-4.1

Piping which is exposed to the atmosphere should be protected against external corrosion by use of corrosion resistant materials or by application of protective coatings or paints.

IV-5.0 MONITORING OF PIPE WALL THINNING DUE TO EROSION/ CORROSION

IV-5.1 Definition

Erosion/corrosion (E/C) is a flow accelerated corrosion process which leads to loss of wall thickness in carbon or low alloy steel pipe exposed to water or wet steam. The parameters that affect the rate of metal loss include water or steam temperature, pH, oxygen content of the fluid, steam quality, flow velocity and piping layout, and the piping chromium, copper, and molybdenum content. This para., IV-5.0, does not apply to other wall thinning mechanisms, such as general corrosion, microbiologically influenced corrosion, or cavitation.

IV-5.2 Systems and Components Susceptible to Erosion/Corrosion

Erosion/corrosion has caused piping failures or severe wall thinning in the following systems:

Feedwater, auxiliary feedwater
Feedwater recirculation
Condensate recirculation
Blowdown
Turbine crossaround/crossover
Extraction steam
Moisture separator reheater
Feedwater heater drains, drips, and vents

Piping damage due to E/C is not limited to these systems and may occur in any system of carbon steel or low alloy piping that is exposed to water or wet steam and operates at a temperature greater than 200°F. System parameters and their effect on E/C rates are shown in Table IV-5.2.

Typical piping components known to experience wall thinning due to E/C include elbows, tees, reducers, and closely coupled fittings. Piping downstream and upstream of these fittings and downstream of orifices and control valves is also susceptible.

IV-5.3 Methods of Detection

Detection of wall thinning due to E/C may be accomplished by a number of NDE techniques including visual, radiographic, ultrasonic, and other measurement methods. However, the most widely used method for detection of wall thinning caused by E/C is ultrasonic thickness examination. Current industry practice sup-

TABLE IV-5.2

Parameter	E/C Rate Increases if Parameter Is
Fluid velocity	Higher (> 10 fps for water) (> 150 fps for steam)
Fluid pH level	Less than 9.2
Fluid oxygen content	Less than 30 ppb
Fluid temperature	200°F–450°F (water) 200°F–500°F (wet steam)
Steam quality	Less than 100 %
Component geometry	Such as to create more turbulence
Component alloy content of chromium, copper, and molybdenum	Lower

ports use of a repeatable grid pattern with identifiable reference points at grid intersections. Grid sizes should not be greater than $2\sqrt{rt_n}$, where r is the outside radius and t_n is the nominal wall thickness of the piping item, except that grid sizes need not be smaller than 1 in. and should not be larger than 6 in. Thickness readings should be recorded at the grid intersection points and the pipe between the grid points scanned for detection of local thinning. If unacceptable thinning is detected, additional readings should be made and recorded with a refined or expanded grid. If thinning is detected within the boundaries of a component grid, a refined grid should be defined within the component to further define the region of wear and provide locations for documentation of measurements. If unacceptable thinning is found at the boundary of a grid, the grid should be expanded in the direction of thinning until thickness readings become acceptable.

IV-5.4 Acceptance Standards

The Code-required wall thickness t_m of each component inspected shall be determined in accordance with para. 104 of the Code. The required wall thickness should include consideration of the minimum wall thickness required to satisfy all of the stress requirements of para. 104.

A calculation of predicted wall thickness t_p at the next examination should be performed for all components with measured wall thickness less than 87.5% of nominal wall thickness t_n.

(A) All components with t_p at the next examination of less than t_m or 70% t_n, whichever is greater, should be identified. Additional examinations during the current inspection should be performed for:

(1) equivalent piping items in other trains when the system containing the subject piping item consists of more than one train;

(2) Additional components in the same system/pipeline which have been determined to be susceptible to E/C.

When (1) and (2) above reveal additional components which meet the criteria of (a)(1) above, this process should be repeated until no additional components meet the criteria.

(B) All components with predicted wall thickness at the next examination of less than or equal to the greater of t_m or $0.3t_n$ shall be repaired, replaced, or evaluated for acceptability for continued service. An acceptable evaluation procedure has been provided in [2] and [3] of para. IV-5.6.

IV-5.5 Repair/Replacement Procedures

Repair or replacement of piping components should be performed in accordance with Appendix V. Erosion rates for chrome-molybdenum alloys are significantly lower than carbon steels and virtually nonexistent for stainless steels. When replacement is chosen, consideration of the increased resistance of alloy steels to E/C should be included in the selection of the replacement component material. The use of backing rings, which can create areas of local turbulence which will promote E/C damage, should be avoided.

IV-5.6 References

[1] ASME Code Case N-480, Approved May 1, 1990.

[2] EPRI Report NP-5911M, "Acceptance Criteria for Structural Evaluation of Erosion/Corrosion Thinning in Carbon Steel Piping," July 1988.

[3] ASME B31G, Manual for Determining the Remaining Strength of Corroded Pipelines.

[4] NUREG-1344, "Erosion/Corrosion-Induced Pipe Wall Thinning in U. S. Nuclear Power Plants," April 1989.

[5] EPRI Report NP-3944, "Erosion/Corrosion in Nuclear Plant Steam Piping: Causes and Inspection Program Guidelines," April 1985.

NONMANDATORY APPENDIX V[1]
RECOMMENDED PRACTICE FOR OPERATION, MAINTENANCE, AND MODIFICATION OF POWER PIPING SYSTEMS

FOREWORD

The B31.1 Power Piping Code prescribes minimum requirements for the construction of power and auxiliary service piping within the scope of para. 100.1. The Code, however, does not provide rules or other requirements for a determination of optimum system function, effective plant operations, or other measures necessary to assure the useful life of piping systems. These concerns are the responsibility of the designer and, after construction turnover, the Operating Company personnel responsible for plant activities.

Past experience has shown that a need exists for the definition of acceptable plant practices for achieving both reliable service and a predictable life in the operation of power piping systems. This nonmandatory Appendix is intended to serve that purpose. For this objective, Appendix V is structured in three parts that recognize and address the following basic concepts.

operation: the design of a piping system is based on specified service requirements and operating limitations. Subsequent operation within these defined limits is assumed and, for some systems, will be important for an acceptable service life.

maintenance: the design of a piping system assumes that reasonable maintenance and plant service will be provided. The lack of this support will, in some cases, introduce an increasing degree of piping system life uncertainty.

modifications: future modifications of a piping system or its operational functions are not assumed in original design unless specified. Modifications must not invalidate the integrity of a piping system design.

The practices in Appendix V are recommended for all plants and systems within the scope of the Power Piping Code, both for new construction and for existing plants in operation. An acceptable implementation of these or equivalent practices will be beneficial for new systems. The application of these practices is recommended for power piping systems in operating plants.

The recommended practices in this Appendix define minimum requirements for establishing a program to accommodate the basic considerations for piping system operation, maintenance, service, modification, and component replacement.

A record-keeping program is prescribed that can serve as a point of reference for analyzing piping system distortions or potential failures. Such a program is intended to identify distortions or failures and assure compatibility between the materials and components of existing piping systems with those portions undergoing repair, replacement, or modification.

DEFINITIONS[2]

Code: ASME Code for Pressure Piping, ASME B31.1 Power Piping

component: equipment, such as vessel, piping, pump, or valve, which are combined with other components to form a system

critical piping systems: those piping systems which are part of the feedwater-steam circuit of a steam generating power plant, and all systems which operate under two-phase flow conditions. Critical piping systems include runs of piping and their supports, restraints, and root valves. Hazardous gases and liquids, at all pressure and temperature conditions, are also included herein. The Operating Company may, in its judgment, consider other piping systems as being critical in which case it may consider them as part of this definition.

examination: an element of inspection consisting of investigation of materials, components, supplies, or services to determine conformance to those specified requirements which can be determined by such investi-

[1] Nonmandatory Appendices are identified by a Roman numeral; mandatory Appendices are identified by a letter. Therefore, Roman numeral I is not used in order to avoid confusion with the letter I.

[2] The definitions pertain specifically to this Appendix.

gation. Examination is usually nondestructive and includes simple physical manipulation, gaging, and measurement.

failure: that physical condition which renders a system, component, or support inoperable

maintenance: actions required to assure reliable and continued operation of a power plant, including care, repair, and replacement of installed systems

modification: a change in piping design or operation and accomplished in accordance with the requirements and limitations of the Code

Operating Company: the Owner, user, or agent acting on behalf of the Owner who has the responsibility for performing the operations and maintenance functions on the piping systems within the scope of the Code

procedure: a document that specifies or describes how an activity is to be performed. It may include methods to be employed, equipment or materials to be used, and sequences of operations

qualification (personnel): demonstration of the abilities gained through training and/or experience that enable an individual to perform a required function

renewal: that activity which discards an existing component and replaces it with new or existing spare materials of the same or better qualities as the original component

repair: to restore the system or component to its designed operating condition as necessary to meet all Code requirements

specification: a set of requirements to be satisfied by a product, material, or process, indicating, whenever appropriate, the procedure by means of which it may be determined whether the requirements given are satisfied

V-1.0 GENERAL

V-1.1 Application

V-1.1.1 This Appendix recommends minimum requirements for programs to operate and maintain ASME B31.1 Power Piping systems and also for the repairs to these systems.

V-1.1.2 Local conditions and the location of piping systems (such as indoors, outdoors, in trenches, or buried) will have considerable bearing on the approach to any particular operating and maintenance procedure. Accordingly, the methods and procedures set forth herein serve as a general guide. The Operating Company is responsible for the inspection, testing, operation and maintenance of the piping system and shall have the responsibility for taking prudent action to deal with inherent plant conditions.

V-1.2 Conformance

V-1.2.1 When conformance with time periods for examination recommended in this document is impractical, an extension may be taken if an evaluation demonstrates that no safety hazard is present.

V-1.3 Requirements

V-1.3.1 This Appendix recommends that the following listed items be established and implemented:

(A) complete design and installation records of the "as built" large bore piping systems, including expansion joints, hangers, restraints, and other supporting components. The Operating Company shall define those sizes considered to be large bore pipe.

(B) records of operation and maintenance history;

(C) programs for periodic inspection and monitoring;

(D) procedures for reporting and analyzing failures;

(E) procedures for maintenance, repairs, and replacements;

(F) procedures for abandoning piping systems and for maintaining piping systems in and out-of-service condition; and

(G) procedures for assuring that all personnel engaged in direct maintenance of such piping systems as defined in para. V-4.2.1(C) are qualified by training or experience for their tasks or work.

V-2.0 OPERATING AND MAINTENANCE PROGRAM

V-2.1

Each Operating Company shall develop an operating and maintenance program comprising a series of written procedures, keeping in mind that it is not possible to prescribe a single set of detailed operating and maintenance procedures applicable to all piping systems. The operating and maintenance procedures shall include: personnel qualifications as defined by the Operating Company, material history and records, and supplementary plans to be implemented in case of piping system failures.

V-2.2

Each plant should maintain and file the following documentation that exists for each unit:

(A) current piping drawings;

(B) construction isometrics (or other drawings) that identify weld locations;

(C) pipeline specifications covering material, outside diameter, and wall thickness;

(D) flow diagrams;

(E) support drawings;

(F) support setting charts;

(G) records of any piping system modifications;

(H) material certification records;

(I) records of operating events that exceed design criteria of the piping or supports;

(J) valve data;

(K) allowable reactions at piping connections to equipment;

(L) welding procedures and records.

V-3.0 REQUIREMENTS OF THE OPERATING, MAINTENANCE, AND MODIFICATION PROCEDURES

V-3.1

The Operating Company shall have procedures for the following:

(A) to perform normal operating and maintenance work. These procedures shall include sufficiently detailed instructions for employees engaged in operating and maintaining the piping systems,

(B) to prescribe action required in the event of a piping system failure or malfunction that may jeopardize personnel safety, safe operation, or system shutdown. Procedures shall consider:

(B.1) requirements defined for piping system operations and maintenance and should include failure conditions under which shutdown may be required. Procedures should include both the action required and the consequence of the action on related systems or subsystems.

(B.2) the designation of personnel responsible for the implementation of required action, and minimum requirements for the instruction, training, and qualification of these personnel.

(C) to periodically inspect and review changes in conditions affecting the safety of the piping system. These procedures shall provide for a system of reporting to a designated responsible person in order that corrective measures may be taken.

(D) to assure that modifications are designed and implemented by qualified personnel and in accordance with the provisions of the Code;

(E) to analyze failures to determine the cause and develop corrective action to minimize the probability of recurrence;

(F) to intentionally abandon unneeded piping systems, or portions thereof, and to maintain those which are out of service for extended periods of time as defined by the Operating Company;

(G) to ensure that instruction books and manuals are consulted in performing maintenance operations;

(H) to log, file, maintain, and update instruction books;

(I) to log operating and maintenance records; and

(J) to periodically review and revise procedures as dictated by experience and changes in conditions.

V-4.0 PIPING AND PIPE SUPPORT MAINTENANCE PROGRAM AND PERSONNEL REQUIREMENTS

V-4.1 Maintenance Program

V-4.1.1 The maintenance program shall include the following listed features:

(A) a purpose for the program;

(B) the frequency for performing all elements of maintenance and inspection listed in the program;

(C) generic requirements as related to initial hanger positions at time of unit startup, changes and adjustments in hanger positions at periodic inspections, and review of manufacturer's instruction and maintenance manuals applicable to components included in the program;

(D) updating and modification as may be desirable by reason of Code revisions and technological advances or other considerations;

(E) steps to keep maintenance and inspection personnel aware of program revisions.

V-4.2 Personnel

V-4.2.1 To the extent necessary for conformance with the maintenance program of the Operating Company, only qualified and trained personnel shall be utilized for the following:

(A) observation, measurement, and recording the position of piping systems and hanger readings;

(B) adjustment of hangers and all other components of support and restraint systems; and

(C) repair and periodic maintenance routines including, but not limited to:

(C.1) routine piping assembly, including welding of integral attachments;

(C.2) mechanical repair of valves, traps, and similar types of piping specialty components, including packings;

(C.3) removal and replacement of piping insulation;

(C.4) lubrication of applicable piping and hanger components, such as valves and constant supports, maintenance of fluid levels in hydraulic restraints; and stroking of hydraulic and mechanical dynamic restraints (snubbers).

(C.5) routine surveillance for changing conditions including changes in position of piping and settings of piping hangers and shock suppressors (snubbers).

V-4.2.2 Review of records and failure reports and decisions concerning corrective actions or repairs should be carried out by or under the direction of a qualified piping engineer.

V-4.2.3 Welding and Heat Treatment Personnel

(A) Welders shall be qualified to approved welding procedures. Qualification of weld procedures and the qualification performance of the welder shall be in accord with the requirements of para. 127.5.

