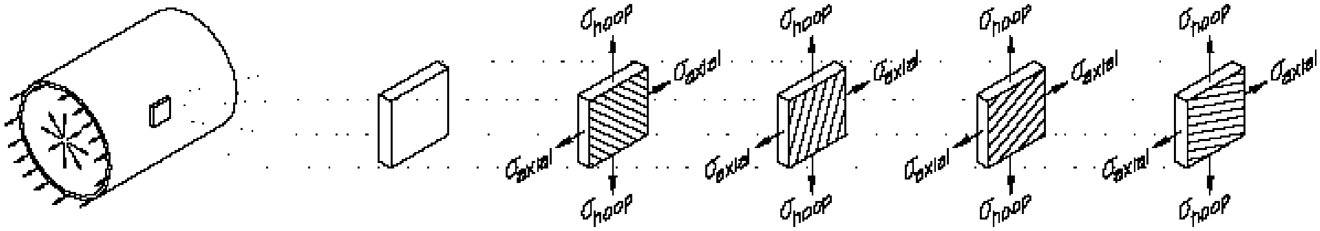
ENGINEERED COMPOSITE PIPING SYSTEMS

The FIBERBOND® Engineering Guide



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What is FRP?

FRP was originally an abbreviation for Fiberglass Reinforced Plastic. As additional fiber reinforcements were introduced, the term has been expanded to refer to Fiber Reinforced Plastic. You may also hear of terms such as GRP (glass reinforced plastic), RTP (reinforced thermosetting plastic) and RTRP (reinforced thermosetting resin pipe). Even more specific, there is GRE (glass reinforced epoxy), GRVE (glass reinforced vinyl ester) and GRUP (glass reinforced unsaturated polyester). The list of terms seems to go on and on.

What these terms do have in common is that they refer to a reinforced plastic with a thermosetting resin as the matrix. Unlike thermoplastics (such as PVC, CPVC, PE, etc.), thermosetting resins are infusible and insoluble when fully cured and thus provide better mechanical properties. Combined with the reinforcing fibers, FRP has an excellent strength-to-weight ratio while maintaining very good corrosion resistance to a wide range of media.

INTRODUCTION

FIBERBOND® Engineered Composite Piping Systems are economical choices for use in corrosive fluid transport. The FIBERBOND® product is an alternative to stainless steels, copper-nickel, and other reinforced and non-reinforced plastics and alloys. FIBERBOND® can be used in environments at temperatures up to 250°F (121°C) and pressures up to 290psig (20barg). The information contained in this Engineering Guide is the first step towards designing the optimum FIBERBOND® Piping System.

FIBERBOND® FRP Piping Systems

All FIBERBOND® Piping Series use a glass-fiber reinforcement bound in a resin matrix. Together, the glass-fibers provide strength and, the resin matrix provides superior corrosion resistance. FIBERBOND® Engineered Composite Piping Series are filament wound products with a winding angle of 54°. This is the principal axis of loading for internal pressure. **FIBERBOND® Series 20HV, 20FR-E, 20JF, 20C, 20FR20, 20FR16, and 110FW** all utilize this winding pattern.

Using the FIBERBOND® Engineering Guide

The purpose of "The FIBERBOND® Engineering Guide" is to help the customer select the proper support spacing, guide spacing, and anchoring for an above ground piping system. Other methods to deal with the flexibility of the system, such as expansion loops, are also evaluated. In addition, "The FIBERBOND® Engineering Guide" will also allow the customer to approximate head losses and water hammer in a FIBERBOND® Piping System.

Future Pipe Industries is committed to supporting its customers. An engineering staff is on hand to answer all your questions or design the system with the customer.

FIBERBOND® Custom Piping Systems

In addition to the FIBERBOND® Engineered Composite Piping Series, Future Pipe Industrieso offers a custom line of piping systems. FIBERBOND® custom products are pipe systems engineered by Future Pipe Industries to meet individual customer specifications. By customizing the system, an optimum pipe product is produced saving the customer time and material. The custom products offered in the FIBERBOND® line are engineered, manufactured, fabricated, and installed by Future Pipe Industries.

Statement of Policy

Standards are a recognized customer need and progress has been made in developing reliable standards for composite pipe. However, one of the major benefits of FIBERBOND® Engineered Composite Piping Systems manufactured by Future Pipe Industries is the ability to engineer the mechanical and physical properties to meet individual customer service requirements. Under certain conditions, industry standards, which are misunderstood and/or misapplied, become a hindrance to the development of new and improved products. It is important that the engineer working with composite pipe is aware of the limits of currently available industry standards and learns how the product is designed and manufactured. We feel it is important that the engineer designing a FIBERBOND® Piping System has a working knowledge of how the raw materials interact to provide the chemical resistance and the mechanical properties of the pipe. Once the engineer understands these basic principles, he or she can truly appreciate the flexibility FIBERBOND® Piping Systems offer in solving difficult corrosion piping problems at the lowest possible cost. The information in the FIBERBOND® Engineering Guide covers the design of Series 20HV, 20FR-E, 20JF, 20FR16, 20FR20, 20JF16 and 110FW. It is our mutual interest that the FIBERBOND® Piping System selected meets the customer's design criteria and is installed at the most economical cost within the guidelines set forth by this engineering guide and other industry standards. The success of your installation is important to our company…after all, our future depends on it.

SUPPORTING FIBERBOND® PIPING SYSTEMS

Supports are designed into a piping system to prevent excessive deflection due to the pipe and fluid weight. When the mid-span deflection is limited to 0.5 in., the bending stress on the pipeline is normally below the allowable levels of the pipe and fittings. However, in designs that are more stringent it may be necessary to use shorter spacing. This can be true if there are a number of heavy in-line components, such as valves, in the system, or if the design pressure and/or temperature are near the product limits. Once support spacing is calculated, the maximum stress levels should be determined. Support conditions are defined as Type I, II, III, or IV. The standard commonly used is the Type II condition in which the pipe spans two or more supports. The Types I, III, and IV conditions refer to single-span, triple-span, and fixed-ends, respectively. For very short runs and anchor locations, these conditions should be considered. Refer to the Support Types diagram for the Types I, II, III, and IV support conditions.

Above 150°F, the support spacing may have to be degraded per the Temperature Correction Factors Table to account for the lower modulus values.

Table 1 Temperature Correction Factors

Temperature	20HV, 20HV-D, 20HV(FDA)	20FR-E, 20JF, 20JF16, 20FR16, 20FR20	110FW
Ambient	1.00	1.00	1.00
150F (65c)	1.00	1.00	1.00
175F (79c)	0.93	0.96	0.99
200F (93c)	N/R	0.92	0.99
225F (107c)		N/R	0.98
250F (121c)			0.97

Correction factors are equivalent to 3.5% per 10°F rise above 150°F for 20HV, and 20HV-D, 1.5% per 10°F for 20FR-E, 20FR-16, 20FR20, and 20JF, and 0.25% per 10°F for 110FW.

Figure 1 Support Type Loading Conditions

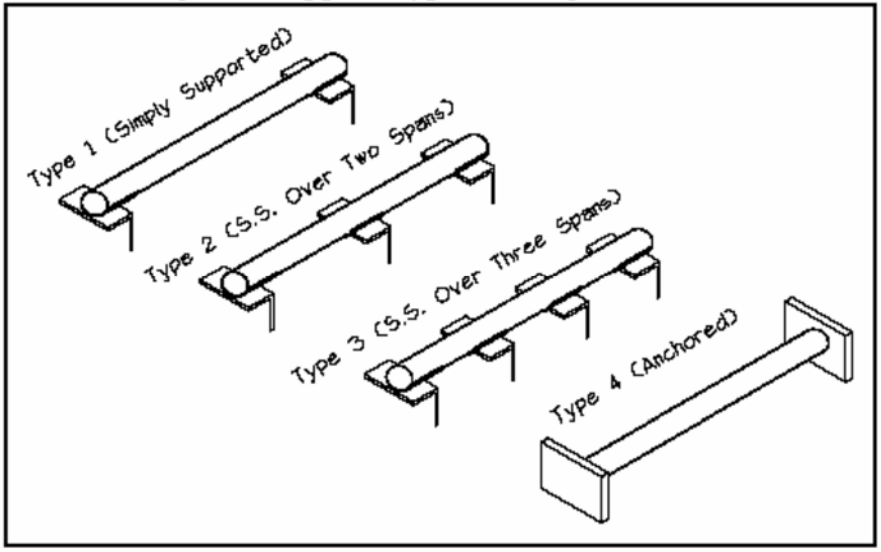


Table 2 Recommended Support Spacing (feet and meters)*

Size	20HV 20FR-E	20JF	110FW	20FR16	20FR20	20C
2in.	9.8 - 12.8 (3.0 - 3.9)	7.8 - 11.8 (2.3 - 3.6)	8.1 - 11.7 (2.5 - 3.6)	9.8 - 12.8 (3.0 - 3.9)	9.8 - 12.8 (3.0 - 3.9)	9.8 - 12.2 (3.0 - 3.7)
3in.	10.6 - 14.5 (3.2 - 4.4)	8.9 - 13.6 (2.7 - 4.1)	8.6 - 13.1 (2.6 - 4.0)	10.6 - 14.5 (3.2 - 4.4)	10.6 - 14.5 (3.2 - 4.4)	10.6 - 13.8 (3.2 - 4.2)
4in.	11.1 - 15.8 (3.4 - 4.8)	9.6 - 15.0 (2.9 - 4.6)	8.9 - 14.2 (2.7 - 4.3)	11.1 - 15.8 (3.4 - 4.8)	11.1 - 15.8 (3.4 - 4.8)	11.1 - 15.0 (3.4 - 4.6)
6in.	12.9 - 18.8 (3.9 - 5.7)	11.6 - 18.1 (3.5 - 5.5)	11.0 - 17.3 (3.3 - 5.3)	11.7 - 17.8 (3.5 - 5.4)	12.7 - 18.6 (3.8 - 5.7)	11.7 - 16.9 (3.5 - 5.1)
8in.	14.5 - 21.3 (4.4 - 6.5)	13.3 - 20.7 (4.0 - 6.3)	12.7 - 20.0 (3.8 - 6.1)	13.5 - 20.5 (4.1 - 6.3)	14.7 - 21.5 (4.5 - 6.6)	13.4 - 19.3 (4.0 - 5.9)
10in.	15.8 - 23.5 (4.8 - 7.2)	14.8 - 23.0 (4.5 - 7.0)	14.2 - 22.3 (4.3 - 6.8)	15.1 - 22.9 (4.6 - 7.0)	16.5 - 24.1 (5.0 - 7.3)	13.6 - 20.6 (4.1 - 6.3)
12in.	17.1 - 25.6 (5.2 - 7.8)	16.2 - 25.1 (4.9 - 7.6)	15.6 - 24.4 (4.7 - 7.4)	16.5 - 25.1 (5.0 - 7.6)	18.2 - 26.5 (5.5 - 8.1)	15.1 - 22.6 (4.6 - 6.9)
14in.	16.4 - 26.0 (5.0 - 7.9)		16.9 - 26.5 (5.1 - 8.1)	18.0 - 27.3 (5.4 - 8.3)	18.8 - 28.0 (5.7 - 8.5)	16.4 - 24.6 (5.0 - 7.5)
16in.	17.6 - 27.8 (5.3 - 8.5)		18.0 - 28.3 (5.5 - 8.6)	19.2 - 29.2 (5.8 - 8.9)	20.1 - 29.9 (6.1 - 9.0)	17.6 - 26.4 (5.3 - 8.0)
18in.	18.7 - 29.6 (5.7 - 9.0)		19.1 - 30.0 (5.8 - 9.0)	20.3 - 30.0 (6.2 - 9.0)	21.4 - 30.0 (6.5 - 9.0)	18.7 - 28.0 (5.7 - 8.5)
20in.	19.8 - 30.0 (6.0 - 9.0)		20.2 - 30.0 (6.1 - 9.0)	21.4 - 30.0 (6.5 - 9.0)		19.8 - 29.6 (6.0 - 9.0)
24in.	21.7 - 30.0 (6.6 - 9.0)		22.1 - 30.0 (6.7 - 9.0)	23.5 - 30.0 (7.1 - 9.0)		21.7 - 30.0 (6.6 - 9.0)
30in.	20.3 - 30.0 (6.2 - 9.0)		20.8 - 30.0 (6.3 - 9.0)	21.7 - 30.0 (6.6 - 9.0)		20.3 - 30.0 (6.2 - 9.0)
36in.	22.3 - 30.0 (6.8 - 9.0)		22.8 - 30.0 (6.9 - 9.0)	23.8 - 30.0 (7.2 - 9.0)		22.3 - 30.0 (6.8 - 9.0)
42in.	17.4 - 30.0 (5.3 - 9.0)		18.0 - 30.0 (5.4 - 9.0)	21.3 - 30.0 (6.5 - 9.0)		17.4 - 30.0 (5.3 - 9.0)
48in.	18.6 - 30.0 (5.6 - 9.1)		19.2 - 30.0 (5.8 - 9.0)	22.8 - 30.0 (6.9 - 9.0)		18.6 - 30.0 (5.6 - 9.0)

*Table is based on Eq.1 and Eq.2 in appendix II. Valid for water and seawater (s.g. = 1.0 to 1.03). The max-recommended support spacing is 30ft (9m). Spans are based on a maximum deflection of 0.50in (12.5mm) and a maximum bending stress that varies from 500psi (3.4MPa) to 1,500psi (10.3MPa). The smaller value is for piping sections with heavy in-line components or very short runs of piping. The higher value is for long straight runs of piping. e.g., for 10" 20FR-E pipe, spans up to 15.8ft (4.8m) should be used for short runs of piping or piping with valves and spans up to 23.5ft (7.2m) can be used for long straight runs of piping.

CALCULATING EXPANSION

Thermal Expansion

The length change for any aboveground piping system must be calculated. The thermal expansion of contact molded and filament wound fiberglass pipe in the axial direction is generally two to five times greater than that of some steels, thus making it important to adequately design for these length changes. The thermal expansion of fiberglass pipe is a function of the expansion coefficient, temperature change, and the total length of the piping system. Thermal expansion coefficients of FRP are generally constant over their designed temperature use, thus making thermal expansion linear.

Pressure Expansion

Although generally neglected, axial expansion due to internal pressure can sometimes be in equal magnitude to thermal expansion due to the low modulus values of fiberglass pipe. The result is a significant pressure expansion, which must be taken into account to achieve accurate results. Throughout the rest of this design guide, *Future Pipe Industries recommends that both thermal and pressure expansion be included in the design calculations when justified. Thus, the Anchor Loads tables, Guide Spacing tables, etc., provide data according to temperature change and total expansion***.** Future Pipe Industries feels that a better design will result from this approach.

Table 3 Thermal Expansion*

ΔT (deg F)	Expansion (in./100ft)
5	0.06
10	0.12
15	0.18
20	0.24
25	0.30
30	0.36
35	0.42
40	0.48
45	0.54
50	0.60
55	0.66
60	0.72
65	0.78
70	0.84
75	0.90
80	0.96
85	1.02
90	1.08
95	1.14
100	1.20

ΔT (deg F)	Expansion (in./100ft)
105	1.26
110	1.32
115	1.38
120	1.44
125	1.50
130	1.56
135	1.62
140	1.68
145	1.74
150	1.80
155	1.86
160	1.92
165	1.98
170	2.04
175	2.10
180	2.16
185	2.22
190	2.28
195	2.34
200	2.40

ΔT (deg C)	Expansion (mm/m)
5	0.09
10	0.18
15	0.27
20	0.36
25	0.45
30	0.54
35	0.63
40	0.72
45	0.81
50	0.90
55	0.99
60	1.08
65	1.17
70	1.26
75	1.35
80	1.44
85	1.53
90	1.62
95	1.71
100	1.80

*Table is based on Eq 2 in appendix II

Table 4 Pressure Expansion (in/100ft and mm/m) @ 50psig (3.4barg)*

Size	**20HV 20FR-E**	**20JF**	**110FW**	**20FR16**	**20FR20**	**20C**
2in.	0.023 (0.019)	0.015 (0.012)	0.038 (0.032)	0.023 (0.019)	0.023 (0.019)	0.029 (0.024)
3in.	0.033 (0.027)	0.020 (0.017)	0.054 (0.045)	0.033 (0.027)	0.033 (0.027)	0.040 (0.034)
4in.	0.042 (0.035)	0.025 (0.021)	0.069 (0.057)	0.042 (0.035)	0.042 (0.035)	0.052 (0.043)
6in.	0.049 (0.040)	0.031 (0.026)	0.070 (0.058)	0.061 (0.050)	0.051 (0.042)	0.075 (0.063)
8in.	0.053 (0.044)	0.036 (0.030)	0.071 (0.059)	0.062 (0.051)	0.051 (0.042)	0.078 (0.065)
10in.	0.056 (0.047)	0.040 (0.033)	0.071 (0.059)	0.062 (0.052)	0.051 (0.043)	0.096 (0.080)
12in.	0.058 (0.048)	0.043 (0.036)	0.071 (0.060)	0.063 (0.052)	0.050 (0.042)	0.095 (0.079)
14in.	0.078 (0.065)		0.073 (0.061)	0.063 (0.053)	0.057 (0.048)	0.096 (0.080)
16in.	0.077 (0.064)		0.073 (0.061)	0.063 (0.053)	0.057 (0.048)	0.095 (0.080)
18in.	0.077 (0.064)		0.073 (0.061)	0.064 (0.053)	0.057 (0.047)	0.095 (0.079)
20in.	0.076 (0.063)		0.073 (0.061)	0.064 (0.053)		0.094 (0.079)
24in.	0.076 (0.063)		0.073 (0.061)	0.063 (0.053)		0.094 (0.078)
30in.	0.112 (0.093)		0.106 (0.089)	0.097 (0.081)		0.138 (0.115)
36in.	0.111 (0.092)		0.106 (0.089)	0.097 (0.081)		0.137 (0.114)
42in.	0.221 (0.184)		0.205 (0.171)	0.144 (0.120)		0.274 (0.229)
48in.	0.220 (0.183)		0.206 (0.172)	0.144 (0.120)		0.272 (0.227)

*Table is based on Eq.4 in appendix II with P = 50psig. For design conditions, multiply the value in this table by (P/50) if P is in psig or (P/3.4) if P is in bar.

CONTROLLING EXPANSION

Anchor Loads

One advantage in the design of fiberglass piping systems is the low modulus values. In general, fiberglass pipe tensile modulus values are 1/15th to 1/30th that of steel. One immediate benefit of this mechanical property is the small end loads created from temperature and pressure effects, allowing lighter anchors. For anchor-to-anchor conditions, it is normally not necessary to include pressure expansion in the design as pressure effects only occur at direction changes. However, for each design case the pressure effects need assessment. The Anchor Loads tables in this section account for the thermal and pressure expansion of FIBERBOND® Engineered Composite Piping Systems. To use these tables, refer to the system design pressure and temperature. For more conservative results the degradation of moduli and strength are neglected in the equations.

Table 5 Anchor Loads (lbs) – Series 20HV, 20FR-E, 20JF*

	Series 20HV and 20FR-E				**Series 20JF**			
Size	**Temperature Change (deg F)**				**Temperature Change (deg F)**			
	20	**60**	**100**	**140**	**20**	**60**	**100**	**140**
	Expansion (in./100 ft)				**Expansion (in./100 ft)**			
	0.24	**0.72**	**1.20**	**1.68**	**0.24**	**0.72**	**1.20**	**1.68**
2in.	495	1,484	2,474	3,464	938	2,814	4,690	6,566
3in.	715	2,144	3,574	5,003	1,323	3,969	6,615	9,260
4in.	935	2,804	4,673	6,542	1,708	5,123	8,539	11,954
6in.	1,735	5,206	8,676	12,147	2,859	8,577	14,294	20,012
8in.	2,763	8,288	13,813	19,338	4,237	12,710	21,184	29,657
10in.	4,017	12,050	20,084	28,118	5,841	17,524	29,207	40,890
12in.	5,498	16,493	27,489	38,485	7,673	23,019	38,364	53,710
14in.	5,652	16,957	28,262	39,567				
16in.	7,367	22,101	36,835	51,569				
18in.	9,308	27,925	46,542	65,159				
20in.	11,477	34,430	57,383	80,336				
24in.	16,493	49,480	82,467	115,454				
30in.	16,974	50,923	84,872	118,821				
36in.	24,410	73,231	122,051	170,871				
42in.	16,428	49,284	82,140	114,997				
48in.	21,441	64,324	107,207	150,090				

*Table is based on Eq.5 in appendix II

Figure 2 Anchors are placed along straight runs of piping to alleviate expansion, especially in higher temperature systems (above 150F, 65c).

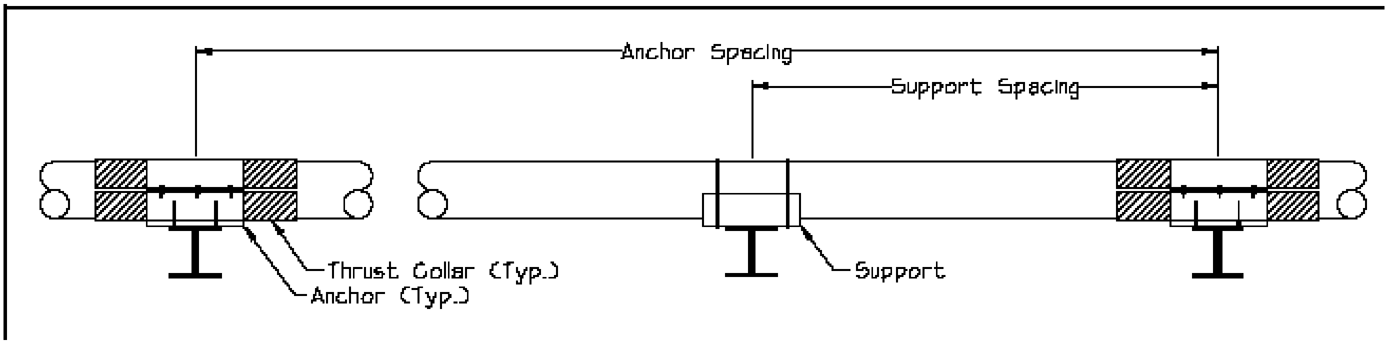


Table 6 Anchor Loads (lbs) – Series 110FW, 20C*

	Series 110FW				**Series 20C**			
Size	**Temperature Change (deg F)**				**Temperature Change (deg F)**			
	20	**60**	**100**	**140**	**20**	**60**	**100**	**140**
	Expansion (in./100 ft)				**Expansion (in./100 ft)**			
	0.24	**0.72**	**1.20**	**1.68**	**0.24**	**0.72**	**1.20**	**1.68**
2in.	495	1,484	2,474	3,464	399	1,198	1,997	2,796
3in.	715	2,144	3,574	5,003	577	1,731	2,884	4,038
4in.	935	2,804	4,673	6,542	754	2,263	3,772	5,281
6in.	1,735	5,206	8,676	12,147	1,109	3,328	5,547	7,766
8in.	2,763	8,288	13,813	19,338	1,844	5,533	9,222	12,910
10in.	4,017	12,050	20,084	28,118	2,288	6,864	11,440	16,017
12in.	5,498	16,493	27,489	38,485	3,295	9,885	16,474	23,064
14in.	7,329	21,988	36,646	51,305	4,562	13,687	22,812	31,936
16in.	9,278	27,833	46,388	64,943	5,946	17,839	29,731	41,624
18in.	11,453	34,358	57,263	80,168	7,513	22,540	37,566	52,593
20in.	13,854	41,563	69,272	96,981	9,263	27,790	46,316	64,843
24in.	19,338	58,015	96,692	135,369	13,312	39,937	66,562	93,187
30in.	20,452	61,355	102,259	143,162	13,701	41,102	68,504	95,905
36in.	28,575	85,724	142,874	200,023	19,702	59,107	98,512	137,917
42in.	21,184	63,551	105,918	148,286	13,260	39,779	66,299	92,819
48in.	26,870	80,611	134,352	188,093	17,306	51,919	86,531	121,144

*Table is based on Eq.5 in appendix II

Table 7 Anchor Loads (lbs) – Series 20FR16, 20FR20*

	Series 20FR16				**Series 20FR20**			
Size	**Temperature Change (deg F)**				**Temperature Change (deg F)**			
	20	**60**	**100**	**140**	**20**	**60**	**100**	**140**
	Expansion (in./100 ft)				**Expansion (in./100 ft)**			
	0.24	**0.72**	**1.20**	**1.68**	**0.24**	**0.72**	**1.20**	**1.68**
2in.	495	1,484	2,474	3,464	495	1,484	2,474	3,464
3in.	715	2,144	3,574	5,003	715	2,144	3,574	5,003
4in.	935	2,804	4,673	6,542	935	2,804	4,673	6,542
6in.	1,374	4,123	6,872	9,621	1,663	4,988	8,313	11,638
8in.	2,342	7,026	11,710	16,394	2,878	8,635	14,391	20,148
10in.	3,564	10,693	17,822	24,951	4,425	13,275	22,125	30,975
12in.	5,042	15,125	25,209	35,292	6,418	19,255	32,091	44,928
14in.	7,025	21,076	35,127	49,178	7,838	23,513	39,188	54,864
16in.	9,047	27,140	45,234	63,328	10,127	30,381	50,634	70,888
18in.	11,323	33,969	56,616	79,262	12,883	38,648	64,414	90,179
20in.	13,854	41,563	69,272	96,981				
24in.	19,911	59,732	99,554	139,376				
30in.	19,615	58,844	98,073	137,303				
36in.	28,074	84,221	140,368	196,515				
42in.	25,295	75,886	126,477	177,068				
48in.	32,765	98,294	163,824	229,353				