(B) Trained personnel shall perform preheat and postheat treatment operations as described in the requirements of para. 131.

V-4.2.4 Examination, Inspection, and Testing Personnel. Trained personnel shall perform nondestructive examinations (NDE), including visual inspections and leak tests (LT), all in accord with the requirements of para. 136.

V-5.0 MATERIAL HISTORY

V-5.1 Records

V-5.1.1 Records shall be maintained to the extent necessary to permit a meaningful failure analysis or reconstruction of a prior condition should the need arise. These records may be limited to those systems identified as critical as defined herein.

V-5.1.2 The records listed below are recommended for inclusion in the materials history and, where possible, be traceable to specific components in a piping system:

(A) procurement documents including specifications;

(B) original service date and operating conditions;

(C) list of materials, both original and replacement, with system location and material specification;

(D) physical and mechanical properties from material test reports (if available), including, the following as applicable:

(D.1) Manufacturer's Material Test Reports or Certificate of Conformance;

(D.2) chemical analysis;

(D.3) impact tests;

(D.4) special processing, i.e., heat treatment, mechanical working, etc.

(E) wall thicknesses where available from construction or maintenance records, including design minimum wall requirements;

(F) record of alterations or repairs;

(G) nondestructive examination reports (including radiographs, if available);

(H) special coatings, linings, or other designs for corrosion or erosion resistance;

(I) failure reports.

V-5.2 Failure Reports

V-5.2.1 The Operating Company shall be responsible for investigating all material failures in critical piping systems. The cause for failure shall be established. A report of the results of this investigation shall be included in the material history file and shall, as a minimum, contain the following information:

(A) summary of design requirements;

(B) record of operating and test experience of failed components;

(C) any previous history of the component;

(D) any special conditions (corrosion, extraordinary loads, thermal excursions, etc.) which may have contributed to failure;

(E) conclusions as to cause;

(F) recommendations for corrective actions to minimize recurrence;

(G) corrective actions that were taken, including verification of satisfactory implementation;

(H) corrective action details and recommendations, if any, for similar action in other piping systems.

V-5.3 Restoration after Failure

V-5.3.1 Defective component(s) shall be repaired or replaced with comparable or upgraded materials permissible by this Code after evaluation of the failure and taking into account conclusions as to cause. Even when materials are replaced by same or upgraded items, a formal failure report should follow as in para. V-5.2.

V-5.3.2 Care shall be exercised when replacing system components to ensure no parts of the system are overstressed. The stresses in the repaired system shall be equal to or less than the original stresses unless analysis permits increased stresses. During the replacement of the component, the piping system should be temporarily supported or restrained on both sides of the component to be removed so as to maintain its as-found cold position until the component(s) is (are) installed. If the desired piping position cannot be maintained, an analysis shall be made to determine the reason for the problem. A new stress analysis may be necessary. Care shall be exercised when working on a system that has been subjected to self-springing or cold pull.

V-5.3.3 Weld preparations and fit-up of the weld joints shall meet the requirements of Chapter V.

V-5.3.4 Welding procedures and preheat/postheat treatments of the weld joints shall meet the minimum requirements of Chapter V.

V-5.4 Weld Records

V-5.4.1 Records shall be maintained for all welds in critical piping systems. These records shall include, but not be limited to, the following:

(A) original installation records, where available;

(B) repair and modification welds including excavation location and depth;

(C) welding procedures and qualification tests;

(D) nondestructive examination reports;

(E) heat treatment performed.

V-5.5 Inspection Program for Materials With Adverse History

V-5.5.1 Materials which have been reported to the industry to exhibit an adverse performance under certain conditions shall be given special attention by the Operating Company through a program of planned examination and testing. This program shall include the development of procedures for repair or replacement of the material when the Operating Company determines that such action is necessary.

V-5.5.2 Methods of surveillance and analysis shall be determined by the Operating Company.

V-5.5.3 The frequency of the material inspection shall also consider the expected service life of the component.

V-5.6 Nondestructive Examination

V-5.6.1 Nondestructive examinations used to investigate any suspect materials or problem areas shall be in accordance with Chapter VI.

V-6.0 PIPING POSITION HISTORY

V-6.1 General

V-6.1.1 Movements of critical piping systems from their design locations shall be used to assess piping integrity. The Operating Company shall have a program requiring such movements be taken on a periodic basis along with a procedure precluding the unnecessary removal of insulation when measurements are taken; refer to para. V-6.3. Piping system movement records shall be maintained. The Operating Company shall evaluate the effects of position changes on the safety of the piping systems and shall take appropriate corrective action.

V-6.1.2 Although the Code recognizes that high temperature piping systems seldom return to their exact original positions after each heat cycle due to relaxation, critical piping systems as defined herein, must be maintained within the bounds of engineering evaluated limitations.

V-6.2 Visual Survey

V-6.2.1 The critical piping systems shall be observed visually, as frequently as deemed necessary, and any unusual conditions shall be brought to the attention of personnel as prescribed in procedures of para. V-3.1. Observations shall include determination of interferences with or from other piping or equipment, vibrations, and general condition of the supports, hangers, guides, anchors, supplementary steel, and attachments, etc..

V-6.3 Piping Position Markers

V-6.3.1 For the purpose of easily making periodic position determinations, it is recommended that permanent markings on critical piping systems be made by providing markings or pointers attached to piping components. The position of these markings or pointers should be noted and recorded with respect to stationary datum reference points.

V-6.3.2 Placement of pointers shall be such that personnel safety hazards are not created.

V-6.4 Hangers and Supports on Critical Piping Systems and Other Selected Systems

V-6.4.1 Hanger position scale readings of variable and constant support hangers shall be determined periodically. It is recommended that readings be obtained while the piping is in its fully hot position, and if practical, when the system is reasonably cool or cold sometime during the year as permitted by plant operation. Pipe temperature at time of reading hangers shall be recorded.

V-6.4.2 Variable and constant support hangers, vibration snubbers, shock suppressors, dampeners, slide supports and rigid rod hangers shall be maintained in accordance with the limits specified by the manufacturers and designers. Maintenance of these items shall include, but not necessarily be limited to, cleaning, lubrication and corrosion protection. All dynamic restraints (snubbers) should be stroked periodically.

V-6.5 Records on Critical Piping Systems and Other Selected Systems

V-6.5.1 Pipe location readings and travel scale readings of variable and constant support hangers shall be recorded on permanent log sheets in such a manner that will be simple to interpret. See Fig. V-6.5 for suggested hanger record data sheet. Records of settings of all hangers shall be made before the original commercial operation of the plant. Log sheets should be accompanied by a pipe support location plan or piping system drawing with hanger mark numbers clearly identified. In addition, records are to be maintained showing movements of or in expansion joints including records of hot and cold or operating and shutdown positions, particularly those not equipped with control rods or gimbals.

V-6.6 Recommendations

V-6.6.1 After complete examination of the records (para. V-6.5), recommendations for corrective actions needed shall be made by a piping engineer or a qualified responsible individual or organization. Repairs and/or modifications are to be carried out by qualified maintenance personnel for all of the following items:

(A) excessively corroded hangers and other support components;

(B) broken springs or any hardware item which is part of the complete hanger or support assembly;

(C) excessive piping vibration; valve operator shaking or movements;

(D) piping interferences;

(E) excessive piping deflection which may require the installation of spring units having a greater travel range;

(F) pipe sagging which may require hanger adjustment or the reanalysis and redesign of the support system;

(G) hanger unit riding at either the top or the bottom of the available travel;

(H) need for adjustment of hanger load carrying capacity;

(I) need for adjustments of hanger rods or turnbuckle for compensation of creep or relaxation of the piping,

(J) loose or broken anchors;

(K) inadequate clearances at guides;

(L) inadequate safety valve vent clearances at outlet of safety valves;

(M) any failed or deformed hanger, guide, U-bolt, anchor, snubber, or shock absorber, slide support, dampener, or supporting steel;

(N) unacceptable movements in expansion joints;

(O) low fluid levels in hydraulic pipe restraints.

V-7.0 PIPING CORROSION

V-7.1 General

V-7.1.1 This section pertains to the requirements for inspection of critical piping systems that may be subject to internal or external corrosion-erosion, such as buried pipe, piping in a corrosive atmosphere, or piping having corrosive or erosive contents. Requirements for inspection of piping systems in order to detect wall thinning of piping and piping components due to erosion/corrosion, or flow-assisted corrosion, is also included. Erosion/corrosion of carbon steel piping may occur at locations where high fluid velocity exists adjacent to the metal surface, either due to high velocity or the presence of some flow discontinuity (elbow, reducer, expander, tee, control valve, etc.) causing high levels of local turbulence. The erosion/corrosion process may be associated with wet steam or high purity, low oxygen content water systems. Damage may occur under both single and two-phase flow conditions. Piping systems that may be damaged by erosion/corrosion include, but are not limited to, feedwater, condensate, heater drains, and wet steam extraction lines. Mainte-

Company ____________________ Plant Name ____________________

System ____________________ Unit No. ____________________

Prepared by ____________________
Sheet __________ Of __________
Date ____________________

				Constant Support Hanger Data		Rigid & Variable Support Data		Design Elev. Cold,[3] ft.-in.	Hanger Scale Reading[4]							
						Design Load, lb			Date:		Date:		Date:		Date:	
Hanger Mk. No.	Hanger Size[1]	Hanger Type[2]	Dsgn. Mvt.	Design Load, lb	Design Total Travel	H	C	(4)	Cold	Read by	Hot	Read by	Cold	Read by	Hot	Read by

NOTES:
(1) Hanger size to be taken from hanger fabrication drawing.
(2) For constant support and variable support types indicate by CS or VS. For rigid, anchor, guide, sliding, or other type support, indicate by letter R, A, G, or S, respectively.
(3) Elevation of center line of pipe after cold springing and final hanger settings with line cold.
(4) "0" indicated the highest scale position with "5" being the midpoint, and "10" being the lowest scale position.

FIG. V-6.5 HANGER RECORD SHEET

nance of corrosion control equipment and devices is also part of this section. Measures in addition to those listed herein may be required.

V-7.1.2 Where corrosion is cited in this section, it is to be construed to include any mechanism of corrosion and/or erosion. Recommended methods for monitoring and detection, acceptance standards, and repair/replacement procedures for piping components subjected to various erosion/corrosion mechanisms, including flow-assisted corrosion, are provided in nonmandatory Appendix IV.

V-7.1.3 Guidance for the evaluation and monitoring of carbon steel piping susceptible to erosion/corrosion (flow assisted corrosion) is provided in Appendix IV, para. IV-5.0.

V-7.2 Procedures

V-7.2.1 The Operating Company shall establish procedures to cover the requirements of this paragraph.

V-7.2.2 Procedures shall be carried out by or under the direction of persons qualified by training or experience in corrosion control and evaluation of piping systems for corrosion damage.

V-7.2.3 Procedures for corrosion control shall include, but not be limited to the following:

(A) maintenance painting to resist external ambient conditions;

(B) coating and/or wrapping for external protection of buried or submerged systems;

(C) lining to resist internal corrosion from system fluid when applicable;

(D) determining the amount of corrosion or erosion of the piping system internals caused by the flowing fluid;

(E) determining the amount of external corrosion caused by ambient conditions, such as atmosphere, buried in soil, installed in tunnels or covered trenches, and submerged underwater;

(F) preparing records which shall include all known leakage information, type of repair made, location of cathodically protected pipe, and the locations of cathodic protection facilities including anodes; and

(G) examining records from previous inspection and performing additional inspections where needed for historical records.

V-7.3 Records

V-7.3.1 Tests, surveys, and inspection records to indicate the adequacy of corrosion control shall be maintained for the service life of the piping system. This should include records of measured wall thickness and rates of corrosion.

V-7.3.2 Inspection and maintenance records of cathodic protection systems shall be maintained for the service life of the protected piping.

V-7.3.3 Observations of the evidence of corrosion found during maintenance or revision to a piping system shall be recorded.

V-7.4 Examination of Records

V-7.4.1 Records shall be examined and evaluated by trained personnel.

V-7.4.2 Where inspections or leakage history indicate that active corrosion is taking place to the extent that a safety hazard is likely to result, applicable portions of the system shall be replaced with corrosion resistant materials or with materials which are protected from corrosion, or other suitable modifications shall be made.

V-7.5 Frequency of Examination

V-7.5.1 Within 3 years after original installation, each piping system shall be examined for evidence of corrosion in accordance with the requirements established by the Operating Company's procedures. Piping in severe service or environmental conditions should be inspected initially within a time frame commensurate with the severity of the service or environment. Corrective measures shall be taken if corrosion is above the amount allowed for in the original design.

V-7.5.2 Continued examination shall be made at intervals based upon the results of the initial inspection, but not to exceed 5 years, with corrective measures being taken each time that active corrosion is found.

V-7.5.3 Examination for evidence of internal corrosion shall be made by one of the following:

(A) drilled hole with subsequent plugging;

(B) ultrasonic test for wall thickness determination;

(C) removal of representative pipe section at flange connections or couplings;

(D) removal of short section of pipe;

(E) radiography for evidence of wall thinning;

(F) borescope or videoprobe examination; or

(G) a method equivalent to those above.

V-7.5.4 Examinations for evidence of external corrosion shall be made after removal of covering, insulation or soil on a representative short section of the piping system taking into consideration varying soil conditions.

V-8.0 PIPING ADDITION TO EXISTING PLANTS

V-8.1 Piping Classification

V-8.1.1 Piping and piping components which are replaced, modified, or added to existing piping systems are to conform to the edition and addenda of the Code used for design and construction of the original systems, or to later Code editions or addenda as determined by the Operating Company. Any additional piping systems installed in existing plants shall be considered as new piping and shall conform to the latest issue of the Code.

V-8.2 Duplicate Components

V-8.2.1 Duplicates of original components and materials are permitted for permanent replacements, provided the renewal is a result of reasonable wear and not the result of the improper application of the material, such as temperature and corrosive environment.

V-8.3 Replacement Piping and Piping Components

V-8.3.1 Where replacement components differ from the original components with respect to weight, dimensions, layout, or material, the design of the affected piping system shall be rechecked for the following design considerations.

(A) Hangers and supports shall be adequate for additional or altered distribution of weight. They shall accommodate the flexibility characteristics of the altered piping system.

(B) Changes in stresses imposed on both existing and replacement components of the piping shall be evaluated and compensation shall be made to prevent overstress in any part of the entire altered piping system.