*Table is based on Eq.5 in appendix II

Table 8 Anchor Loads (kN)

Series 20HV, 20FR-E, 20JF, 20HV-C, 20HV(FDA), 20FR-EC, 20JF-C*

Size	Series 20HV and 20FR-E					Series 20JF				
	Temperature Change (deg C)					Temperature Change (deg C)				
	10	30	50	70	90	10	30	50	70	90
	Expansion (mm/m)					Expansion (mm/m)				
	0.18	0.54	0.90	1.26	1.62	0.18	0.54	0.90	1.26	1.62
	Anchor Load (kN)					Anchor Load (kN)				
1"	1.1	3.3	5.5	7.7	10.0	2.2	6.7	11.1	15.6	20.0
1.5"	1.5	4.6	7.7	10.8	13.9	3.0	9.0	15.0	21.0	27.0
2"	2.0	6.0	10.0	13.9	17.9	3.8	11.3	18.9	26.4	34.0
2.5"	2.4	7.3	12.2	17.0	21.9	4.5	13.6	22.7	31.8	40.9
3"	2.9	8.6	14.4	20.1	25.9	5.3	16.0	26.6	37.3	47.9
4"	3.8	11.3	18.8	26.3	33.8	6.9	20.6	34.4	48.1	61.8
5"	4.8	14.3	23.8	33.3	42.8	8.3	25.0	41.6	58.3	74.9
6"	7.0	20.9	34.9	48.9	62.8	11.5	34.5	57.5	80.5	103.5
8"	11.1	33.3	55.6	77.8	100.0	17.0	51.1	85.2	119.3	153.4
10"	16.2	48.5	80.8	113.1	145.4	23.5	70.5	117.5	164.5	211.5
12"	22.1	66.4	110.6	154.8	199.1	30.9	92.6	154.3	216.1	277.8
14"	22.7	68.2	113.7	159.2	204.7	32.9	98.7	164.5	230.3	296.1
16"	29.6	88.9	148.2	207.5	266.7	41.2	123.6	206.0	288.5	370.9
18"	37.4	112.3	187.2	262.1	337.0	50.4	151.3	252.1	353.0	453.9
20"	46.2	138.5	230.9	323.2	415.5					
24"	66.3	199.0	331.7	464.4	597.1					
30"	68.3	204.9	341.4	478.0	614.6					
36"	98.2	294.6	491.0	687.4	883.8					
42"	66.1	198.3	330.4	462.6	594.8					
48"	86.3	258.8	431.3	603.8	776.3					
54"	109.1	327.3	545.5	763.8	982.0					
60"	134.6	403.9	673.2	942.4	1211.7					

* Table is based on Equation 5 in Appendix II.

Table 9 Anchor Loads (kN)

Series 110FW, 20C*

Size	Series 110FW					Series 20C				
	Temperature Change (deg C)					Temperature Change (deg C)				
	10	30	50	70	90	10	30	50	70	90
	Expansion (mm/m)					Expansion (mm/m)				
	0.18	0.54	0.90	1.26	1.62	0.18	0.54	0.90	1.26	1.62
	Anchor Load (kN)					Anchor Load (kN)				
1"	1.1	3.3	5.5	7.7	10.0	1.1	3.3	5.5	7.7	10.0
1.5"	1.5	4.6	7.7	10.8	13.9	1.5	4.6	7.7	10.8	13.9
2"	2.0	6.0	10.0	13.9	17.9	2.0	6.0	10.0	13.9	17.9
2.5"	2.4	7.3	12.2	17.0	21.9	2.4	7.3	12.2	17.0	21.9
3"	2.9	8.6	14.4	20.1	25.9	2.9	8.6	14.4	20.1	25.9
4"	3.8	11.3	18.8	26.3	33.8	3.8	11.3	18.8	26.3	33.8
5"	4.6	13.9	23.2	32.5	41.8	4.6	13.9	23.2	32.5	41.8
6"	7.0	20.9	34.9	48.9	62.8	5.5	16.6	27.6	38.7	49.8
8"	11.1	33.3	55.6	77.8	100.0	9.2	27.6	46.0	64.3	82.7
10"	16.2	48.5	80.8	113.1	145.4	11.4	34.2	57.0	79.8	102.6
12"	22.1	66.4	110.6	154.8	199.1	16.4	49.3	82.1	115.0	147.8
14"	29.5	88.5	147.4	206.4	265.4	22.7	68.2	113.7	159.2	204.7
16"	37.3	112.0	186.6	261.3	335.9	29.6	88.9	148.2	207.5	266.7
18"	46.1	138.2	230.4	322.5	414.7	37.4	112.3	187.2	262.1	337.0
20"	55.7	167.2	278.7	390.2	501.6	46.2	138.5	230.9	323.2	415.5
24"	77.8	233.4	389.0	544.6	700.2	66.4	199.1	331.8	464.5	597.2
30"	82.3	246.8	411.4	575.9	740.5	68.3	204.9	341.4	478.0	614.6
36"	115.0	344.9	574.8	804.7	1034.6	98.2	294.6	491.0	687.4	883.8
42"	85.2	255.7	426.1	596.6	767.0	66.1	198.3	330.5	462.6	594.8
48"	108.1	324.3	540.5	756.7	972.9	86.3	258.8	431.3	603.8	776.3
54"	133.7	401.0	668.3	935.6	1202.9	109.1	327.3	545.5	763.8	982.0
60"	161.9	485.7	809.5	1133.3	1457.1	134.6	403.9	673.2	942.5	1211.8

* Table is based on Equation 5 in Appendix II.

Table 10 Anchor Loads (kN)

Series 20FR16, 20FR16-C, 20FR20, 20FR20-C*

Size	Series 20FR16					Series 20FR20				
	Temperature Change (deg C)					Temperature Change (deg C)				
	10	30	50	70	90	10	30	50	70	90
	Expansion (mm/m)					Expansion (mm/m)				
	0.18	0.54	0.90	1.26	1.62	0.18	0.54	0.90	1.26	1.62
	Anchor Load (kN)					Anchor Load (kN)				
1"	1.1	3.3	5.5	7.7	10.0	1.1	3.3	5.5	7.7	10.0
1.5"	1.5	4.6	7.7	10.8	13.9	1.5	4.6	7.7	10.8	13.9
2"	2.0	6.0	10.0	13.9	17.9	2.0	6.0	10.0	13.9	17.9
2.5"	2.4	7.3	12.2	17.0	21.9	2.4	7.3	12.2	17.0	21.9
3"	2.9	8.6	14.4	20.1	25.9	2.9	8.6	14.4	20.1	25.9
4"	3.8	11.3	18.8	26.3	33.8	3.8	11.3	18.8	26.3	33.8
5"	4.6	13.9	23.2	32.5	41.8	4.6	13.9	23.2	32.5	41.8
6"	5.5	16.6	27.6	38.7	49.8	6.7	20.1	33.4	46.8	60.2
8"	9.4	28.3	47.1	66.0	84.8	11.6	34.7	57.9	81.1	104.2
10"	14.3	43.0	71.7	100.4	129.1	17.8	53.4	89.0	124.6	160.2
12"	20.3	60.8	101.4	142.0	182.5	25.8	77.5	129.1	180.7	232.4
14"	28.3	84.8	141.3	197.8	254.4	31.5	94.6	157.7	220.7	283.8
16"	36.4	109.2	182.0	254.8	327.6	40.7	122.2	203.7	285.2	366.7
18"	45.6	136.7	227.8	318.9	410.0	51.8	155.5	259.1	362.8	466.5
20"	55.7	167.2	278.7	390.2	501.6					
24"	80.1	240.3	400.5	560.7	720.9					
30"	78.9	236.7	394.6	552.4	710.2					
36"	112.9	338.8	564.7	790.6	1016.5					
42"	101.8	305.3	508.8	712.4	915.9					
48"	131.8	395.4	659.1	922.7	1186.3					
54"	85.2	255.5	425.8	596.1	766.4					
60"	103.2	309.5	515.8	722.1	928.4					

* Table is based on Equation 5 in Appendix II.

Guide Spacing

In the pipe wall, compressive forces from expansion may result in buckling, and in general, instability, unless the piping system is properly restrained with guides. Guides are rigidly fixed to the supporting structure to provide pipe support and prevent buckling due to expansion while still allowing the pipe to move in the axial direction. Under normal conditions, the linear expansion of the piping system between anchor points can be controlled without exceeding the allowable axial stress levels of the pipe and fittings. The bending-compressive modulus ratio that is used is only valid at ambient temperatures. However, if the modulus values degrade above 150°F at similar rates, the ratio will not be affected. The recommended guide spacing design, however, does not take into account the combined loading effects of buckling and dead weight. If a more conservative design is desired, this phenomenon should be investigated further. Since guides act as supports, the guide spacing should be designed with the support spacing for optimum results. The guide spacing data is based on fixed ends. If the system has direction changes, expansion loops, or expansion joints, guide spacing may be increased. This increase is dependent upon a total system evaluation.

Table 11 Guide Spacing (ft) – Series 20HV, 20FR-E, 20JF*

	Series 20HV, 20FR-E				**Series 20JF**			
Size	**Temperature Change (deg F)**				**Temperature Change (deg F)**			
	20	**60**	**100**	**140**	**20**	**60**	**100**	**140**
	Expansion (in./100 ft)				**Expansion (in./100 ft)**			
	0.24	**0.72**	**1.20**	**1.68**	**0.24**	**0.72**	**1.20**	**1.68**
2in.	14.9	8.6	6.7	5.6	14.9	8.6	6.7	5.6
3in.	21.5	12.4	9.6	8.1	21.5	12.4	9.6	8.1
4in.	28.0	16.2	12.5	10.6	28.0	16.2	12.5	10.6
6in.	41.5	24.0	18.6	15.7	41.5	24.0	18.6	15.7
8in.	55.0	31.8	24.6	20.8	55.0	31.8	24.6	20.8
10in.	68.5	39.5	30.6	25.9	68.5	39.5	30.6	25.9
12in.	82.0	47.3	36.7	31.0	82.0	47.3	36.7	31.0
14in.	96.3	55.6	43.1	36.4				
16in.	109.8	63.4	49.1	41.5				
18in.	123.3	71.2	55.1	46.6				
20in.	136.8	79.0	61.2	51.7				
24in.	163.8	94.6	73.3	61.9				
30in.	202.2	116.8	90.4	76.4				
36in.	242.3	139.9	108.4	91.6				
42in.	279.5	161.4	125.0	105.7				
48in.	319.2	184.3	142.8	120.7				

*Table is based on Eq.6 in appendix II

Figure 3 Guides are added to control expansion and prevent buckling and instability in the system.

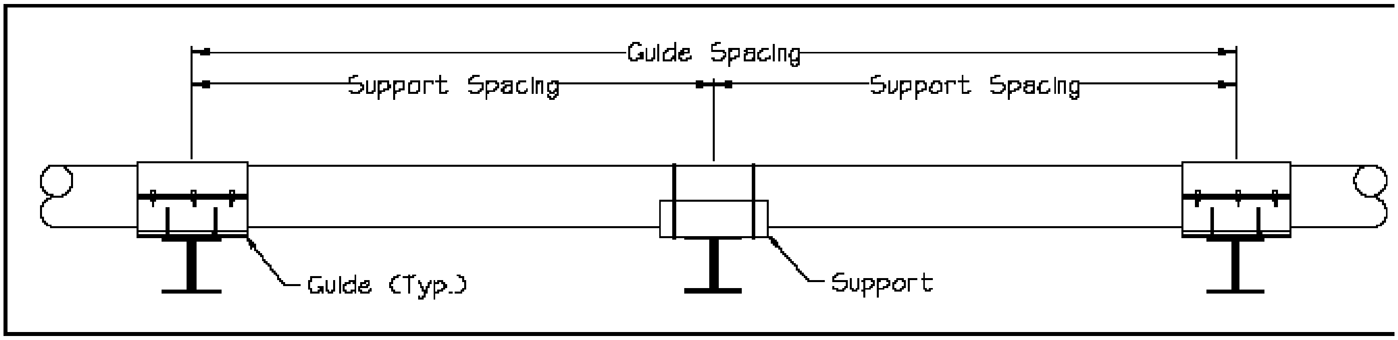


Table 12 Guide Spacing (ft) – Series 110FW, 20C*

	Series 110FW				**Series 20C**			
Size	**Temperature Change (deg F)**				**Temperature Change (deg F)**			
	20	**60**	**100**	**140**	**20**	**60**	**100**	**140**
	Expansion (in./100 ft)				**Expansion (in./100 ft)**			
	0.24	**0.72**	**1.20**	**1.68**	**0.24**	**0.72**	**1.20**	**1.68**
2in.	15.5	8.9	6.9	5.8	14.9	8.6	6.7	5.6
3in.	22.0	12.7	9.8	8.3	21.5	12.4	9.6	8.1
4in.	28.6	16.5	12.8	10.8	28.0	16.2	12.5	10.6
6in.	42.1	24.3	18.8	15.9	41.1	23.7	18.4	15.5
8in.	55.6	32.1	24.8	21.0	54.6	31.5	24.4	20.6
10in.	69.1	39.9	30.9	26.1	67.7	39.1	30.3	25.6
12in.	82.6	47.7	36.9	31.2	81.2	46.9	36.3	30.7
14in.	97.7	56.4	43.7	36.9	96.3	55.6	43.1	36.4
16in.	111.2	64.2	49.7	42.0	109.8	63.4	49.1	41.5
18in.	124.7	72.0	55.8	47.1	123.3	71.2	55.1	46.6
20in.	138.2	79.8	61.8	52.2	136.8	79.0	61.2	51.7
24in.	165.2	95.4	73.9	62.5	163.8	94.6	73.3	61.9
30in.	203.7	117.6	91.1	77.0	202.2	116.8	90.4	76.4
36in.	243.8	140.7	109.0	92.1	242.3	139.9	108.4	91.6
42in.	280.9	162.2	125.6	106.2	279.5	161.4	125.0	105.7
48in.	320.6	185.1	143.4	121.2	319.2	184.3	142.8	120.7

*Table is based on Eq.6 in appendix II

Table 13 Guide Spacing (ft) – Series 20FR16, 20FR20*

	Series 20FR16				Series 20FR20			
Size	**Temperature Change (deg F)**				**Temperature Change (deg F)**			
	20	**60**	**100**	**140**	**20**	**60**	**100**	**140**
	Expansion (in./100 ft)				**Expansion (in./100 ft)**			
	0.24	**0.72**	**1.20**	**1.68**	**0.24**	**0.72**	**1.20**	**1.68**
2in.	14.9	8.6	6.7	5.6	14.9	8.6	6.7	5.6
3in.	21.5	12.4	9.6	8.1	21.5	12.4	9.6	8.1
4in.	28.0	16.2	12.5	10.6	28.0	16.2	12.5	10.6
6in.	41.1	23.7	18.4	15.5	41.4	23.9	18.5	15.6
8in.	54.6	31.5	24.4	20.6	55.1	31.8	24.6	20.8
10in.	68.2	39.4	30.5	25.8	68.8	39.7	30.8	26.0
12in.	81.7	47.2	36.6	30.9	82.5	47.7	36.9	31.2
14in.	97.0	56.0	43.4	36.7	97.4	56.2	43.6	36.8
16in.	110.5	63.8	49.4	41.8	111.0	64.1	49.7	42.0
18in.	124.1	71.7	55.5	46.9	124.7	72.0	55.8	47.1
20in.	137.7	79.5	61.6	52.0				
24in.	164.8	95.2	73.7	62.3				
30in.	202.9	117.1	90.7	76.7				
36in.	243.1	140.3	108.7	91.9				
42in.	281.1	162.3	125.7	106.2				
48in.	320.9	185.3	143.5	121.3				

*Table is based on Eq.6 in appendix II

Table 14 Guide Spacing (m)

Series 20HV, 20FR-E, 20JF, 20HV-C, 20HV(FDA), 20FR-EC, 20JF-C*

Size	Series 20HV and 20FR-E					Series 20JF				
	Temperature Change (deg C)					Temperature Change (deg C)				
	10	30	50	70	90	10	30	50	70	90
	Expansion (mm/m)					Expansion (mm/m)				
	0.18	0.54	0.90	1.26	1.62	0.18	0.54	0.90	1.26	1.62
	Anchor Load (kN)					Anchor Load (kN)				
1"	2.7	1.6	1.2	1.0	0.9	2.7	1.6	1.2	1.0	0.9
1.5"	3.8	2.2	1.7	1.4	1.3	3.8	2.2	1.7	1.4	1.3
2"	4.8	2.8	2.1	1.8	1.6	4.8	2.8	2.1	1.8	1.6
2.5"	5.8	3.4	2.6	2.2	1.9	5.8	3.4	2.6	2.2	1.9
3"	6.9	4.0	3.1	2.6	2.3	6.9	4.0	3.1	2.6	2.3
4"	9.0	5.2	4.0	3.4	3.0	9.0	5.2	4.0	3.4	3.0
5"	11.1	6.4	5.0	4.2	3.7	11.1	6.4	5.0	4.2	3.7
6"	13.3	7.7	6.0	5.0	4.4	13.3	7.7	6.0	5.0	4.4
8"	17.7	10.2	7.9	6.7	5.9	17.7	10.2	7.9	6.7	5.9
10"	22.0	12.7	9.8	8.3	7.3	22.0	12.7	9.8	8.3	7.3
12"	26.3	15.2	11.8	10.0	8.8	26.3	15.2	11.8	10.0	8.8
14"	30.9	17.9	13.8	11.7	10.3	30.9	17.9	13.8	11.7	10.3
16"	35.3	20.4	15.8	13.3	11.8	35.3	20.4	15.8	13.3	11.8
18"	39.6	22.9	17.7	15.0	13.2	39.6	22.9	17.7	15.0	13.2
20"	44.0	25.4	19.7	16.6	14.7					
24"	52.6	30.4	23.5	19.9	17.5					
30"	65.0	37.5	29.1	24.6	21.7					
36"	77.9	45.0	34.8	29.4	26.0					
42"	89.8	51.9	40.2	33.9	29.9					
48"	102.6	59.2	45.9	38.8	34.2					
54"	115.3	66.6	51.6	43.6	38.4					
60"	128.1	73.9	57.3	48.4	42.7					

* Table is based on Equation 6 in Appendix II.

Table 15 Guide Spacing (m)

Series 110FW, 20C*

Size	Series 110FW					Series 20C				
	Temperature Change (deg C)					Temperature Change (deg C)				
	10	30	50	70	90	10	30	50	70	90
	Expansion (mm/m)					Expansion (mm/m)				
	0.18	0.54	0.90	1.26	1.62	0.18	0.54	0.90	1.26	1.62
	Anchor Load (kN)					Anchor Load (kN)				
1"	3.4	2.0	1.5	1.3	1.1	2.7	1.6	1.2	1.0	0.9
1.5"	4.8	2.8	2.2	1.8	1.6	3.8	2.2	1.7	1.4	1.3
2"	6.2	3.6	2.8	2.3	2.1	4.8	2.8	2.1	1.8	1.6
2.5"	7.6	4.4	3.4	2.9	2.5	5.8	3.4	2.6	2.2	1.9
3"	9.0	5.2	4.0	3.4	3.0	6.9	4.0	3.1	2.6	2.3
4"	11.8	6.8	5.3	4.5	3.9	9.0	5.2	4.0	3.4	3.0
5"	14.6	8.4	6.5	5.5	4.9	11.1	6.4	5.0	4.2	3.7
6"	16.4	9.5	7.3	6.2	5.5	13.2	7.6	5.9	5.0	4.4
8"	20.8	12.0	9.3	7.9	6.9	17.5	10.1	7.8	6.6	5.8
10"	25.3	14.6	11.3	9.5	8.4	21.7	12.5	9.7	8.2	7.2
12"	29.7	17.1	13.3	11.2	9.9	26.1	15.1	11.7	9.9	8.7
14"	34.6	20.0	15.5	13.1	11.5	30.9	17.9	13.8	11.7	10.3
16"	39.0	22.5	17.4	14.7	13.0	35.3	20.4	15.8	13.3	11.8
18"	43.4	25.0	19.4	16.4	14.5	39.6	22.9	17.7	15.0	13.2
20"	47.7	27.5	21.3	18.0	15.9	44.0	25.4	19.7	16.6	14.7
24"	56.4	32.6	25.2	21.3	18.8	52.6	30.4	23.5	19.9	17.5
30"	70.5	40.7	31.5	26.6	23.5	65.0	37.5	29.1	24.6	21.7
36"	83.4	48.1	37.3	31.5	27.8	77.9	45.0	34.8	29.4	26.0
42"	100.3	57.9	44.8	37.9	33.4	89.8	51.9	40.2	33.9	29.9
48"	113.1	65.3	50.6	42.7	37.7	102.6	59.2	45.9	38.8	34.2
54"	125.9	72.7	56.3	47.6	42.0	115.3	66.6	51.6	43.6	38.4
60"	138.7	80.1	62.0	52.4	46.2	128.1	73.9	57.3	48.4	42.7

* Table is based on Equation 6 in Appendix II.

Table 16 Guide Spacing (m)

Series 20FR16, 20FR16-C, 20FR20, 20FR20-C*

Size	Series 20FR16					Series 20FR20				
	Temperature Change (deg C)					Temperature Change (deg C)				
	10	30	50	70	90	10	30	50	70	90
	Expansion (mm/m)					Expansion (mm/m)				
	0.18	0.54	0.90	1.26	1.62	0.18	0.54	0.90	1.26	1.62
	Anchor Load (kN)					Anchor Load (kN)				
1"	2.7	1.6	1.2	1.0	0.9	2.7	1.6	1.2	1.0	0.9
1.5"	3.8	2.2	1.7	1.4	1.3	3.8	2.2	1.7	1.4	1.3
2"	4.8	2.8	2.1	1.8	1.6	4.8	2.8	2.1	1.8	1.6
2.5"	5.8	3.4	2.6	2.2	1.9	5.8	3.4	2.6	2.2	1.9
3"	6.9	4.0	3.1	2.6	2.3	6.9	4.0	3.1	2.6	2.3
4"	9.0	5.2	4.0	3.4	3.0	9.0	5.2	4.0	3.4	3.0
5"	11.1	6.4	5.0	4.2	3.7	11.1	6.4	5.0	4.2	3.7
6"	13.2	7.6	5.9	5.0	4.4	13.3	7.7	5.9	5.0	4.4
8"	17.5	10.1	7.8	6.6	5.8	17.7	10.2	7.9	6.7	5.9
10"	21.9	12.6	9.8	8.3	7.3	22.1	12.8	9.9	8.4	7.4
12"	26.3	15.2	11.7	9.9	8.8	26.5	15.3	11.9	10.0	8.8
14"	31.2	18.0	13.9	11.8	10.4	31.3	18.1	14.0	11.8	10.4
16"	35.5	20.5	15.9	13.4	11.8	35.7	20.6	16.0	13.5	11.9
18"	39.9	23.0	17.8	15.1	13.3	40.1	23.1	17.9	15.1	13.4
20"	44.2	25.5	19.8	16.7	14.7					
24"	53.0	30.6	23.7	20.0	17.7					
30"	65.2	37.6	29.2	24.6	21.7					
36"	78.1	45.1	34.9	29.5	26.0					
42"	90.3	52.1	40.4	34.1	30.1					
48"	103.1	59.5	46.1	39.0	34.4					
54"	115.0	66.4	51.5	43.5	38.3					
60"	127.8	73.8	57.1	48.3	42.6					

* Table is based on Equation 6 in Appendix II.