V-9.0 SAFETY, SAFETY RELIEF, AND RELIEF VALVES

V-9.1 General

V-9.1.1 This section is applicable to safety, safety relief, and relief valve installations (see Appendix II for definitions of these terms.) Except as otherwise noted, all reference to "safety" valve(s) shall be considered to include all three types. Safety valves shall be maintained in good working condition. Also, discharge pipes and their supports shall be inspected routinely and maintained properly. Any evidence of blowback at the drip pan of open safety valve vent systems should be noted and its cause determined and corrected.

V-9.2 Testing and Adjustment

V-9.2.1 Testing of safety valves for pressure setting shall be in accordance with written procedures which incorporate the requirements of regulatory agencies and manufacturer's instructions. Testing should be performed just prior to a planned outage so that any required repair or maintenance, except spring and blowdown ring adjustments, can be performed during the outage, thereby assuring tight valves upon return to service.

V-9.2.2 The setting or adjustment of safety valves shall be done by personnel trained in the operation and maintenance of such valves. Safety valves shall be tested after any change in setting of the spring or blowdown ring. Appropriate seals should be used to assure that there is no unauthorized tampering with valve settings. Repairs to safety valves and disassembly, reassembly, and/or adjustments affecting the pressure relief valve function, which are considered a repair, should be performed by an authorized repair organization.[3]

V-9.3 Operation

V-9.3.1 The precautions stated in the manufacturer's operating manual or instruction books shall be followed when operating safety valves. In general, these precautions will include the following.

(A) Hand lifting is permitted. Assistance, as required, may be accomplished by the use of small wires or chains.

(B) Striking or hammering the valve body shall not be permitted. Only the hand-test lever shall be used.

(C) Attempts to stop leakage through the valve seat shall not be made by compressing the spring.

V-10.0 DYNAMIC LOADING

V-10.1 Water Hammer

V-10.1.1 Water hammer includes any water or other liquid transient event such as pressure surge or impact loading resulting from sudden or momentary change in flow or flow direction.

[3] Examples of organizations which may be authorized by the owner or by the local jurisdiction to perform repairs on safety valves include but are not limited to the original valve manufacturer or a repair organization which holds a National Board of Boiler and Pressure Vessel Inspectors (NB-23) VR stamp.

V-10.1.2 Should significant water hammer develop during plant operation, the cause should be determined and corrective action taken. Water hammer could be the result of an incorrectly sloped pipe intended for steam condensate drainage. Water hammer in piping systems may cause damage to hangers, valves, instrumentation, expansion joints, piping and equipment integral with the piping. The Operating Company should develop procedures to deter water hammer and to determine when corrective action is necessary.

V-10.1.3 Water hammer problems resulting from accumulated condensate in a steam line cannot be solved simply by adding restraints. Corrective action may include changing line slopes, adding drain pots, adding warm-up lines around valves, checking for leaking desuperheaters, faulty electrical controls on automatic drains, etc.

V-10.1.4 Water hammer due to column separation in feedwater or booster pump suction piping results when the deaerator pegging pressure is not maintained. This type of water hammer can be particularly severe and requires prompt attention to control and reduce it.

V-10.1.5 As a priority, corrective action should address the cause of waterhammer first. If such corrective action is ineffective in reducing the effects of water hammer to acceptable levels, installation of restraints may be necessary to limit piping displacements and/or damage from fatigue.

V-10.2 Steam Hammer

V-10.2.1 Dynamic loads due to rapid changes in flow conditions and fluid state in a steam piping system are generally called steam hammer loads. Piping response to these momentary unbalanced loads can be significant in high pressure steam systems, such as main steam, hot and cold reheat steam, bypass and auxiliary steam systems that are subject to rapid interruption or establishment of full steam flow.

V-10.2.2 The Operating Company should develop procedures to determine any adverse effects of steam hammer, such as excessive pipe movement, damage to hangers and restraints, and high pipe stress and reactions at pipe connections to equipment. Where such movements, stresses, and reactions exceed safe limits or allowable loadings, a program of remedial action should be implemented.

V-11.0 HIGH TEMPERATURE CREEP

V-11.1 General

V-11.1.1 Catastrophic failure, including rupture, can occur due to excessive creep strains resulting from operation of the piping above design pressure, or temperatures, or both, for extended periods of time. The expected life of a piping system operating in the creep range can be reduced significantly through prolonged exposure to pressure or temperature, particularly temperature, above design values. Paragraph 102.2.4 provides criteria for occasional short operating periods at higher than design pressure or temperature.

V-11.1.2 This section provides the minimum requirements for evaluating critical piping systems in order to detect creep damage and to assist in predicting the remaining life under expected operating conditions. The remaining useful life may be estimated by determining the extent of creep damage sustained by the pipe.

V-11.2 Procedures

V-11.2.1 The Operating Company shall establish procedures to cover the requirements of this paragraph.

V-11.2.2 The procedures shall be carried out by or under the direction of persons qualified by training or experience in metallurgical evaluation of high temperature creep effects in power plant piping.

V-11.2.3 An evaluation program to determine the extent of creep damage and estimate remaining life of high temperature piping shall be carried out in three phases, as follows:

(A) review of material specifications, design stress levels, and operating history;

(B) indirect measurements to determine extent of creep damage. These would include diametral measurements to detect creep swelling. In addition, dye penetrant, magnetic particle, ultrasonic, and radiographic methods may be used to detect internal and surface cracks.

(C) examination of the microstructure to determine the degree of material degradation. This can be performed by replication techniques or by metallography using specimens obtained by boat-sampling or trepanning.

V-11.3 Records

V-11.3.1 Records of creep damage evaluation survey findings shall be maintained for the service life of high temperature piping systems operating in the creep range.

V-11.4 Examination of Records

V-11.4.1 Records of creep damage surveys and test reports shall be examined by personnel qualified by training and experience to evaluate and interpret NDE and metallographical studies.

V-11.4.2 Where surveys and inspections of critical piping systems indicate that high temperature creep damage has progressed to an unacceptable level, affected portions of the piping system shall be replaced.

V-11.5 Frequency of Examination

V-11.5.1 Periodically, all critical piping systems operating within the creep range shall be examined for evidence of high temperature creep damage. Particular attention shall be given to welds.

V-11.5.2 The examination shall be repeated at periodic intervals which shall be established on the basis of earlier survey findings, operating history, and severity of service.

V-12.0 RERATING PIPING SYSTEMS

V-12.1 Conditions

V-12.1.1 An existing piping system may be rerated for use at a higher pressure and/or temperature if all of the following conditions are met:

(A) a design analysis shall be performed to demonstrate that the piping system meets the requirements of the Code at the new design conditions;

(B) the condition of the piping system and support/restraint scheme shall be determined by field inspections and the examination of maintenance records, manufacturer's certifications, and/or other available information to ensure conformance with the Code requirements for the new design conditions;

(C) necessary repairs, replacements, or alterations to the piping system are made to conform with the requirements prescribed in (A) and (B) above;

(D) the system has been leak tested to a pressure equal to or greater than that required by the Code for a new piping system at the new design conditions;

(E) the rate of pressure and temperature increase to the higher maximum allowable operating conditions shall be gradual so as to allow sufficient time for periodic observations of the piping system movements and leak tightness;

(F) records of investigations, work performed, and pressure tests conducted in rerating the piping systems shall be preserved for the service life of the piping systems; and

(G) all safety valves, relief valves, and other pressure relieving devices must be examined, and recertified for the new pressure/temperature design conditions. Capacity of relieving equipment shall be investigated if the design pressure and/or temperature are changed in rerating a piping system.

NONMANDATORY APPENDIX VI[1]
APPROVAL OF NEW MATERIALS

The ASME B31.1 Committee considers requests for adoption of new materials desired by the owner/user or fabricator, manufacturer, installer, assembler of piping or piping components constructed to the Code. In order for the material to receive proper consideration, information and data are required to properly categorize the material. In general this information and data include, but are not necessarily limited to the following:

(A) the chemical composition of the material including those elements that establish the characteristics and behavior of the material;

(B) the mechanical properties of the material, including tensile test data, ductility data, and other special mechanical test data, which will assist the Committee in its review of the material and its application:

(B.1) tensile test data (per ASTM E 21), including both ultimate tensile strength and yield strength, at room temperature and at 100°F or 50°C intervals to a temperature at least 100°F higher than the intended use of the material.

(B.2) when creep properties are expected to limit the allowable stress, creep and creep rupture data at temperature intervals of 100°F or 50°C are also required. Such data should be for four or more time intervals, one of which should be longer than 2000 hr but less than 6000 hr, and one of which should be longer than 6000 hr.

(C) if the material is to be used in welded construction, data from actual welding tests made in accordance with Section IX of the ASME Boiler and Pressure Vessel Code should be submitted. Welding test data should include:

(C.1) the welding processes and weld filler metal(s) intended for the fabrication of the material;

(C.2) all-weld-metal tensile test data for temperatures representative of intended service;

(C.3) any special restrictions on the welding of the material;

(C.4) the appropriate preheat and postweld heat treatment, if any, which will be given the material. If postweld heat treatment results in embrittlement of the material, the significance of such treatments with substantiating data should be forwarded. Toughness data on weld metal and heat affected zone in the as-welded and postweld heat treated conditions, when appropriate, should be submitted.

(D) where the material is intended for special applications, requires special handling or special welding procedures, or has known limitations or susceptibility to failure in certain services, precautionary requirements and information should also be submitted for review by the Committee.

(E) applicable product form(s) of the material, such as sheet, strip, plate, bars, shapes, seamless or welded pipe or tube forgings, castings, etc., for which application is to be considered must be identified.

The general data recommended should be submitted on a minimum of three heats, preferably commercial heats, of the material. Where the range of chemical composition affect the mechanical properties, the heats selected should cover both the high and low range of the effective chemical elements to show the effect on the mechanical properties. Any special heat treatment, whether applied by the material supplier or the fabricator, should be applied to the test pieces used to obtain the data.

If the material is covered by an ASTM specification, the specification number(s) and grade(s) involved must be identified in the application. If the material is not covered by an ASTM specification, application must be made to ASTM for specification coverage of this material.

Should there be a need for Code use prior to the inclusion of the material in ASTM specifications, the Committee will consider issuing a Code Case.

In addition to the information and data noted above, the Committee should be provided with an indication of user need, a copy of the letter to ASTM requesting specification coverage, and sufficient information for the Committee to modify an appropriate existing ASTM specification to establish the material specification requirements for the material product form.

When the new material is a minor modification of a material which is currently accepted by the Code,

[1] Nonmandatory appendices are identified by a roman numeral; mandatory appendices are identified by a letter. Therefore, roman numeral I is not used in order to avoid confusion with the letter I.

the data required may be reduced with the concurrence of the Committee. When the data supplied are insufficient for an adequate evaluation, the Committee will request additional data. Such requests will be returned, indicating those areas in which additional information is required.

NONMANDATORY APPENDIX VII[1] PROCEDURES FOR THE DESIGN OF RESTRAINED UNDERGROUND PIPING

FOREWORD

The Code contains rules governing the design, fabrication, materials, erection, and examination of power piping systems. Experience over the years has demonstrated that these rules may be conservatively applied to the design and analysis of buried piping systems. However, the ASME B31.1 rules were written for piping suspended in open space, with the supports located at local points on the pipe. Buried piping, on the other hand, is supported, confined, and restrained continuously by the passive effects of the backfill and the trench bedding. The effects of continuous restraint cannot be easily evaluated by the usual methods applied to exposed piping, since these methods cannot easily accommodate the effects of bearing and friction at the pipe/soil interface. Accordingly, this Appendix has been prepared to illustrate and clarify the application of Code rules to restrained buried piping.

All components in the buried piping system must be given consideration, including the building penetrations, branches, bends, elbows, flanges, valves, grade penetrations, and tank attachments. It is assumed that welds are made in accordance with this Code and that appropriate corrosion protection procedures are followed for buried piping.

This Appendix provides analytic and nomenclature definition figures to assist the designer, and is not intended to provide actual design layout. Sample calculations for various configurations of semirigid buried piping have been provided at the end of the text to assist the designer in the application of these procedures.

VII-1.0 SCOPE AND DEFINITIONS

VII-1.1 Scope

The scope of this Appendix is confined to the design of buried piping as defined in para. VII-1.2. Thermal expansion in buried piping affects the forces, the resulting bending moments and stresses throughout the burried portions of the system, particularly at the anchors, building penetrations, buried elbows and bends, and branch connections, and it is the designer's responsibility to consider these forces. This Appendix, however, deals only with the buried portions of the system, and not the complete system.

The design and analysis of buried piping requires that careful attention be paid to:

(A) all loads acting on the system;

(B) the forces and the bending moments in the piping and piping components resulting from the loads;

(C) the loading and stress criteria;

(D) general design practices.

VII-1.2 Definitions

confining pressure: the pressure imposed by the compacted backfill and overburden on a buried pipe. Confining pressure is assumed to act normal to the pipe circumference.

flexible coupling: a piping component that permits a small amount of axial or angular movement while maintaining the pressure boundary

friction: the passive resistance of soil to axial movement. Friction at the pipe/soil interface is a function of confining pressure and the coefficient of friction between the pipe and the backfill material. Friction forces exist only where there is actual or impending slippage between the pipe and soil

influence length: that portion of a transverse pipe run which is deflected or "influenced" by pipe thermal expansion along the axis of the longitudinal run

modulus of subgrade reaction: the rate of change of soil bearing stress with respect to compressive deformation of the soil. It is used to calculate the passive spring rate of the soil

[1] Nonmandatory appendices are identified by a roman numeral; mandatory appendices are identified by a letter. Therefore, roman numeral I is not used in order to avoid confusion with the letter I.

penetration: the point at which a buried pipe enters the soil either at grade or from a wall or discharge structure

settlement: the changes in volume of soil under constant load which results in the downward movement, over a period of time, of a structure or vessel resting on the soil

virtual anchor: a point or region along the axis of a buried pipe where there is no relative motion at the pipe/soil interface

VII-1.3 Nomenclature

a, b, c = quadratic equation functions
A = cross sectional metal area of pipe, in.^{2}
A_c = surfaced area of a 1-in. long pipe segment, in.^{2}
B_d = trench width at grade, in.
C_D = soil bearing parameter from Table VII-3.2.3, dimensionless
C_k = horizontal stiffness factor for backfill [8],[2] dimensionless
D = pipe outside diameter, in.
dL = length of pipe element, in.
E = Young's modulus for pipe, psi
f = unit friction force along pipe, lb/in.
f_{min}, f_{max} = minimum, maximum unit friction force on pipe, lb/in.
F_f = total friction force along effective length, lb
F_{max} = maximum axial force in pipe, lb
H = pipe depth below grade, in.
I = pipe section moment of inertia, in.^{4}
k = soil modulus of subgrade reaction, psi
k_h = soil horizontal modulus of subgrade reaction, psi
$k_{i,j}$ = orthogonal soil springs on pipe, lb/in.
k_v = soil vertical modulus of subgrade reaction, psi
L_1 = length of transverse pipe run, in.
L_2 = length of longitudinal pipe run, in.
L_m = minimum slippage length of pipe, in.
L' = effective slippage length for short pipes, in.
L'' = effective slippage length for long pipes, in.
n = number of modeling elements for pipe springs, dimensionless
N_h = horizontal force factor [8], dimensionless
P = maximum operating pressure in pipe, psi
P_c = confining pressure of backfill on pipe, psi
S_A = allowable expansion stress range, psi
SE = expansion stress, psi
S_h = basic material allowable stress at T degrees fahrenheit, psi
t = pipe wall thickness, in.
T = maximum operating temperature, °F
T_o = ambient temperature of pipe, °F
w = soil density, pfc, pci
W_p = unit weight of pipe and contents, lb/in.
α = coefficient of thermal expansion of pipe, in./in./°F
β = pipe/soil system characteristic [2], in.$^{-1}$
ϵ = pipe unit thermal expansion, in./in.
μ = coefficient of friction, dimensionless
Ω = effective length parameter, in.