Guide Spacing for Direction Changes

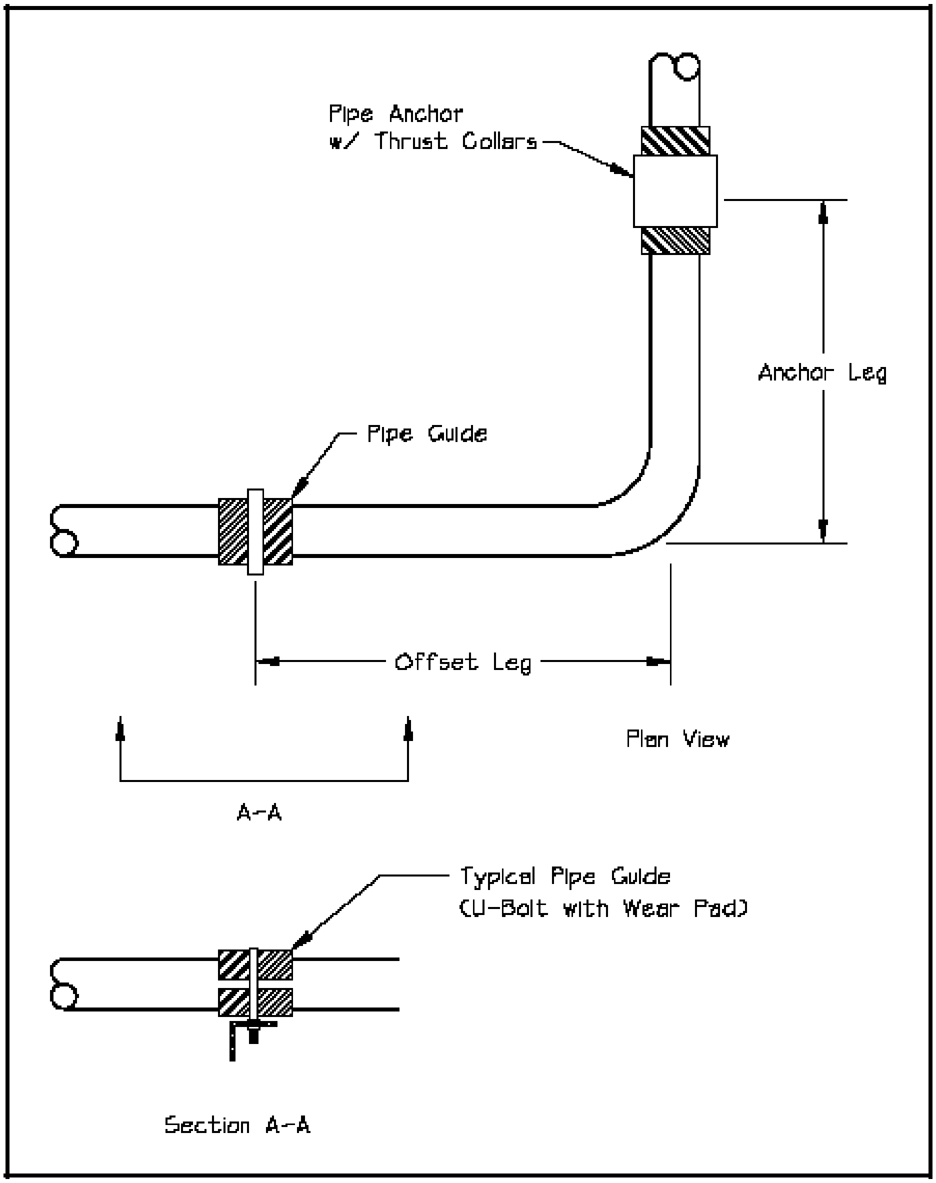
Directional changes, as part of the geometry of the piping system, can alleviate the stresses created due to thermal and pressure expansion. However, the stress levels created in the fiberglass fittings, specifically elbows, at directional changes must be kept below the allowable bending stress level of the pipe and fittings. The stress level in the pipe and fittings depends on the total length change and the distance to the first guide or hanger. The equation used by Future Pipe Industries approximates a cantilever beam deflected due to thermal and pressure expansion. There are more accurate equations, however, since

Table 17 Guide Spacing at Direction Changes (ft and m) – All Series*

Size	**Series 20HV, 20FR-E**				**Series 20JF**			
	Total Expansion (in. and mm)				**Total Expansion (in. and mm)**			
	0.5 (12.5)	**1.5 (37.5)**	**2.5 (62.5)**	**3.5 (87.5)**	**0.5 (12.5)**	**1.5 (37.5)**	**2.5 (62.5)**	**3.5 (87.5)**
2in.	5.3 (1.6)	9.2 (2.8)	11.8 (3.6)	14.0 (4.2)	5.7 (1.7)	9.8 (3.0)	12.7 (3.8)	15.0 (4.5)
3in.	6.3 (1.9)	10.8 (3.3)	14.0 (4.2)	16.6 (5.0)	6.6 (2.0)	11.4 (3.5)	14.7 (4.5)	17.4 (5.3)
4in.	7.1 (2.1)	12.3 (3.7)	15.9 (4.8)	18.8 (5.7)	7.4 (2.2)	12.8 (3.9)	16.5 (5.0)	19.5 (5.9)
6in.	8.6 (2.6)	14.9 (4.5)	19.2 (5.8)	22.8 (6.9)	8.8 (2.7)	15.3 (4.6)	19.8 (6.0)	23.4 (7.1)
8in.	9.9 (3.0)	17.1 (5.2)	22.1 (6.7)	26.2 (7.9)	10.1 (3.1)	17.5 (5.3)	22.6 (6.8)	26.7 (8.1)
10in.	11.0 (3.3)	19.1 (5.8)	24.7 (7.5)	29.2 (8.8)	11.2 (3.4)	19.4 (5.9)	25.1 (7.6)	29.7 (9.0)
12in.	12.1 (3.7)	20.9 (6.3)	27.0 (8.2)	31.9 (9.7)	12.2 (3.7)	21.2 (6.4)	27.3 (8.3)	32.4 (9.8)
14in.	13.0 (3.9)	22.5 (6.8)	29.1 (8.8)	34.4 (10.4)				
16in.	13.9 (4.2)	24.1 (7.3)	31.1 (9.4)	36.7 (11.1)				
18in.	14.7 (4.5)	25.5 (7.7)	32.9 (10.0)	38.9 (11.8)				
20in.	15.5 (4.7)	26.9 (8.1)	34.7 (10.5)	41.0 (12.4)				
24in.	17.0 (5.1)	29.4 (8.9)	37.9 (11.5)	44.9 (13.6)				
30in.	18.8 (5.7)	32.5 (9.8)	42.0 (12.7)	49.7 (15.0)				
36in.	20.5 (6.2)	35.6 (10.8)	45.9 (13.9)	54.4 (16.5)				
42in.	22.0 (6.7)	38.0 (11.5)	49.1 (14.9)	58.1 (17.6)				
48in.	23.5 (7.1)	40.6 (12.3)	52.5 (15.9)	62.1 (18.8)				

*Table is based on Eq.7 in appendix II; since the values in this table are a function of the pipe O.D., the values will actually vary slightly from series to series.

Figure 4 A properly guide FRP system at direction changes is one form of controlling thermal and pressure expansion.



a more conservative result is produced form this equation, this method is recommended. However, Future Pipe Industries does recommend a more conservative governing equation when adhesive bonded joints are used. This equation accounts for the bending strength of the elbow joint, not the pipe, with a safety factor of 8.0. In general, if the elbow joint strength is neglected, guide spacing requirements increase from 25% in large diameter pipe to 200% in small diameter pipe. A larger directional guide spacing requirement can mean less flexibility in designing the system. Refer to Appendix II for the design equations. The Guide Spacing for Direction Changes table in this section provides the minimum recommended guide spacing after a directional change. The values are valid only for the expansions given. The guide spacing values in these tables are for butt-welded joints. The butt weld has a higher bending strength than an adhesive bond. This factor should be taken into account in the design of FIBERBOND® Engineered Composite Piping Systems.

Expansion Loops

An expansion loop is another method used to alleviate stresses due to length changes in the piping system. Expansion loops are generally employed between extremely long straight runs of pipe to alleviate the end loads and buckling between anchors. As with Guide Spacing for Direction Changes, the design recommended by Future Pipe Industries is a simplified approach, however, it leads to more conservative data. Other equations are more accurate, taking into account the flexibility of the entire loop, but again, they are omitted for the reasons stated in the previous section. Again, the design parameters include thermal and pressure expansion, not just temperature change. In addition, as in all other calculations, the modulus values have not been degraded above 150°F. Degrading the moduli leads to results that are more conservative and should be considered in any detailed design. Other effects, like seismic loads, but especially wind loads, have not been accounted for in this design. With longer and longer expansion-loop leg lengths, the stresses in the elbows increase due to the moments created. This combined loading condition should be evaluated in the detailed design. The Expansion Loop table in this section contains the recommended lengths for the expansion loop legs perpendicular to the piping system.

Figure 5 Expansion loops are another form of controlling thermal and pressure expansion in a fiberglass piping system.

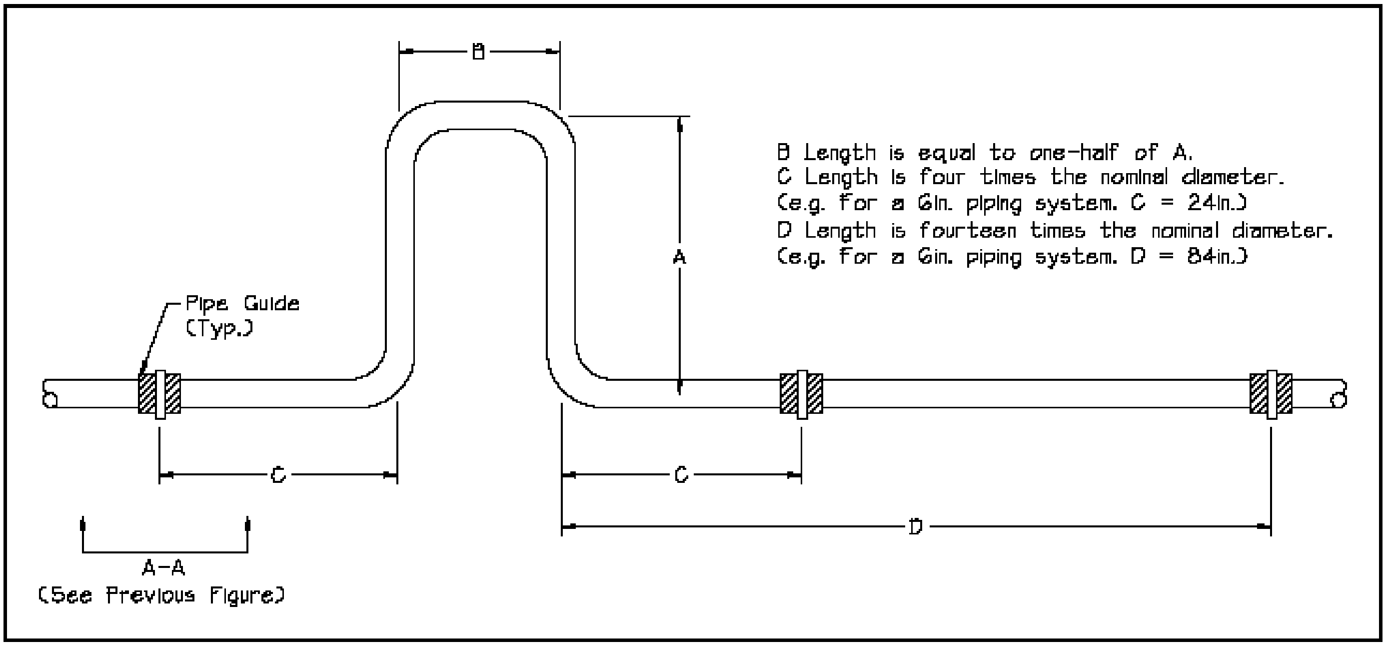


Table 18 Expansion Loop Leg Lengths - "A" Leg (ft and m) – Series 20HV, 20FR-E, 20JF*

Size	**Series 20HV, 20FR-E**				**Series 20JF**			
	Total Expansion (in. and mm)				**Total Expansion (in. and mm)**			
	1.0 (25)	**3.0 (75)**	**5.0 (125)**	**7.0 (175)**	**1.0 (25)**	**3.0 (75)**	**5.0 (125)**	**7.0 (175)**
2in.	5.3 (1.6)	9.2 (2.8)	11.8 (3.6)	14.0 (4.2)	5.7 (1.7)	9.8 (3.0)	12.7 (3.8)	15.0 (4.5)
3in.	6.3 (1.9)	10.8 (3.3)	14.0 (4.2)	16.6 (5.0)	6.6 (2.0)	11.4 (3.5)	14.7 (4.5)	17.4 (5.3)
4in.	7.1 (2.1)	12.3 (3.7)	15.9 (4.8)	18.8 (5.7)	7.4 (2.2)	12.8 (3.9)	16.5 (5.0)	19.5 (5.9)
6in.	8.6 (2.6)	14.9 (4.5)	19.2 (5.8)	22.8 (6.9)	8.8 (2.7)	15.3 (4.6)	19.8 (6.0)	23.4 (7.1)
8in.	9.9 (3.0)	17.1 (5.2)	22.1 (6.7)	26.2 (7.9)	10.1 (3.1)	17.5 (5.3)	22.6 (6.8)	26.7 (8.1)
10in.	11.0 (3.3)	19.1 (5.8)	24.7 (7.5)	29.2 (8.8)	11.2 (3.4)	19.4 (5.9)	25.1 (7.6)	29.7 (9.0)
12in.	12.1 (3.7)	20.9 (6.3)	27.0 (8.2)	31.9 (9.7)	12.2 (3.7)	21.2 (6.4)	27.3 (8.3)	32.4 (9.8)
14in.	13.0 (3.9)	22.5 (6.8)	29.1 (8.8)	34.4 (10.4)				
16in.	13.9 (4.2)	24.1 (7.3)	31.1 (9.4)	36.7 (11.1)				
18in.	14.7 (4.5)	25.5 (7.7)	32.9 (10.0)	38.9 (11.8)				
20in.	15.5 (4.7)	26.9 (8.1)	34.7 (10.5)	41.0 (12.4)				
24in.	17.0 (5.1)	29.4 (8.9)	37.9 (11.5)	44.9 (13.6)				
30in.	18.8 (5.7)	32.5 (9.8)	42.0 (12.7)	49.7 (15.0)				
36in.	20.5 (6.2)	35.6 (10.8)	45.9 (13.9)	54.4 (16.5)				
42in.	22.0 (6.7)	38.0 (11.5)	49.1 (14.9)	58.1 (17.6)				
48in.	23.5 (7.1)	40.6 (12.3)	52.5 (15.9)	62.1 (18.8)				

*Table is based on Eq.7 in appendix II; since the values in this table are a function of the pipe O.D., the values will actually vary slightly from series to series.

HYDRAULICS

FIBERBOND® Engineered Composite Piping Systems offer significant advantages in flow properties over stainless steels, lined steels, and other alloys due to its smooth resin rich interior surface and resistance to corrosion. Flow capacities are greater and the possibility of fouling is greatly reduced. The engineer should take advantage of the superior flow properties of fiberglass over alternative pipe system materials.

Maximum Flow Velocity

The continuous flow velocities for most liquids in fiberglass piping will generally fall between 1 and 5 meters per second (3.3 and 16.4 ft/sec). One general rule equation to determine the maximum continuous flow velocity is:

$$u_{\max} = \frac{48}{\rho^{0.33}} \, to \, \frac{64}{\rho^{0.33}}$$

In the above equations, $u_{\max}$ is in ft/sec and ρ is in lb/ft^3. For erosive fluids, the maximum velocity can be as little as half of the values from this equation.

If the volume flow rate (GPM) and pipe size are the known variables, then the actual flow velocity can be calculated with the following equation.

$$u = \frac{Q}{A}\left(\frac{231 in.^3}{1 gal}\right)\left(\frac{1 \min}{60 \sec}\right)\left(\frac{1 ft}{12 in.}\right)$$

In the above equation, u is in ft/sec, Q is the volume flow rate in GPM, and A is the internal cross-sectional area in sq. in.:

$$A = \left(\frac{\pi}{4}\right) ID^2$$

This velocity should be below the maximum allowable velocity in the system.

Factors Affecting Velocity

Pressure loss obviously needs to be considered when selecting pipe sizes and volume flow rates. This is especially true in small bore pipe sizes where pressure losses can reach 10psi per 100-feet or more even at velocities of 16ft/sec or less.

Intermittent excursions can reach as high as 10m/sec (32.8ft/sec). Some studies have been done for periods as long as 3 months and at continuous velocities up to 7.6m/sec (25ft/sec) that have shown little or no degradation of the FRP piping.

Other factors to consider when sizing the pipes include 1) erosion, 2) cavitation, and 3) water hammer.

Turbulence

The information in this section concerning head losses is only valid for turbulent flows. Generally, for pipes, a Reynolds number greater than 5000 defines turbulent flow. The Reynolds number is defined as:

$$R_e = \frac{uD}{v}\left(\frac{1 ft}{12 in.}\right)$$

In the above equation, u is the velocity in ft/sec, D is the diameter of the pipe in inches, and ν is the kinematic viscosity in ft^2/sec. If the flow is laminar or transitional (R_e <5000), different equations must be applied or correction factors must be used. One example of a correction factor is:

$$\frac{L}{D})_{lam} = \frac{L}{D})_{turb} \left(\frac{R_e}{1000}\right)$$

In this equation, L is the equivalent length in feet and D is the diameter in inches.

Other Flows

More complex situations, such as gas flows, and in general, compressible flows, two-phase flows, and non-Newtonian flows (where the viscosity is not a constant), are beyond the scope of

Example Hydraulic Calculations:

Consider an FRP system that is pumping water from a station to a discharge line. The pumps operate at 6500GPM and the size is 18in., FIBERBOND® Series 110FW. Calculate the velocity and check for turbulence.

With Q = 6500GPM, the actual velocity is:

$u = 6500 / (\pi/4 * 18^2) * 231 / 60 / 12 = 8.2$ ft/sec

The Reynold's number is:

$Re = 8.2 * 18 / 0.00001076 / 12 = 1.14 * 10^6$

Therefore, the flow is turbulent and the graphs and tables in this section can be used.

Table 19 Properties of Common Fluids and Gases (@ 68F, 20c)*

Fluid	Specific Gravity	Density (lb/cu ft)	Kinematic Viscosity (cSt)	Dynamic Viscosity (cP)
Air	0.001225	0.0765	14.6	0.0179
Water	1.0	62.4	1.005	1.005
Sea Water	1.025	64.0	1.064	1.091
Brine, 20% NaCl	1.149	71.7	1.498	1.722
Ethanol (ethyl alcohol)	0.789	49.2	1.525	1.20
Jet Fuel	0.62 - 0.88	38.7 - 54.9	1.2 - 1.5 @ 40c	0.74 - 1.32
Kerosene	0.78 - 0.82	48.7 - 51.2	2.71	2.11 - 2.22
Light Crude Oil	0.855	53.4	9.234	7.895
Medium Crude Oil	0.855	53.4	4.620	3.95
Methanol (methyl alcohol)	0.810	50.5	0.731	0.592
20% Sodium Hydroxide	1.22	76.1	4.0	4.88
Sulfuric Acid	1.841	114.9	13.8	25.4
HCl (31.5%, liquid)	1.05	65.5	1.9	1.54

- All values are temperature dependent and valid only for ambient temperature unless noted otherwise. Dynamic (absolute) viscosity = kinematic viscosity * S.G.
- 1S.G. = 1kg/m^3 = 62.4lb/ft^3. 1cSt = 0.03875ft^2/hr = 0.01cm^2/sec (Stokes). 1cP = 3.6kg/m-hr = 0.000672lb/ft-sec = 0.01g/cm-sec (Poise).

this guide. The engineer is directed to the references listed in the back of this guide for further information.

Head Losses in Straight Lengths of Pipe

One source of head loss is due to the frictional resistance of the pipe material. This pressure drop in FIBERBOND® Piping Systems can be accounted for with the Darcy-Weisbach equation for water. This analysis calculates the head loss based on the volume flow rate, pipe inside diameter, and the friction factor, which is a function of the surface roughness and flow rate. A surface roughness value of 0.00021 in. is used to account for the smooth fiberglass pipe interior.

The tables/graphs on the following pages can be used to calculate the pressure drop in psi for all FIBERBOND® Piping Series. Knowing the flow rate in ft/s and the nominal pipe diameter, the head loss and flow velocity can be determined. The information in this section is valid only for seawater (SG = 1.025). Refer to the Fluid Conversion Factors to calculate the head losses for other fluids. These factors are a function of the fluid specific gravity and kinematic viscosity. For more accurate results, however, the conversion factors should not be used. Refer to the hydraulic equations in Appendix II. Also, a different equation must be used to account for laminar flows. Poiseuille's equation for head losses in laminar flow can be used:

$$H_f = \frac{0.000273 vLQ}{d^4}$$

In this equation, v is the absolute viscosity in centipoises, L is the pipe length in feet, d is the internal diameter in inches, and Q is the volume flow rate in GPM. Notice that the surface roughness of the pipe is not a factor.

Head Losses in Fittings

Elbows, reducers, tees, etc., also produce pressure losses. For example, in standard elbows, the pressure loss is created by the resistance due to the length and due to the bending in the elbow. On the other hand, reducers create pressure losses due to the reduction in size. All fittings have specific characteristics that lead to pressure losses. One way to account for these losses is to represent the fitting by an equivalent length and treat this length as in the previous section. This method provides an accurate estimate of the pressure losses in a system. However, since all manufacturers have their own data for their products, it is impossible to amass all of the data needed to evaluate every system. It is recommended that the engineer make reference to the manufacturer's literature for other fittings outside of this engineering guide.

The Equivalent Pipe Length for Fittings table provides the engineer data for standard fiberglass fittings. To use the table, simply read the value under the fitting heading for the particular nominal diameter desired. This value can then be used as an equivalent straight length of pipe and the pressure losses can be calculated as in the previous section. Since this approximation is only true for turbulent flow, an approximation must be made for laminar flow: In this equation, L is the equivalent length in feet and D is the inside diameter in inches.

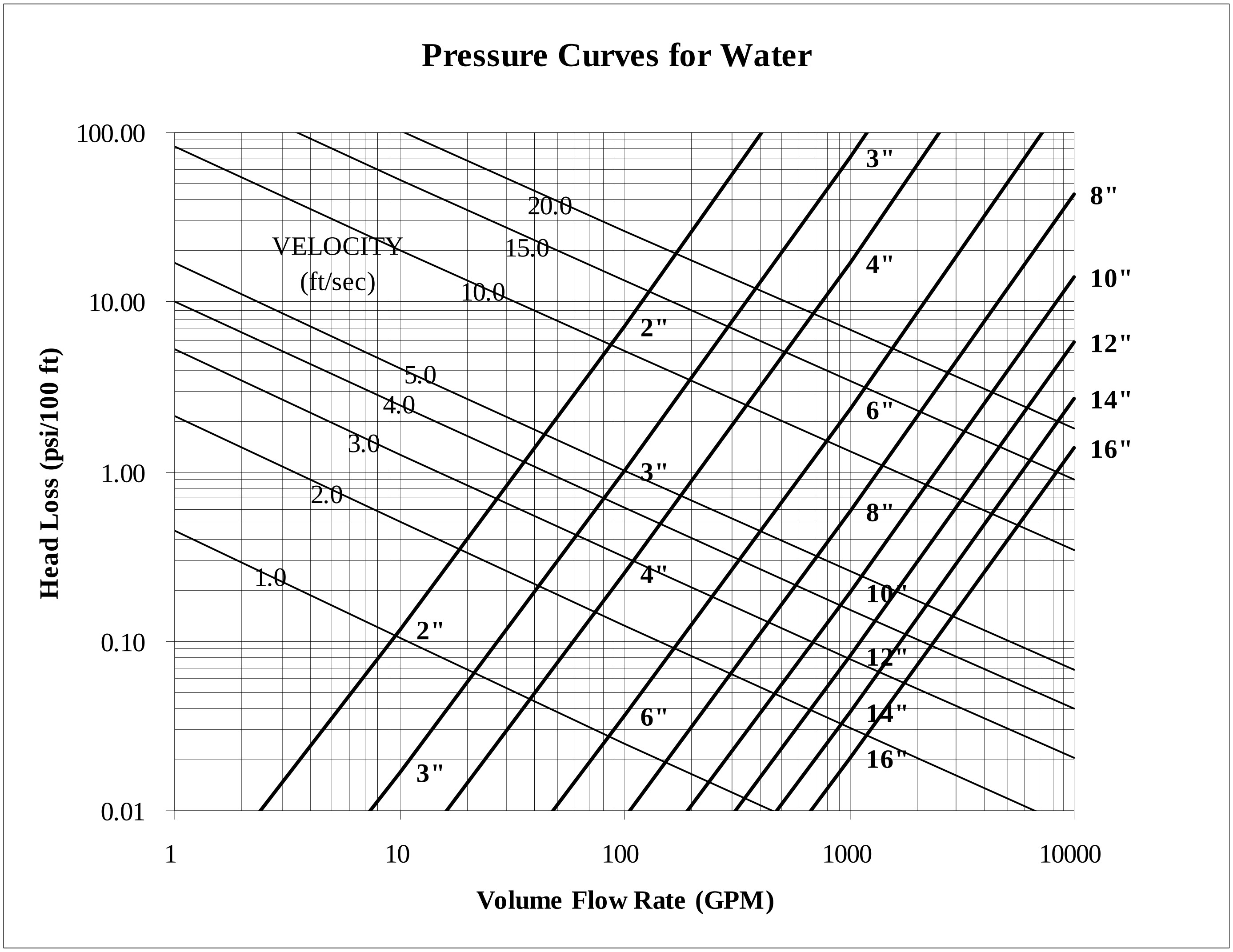
$$\left(\frac{L}{D}\right)_{lam} = \left(\frac{L}{D}\right)_{turb}\left(\frac{R_e}{1000}\right)$$

One additional item should be mentioned regarding pressure losses and an adhesive bonded system. It is imperative that qualified FRP pipe fitters install the piping system. It is very common to have inexperienced fitters place too much adhesive on the fittings which will result in as much as 50% pipe closure at a fitting. This results in huge pressure losses in the system. No matter how careful the system is designed, the quality, reliability, and efficiency of the system is only as good as the FRP field crew.