[2] Numbers enclosed in brackets [ ] correspond to references cited in VII-7.0.

VII-2.0 LOADS

VII-2.1 Thermal Expansion

Thermal displacements at the elbows, branch connections, and flanges in a buried piping system and the forces and moments resulting from the displacements may be determined by analyzing each buried run of pipe by the method described in this Appendix.

VII-2.1.1 Installations With Continuous Runs. For buried piping installations that contain continuous runs without flexible couplings, the passive restraining effects of soil bearing on the transverse legs at the ends of long runs subject to thermal expansion may be significant and result in high axial forces and elbow or branch connection bending moments.

VII-2.1.2 Installations With Flexible Couplings. For buried piping installations that incorporate flexible couplings into the pipe runs subject to thermal expansion, the bending moments and stresses may be substantially reduced. However, the flexible couplings must be chosen carefully to accommodate the thermal expansion in the pipe, and the friction forces or stiffness in the coupling must be considered.

VII-2.1.3 Installations With Penetration Anchors. For buried piping systems in which the building penetration provides complete restraint to the pipe, it is necessary to calculate the penetration reactions to thermal

expansion in the initial buried run. If this run incorporates flexible couplings, piping reactions at the penetration resulting from unbalanced forces due to internal pressure must be considered.

VII-2.1.4 Installations With Flexible Penetrations. For buried piping systems in which the building penetrations permit some axial or angular movements, the interaction between the buried run outside the penetration and the point-supported portion of the system inside the building must be considered.

VII-2.2 Pressure

Pressure loads in buried piping are important for two primary reasons.

VII-2.2.1 In pipe runs which incorporate flexible couplings, there is no structural tie between the coupled ends, with the result that internal pressure loads must be reacted externally. External restraint may be provided by thrust blocks, external anchors, soil resistance to elbows or fittings at each end of the pipe run, or by control rods across the coupling. Where one or both of the ends terminate at a penetration or an anchor, or at connected equipment such as a pump or vessel, the pressure forces can be quite high and must be considered in the anchor or equipment design.

VII-2.2.2 For discharge strctures, the reaction forces due to upstream pressure and mass flow momentum in the discharge leg may be high and must be considered in the design of the last elbow or bend before the discharge.

VII-2.3 Earthquake

An earthquake subjects buried piping to axial loads and bending moments from soil strain due to seismic waves, or from ground faulting across the axis of the pipe. The seismic soil strain can be estimated for a design earthquake in a specific geographical region, from which design values for forces and moments in buried piping can be calculated. However, consideration of the magnitude and effects of seismic ground faulting on buried piping is beyond the scope of this Appendix.

VII-3.0 CALCULATIONS

The calculations for stresses in restrained underground piping are carried out in four steps, as follows.

VII-3.1 Assembling the Data

The pipe material and dimensions, soil characteristics, and operating conditions must be established.

VII-3.1.1 Pipe Data

(A) pipe outside diameter D, in.

(B) wall thickness t, in.

(C) length of pipe runs L_1 (transverse) and L_2 (longitudinal), in.

(D) Young's modulus E, psi, (from Appendix C)

(E) pipe depth below grade H, in.

VII-3.1.2 Soil Characteristics

(A) soil density w, pcf (from site tests)

(B) type of backfill

(C) pipe trench width at grade B_d, in.

(D) range of coefficient of friction μ between pipe and backfill

VII-3.1.3 Operating Conditions

(A) maximum operating pressure P, psi

(B) maximum pipe temperature T, °F

(C) ambient pipe temperature T_o, °F

(D) pipe coefficient of thermal expansion α, in./in./°F

VII-3.2 Calculations of Intermediate Parameters

The following parameters must be calculated.

VII-3.2.1 Maximum Relative Strain ϵ at the Pipe/Soil Interface, in./in. For thermal expansion, this is the unit thermal elongation of the unrestrained pipe.

$$\epsilon = \alpha(T - T_o) \tag{1}$$

where

α = coefficient of thermal expansion

$T - T_o$ = difference between operating and installation temperatures

VII-3.2.2 Modulus of Subgrade Reaction k, psi. This is a factor which defines the resistance of the soil or backfill to pipe movement due to the bearing pressure at the pipe/soil interface. Several methods for calculating k have been developed in recent years byAudibert and Nyman, Trautmann and O'Rourke, and others [4, 5, 6, 7, 8]. For example [8], for pipe movement horizontally, the modulus of subgrade k_h may be found by

$$k_h = C_k N_h w D \text{ psi} \tag{2}$$

where

C_k = a dimensionless factor for estimating horizontal stiffness of compacted backfill. C_k may be estimated at 20 for loose soil, 30 for medium soil, and 80 for dense or compacted soil.

w = soil density, lb/in.^{3}

D = pipe outside diameter, in.

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

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

where

H = the depth of pipe below grade at the pipe center line, in.

For pipe movement upward or downward,the procedures recommended in [4] may be applied. Conservatively, the resistance to upward movement may be considered the same as for horizontal movement with additional consideration for the weight of the soil. Resistance to downward movement may conservatively be considered as rigid for most expansion stress analysis.

VII-3.2.3 Unit Friction Force at the Pipe/Soil Interface f

$$f = \mu\,(P_cA_c + W_p)\ \text{lb/in.} \qquad (3)$$

where

μ = coefficient of friction between pipe and soil
P_c = confining pressure of soil on pipe, psi
A_c = surface area of a pipe segment, in.^{2}
W_p = unit weight of pipe and contents, lb/in.

For piping which is buried within 3 pipe diameters of the surface, confining pressure P_c may be estimated by

$$P_c = wH\ \text{lb/in.}^2$$

where

w = the soil density, lb/in.^{3}
H = the depth below grade, in.

For piping which is buried more than 3 pipe diameters below grade, confining pressure P_c is found by using the modified Marston equation [9]:

$$P_c = wC_DB_D\ \text{lb/in.}^2$$

where

C_D = a dimensionless parameter obtained from Table VII-3.2.3
B_D = the trench width, with a maximum value of 24 in. plus the pipe diameter

TABLE VII-3.2.3
APPROXIMATE SAFE WORKING VALUES OF C_D FOR USE IN MODIFIED MARSTON FORMULA

Ratio H/B_D	Damp Top Soil and Dry and Wet Sand	Saturated Top Soil	Damp Yellow Clay	Saturated Yellow Clay
0.5	0.46	0.47	0.47	0.48
1.0	0.85	0.86	0.88	0.90
1.5	1.18	1.21	1.25	1.27
2.0	1.47	1.51	1.56	1.62
2.5	1.70	1.77	1.83	1.91
3.0	1.90	1.99	2.08	2.19
3.5	2.08	2.18	2.28	2.43
4.0	2.22	2.35	2.47	2.65
4.5	2.34	2.49	2.53	2.85
5.0	2.45	2.61	2.19	3.02
5.5	2.54	2.72	2.90	3.18
6.0	2.61	2.91	3.01	3.32
6.5	2.68	2.89	3.11	3.44
7.0	2.73	2.95	3.19	3.55
7.5	2.78	3.01	3.27	3.65
8.0	2.82	3.06	3.33	3.74
9.0	2.88	3.14	3.44	3.89
10.0	2.92	3.20	3.52	4.01
11.0	2.95	3.25	3.59	4.11
12.0	2.97	3.28	3.63	4.19
13.0	2.99	3.31	3.67	4.25
14.0	3.00	3.33	3.70	4.30
15.0	3.01	3.34	3.72	4.34
∞	3.03	3.38	3.79	4.50

VII-3.2.4 Pipe/Soil System Characteristic [2]

$$\beta = [k/(4EI)]^{1/4}\ \text{in.}^{-1} \qquad (4)$$

where

k = soil modulus of subgrade reaction k_h or k_v, psi
E = Young's modulus for pipe, psi
I = area moment of inertia for pipe, in.^{4}

VII-3.2.5 Minimum Slippage Length L_m [1]

$$L_m = \epsilon AE/f\ \text{in.} \qquad (5)$$

where

A = pipe cross section area

VII-3.2.6 Maximum Axial Force F_{max} in the Longitudinal Pipe Run. The maximum axial force in a pipe long enough for friction force to develop to the point where a region of the pipe is totally restrained longitudinally by the soil is found by

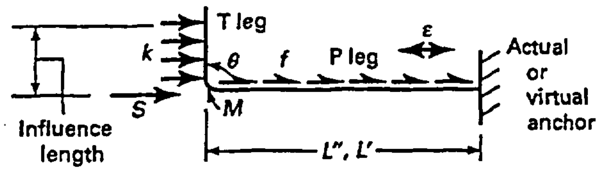


FIG. VII-3.3.2-1 ELEMENT CATEGORY A, ELBOW OR BEND

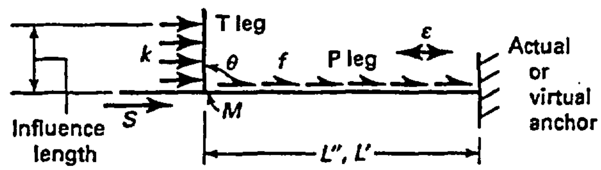


FIG. VII-3.3.2-2 ELEMENT CATEGORY B, BRANCH PIPE JOINING THE P LEG

$$F_{max} = fL_m = \epsilon AE \text{ lb} \qquad (6)$$

VII-3.3 Classification of the Pipe Runs

VII-3.3.1 Purpose. The classification and subclassification of the buried pipe elements is used in choosing the proper equation for effective slippage length L' or L'' which is then used in calculating piping forces and stresses. The pipe segment identified by the dimension L' or L'' always begins at either an elbow, bend, tee, or branch connection and terminates at the point (described below as the "virtual anchor") at which there is no slippage or relative movement at the pipe/soil interface.

VII-3.3.2 Classification of the Pipe Elements. It is in the bends, elbows, and branch connections that the highest stresses are found in buried piping subject to thermal expansion of the pipe. These stresses are due to the soil forces that bear against the transverse run (the run running perpendicular or at some angle to the direction of the pipe expansion). The stresses are proportional to the amount of soil deformation at the elbow or branch connection.

Piping elements are divided into three major categories depending upon what type of transverse element is being analyzed, as follows:

Category A: elbow or bend (see Fig. VII-3.3.2-1)

Category B: branch pipe joining the longitudinal run (see Fig. VII-3.3.2-2)

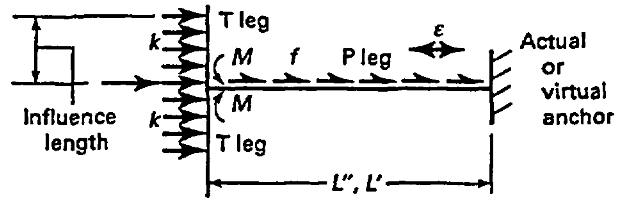
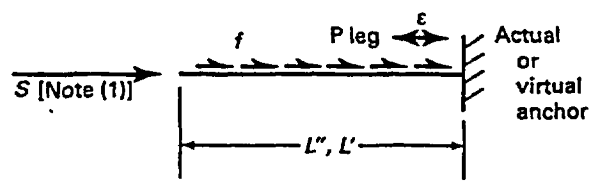


FIG. VII-3.3.2-3 ELEMENT CATEGORY C, TEE ON END OF P LEG



NOTE:
(1) Expansion joint pressure load plus sliding or convolution loads.

FIG. VII-3.3.2-4 ELEMENT CATEGORY D, STRAIGHT PIPE

Category C: longitudinal run ending in a tee (see Fig. VII-3.3.2-3)

Category D: straight pipe, no branch or transverse run (see Fig. VII-3.3.2-4)

Categories A, B, and C are further divided into three subcategories depending on the configuration of the pipe run at the end opposite that being analyzed. The piping elements are classified as follows:

A1, B1, C1: other end free or terminating in a flexible coupling or joint

A2, B2, C2: other end contains an elbow or tee

A3, B3, C3: other end is anchored

Category D elements include straight runs between an anchor (either actual or virtual) and a free end or a pipe section that is connected to an expansion joint.

The elements are further broken down into subtypes depending upon whether the longitundinal run (the pipe or P leg) and the transverse run (called the T leg) are long or short with respect to certain criteria. The transverse or T leg is the run against which the soil bears, producing an in-plane bending moment in elbow, branch, or tee. (Category D elements have no transverse leg.)

The strict criterion for a long or short transverse leg is whether the length of the transverse run L_1 is longer or shorter than $3\pi/4\beta$, the length at which the hyperbolic functions in Hetenyi's equations [2] approach unit. The critical value for L_1 is often called the "influence" length, or that portion of transverse or T run which is deflected or "influenced" by seismic soil strain or pipe thermal expansion along the axis of the longitudinal or P run. In practice, a critical influence length L_1 of $1/\beta$ to $1.2/\beta$ may often be used, since there is very little deformation or load in that portion of the transverse run which exceeds this length. This implies that the vast majority of the bearing load on the transverse or T leg occurs in the first several feet of the pipe at the bend or branch. In summary, a transverse pipe is "long" if

$$L_1 \geq 3\pi/4\beta \text{ (conservative)}$$

or

$$L_1 \geq 1/\beta \text{ to } 1.2/\beta \text{ (usually acceptable)}$$

The criterion for a short or long P leg is whether or not its length L_2 is sufficiently long to experience the maximum force that can develop at the friction interface. For full maximum friction force ($F_{max} = \epsilon AE$) to occur in a straight pipe axially free at each end, its length L_2 would have to equal or exceed $2L_m$ with L_m calculated by Eq. (5). If one end terminates in an elbow or a tee, with the other end remaining axially unrestrained, the total length L_2 necessary for full friction to develop is $L'' + L_m$; the friction force over L_m is equal to the soil bearing force S plus the friction force acting on the length L' or L'', which is called the effective slippage length. The effective slippage length is the maximum length along which slippage occurs at the pipe/soil interface of a pipe with a transverse leg or branch. The effective slippage length L'' for long pipes with long transverse legs is calculated by

$$L'' = \Omega[(1 + 2F_{max}/f\Omega)^{1/2} - 1] \text{ in.} \tag{7}$$

where

$\Omega = AE\beta/k$

and F_{max} is calculated by Eq. (6).