Table 20 Equivalent Lengths of Fiberglass Fittings (ft)

Size (in.)	**90° Elbow**		**45° Elbow**	**Tee**		**Reducer**
	Long	**Short**		**Run**	**Branch**	
2in.	7	9	5	4	18	2
3in.	9	12	7	4	25	2
4in.	11	14	10	5	32	3
6in.	15	19	13	8	46	4
8in.	18	23	16	10	59	5
10in.	21	27	19	12	72	7
12in.	24	31	22	14	85	8
14in.	27	32	24	16	97	9
16in.	29	38	27	18	109	10
18in.	32	41	29	20	121	11
20in.	34	44	31	22	132	12
24in.	39	50	35	26	155	14
30in.	45	59	41	31	188	17
36in.	51	67	47	37	220	20
42in.	57	74	52	42	251	23
48in.	63	81	57	47	282	27
54in.	68	88	62	52	312	28
60in.	73	95	67	57	342	31

* Based on equations in Benedict * Valid for a flow rate of 10 ft/sec. For 1 ft/sec, multiply by 1.9, for 5 ft/sec, by 1.2, and for 15 ft/sec, by 0.89. Reducer values are for one size reduction, e.g., a 12in. x 10in. reducer is equal to 8 ft of 12in. pipe.

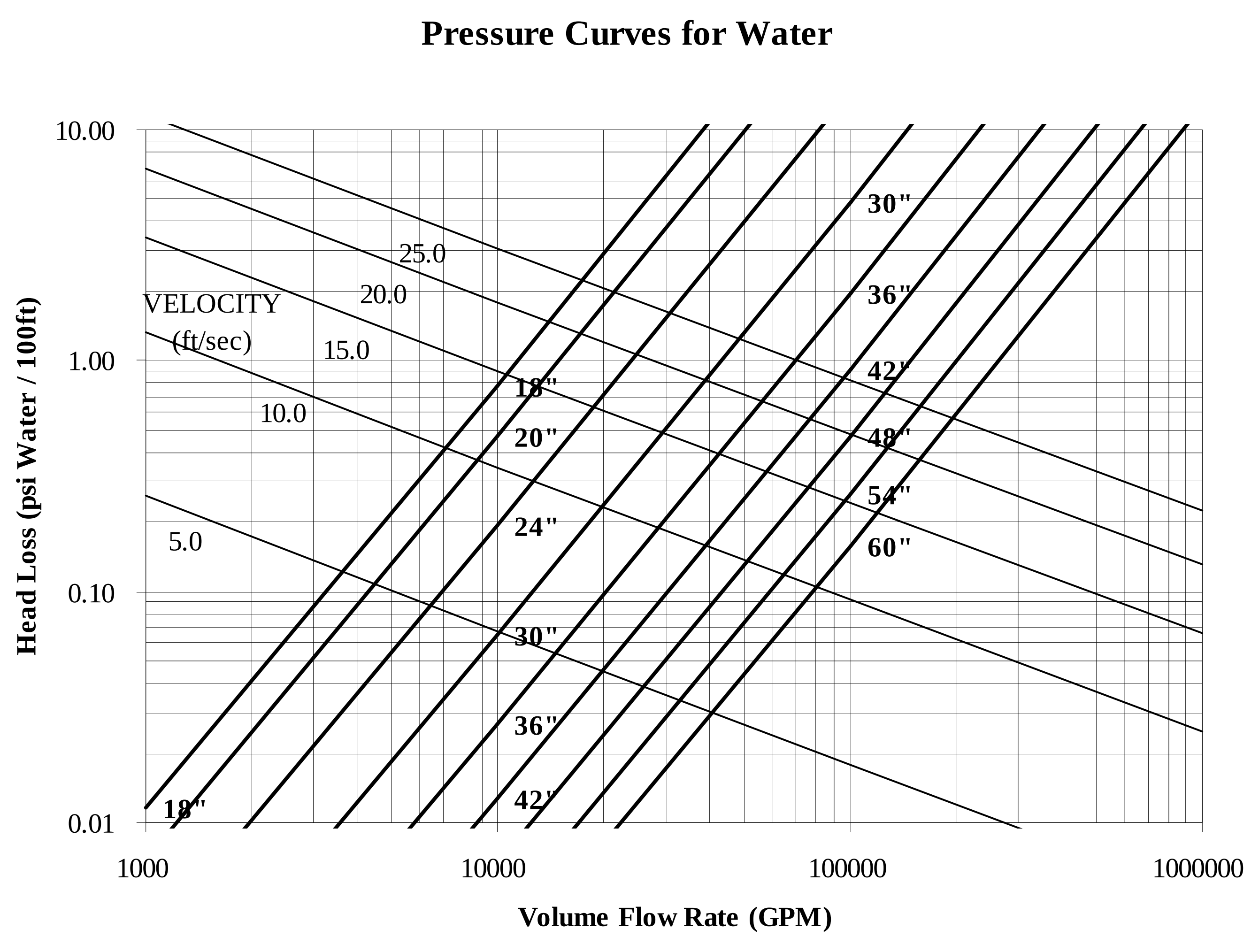


* All values are based on Sea Water at ambient temperature.

Table 21 Pressure Curves Conversion Factors

Fluid / Gas	Conversion Factor
Seawater	1.014
Brine, 10% NaCl	1.083
Light Crude Oil	1.654 +/- 20%
Medium Fuel Oil	1.378 +/- 12%
Methanol	0.943
HCl (31.5% liquid)	1.129

Conversion factors are based on the fluid/gas specific gravity and kinematic viscosity. Conversion factors are dependent upon each fluid with a maximum deviation of 5% unless otherwise noted. Conversion factors were calculated from the Colebrook equation, which has a 1% uncertainty.



* All values are based on Sea Water at ambient temperature. *See conversion percentages to deviate between different fluids.

Water Hammer and Transients

When pumping fluid through an FRP system under normal conditions, the internal pressure is maintained. However, during pump startup/shutdown, or when valves are opened or closed quickly, pressure surges and transients can be created that are detrimental to the piping system. The term water hammer describes the pressure surge that is created when a valve is opened or closed too rapidly and there is a sudden large change in the momentum of the fluid. The term transient flow describes the unsteady flow conditions created by one or more of the above-mentioned occurrences. Both of the subjects are very detailed and involved, however, their effects on an FRP system can not be overlooked. In general, Future Pipe Industries recommends the following guidelines to deal with water hammer: 1. Use valves with closing times in the 3-5 second range. For high flow rates or for large bore piping (> 24in., 600mm), even longer closing times may be needed. 2. Never start pumps into empty discharge lines without the use of actuated valves. 3. Consider the design of surge tanks or pressure accumulators into pipelines when the potential for water hammer exists.

Table 11 in this section refers to recommended minimum valve closure/opening times. These times give an approximate pressure surge equivalent to the maximum shut-in pressure (133% of design pressure). It should be noted that these times are based on particular flow rates and do not eliminate the potential negative effects of water hammer. By keeping valve closing times to these numbers or higher, you are simply reducing the surge that is created. A second note should be made about butterfly valves and other valves that do not have linear closing times. Some butterfly valves that are closed to 80% still have flow rates of 50% or more. Therefore, closing times may have to be lengthened to take this into account.

OTHER DESIGN CONSIDERATIONS

Thermal Conductivity

Thermal conductivity is defined as the rate of heat transfer per unit area, per unit temperature differential, per unit thickness, per unit time. Thermal conductivity is usually expressed in W/(m-°K), BTU/(hr-ft-°F), or BTU-in/(hr-ft2-°F). Most fiberglass products have thermal conductivity values that are less than 1% of steel and which are only 4 - 8 times greater than that of common insulating materials, such as fiberglass or elastomeric foam Because of this, there are not nearly as many applications of fiberglass piping that require insulation. However, when the need for insulation is required, whether it is for controlling heat loss, providing personnel protection, or reducing heat gain, the insulation materials for fiberglass piping can be chosen in the same manner as for steel piping.

Heat Tracing

Heat tracing, for freeze protection and/or for maintaining the process fluid at a specified temperature, by means of electrical tracing is acceptable for fiberglass pipe as long as certain precautions are taken. 1. The average wall temperature created from the heat tracing must be less than the fiberglass temperature rating of the product. 2. The maximum tracing temperature must be no more than 100°F above the temperature rating of the fiberglass product. 3. The maximum temperature at the inside wall of the fiberglass product must be less than the temperature rating of the fiberglass product for the particular fluid in the piping. In addition to the above precautions, it is important that a spiral wrap be used for heat tracing. Because of the low thermal conductivity of fiberglass pipe, if only one side of the pipe is heated, the heat will not transfer properly creating the potential for bowing to occur in the piping. It is also a good recommendation to use the minimum heat tracing temperature that will meet the design requirements. It is not uncommon in freeze protection applications that a tracing temperature of as low as 120°F will suffice.

Abrasive Fluids

Fiberglass piping has been used successfully in a number of different services where abrasion is present. However, because of the large number of variables involved in designing systems for abrasion, including fluid velocity, particle size and shape, and temperature, it is difficult to determine the suitability of a product in a particular service without actual test data. Future Pipe Industries offers a custom manufactured fiberglass product with abrasion resistant additives built into the liner. Again, because of the number of variables involved in the design, it is recommended that field test results be obtained from test spools installed in actual service conditions.

Low Temperature Service

Many fiberglass products, including FIBERBOND®, are suitable for use at low temperatures. Tests conducted as low as -45°F have shown little or no degradation in the mechanical properties of the fiberglass products. In designs at low temperatures, the effect of contraction should be investigated carefully. In addition, freezing of the fluid carried inside the piping system must be prevented to avoid bursting of the fiberglass piping system.

Static Electricity - Internal Charges

Static electricity is generated when two dissimilar materials generate friction from contact. Two typical examples of the potential internal generation of static electricity in fiberglass piping systems are 1) dry gas flowing through a duct system at high velocity with non-conductive particle trapped in the flow and 2) non-conductive liquids flowing through a pipe or falling through into a collection tank. In most applications for fiberglass pipe, there is little or no concern for the generation of static electricity. However, in applications such as those described above, static electricity can be a serious concern that must be addressed in the design phase of the project. Typical fiberglass composites have a volume resistivity of 10^13 - 10^15 ohms-meter. A volume conductive material typically has a volume resistivity of less than 10^6 ohms-meter. The **FIBERBOND® 20C Series** achieves this level of volume resistivity through the use of a homogenously conductive laminate. By making the piping product homogenously conductive, the static electricity that is generated can be dissipated through grounding straps as in steel systems.

Static Electricity - Hazardous Areas

Static electricity in hazardous areas is a completely different phenomena than those created from internal charges. In hazardous areas, the threat is from 1) a static charge source being generated in the vicinity of the FRP piping, 2) that generated charge accumulating on the exterior of the piping system, and 3) the accumulated charge then creating a spark that could ignite the flammable atmosphere in the hazardous area. While the likelihood of all of these events occurring at the right times is very low, the negative consequences from this combination of events could be catastrophic.

When static electricity cannot be ruled out, we have developed several FIBERBOND® product lines just for these applications. These include Series 20FR-EC, 20JF-C, 20JF16-C, 20FR16-C, 20FR20-C, and 20HV-C. All of these product lines are identical to their base product (20FR-E for example) except for the incorporation of an electrically conductive exterior that can be grounded to earth. Grounding to earth is very important as conductive materials that are ungrounded pose a greater danger (due to their increased ability to accumulate charges) than non-conductive materials.

Vacuum Considerations

The potential for vacuum collapse can occur in any system. **All FIBERBOND® products with pressure ratings of 150psig or higher are rated for full vacuum.** Vacuum mainly becomes a concern with larger diameter piping (> 12in. diameter) and with very thin wall piping, such as those used for duct service. When piping such as these are used in services where vacuum may occur, it is important to verify the allowable vacuum rating of the product. When economical, stiffener rings are sometimes manufactured into the piping product to improve the vacuum rating.

This, however, is mainly limited to duct service and very large diameter piping (>24in. diameter).

Vibration

Vibration can be a problem in fiberglass piping systems if it is not designed for properly. The two concerns of vibration include damage to the piping system because of high stresses and damage to the piping system because of abrasion to the pipe at supports. When high stresses are created from vibration, it is important to isolate the source. In these severe cases, a flexible connection should be made between the source and the fiberglass piping. The abrasion at supports can be easily avoided by using wear pads at all steel interfaces. It is standard practice in FIBERBOND® Piping Systems to use wear pads or some other form of rubber padding at all FRP / Steel interfaces to prevent this abrasion problem.