Equation (7) applies to bends, tees, and branches. Although Eq. (7) was developed for the case where $L_2 = L'' + L_m$, it applies also for any case where $L_2 > L'' + L_m$, since the length of the region where there is zero slippage at the friction interface is immaterial [1]. Using L'' as calculated by Eq. (7), it can now be established that a P leg is classified long if it meets these criteria:

(A) For Types A1, B1, C1, $L_2 \geq L_m + L''$;

(B) For Types A2, B2, C2, $L_2 \geq 2L''$;

(C) For Types A3, B3, C3, D, $L_2 \geq L''$.

That point which is located a distance L' or L'' from the bend, branch, or tee, is called the virtual anchor, since it acts as if it were a three-axis restraint on the pipe.

VII-3.3.4 Locating the Virtual Anchor. Calculation of the forces and moments in buried piping at the changes in direction requires that the location of the virtual anchor (the effective slippage length L' away from the bend or branch element) in the P run and deformation δ of the soil at the buried element be established. For elements of all types with long P legs, L'' may be calculated by Eq. (7).

For Types A1, B1, and C1 elements (with one end of the P leg free or unrestrained axially) with "short" P legs L' must be found by a less direct method as follows [1]:

$$L' = [-b + (b^2 - 4ac)^{1/2}]/2a \text{ in.} \tag{8}$$

where

$a = 3f/(2AE)$

$b = \epsilon - fL_2/(AE) + 2f\beta/k$

$c = -f\beta L_2/k$

However, the most highly stressed runs in a buried piping system typically are restrained at both ends, either by a combination of transverse runs or a transverse and an anchor (either real or virtual).

For Types A2, B2, and C2 elements with short P legs, L' is expressed by

$$L' = L_2/2 \text{ in.} \tag{9}$$

For Types A3, B3, C3, and D elements with short P legs, L' is expressed by

$$L' = L_2 \text{ in.} \tag{10}$$

VII-4.0 COMPUTER MODELING OF BURIED PIPING

VII-4.1 Determination of Stresses

With f, k, and L' or L'' established, the stresses in a buried pipe due to thermal expansion can be determined with a general purpose pipe stress computer program. A buried piping system can be modeled

with a typical mainframe or microcomputer pipe stress program by breaking the buried portions into elements of convenient length and then imposing a transverse spring at the center of each element to simulate the passive resistance of the soil. The entire pipe can be divided into spring-restrained elements in this manner; however, the only regions of the pipe that really need to be modeled in this manner are the lengths entering and leaving elbows or tees. The analyst should refer to the program users' manual for guidance in modeling soil springs.

All pipe stress computer programs with buried piping analysis options require that the following factors be calculated or estimated:

(A) Location of the virtual anchor (dimension L' or L'')

(B) Soil spring rate $k_{i,j}$, which is a function of the modulus of subgrade reaction k.

(C) Influence length, also a function of k.

Some programs ignore the friction at the pipe/soil interface; this is conservative for calculating bending stresses on the buried elbows and branch connections, but may be unconservative for calculating anchor reactions.

VII-4.2 Determination of Element Lengths

The element lengths and transverse soil spring rates for each element are calculated by the following procedure:

VII-4.2.1 Establish the element length dL and the number n of elements, as follows:

(A) Set the element length to be equal to between 2 and 3 pipe diameters. For example, dL for a NPS 6 may be set at either 1 ft or 2 ft, whichever is more convenient for the analyst.

(B) Establish the number n of elements by:

$$n = (3\pi/4\beta)/dL \qquad (11)$$

This gives the number of elements, each being dL inches in length, to which springs are to be applied in the computer model. The number n of elements is always rounded up to an integer.

VII-4.2.2 Calculate the lateral spring rate $k_{i,j}$ to be applied at the center of each element.

$$k_{i,j} = kdL \text{ lb/in.} \qquad (12)$$

where

k = the modulus of subgrade reaction calculated from Eq. (2).

VII-4.2.3 Calculate the equivalent axial load necessary to simulate friction resistance to expansion. The friction resistance at the pipe/soil interface can be simulated in the computer model by imposing a single force F_f in a direction opposite that of the thermal growth.

$$F_f = fL'/2 \text{ or } fL''/2 \text{ lb} \qquad (13)$$

VII-4.2.4 Incorporate the springs and the friction force in the model. The mutually orthogonal springs $k_{i,j}$ are applied to the center of each element, perpendicular to the pipe axis. Shorter elements, with proportionally smaller values for the springs on these elements, may be necessary in order to model the soil restraint at elbows and bends. The friction force F_f for each expanding leg is imposed at or near the elbow tangent node, opposite to the direction of expansion.

VII-4.3 Determination of Soil Parameters

Soil parameters are difficult to establish accurately due to variations in backfill materials and degree of compaction. Consequently, values for elemental spring constants on buried pipe runs can only be considered as rational approximations. Stiffer springs can result in higher elbow stresses and lower bending stresses at nearby anchors, while softer springs can have the opposite effects. Backfill is not elastic, testing has shown that soil is stiffest for very small pipe movements, but becomes less stiff as the pipe movements increase. References [4], [7], and [8] discuss soil stiffness and recommend procedures for estimating values for k which are consistent with the type of soil and the amount of pipe movement expected. The analyst should consult the project geotechnical engineer for assistance in resolving any uncertainties in establishing soils parameters, such as the modulus of subgrade reaction k, confining pressure p_c, and coefficient of friction μ.

VII-4.4 Pipe With Expansion Joints

An expansion joint must be considered as a relatively free end in calculating stresses on buried elbows and loads on anchors. Since incorporation of expansion joints or flexible couplings introduces a structural discontinuity in the pipe, the effects of the unbalanced pressure load and the axial joint friction or stiffness must be superimposed on the thermal expansion effects

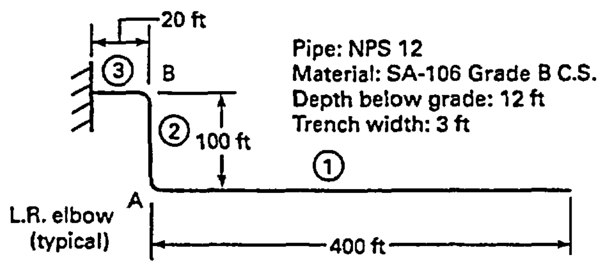


FIG. VII-5.0 PLAN OF EXAMPLE BURIED PIPE

in order to determine the maximum pipe stresses and anchor loads.

VII-4.5 Pipe Stresses at Building Penetrations

Stresses at building penetrations can be calculated easily after the reactions due to thermal expansion in the buried piping have been determined. If the penetration is an anchor, then the stress due to the axial force F_{max} and the lateral bending moment M can be found by

$$S_E = F_{max}/A + M/Z \text{ psi} \qquad (14)$$

If the penetration is not an anchor, but is instead a simple support with a flexible water seal, it is necessary to determine the stiffness affects of the water seal material in order to calculate the stress in the pipe at the penetration. Differential movement due to building or trench settlement can generate high theoretical stresses at piping penetrations to buildings. Calculation of such stresses is beyond the scope of this Appendix.

VII-5.0 ALLOWABLE STRESS IN BURIED PIPE

Buried piping under axial stress can theoretically fail in one of two ways: either by column buckling (pipe pops out of the ground at mid-span) or local failure by crippling or tensile failure (much more serious than column buckling). Since buried piping stresses are secondary in nature, and since the piping is continuously supported and restrained (see Fig. VII-5.0), higher total stresses may be permitted as follows:

$$S_C \leq S_A + S_h \qquad (15)$$

where S_A and S_h are as defined in para. 102.3.2.

VII-6.0 EXAMPLE CALCULATIONS

VII-6.1 Assemble the Data

VII-6.1.1 Pipe Data

(A) diameter D = 12.75 in.
(B) wall thickness = 0.375 in.
(C) length of runs:
(C.1) Run 1: L_1 = 100 ft, L_2 = 400 ft
(C.2) Run 2: L_1 = 20 ft, L_2 = 100 ft
(C.3) Run 3: L_1 = 100 ft, L_2 = 20 ft
(D) Young's modulus $E = 27.9 \times 10^6$ psi
(E) moment of inertia $I = 279.3$ in^4
(F) cross section metal area $A = 14.57$ in.^{2}

VII-6.1.2 Soil Characteristics

(A) soil density w = 130 lb/ft^3
(B) pipe depth below grade H = 12 ft (144 in.)
(C) type of backfill: dense sand
(D) trench width B_d = 3 ft (36 in.)
(E) coefficient of friction μ = 0.3 min. to 0.5 max. (estimated)
(F) horizontal soil stiffness factor C_k = 80

VII-6.1.3 Operating Conditions

(A) pressure P = 100 psig
(B) temperature = 140°F
(C) ambient temperature = 70°F

VII-6.2 Calculate the Intermediate Parameters

VII-6.2.1 Relative Strain at the Pipe/Soil Interface. Thermal expansion for SA-106 Grade B carbon steel pipe from 70°F to 140°F is 0.0053 in./ft. Therefore,

$$\epsilon = (0.0053 \text{ in./ft})/(12 \text{ in./ft}) = 0.000424 \text{ in./in.}$$

VII-6.2.2 Modulus of Subgrade Reaction k [8]. Since the expansion is in the horizontal plane, use k_h from Eq. (2):

$$k_h = C_k N_h w D \qquad (2)$$

$$C_k = 80$$

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

$$= 0.285\,(12 \text{ ft})(12 \text{ in./ft})/12.75 \text{ in.} + 4.3$$

$$= 7.519$$

$$w = 130 \text{ pcf}/(1728 \text{ in.}^3/\text{ft}^3)$$

$$= 0.0752 \text{ lb/in.}^3$$

$$D = 12.75 \text{ in.}$$

$$k_h = (80)(7.519)(0.0752)(12.75) = 577 \text{ lb/in.}^2$$

VII-6.2.3 Friction Forces per Unit Length Acting at the Pipe/Soil Interface

$$f = \mu(P_c A_c + W_p) \quad (3)$$

Since the pipe lies more than 3 diameters below grade, the modified Marston equation from [1] is used to determine the confining pressure P_c of soil on the pipe.

$$P_c = wC_D B_d$$

$$C_D = 2.22 \text{ for } H/B_d = 12 \text{ ft./3 ft.}$$

$$= 4 \text{ (see Table VII-3.2.3 for sand)}$$

$$P_c = (130 \text{ pcf})(2.22)(3 \text{ ft.})/(144 \text{ in.}^2/\text{ft}^2)$$

$$= 6.01 \text{ psi}$$

$$A_c = D(1 \text{ in.}) = (12.75 \text{ in.})(1 \text{ in.})$$

$$= 40.05 \text{ in.}^2/\text{in. of length}$$

$$W_p = 8.21 \text{ lb/in. for water-filled carbon steel pipe}$$

Maximum value of friction force per unit length f_{max}:

$$f_{max} = 0.5 \, [(6.01 \text{ psi})(40.05 \text{ in.}^2/\text{in.}) + 8.21 \text{ lb/in.}] \quad (3)$$

$$= 124.5 \text{ lb/in.}$$

Minimum value of friction force per unit length f_{min}:

$$f_{min} = 0.3 \, [(6.01)(40.05) + 8.21] \quad (3)$$

$$= 74.7 \text{ lb/in.}$$

VII-6.2.4 Pipe/Soil System Characteristic β [2]

$$\beta = [k_h/(4EI)]^{1/4} \quad (4)$$

$$= [577 \text{ psi}/4(27.9 \times 10^6 \text{ psi})(279.3 \text{ in.}^4)]^{1/4}$$

$$= 0.01166 \text{ in.}^{-1}$$

VII-6.2.5 Minimum Slippage Length L_m

$$L_m = \epsilon AE/f_{min} \quad (5)$$

$$= (0.000424 \text{ in./in.})(14.57 \text{ in.}^2)(27.9 \times 10^6 \text{ psi}) / 74.7 \text{ lb/in.}$$

$$= 2307 \text{ in. or 192 ft 4 in.}$$

VII-6.2.6 Maximum Axial Force F_{max} Corresponding to L_m

$$F_{max} = \epsilon AE = (0.000424)(14.57)(27.9 \times 10^6) \quad (6)$$

$$= 172{,}357 \text{ lb}$$

VII-6.3 Classification of Runs

Classify the pipe runs in accordance with the models given in Table VII-6.3 and calculate the effective slippage length L' or L'' for each run.

VII-6.3.1 Run 1 is a Category A1 (elbow on one end, the other end free). Check to see if the transverse leg L_1 is long or short.

$$L_1 = 1200 \text{ in.}$$

$$3\pi/(4)(0.01166 \text{ in.}^{-1}) = 202 \text{ in.}$$

Since 1200 in. > 202 in., L_1 is long. Check to see if the longitudinal leg L_2 is long or short, that is, longer or shorter than $L_m + L''$. Using Eq. (7) to calculate L'',

TABLE VII-6.3
EQUATIONS FOR CALCULATING EFFECTIVE LENGTH L' OR L''

Element Category	Equations for L' or L'': Short P Leg L'		Long P Leg L''	
A1, B1, C1	If $L_2 < L_m + L''$, $L' = [-b + (b^2 - 4ac)^{1/2}]/2a$ where $a = 3f/(2AE)$, $b = \epsilon - fL_2/(AE) + 2f\beta/k$, $c = -f\beta L_2/k$	(8)	If $L_2 \geq L_m + L''$, $L'' = \Omega[(1 + 2F_{max}/f_{min}\Omega)^{1/2} - 1]$	(7)
A2, B2, C2	If $L_2 < 2L''$, $L' = L_2/2$	(9)	If $L_2 \geq 2L''$, $L'' = \Omega[(1 + 2F_{max}/f_{min}\Omega)^{1/2} - 1]$	(7)
A3, B3, C3	If $L_2 < L''$, $L' = L_2$	(10)	If $L_2 \geq L''$, $L'' = \Omega[(1 + 2F_{max}/f_{min}\Omega)^{1/2} - 1]$	(7)
D	If $L_2 < L_m$, $L' = L_2$	(10)	If $L_2 \geq L_m$, $L'' = L_m = \epsilon AE/f$	(5)

$$L'' = \Omega[(1 + 2F_{max}/f_{min}\Omega)^{1/2} - 1] \quad (7)$$

$$\Omega = AE\beta/k = (14.57 \text{ in.}^2)(27.9 \times 10^6 \text{ psi}) \times (0.01166 \text{ in.}^{-1})/577 \text{ psi} = 8214 \text{ in.}$$

$$L'' = 8214\{[1 + 2 \times 172{,}357/(74.7 \times 8214)]^{1/2} - 1\} = 2051 \text{ in.}$$

$$L_m + L'' = 2307 + 2051 = 4358 \text{ in.}$$

Since L_2 = 400 ft or 4800 in., then since 4800 > 4358, the pipe run length L_2 is long, and Run 1 can be fully classified as Category A1 (long transverse, long pipe).

NOTE: If $L_m + L''$ would have exceeded L_2, then L' would be recalculated using Eq. (8), the correct equation for a short pipe.

VII-6.3.2 Run 2 is a Category A2 (elbow on each end). Check to see if the legs L_1 and L_2 are long or short.

Since $L_1 > 3\pi/4\beta$ (240 in. > 202 in.) and since $L_2 < 2L''$ [1200 in. < 2(2051 in.)], then Run 2 can be fully classified as a Category A2 (long transverse, short pipe). Then

$$L' = L_2/2 = (1200 \text{ in.})/2 = 600 \text{ in.}$$

VII-6.3.3 Run 3 is a Category A3 (anchor on one end, elbow on the other). Check to see if the legs L_1 and L_2 are long or short.

Since $L_1 > 3\pi/4\beta$ (1200 in. > 202 in.) and $L_2 < L''$ (240 in. < 2051 in.), then Run 3 can be fully classified as a Category A3 (long transverse, short pipe). Then

$$L' = L_2 = 240 \text{ in.}$$

NOTE: In order to fully qualify a buried piping system, it may also be necessary to include stresses due to weight of overburden (backfill) and vehicular loads [5, 6].

VII-6.4 Computer Modeling

Calculate the soil springs and friction force for use in a computer model of the buried pipe.

VII-6.4.1 Element Length. Set the element length to be ≈ 3 pipe diameters. dL = 36 in.

VII-6.4.2 Number of Elements. Only the soil within a length $3\pi/4\beta$ from the elbow will be subject to bearing force from the pipe. For the example system, $3\pi/4\beta$ = 202 in. Therefore, the number of elements needed is found by

$$n = (3\pi/4\beta)/dL = 202/36 = 5.61 \quad (11)$$

Therefore, use 6 elements, each 36 in. long.

VII-6.4.3 Spring Rate $k_{i,j}$. The spring rate to be applied to each element is found by

$$k_{i,j} = kdL \qquad (12)$$

where k is from Eq. (2)

$$k_{i,j} = (577 \text{ psi})(36 \text{ in.}) = 20{,}772 \text{ lb/in.}$$

This is the theoretical spring rate to be imposed at the center of each element and normal to the surface of the pipe, with k_i in the plane of the expansion, and k_j perpendicular to the plane of expansion.

VII-6.4.4 Friction Force F_f. The friction forces to be applied at the elbow tangent points in Runs 1 and 2 are calculated as follows:

Parallel to Run 1:

$$F_f = fL''/2 \qquad (13)$$

where

$f = f_{min} = 74.7$ lb/in.
$L'' = 2051$ in.

$$F_f = (74.7 \text{ lb/in.})(2051 \text{ in.})/2 = 76{,}605 \text{ lb}$$

Parallel to Run 2:

$$F_f = (74.7 \text{ lb/in.})(600 \text{ in.})/2 = 22{,}410 \text{ lb} \qquad (13)$$

The friction force to be applied at the elbow tangent point in Run 3 is calculated as follows:

Parallel to Run 3:

$$F_f = (74.7 \text{ lb/in.})(240 \text{ in.})/2 = 8964 \text{ lb} \qquad (13)$$

The computer model then appears as is shown in Fig. VII-6.4.4.

VII-6.5 Results of Analysis

Computer analysis of the model shown in Fig. VII-6.4.4 gives combined stress S_C at various locations in the buried pipe as follows:

Location	S_C, psi
Virtual anchor	7,036
Elbow A	26,865
Elbow B	9,818
Penetration anchor	2,200

NOTE: S_C for this example includes longitudinal pressure stress, intensified bending stresses, and direct stresses due to axial loads from friction and soil bearing loads. It does not include weight of backfill or live loads.

The allowable stress as given by Eq. (15) is $S_A + S_h$, which for SA-106 Grade B steel pipe is 22,500 psi + 15,000 psi = 37,500 psi. Therefore, since the maximum S_C of 26,865 psi < 37,500 psi, the Code conditions are met.

VII-6.6 Anchor Load Example

If Element 1 were simply a straight pipe anchored at one end with the other end terminating in an expansion joint (see Fig. VII-6.6), the load on the anchor is found as follows.

(A) Calculate the maximum friction force acting along the friction interface.

$$F_f = F_{max} = \epsilon AE \qquad (6)$$

$$F_{max} = \epsilon AE = (0.000424)(14.57)(27.9 \times 10^6) \qquad (6)$$

$$= 172{,}357 \text{ lb}$$

(B) Calculate the load S at the expansion joint.

$$S = F_j + S_p$$

where

F_j = expansion joint friction force
= 9000 lb (from vendor data)
S_p = pressure force
= PA_s
where
P = design pressure
= 100 psig
A_s = effective cross-sectional area
= $\pi D^2/4$
= $\pi\,(12.75^2)/4$
= 127.6 in.^{2}

$$S_p = (100)(127.6) = 12{,}760 \text{ lb}$$

$$S = 9{,}000 + 12{,}760 = 21{,}760 \text{ lb}$$

(C) The total axial load F_a at the anchor then becomes

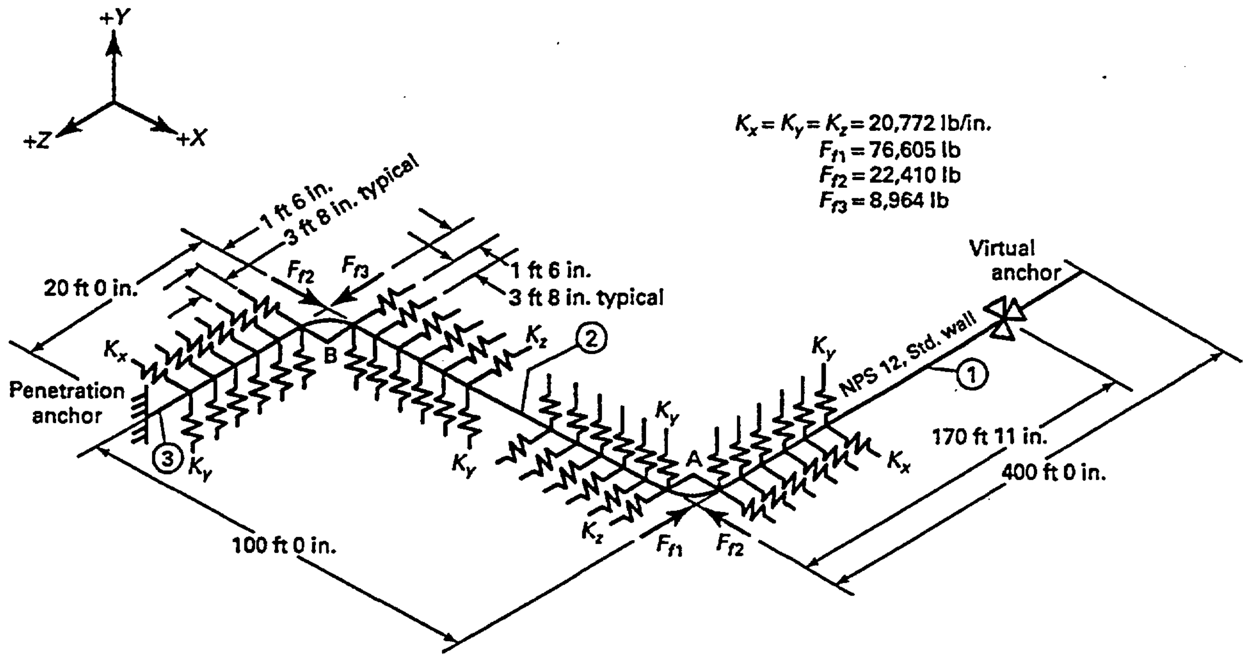


FIG. VII-6.4.4 COMPUTER MODEL OF EXAMPLE PIPE

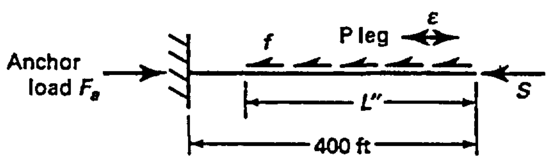


FIG. VII-6.6 EXAMPLE PLAN OF ELEMENT 1 AS A CATEGORY D ELEMENT

$$F_a = 172{,}357 + 21{,}760 = 194{,}117 \text{ lb}$$

If anchor loads must be limited, then the expansion joint should be located closer to the anchor in order to reduce the force due to friction at the pipe/soil interface.

VII-7.0 REFERENCES

[1] Goodling, E. C., "Buried Piping — An Analysis Procedure Update," ASME Publication PVP — Vol. 77, pp. 225–237, ASME Pressure Vessels and Piping Conference, Portland, June 1983

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[8] Trautmann, C. H., and O'Rourke, T. D., "Lateral Force-Displacement Response of Buried Pipes," Journal of Geotechnical Engineering, ASCE, Vol. 111, No. 9, September 1985, pp. 1077–1092

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[10] Goodling, E. C., "Restrained Underground Piping — Some Practical Aspects of Analysis and Design," Third U.S. Conference on Lifeline Earthquake Engineering, ASCE, Los Angeles, August 22–24, 1991

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NOTE:

(1) USAS B31.2-1968 was withdrawn as an American National Standard on February 18, 1988. ASME will continue to make available USAS B31.2-1968 as a historical document for a period of time.

ASME B31.1

INTERPRETATIONS VOL. 35

Replies to Technical Inquiries
January 1, 2000, Through June 30, 2000

It has been agreed to publish intepretations issued by the B31 Committee concerning B31.1 as part of the update service to the Code. The interpretations have been asssigned numbers in chronological order. Each interpretation applies either to the latest Edition or Addenda at the time of issuance of the interpretation or the Edition or Addenda stated in the reply. Subsequent revisions to the Code may have superseded the reply.

The replies are taken verbatim from the original letters, except for a few typographical and editorial corrections made for the purpose of improved clarity. In some instances, a review of the interpretation revealed a need for corrections of a technical nature. In these cases, a revised reply bearing the original interpretation number with the suffix R is presented. In the case where an interpretation is corrected by Errata, the original interpretation number with the suffix E is used.

ASME procedures provide for reconsideration of these interpretations when or if additional information is available which the inquirer believes might affect the interpretation. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. As stated in the Statement of Policy in the Code documents, ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

Interpretations Nos. 2 through 7 were included with the update service to the 1983 Edition and Interpretations Nos. 8 through 13 were included with the update service to the 1986 Edition. Interpretations Nos. 14 through 19 were included with the update service to the 1989 Edition. Interpretations Nos. 20 through 25 were included with the update service to the 1992 Edition. Interpretations Nos. 26 through 30 were included with the update service to the 1995 Edition. Interpretations Nos. 31 through 34 were included with the update service to the 1998 Edition. For the 2001 Edition, interpretations will be issued as necessary up to twice a year until the publication of the 2004 Edition.

B31.1

Interpretation: 35-1

Subject: B31.1, Welding of Butt Welded Fittings

Date Issued: April 24, 2000

File: B31-97-055

Question: Does ASME B31.1 prohibit butt welding fittings to be welded directly to fillet welding fittings (e.g., a butt welding elbow to a slip on flange) using fillet welds?

Reply: No, if neither fitting is modified to fabricate the assembly. However, if one or both of the fittings are modified, the fitting or fittings may no longer be considered to be standard fittings and shall be qualified in accordance with para. 104.7.2. The requirements of para. 104.8 shall be met considering the effect of any modifications

Interpretation: 35-2

Subject: B31.1, Para. 136.4.3(B), Magnetic Particle Examination

Date Issued: April 24, 2000

File: B31-99-015

Question: When using MT, what size of indication is considered relevant?

Reply: All MT indications that do not meet the acceptance criteria of para. 136.4.3(B) are considered relevant.

Interpretation: 35-3

Subject: B31.1, Para. 124, ASTM A 671, CC70 Class 22 Pipe Material Application

Date Issued: June 9, 2000

File: B31-99-036

Question: Does ASME B31.1 prohibit the use of ASTM A 671, CC70, Class 22, Specification for Electric-Fusion Welded Steel Pipe for Atmospheric and Lower Temperatures, for service at temperatures for which allowable stress values are listed in Appendix A?

Reply: No. Refer to para. 124.9.

ASME B31.1

INTERPRETATIONS VOL. 36

Replies to Technical Inquiries
July 1, 2000, Through December 31, 2000

It has been agreed to publish intepretations issued by the B31 Committee concerning B31.1 as part of the update service to the Code. The interpretations have been asssigned numbers in chronological order. Each interpretation applies either to the latest Edition or Addenda at the time of issuance of the interpretation or the Edition or Addenda stated in the reply. Subsequent revisions to the Code may have superseded the reply.

The replies are taken verbatim from the original letters, except for a few typographical and editorial corrections made for the purpose of improved clarity. In some instances, a review of the interpretation revealed a need for corrections of a technical nature. In these cases, a revised reply bearing the original interpretation number with the suffix R is presented. In the case where an interpretation is corrected by Errata, the original interpretation number with the suffix E is used.

ASME procedures provide for reconsideration of these interpretations when or if additional information is available which the inquirer believes might affect the interpretation. Further, persons aggrieved by an interpretation may appeal to the cognizant ASME committee or subcommittee. As stated in the Statement of Policy in the Code documents, ASME does not "approve," "certify," "rate," or "endorse" any item, construction, proprietary device, or activity.

Interpretations Nos. 2 through 7 were included with the update service to the 1983 Edition and Interpretations Nos. 8 through 13 were included with the update service to the 1986 Edition. Interpretations Nos. 14 through 19 were included with the update service to the 1989 Edition. Interpretations Nos. 20 through 25 were included with the update service to the 1992 Edition. Interpretations Nos. 26 through 30 were included with the update service to the 1995 Edition. Interpretations Nos. 31 through 34 were included with the update service to the 1998 Edition. For the 2001 Edition, interpretations will be issued as necessary up to twice a year until the publication of the 2004 Edition.

B31.1

Interpretation: 36-1

Subject: B31.1, Para. 104.3.1(E), Branch Connections

Date Issued: October 3, 2000

File: B31-99-014

Question (1): Per 1998 Edition of ASME B31.1, Power Piping, is Formula (3) or (3A) given in para. 104.1.2 to be used to determine t_{mh} when designing a branch connection for external pressure?

Reply (1): Neither; t_{mh} shall be determined in accordance with para. 104.1.3, provided D_{oh}, D_{ob}, and t_r if reinforcement is required, are reduced to compensate for external corrosion.

Question (2): Is t_{mh} then used in the formula in paragraph 104.3.1(E) to determine the required reinforcement area?

Reply (2): Yes.

Interpretation: 36-2

Subject: B31.1, Para. 102.3.1(C), Allowable Stresses

Date Issued: October 3, 2000

File: B31-99-016

Question: May the allowable stresses listed in Tables 1A and 1B of Section II, Part D of the ASME Boiler and Pressure Vessel Code, for usage by Section I of that Code, be used in B31.1 designs, provided that the material has been approved by B31.1?

Reply: No. B31.1 does not permit the use of Section II values.

B31.1 — Cases No. 27

A Case is the official method of handling a reply to an inquiry when study indicates that the Code wording needs clarification, or when the reply modifies the existing requirements of the Code, or grants permission to use new materials or alternative constructions.

ASME has agreed to publish Cases issued by the B31 Committee concerning B31.1 as part of the update service to B31.1. The text of proposed new and revised Cases and reaffirmations of current Cases appear in *Mechanical Engineering* for public review. A notice also appears in *Mechanical Engineering* when new and revised Cases are approved. New and revised Cases, as well as announcements of reaffirmed Cases and annulments, then appear in the next update. All Cases currently in effect at the time of publication of the 1989 Edition of the Code were included in the update that immediately followed, Interpretations No. 14 and Cases No. 9. As of the 1992 and later Editions, all Cases currently in effect at the time of publication of an Edition are included with it as an update.

This update, Cases No. 27, which is included after the last page of the 2001 Edition and the Interpretations No. 35 that follow, contains the following Cases.

145	153	163	165	173
146-1	162	164	170	

Cases 147, 151, 154, 159, 161, and 168, which were included in the first update to the 1998 Edition (Cases No. 25), were allowed to expire. Case 169, which was included in the second update (Cases No. 26), was also allowed to expire.

The page numbers for the Cases supplements included with updates to the 2001 Edition start with C-1 and will continue consecutively through the last update to this Edition. The Cases affected by this supplement are as follows:

Page	*Location*	*Change*
C-1	Case 145	(1) Reaffirmed: July 2000 (2) New expiration date: July 31, 2003
C-2, C-3	Case 146-1	(1) Reaffirmed: March 2001 (2) New expiration date: March 31, 2004
C-8, C-9	Case 163	(1) Reaffirmed: July 2000 (2) New expiration date: July 31, 2003
C-10	Case 164	(1) Reaffirmed: September 2000 (2) New expiration date: September 30, 2003
C-11	Case 165	(1) Reaffirmed: July 2001 (2) New expiration date: July 31, 2004
C-14	Case 173	Added

B31 CASE 145
Nickel–Molybdenum–Chromium Alloys (UNS N10276), ANSI/ASME B31.1 Construction

Approval Date: August 1985
Reaffirmation Date: July 2000

This case shall expire on July 31, 2003, unless previously annulled or reaffirmed

Inquiry: May nickel–molybdenum–chromium alloy (UNS N10276) fittings, rod, plate, and strip, seamless and welded pipe and tube conforming to ASTM B 366, B 574, B 575, B 619, B 622, and B 626 be used for ANSI/ASME B31.1 construction?

Reply: It is the opinion of the Committee that nickel–molybdenum–chromium alloy (UNS N10276) may be used in ANSI/ASME B31.1 construction provided:

(1) the maximum allowable stress values for the material shall be those given in Table I. For welded components, these values shall be multiplied by a factor of 0.85.

(2) welded fabrication shall conform to the applicable requirements of B31.1:

(a) Welding Procedure and Performance Qualifications shall be conducted in accordance with Section IX, ASME Boiler and Pressure Vessel Code.

(b) Welding shall be done by any welding process capable of meeting the requirements.

(c) All filler metal, including consumable insert material, shall comply with the requirements of Section IX.

(d) When welding repair of a defect is required, it shall be in accordance with ANSI/ASME B31.1, para. 127.4.11. When a defect is removed but welding repair is unnecessary, the surface shall be contoured to eliminate any sharp notches or corners. The contoured surface shall be reinspected by the same means originally used for locating the defect to assure it has been completely removed.

(e) Heat treatment after fabrication or forming is neither required nor prohibited.

(3) this Case number shall be identical in the Data Report.

TABLE I

For Metal Temperature Not Exceeding, °F	Maximum Allowable Stress, ksi[1]	Maximum Allowable Stress, ksi
100	25.0	25.0
200	25.0	25.0
300	25.0	23.0
400	24.3	21.2
500	23.9	20.0
600	23.5	18.8
650	23.3	18.3
700	23.1	17.8
750	22.9	17.4
800	22.8	17.1
850	22.6	16.8
900	22.3	16.6
950	22.1	16.5
1000	21.8	16.5

NOTE:
(1) Due to the relatively low yield strength of these materials, these higher stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed 67% but do not exceed 90% of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for the flanges of the gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

B31 CASE 146-1
Nickel–Chromium–Molybdenum–Columbium Alloy (UNS N06625) in ASME B31.1 Construction

Approval Date: March 1989
Reaffirmation Date: March 2001

This case shall expire on March 31, 2004, unless previously annulled or reaffirmed

Inquiry: May nickel–chromium–molybdenum–columbium alloy (UNS N06625) conforming to the specifications listed in Table I be used for construction of ASME B31.1 Power Piping systems?

Reply: It is the opinion of the Committee that nickel–chromium–molybdenum–columbium alloy (UNS N06625) conforming to the product specifications shown in Table I may be used in the construction of power piping complying with the rules of ASME B31.1 provided the following additionl requirements are met.

(1) THESE MATERIALS SHALL NOT BE USED FOR BOILER EXTERNAL PIPING. See para. 100.1.2(A).

(2) The allowable stress values shall be those listed in Table II.

(3) All longitudinal welds in any of the materials listed in Table I shall be completely examined by radiography. Radiographic examination shall be in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section VIII, latest edition, para. UW-51.

(4) The welding procedure qualification and performance qualifications shall be conducted in accordance with ASME Boiler and Pressure Vessel Code, Section IX. For qualifying welding procedures, the material is P-No. 43.

(5) Postweld heat treatment of this material is neither required nor prohibited. However, no postweld heat treatment shall be performed except by agreement between the owner and the manufacturer, installer, or erector. The temperature, time, and method of heat treatment shall be covered by the agreement.

(6) Longitudinally seam welded pipe, with or without filler metal added, is permitted. Longitudinally seam welded pipe shall be fabricated from plate meeting the requirements of ASTM B 443. All seam welded pipe shall comply with the following requirements.

(a) The welds shall be made by an electric arc process.

(b) The joints shall be full penetration double-welded or single-welded butt joints employing fusion welding processes as defined under para. 100.2 Definitions of ASME B31.1. Where backing rings or strips are used, the ring or strip material shall be of the same P-Number as the plate being joined. Backing rings or strips shall be completely removed after welding prior to radiography, and the exposed weld surface shall be examined visually for conformance to the requirement of the following paragraph. Welds made by procedures using backing rings which remain in place are prohibited.

(c) The weld surface on the outside diameter side of the pipe shall be flush with the base plate or shall have a reasonably uniform crown in accordance with Table 127.4.2 of ASME B31.1. The weld reinforcement on the inside diameter side of the pipe may be removed at the manufacturer's option or by agreement between the manufacturer and purchaser. The contour of the reinforcement shall be reasonably smooth and free of irregularities. The deposited metal shall be fused uniformly into the plate surface. No concavity of contour is permitted.

(d) Weld defects shall be repaired by removal to sound metal and rewelding. Subsequent heat treatment and inspection shall be as required on the original welds.

(e) When heat treatment is required, such heat treatment shall be done in accordance with para. 5, after all welding.

(f) The requirements of ASTM A 530 for welded pipe shall be met. Variations in wall thickness and length for longitudinally seam welded pipe with filler metal added shall be the same as required in ASTM A 530 for seamless or longitudinally seam welded pipe without filler metal.

TABLE I

Plate, Sheet, and Strip	B 443-84
Seamless Pipe and Tube	B 444-84
Rod and Bar	B 446-84
Forgings	B 564-86
Wrought Fittings	B 366-87

TABLE II
ALLOWABLE STRESS VALUES

Spec No.	Metal Temp. [Note (1)], °F, Not Exceeding	Allowable [Notes (2), (3)] Stress Values, ksi	Spec No.	Metal Temp. [Note (1)], °F, Not Exceeding	Allowable [Notes (2), (4)] Stress Values, ksi
B 443 Grade 1	300	27.5	B 443 Grade 2	100	25.0
B 444 Grade 1	400	26.8	B 444 Grade 2	200	24.6
B 446 Grade 1	500	26.1	B 446 Grade 2	300	24.0
B 564	600	25.4	B 366 (made	400	22.5
B 366 (made	700	25.0	with Grade	500	21.7
with Grade	800	24.6	2 material)	600	21.0
1 material)	900	24.0		700	20.7
	1000	23.7		800	20.1
	1100	23.4		900	19.8
	1150	21.0		1000	19.6
	1200	13.2		1100	19.3
				1150	19.3
				1200	19.3

NOTES:
(1) Alloy 625 suffers severe loss of impact strength after longtime aging in the temperature range 1000°F–1400°F.
(2) These stress values may be interpolated to determine values for intermediate temperatures.
(3) Allowable stresses are based on 110,000 psi tensile strength, the minimum strength for annealed material (Grade 1).
(4) Allowable stresses are based on 100,000 psi tensile strength, the minimum strength for solution annealed material (Grade 2).

B31 CASE 153
Use of Alloy UNS S31803 Material in ASME B31.1 Construction

Approval Date: November 1989
Reaffirmation Date: November 1998

This case shall expire on November 30, 2001, unless previously annulled or reaffirmed

TABLE 1
ASTM PRODUCT SPECIFICATIONS

Piping	A 790-87
Tubing	A 789-87
Forgings	A 182-87
Plate, Sheet, and Strip	A 240-87
Bars and Shapes	A 276-87
Wrought Piping Fittings	A 815-86

Inquiry: May solution annealed austenitic–ferritic stainless steel, 22Cr–5½Ni–3Mo alloy (UNS S31803), materials be used in ASME B31.1 construction?

Reply: The product specifications shown in Table 1 for solution annealed ferritic–austenitic steel, 22Cr–5½Ni–3Mo alloy, may be used in the construction of power piping complying with the rules of ASME B31.1, provided the following additional requirements are met.

(1) These materials shall not be used for Boiler External Piping. See para. 100.1.2(A).

(2) Material shall be furnished in the heat treated condition. The heat treatment shall be performed at 1870°F to 2010°F with subsequent quenching in water or rapid cooling by other means.

(3) The allowable stress values shall be as follows:

For Metal Temperature Not Exceeding, °F	Max. Allowable Stress Values, ksi
100	22.5
200	22.5
300	21.7
400	20.9
500	20.4
600	20.2

(4) All longitudinal weld joints shall be completely examined by radiography. Radiographic examination shall be in accordance with the requirements of the ASME Boiler and Pressure Vessel Code, Section VIII, latest Edition, UW-51.

(5) The Welding Procedure Qualification and Performance Qualifications shall be conducted in accordance with Section IX. For qualifying welding procedures, the material shall be considered as P-No. 10H Gr. No. 1 of QW-422.

(6) Heat treatment after forming or fabrication is neither required nor prohibited [except as noted in para. (7)(e)], but any heat treatment applied shall be performed at 1870°F to 2010°F, followed by a rapid cool.

(7) Plate may be made into longitudinally welded pipe with filler metal added. Requirements of A 790 shall be met with the following modifications.

(a) The welds shall be made by an electric arc process involving the deposition of filler metal.

(b) The joints shall be full penetration double-welded or single-welded butt joints employing fusion welding processes, as defined under "Definitions," ASME Boiler and Pressure Vessel Code, Section IX. Where backing rings or strips are employed, the ring or strip material shall be of the same P-Number (QW-422 of Section IX) as the plate being joined. Backing rings or strips shall be completely removed after welding, prior to any required radiography, and the exposed weld surface shall be examined visually for conformance to the requirements of the following paragraph. Welds made by procedures employing backing rings which remain in place are prohibited.

(c) The weld surface on the O.D. side of the pipe shall be flush with the base plate or shall have a reasonably uniform crown in accordance with Table 127.4.2 in the Code. The weld surface on the I.D. side of the reinforcement may be removed at the manufacturer's option or by agreement between the manufacturer and purchaser. The contour of the reinforcement shall be reasonably smooth and free of irregularities. The deposited metal shall be fused uniformly into the plate surface. No concavity of contour is permitted unless the resulting thickness of the weld metal is equal to or greater than the minimum thickness of the adjacent base metal.

(d) Weld defects shall be repaired by removal to sound metal and rewelding. Subsequent heat treatment and inspection shall be as required on the original welds.

(e) All welding shall be done prior to heat treatment. After welding, solution heat treatment shall be in accordance with para. 2.

(8) CAUTIONARY NOTE: This Case allows the use of this material only for the temperature range given in para. (3). This material may be expected to exhibit embrittlement at room temperature after service above 600°F.

B31 CASE 162
Use of 21Cr–11Ni–N Alloy (S30815) for ASME B31.1 Construction

Approval Date: September 1992
Reaffirmation Date: September 1998

This case shall expire on September 30, 2001, unless previously annulled or reaffirmed

Inquiry: May solution annealed 21Cr–11Ni–N Alloy (S30815) seamless tubes and pipes, welded tubes and pipes, plate, sheet, strip, forging, and bar, conforming to the specifications of A 213, A 312, A 249, A 358, A 409, A 240, A 182 and A 479 be used in ASME B31.1 construction?

Reply: It is the opinion of the Committee that solution annealed 21Cr–11Ni–N Alloy (UNS S30815) seamless tubes and pipes, welded tubes and pipes, plate, sheet, strip, forging, and bar as described in the Inquiry may be used in ASME B31.1 construction provided:

(a) the material meets the chemical analysis and minimum tensile requirements detailed in the specification and noted here in Tables 1 and 2, respectively; otherwise conforming to all other requirements of the respective ASTM material specification;

(b) the maximum allowable design stress values shall be as given in Table 3, except that for welded tube and pipe, a joint efficiency factor, E_j, of 0.85 shall be used;

(c) welding shall be performed using any welding process or combination of processes capable of meeting the requirements of Section IX for P-No. 8, Group No. 2 materials. If postweld heat treatment is performed, the material shall be heated to 1560–1740°F for 10–15 minutes, followed by cooling in air.

TABLE 1
CHEMICAL REQUIREMENTS

Element	Percent
Carbon	0.05–0.10
Manganese, max	0.80
Phosphorus, max	0.40
Sulphur, max	0.030
Silicon	1.40–2.00
Nickel	10.0–12.0
Chromium	20.0–22.0
Nitrogen	0.14–0.20
Cerium	0.03–0.08
(Balance Iron)	

TABLE 2
MECHANICAL PROPERTY REQUIREMENTS

Tensile strength, min, ksi	87
Yield strength, 0.2% offset min, ksi	45
Elongated in 2 in. min, %	40

(d) heat treatment after forming is neither required nor prohibited. If heat treatment is used, the solution treatment shall consist of heating to a temperature of 1920°F to 2100°F and quenching in water or rapidly cooling by other means.

(e) this Case number shall be referenced in the documentation and marking of the material and recorded on the Manufacturer's Data Report.

TABLE 3

For Metal Temperature Not Exceeding, °F	Max. Allowable Stress Values, ksi		For Metal Temperature Not Exceeding, °F	Max. Allowable Stress Values, ksi	
	...	Note (1)		...	Note (1)
100	21.8	21.8	1050	11.6	11.6
200	21.6	21.6	1100	9.0	9.0
300	20.4	20.4	1150	6.9	6.9
400	19.6	19.6	1200	5.2	5.2
500	18.4	19.1	1250	4.0	4.0
600	17.7	18.7	1300	3.1	3.1
650	17.5	18.6	1350	2.4	2.4
700	17.3	18.4	1400	1.9	1.9
750	17.1	18.2	1450	1.6	1.6
800	16.8	18.0	1500	1.3	1.3
850	16.6	17.8	1550	1.0	1.0
900	16.3	17.5	1600	0.86	0.86
950	16.1	17.2	1650	0.71	0.71
1000	14.9	14.9			

NOTE:
(1) Due to the relatively low yield strength of these materials, these higher stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed 67%, but do not exceed 90% of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

B31 CASE 163
Use of Ni–Cr–Co–Mo Alloy (UNS N06617) for ASME B31.1 Construction

Approval Date: July 1994
Reaffirmation Date: July 2000

This case shall expire on July 31, 2003, unless previously annulled or reaffirmed

Inquiry: May solution annealed Ni–Cr–Co–Mo alloy (UNS N06617) wrought plate, sheet, rod, bar, forgings, welded pipe, and seamless tube that meet the chemical composition requirements given in Table 1, the mechanical property requirements given in Table 2, and that further meet all other applicable requirements of the specifications listed in Table 3 be used in ASME B31.1, welded construction at temperatures up to and including 1500°F?

Reply: It is the opinion of the Committee that solution annealed Ni–Cr–Co–Mo alloy (UNS N06617) as described in the Inquiry may be used for construction, provided that all applicable requirements of ASME B31.1 and the following additional requirements are met.

(a) This material shall not be used for boiler external piping. See para. 100.1.2(A).

(b) Material shall be solution annealed at a temperature of 2100°F–2250°F and quenched in water or rapidly cooled by other means.

(c) The maximum allowable stress values for the material shall be those given in Table 4. For welded components, these values shall be multiplied by a factor of 0.85, except when 100% radiography is performed as noted in para. 136.4.5.

(d) Separate welding procedures and performance qualifications shall be required for this material. The welding procedure qualifications and performance qualification shall be conducted as prescribed in Section IX of the ASME Boiler and Pressure Vessel Code.

(e) Heat treatment after forming or fabrication is neither required nor prohibited. When heat treatment is performed, it shall be in accordance with (b) above.

(f) For external pressure design, refer to para. 104.1.3.

(g) For para. 104.1.2, which requires a temperature dependent parameter *y*, the *y* values are the same as nickel alloys listed in Table 104.1.2(A) and shall be as follows:

1150°F and below	$y = 0.4$
1200°F	$y = 0.5$
1250°F and above	$y = 0.7$

TABLE 1
CHEMICAL REQUIREMENTS

Element	Percent
Carbon	0.05–0.15
Manganese, max.	1.0
Silicon, max.	1.0
Sulfur, max.	0.015
Iron, max.	3.0
Chromium	20.00–24.00
Cobalt	10.0–15.0
Molybdenum	8.0–10.0
Aluminum	0.8–1.5
Titanium, max.	0.6
Copper, max.	0.5
Boron, max.	0.006
Nickel, min.	44.5

TABLE 2
MECHANICAL PROPERTY REQUIREMENTS

Tensile strength, min., ksi	95
Yield strength, min., ksi	35
Elongation in 2 in. or 4 diameters, min., %	35

TABLE 3
PRODUCT SPECIFICATIONS

Rod and bar	B 166
Plate, sheet, and strip	B 168
Tube	B 444
Forgings	B 564
Welded pipe	B 546

(h) Pressure parts machined from bar shall be restricted to NPS 4 or smaller. Hubbed flanges, elbows, return bends, tees, and header tees shall not be machined directly from bar stock.

TABLE 4

For Metal Temperature Not Exceeding, °F	Maximum Allowable Stress, ksi	Maximum Allowable Stress, ksi [Note (1)]
100	23.3	23.3
200	20.5	23.3
300	19.1	23.3
400	18.1	23.3
500	17.3	23.3
600	16.7	22.5
700	16.2	21.9
800	15.9	21.5
900	15.7	21.1
1000	15.5	20.9
1100	15.4	20.7
1150	15.4	20.7
1200	15.3	16.9
1250	13.0	13.0
1300	10.0	10.0
1350	7.7	7.7
1400	6.0	6.0
1450	4.6	4.6
1500	3.6	3.6

NOTE:

(1) Due to the relatively low yield strength of this material, these higher stress values were established at temperatures where the short time tensile properties govern to permit the use of these alloys where slightly greater deformation is acceptable. These higher stress values exceed 67%, but do not exceed 90% of the yield strength at temperature. Use of these stresses may result in dimensional changes due to permanent strain. These stress values are not recommended for flanges of gasketed joints or other applications where slight amounts of distortion can cause leakage or malfunction.

B31 CASE 164
Use of Micro-Alloyed Carbon Steel Bar in ASME B31.1 Construction

Approval Date: September 1994
Reaffirmation Date: September 2000

This case shall expire on September 30, 2003, unless previously annulled or reaffirmed

Inquiry: May micro-alloyed carbon steel bar with additions of aluminum, vanadium, and nitrogen, a chemical composition as specified in Table 1, material properties as specified in Table 2, and otherwise conforming to the requirements of ASTM A 675 be used for ASME B31.1 construction?

Reply: It is the opinion of the Committee that the hot rolled bar material described in this Case may be used in welded and unwelded construction under the rules of ASME B31.1 provided the following additional requirements are met.

(a) The allowable stress values tabulated in Table 3 shall not be exceeded. The material shall not be used for design temperatures above or below those for which the allowable stress values are given in this Code Case.

(b) The material shall be limited to service application NPS 2 and smaller and supplied for manufacturer as round bar not exceeding 4 in. diameter.

(c) Separate welding procedures and performance qualifications shall be required for this material. The welding process shall be GTAW. The welding procedure qualification and performance qualification shall be conducted in accordance with the ASME Boiler and Pressure Vessel Code, Section IX.

(d) The material shall not be used for Boiler External Piping.

(e) The material described in this Inquiry is one of the highest tensile strength materials approved for use in ASME pressure component applications. The ASME materials data base has little fatigue data on these high strength materials. When calculating the allowable expansion stress range S_A using Eq. (1) in para. 102.3.2(C), the allowable stresses for A 106 Grade B shall be used. Further, fittings manufactured using this material shall be fatigue tested to assure comparable behavior with ASME materials to be used in installed assemblies.

(f) All applicable requirements of ASME B31.1 shall be met.

TABLE 1
CHEMICAL COMPOSITION
(Heat or Cast Analysis)

Element	Percent Weight
Carbon	0.19–0.26
Manganese	1.35–1.65
Phosphorus	0.040 max.
Sulfur	0.050 max.
Silicon	0.15–0.35
Vanadium	0.02–0.20
Aluminum	0.015–0.050
Nitrogen	0.03 max.

GENERAL NOTE: Addition of elements intended to enhance machinability, such as lead, selenium, bismuth and tellurium, is not allowed.

TABLE 2
MINIMUM MECHANICAL PROPERTIES

Property	Value
Tensile Strength	110 ksi
Yield Strength (0.2% offset)	80 ksi min.
Elongation (in 2 in.)	15% min.

TABLE 3
ALLOWABLE STRESS VALUES

For Metal Temperature Not Exceeding, °F	Maximum Stress Value, ksi
−20 to 650	23.8

GENERAL NOTE: The allowable stress value is based on a tensile strength value of 95 ksi.

B31 CASE 165
Use of Alloy S32550 (25.5Cr–5.5Ni–3.5Mo–Cu), P-No. 10H in ASME B31.1 Construction

Approval Date: July 1995
Reaffirmation Date: July 2001

This Case shall expire on July 31, 2004, unless previously annulled or reaffirmed

Inquiry: May Alloy S32550 (25.5Cr–5.5Ni–3.5Mo–Cu), P-No. 10H, be used in power piping applications constructed in accordance with the B31.1 Code at temperatures up to and including 500°F?

Reply: Alloy S32550 may be used for ASME B31.1 construction to the specifications noted in this Code Case provided that all of the following requirements are met.

(a) THESE MATERIALS ARE NOT ACCEPTABLE FOR USE ON BOILER EXTERNAL PIPING — SEE PARA. 100.1.2.

(b) All applicable requirements of ASME B31.1 shall be met.

(c) Allowable stress values shown in Table 1 shall not be exceeded. These materials shall not be used at temperatures above those for which allowable stress values are given in this Code Case.

(d) All openings 4 in. and larger shall conform to para. 127.4.8 except that full penetration welds shall be used and separate reinforcing pads shall not be used.

(e) Butt weld joints shall be examined radiographically for their full length as prescribed in para. 136.4.5 when the wall thickness at the weld joint exceeds $1\frac{1}{2}$ in.

(f) Branch connection welds shall be radiographically (para. 136.4.5) or U.T. (para. 136.4.6) examined. See Table 136.4 when the size of the branch exceeds NPS 4.

(g) All welds where material thickness exceeds $\frac{3}{4}$ in. shall be examined by the liquid penetrant method.

(h) Pipe under external pressure shall meet requirements of para. 104.1.3.

(i) Heat treatment of product form is neither required nor prohibited but if performed shall be done in accordance with respective product specifications. See Table 132.

(j) Charpy impact testing shall be done in accordance with requirements of UHA-51(c)(2) when material wall thickness is greater than $\frac{3}{8}$ in.

TABLE 1

Spec. No.	Notes	Specified Minimum Tensile, ksi	Maximum Allowable Stress Values in Tension, ksi, for Metal Temperature up to and Including 500°F. [Note (1)]				
			-20 to 100	200	300	400	500
Seamless Pipe and Tube							
A789	...	110	27.5	27.4	25.7	24.7	24.7
A790	...	110	27.5	27.4	25.7	24.7	24.7
Welded Pipe and Tube							
A789	(2)	110	23.4	23.3	21.9	21.0	21.0
A790	(2)	110	23.4	23.3	21.9	21.0	21.0
Plate							
A240	...	110	27.5	27.4	25.7	24.7	24.7
Bar							
A479	...	110	27.5	27.4	25.7	24.7	24.7

NOTES:
(1) This steel may be expected to develop embrittlement after exposure to temperatures above 500°F for prolonged times. See ASME Boiler and Pressure Vessel Code, Section VIII, Division 1, UHA-109.
(2) A factor of 0.85 has been applied in arriving at the maximum allowable stress values in tension for this material. Divide tabulated values by 0.85 for maximum allowable longitudinal tensile stress.

B31 CASE 170
PWHT Exemptions for P-Nos. 4 and 5A Materials for ASME B31.1 Construction

Approval Date: March 1999

This Case shall expire on March 31, 2002, unless previously annulled or reaffirmed

Inquiry: What additional exemption to postweld heat treatment may be taken for P-Nos. 4 and 5A materials used for ASME B31.1 construction?

Reply: An additional exemption may be taken for nominal pipe sizes greater than NPS 4. All other rules for exemption in Table 132 for P-Nos. 4 and 5A shall remain in effect. .

If this Case is used on boiler external piping, the Case number shall be identified in the Manufacturer's Data Report Form.

B31 CASE 173
Alternative Maximum Allowable Stresses Based on a Factor of Safety of 3.5 on Tensile Strength for ASME B31.1 Construction

Approval Date: May 2001

This Case shall expire on May 31, 2004, unless previously annulled or reaffirmed

Inquiry: New maximum allowable stresses based on a factor of 3.5 on tensile strength and the other existing B31.1 criteria for establishing maximum allowable stresses are under development for incorporation into the B31.1 Code. Until the development and incorporation of new maximum allowable stresses into B31.1 are completed, may alternative allowable stresses be used?

Reply: It is the opinion of the committee that allowable stresses other than those listed in B31.1, Appendix A may be used for B31.1 construction provided the following requirements are met.

(a) The materials shall be limited to ASTM materials listed in Table 126.1 that have a corresponding ASME material, as allowed by B31.1, para. 123.1 (D).

(b) Boiler external piping shall use maximum allowable stress values provided in ASME BPVC, Section II, Part D, 1999 Addenda, Tables 1A and 1B, as permitted for Section I design. Only ASME materials shall be used.

(c) Nonboiler external piping shall use maximum allowable stress values provided in either ASME BPVC, Section II, Part D, 1999 Addenda, Tables 1A and 1B as permitted for Section I design, or ASME BPVC, Section II, Part D, 1999 Addenda, Tables 1A and 1B as permitted for Section VIII, Division 1 design.

(d) For materials with a minimum tensile strength of over 70 ksi, the allowable expansion stress range S_A shall be calculated using allowable stresses for A 106 Grade B in Eq. (1) of para. 102.3.2(C) and Eq. (13) of para. 104.8.3.

(e) This Case number and the materials for which it applies shall be shown on the Manufacturer's Data Report (if applicable).