Pulsation

Pulsation is usually caused by the acceleration and deceleration of a pumped liquid from a reciprocating pump. The forces from this action can create pressure spikes several times larger than the operating pressure of the system. From visual inspection, the pipe appears to be vibrating and eventually damage will be caused to seals, gauges, and even the piping material itself.

The best defense against pulsation is to use a pulsation dampener such as a hydro-pneumatic dampener which essentially consists of a pressure vessel containing a compressed gas that is separated from the liquid by a bladder. Normally, the dampener should be placed as close to the pump as possible. Note that pulsation is normally uncommon with centrifugal pumps.

UV / Weathering

All fiberglass piping will experience some changes in appearance when exposed to sunlight. The exposure to UV will cause degradation of some form. While this degradation generally does not affect the performance of the product, it is an aesthetic problem similar to rusting of steel piping. Unlike steel piping, however, it is a problem that can be avoided. All FIBERBOND® products designed for use in aboveground applications are manufactured with an external corrosion barrier, which contains UV inhibitors and a special polyester fabric. This external corrosion barrier prevents the “fiber bloom” associated with fiberglass products that are not manufactured with an external corrosion barrier. In addition, this external corrosion barrier makes the FIBERBOND® product splash-resistant to seawater, freshwater, and oils.

Fungal / Bacterial Attack

Fiberglass products are considered inert to marine life. They offer neither nourishment nor toxic effects. Therefore, while marine fouling can occur, long-term studies have shown that this fouling can easily be cleaned. Fouling is most common in lines which are stagnant for long periods of time. Studies at one facility where FRP pipes were left under stagnant conditions for one-month showed some fouling to occur. Other facilities have had FRP systems in operation for 5 years with maximum flow velocities of 5ft/sec with no signs of fouling. When continuous operating lines maintain flow velocities, fouling is uncommon.

Marine life, such as oysters, mussels, and barnacles tend to attach less to FRP pipes compared to steel due to the smooth interior surface of FRP.

Hypochlorination is an effective method to prevent fouling problems. Some studies have shown continuous chlorination concentrations as low as 0.25 to 0.5ppm to be effective.

Water Hammer

Water hammer is the surge of internal pressure created when the liquid velocity suddenly changes. Since the liquid is essentially incompressible, any energy that is applied to it is instantly transmitted somewhere else (to the pipes, fittings, joints, valves, even supports).

The biggest cause of water hammer in FRP systems is the quick closing valve. Unfortunately, there is no simple calculation to determine whether water hammer is a concern or not. Negative factors that affect the magnitude of water hammer are 1) fast valve closing times, 2) long straight runs of piping with no fittings nor branches, and 3) high operating velocities.

Factors that are positive and can help reduce the effect of water hammer include 1) slow closing/opening valves, 2) complex systems with many branches and short runs of piping, and and 3) low operating velocities.

The best solution to the water hammer problem is elimination of the source. If these sources can not be eliminated and the water hammer problem is severe, some type of surge tank or pressure accumulator should be designed into the system. As with all systems, the surge pressures due to water hammer should be kept below the maximum allowable pressure rating of the piping system.

Cavitation

If the pressure in a closed piping system were to drop below the fluid's vapor pressure, then cavities would form. These cavities are air spaces and the phenomena is also known as water column separation. This is another consequence of quick closing valves since the same pressure wave that causes a pressure surge also causes a pressure drop.

The result is essentially a vacuum on the piping system, which if large enough, can lead to collapse of the pipe wall. And when the water columns rejoin, the result is usually a pressure spike in the system. This is especially true in large diameter piping systems with thin pipe walls. With water or seawater systems, water column separation is less likely to occur because of the very low vapor pressure of the fluid. For water, the vapor pressure is about 0.5psia (14.2psig below atmospheric) at ambient temperature and about 3.5psia (11.2psig below atmospheric) at 150F.

Fatigue Loading

The standard long term test method for FRP materials is the ASTM D2992 Procedure "B" which is a static long term internal pressure test procedure. Typically, when the number of cycles in the design life of the system is less than 7000 (about one cycle per day in a 20-year design), the system can be considered static and no consideration needs to be given to fatigue loading.

When fatigue loading is a concern, fatigue data should be used for determining the allowable stresses. Depending upon the severity of the fatigue loading, the allowable fatigue stress can be as little as half of the static value. This can be true at 10^8 cycles of loading.

It should be noted that occasional loads, such as a 50-year storm design, are typically not fatigue cases since the number of cycles is below 7000. Daily wave action, on the other hand, can be a fatigue case.

An alternative to the fatigue data is in ISO14692 which has a "factor" for de-rating the static allowable stress to a "cyclic" allowable stress. This is the so-called "A3" factor for de-rating for cyclic service. Reference should be made to Part 3 (design) of ISO14692.

Sodium Hypochlorite

Sodium Hypochlorite (NaOCl) is a very strong oxidizer that, at certain concentrations, can be detrimental to the performance of FRP. Most FIBERBOND® products are suitable for exposure to NaOCl up to 100ppm and up to 120F (49c). Above this concentration, special liners may be required. Corrosion resistant testing has been performed at concentrations as high as 15% (150,000ppm) with satisfactory performance. However, at concentrations above 10%, a dual-laminate (a PVC, CPVC, or PTFE liner with FRP structure) may be more suitable.

Corrosion Resistance

While metallic corrosion is dominated by electrochemical corrosion mechanisms, FRP corrosion is dominated by either physical or chemical mechanisms or a combination of both. In aqueous media, a physical attack can occur on the FRP due to the osmotic permeation of the resin by the fluid. The physical attack on FRP is often more severe when the fluid is pure water rather than ionic solutions. These physical attacks can result in delaminations or blisterings.

Chemical attacks can also occur. An example is the saponification by sodium hydroxide or the oxidation by sodium hypochlorite.

Safety Factors

Safety factors (the inverse of the service factors in ASME B31.3 or the partial factors in ISO14692) can vary widely for FRP materials, depending upon the test method, duration, loading condition, etc. For example, for a short term "burst" test such as ASTM D1599, 4.0 is a typical safety factor. For a long term regression analysis such as ASTM D2992, the safety factor would be closer to 1.5. Long term safety factors for occasional loads can be even lower, closer to 1.12.

PHYSICAL AND MECHANICAL PROPERTIES

Table 22 Typical Strengths and Moduli

Property	20HV, 20HV-C, 20HV(FDA), 20HV-D	20FR-E, 20FR-EC, 20FR16, 20FR16-C, 20FR20, 20FR20-C, 20JF, 20JF-C	110FW	20C
Temp Rating	150F (65c)	185F (85c)	250F (121c)	185F (85c)
Axial Tensile Strength	8,400psi (57.9MPa)	8,400psi (57.9MPa)	8,400psi (57.9MPa)	6,780psi (46.7MPa)
Axial Tensile Modulus	1,400,000psi (9.7GPa)	1,400,000psi (9.7GPa)	1,400,000psi (9.7GPa)	1,130,000psi (7.8GPa)
Hoop Tensile Strength	26,400psi (182.0MPa)	26,400psi (182.0MPa)	26,400psi (182.0MPa)	20,400psi (140.7MPa)
Hoop Tensile Modulus	2,200,000psi (15.2GPa)	2,200,000psi (15.2GPa)	2,200,000psi (15.2GPa)	1,700,000psi (11.7GPa)
Bending Strength	16,800psi (115.8MPa)	16,800psi (115.8MPa)	16,800psi (115.8MPa)	13,560psi (93.5MPa)
Bending Modulus	1,400,000psi (9.7GPa)	1,400,000psi (9.7GPa)	1,400,000psi (9.7GPa)	1,130,000psi (7.8GPa)
Density	0.06lb/in.^{3} 1.7g/m^3	0.06lb/in.^{3} 1.7g/m^3	0.06lb/in.^{3} 1.7g/m^3	0.06lb/in.^{3} 1.7g/m^3
Thermal Expansion Coefficient	0.00001in./in./F 0.000018mm/mm/C	0.00001in./in./F 0.000018mm/mm/C	0.00001in./in./F 0.000018mm/mm/C	0.00001in./in./F 0.000018mm/mm/C
Major Poisson's Ratio, Ea/Eh*vha=vah	0.35	0.35	0.35	0.35
Minor Poisson's Ratio, vmin=vha	0.55	0.55	0.55	0.55
Hazen Williams	150	150	150	150
Specific Roughness	0.0002in (0.0005cm)	0.0002in (0.0005cm)	0.0002in (0.0005cm)	0.0002in (0.0005cm)

APPENDIX I: REFERENCES

Many excellent texts and other references were utilized in the writing of this Engineering guide and the following are recommended for further information:

American Society of Mechanical Engineers, ASME Code for Pressure Piping B31.3, Chemical Plant and Petroleum Refining Piping, ASME, New York, 1996 Edition.

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Wylie, Benjamin E., *Fluid Transients*, FEB Press, Ann Arbor, MI, Corrected Edition, Copyright 1983.

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APPENDIX II: REVISION LOG

March 2010: clarified major and minor poisson's ratio; updated wording on fatigue loading.

June 2015: No major changes; updated some wording to maintain consistency from one section to another and with other documents.

April 2016: Added equation for pressure drop per the Hazen-Williams equation; added equation for calculating the Reynolds number.

APPENDIX III: GOVERNING EQUATIONS

The following equations were used in the calculations of design standards for all FIBERBOND® Engineered Composite Piping Series. The full derivation of each equation is not included here. The engineer is directed to the references at the end of this guide for further information.

SUPPORT SPACING
Deflection Based Design

$$L_s = \left(\frac{E_b I_r \Delta}{K w_o}\right)^{1/4}\left(\frac{1\,ft.}{12\,in.}\right) \qquad \textbf{(1)}$$

L_s - Support spacing, ft
E_b - Axial flexural (bending) modulus, psi
I_r - Moment of inertia, reinforced, in^4
Δ - Allowable deflection = 0.5in.
w_o - Pipe and fluid weight, lb/in.
K - Support type factor
= 0.013 for Type I
= 0.0069 for Type II
= 0.0065 for Type III
= 0.0026 for Type IV

Example 1 Calculations:
Consider a 3in. 20HV Series (200psig) piping system operating at ambient temperature and 100psig and carrying a fluid with a specific gravity of 1.2. Calculate the required support spacing based on a deflection of 0.5" and a bending stress of 1,000psi.

E_b = 1,400,000 psi
$I_r = \pi/64\,(3.5^4 - 3.04^4) = 3.17\ in.^4$
Δ = 0.5 in.
K = 0.0065
$w_o = \pi/4\,(3.5^2 - 3.0^2)\,(0.06) + \pi/4\,(3.0^2)\,(0.0361)\,(1.2) =$ 0.46 lb/in.
L_s = 13.8 ft

SUPPORT SPACING
Stress Based Design

$$L_s = \sqrt{\frac{I_r\sigma}{\frac{w_o c}{8}\left(\frac{144\,in.^2}{1\,ft.^2}\right)}}$$

(2)

L_s - Support spacing, ft
σ - Bending stress, psi
I_r - Moment of inertia, reinforced, in^4
c - Pipe outside radius, in
w_o - Pipe and fluid weight, lb/in.

Consider Example 1, except, now design the supports for a maximum bending stress of 500psi:

σ = 500 psi
$I_r = \pi/64\,(3.5^4 - 3.04^4) = 3.17\ in.^4$
c = 1.75 in.
$w_o = \pi/4\,(3.5^2 - 3.0^2)\,(0.06) + \pi/4\,(3.0^2)\,(0.0361)\,(1.2) =$ 0.46 lb/in.
L_s = 10.5 ft

THERMAL EXPANSION

$$\Delta_{Thermal} = C_t \Delta T (100\,ft)\left(\frac{12\,in.}{1\,ft.}\right) \qquad \textbf{(3)}$$

$\Delta_{Thermal}$ - Thermal expansion, in./100 ft
C_t - Coefficient of thermal expansion, in./in./°F
Δ T - Temperature change, °F

- For total thermal expansion, multiply $\Delta_{Thermal}$ by (Length / 100ft).

Example 2 Calculations:
Consider a pipeline, made of 24in. piping, Series 110 (100psig). The operating temperature of the system is 180°F. The installation temperature is 75°F. Calculate the thermal expansion for a 90 ft section of piping.

C_t = 0.000010 in./in./°F
Δ T = 105°F
$\Delta_{Thermal}$ = 1.26 in./100 ft = (90/100) * 1.26 = 1.13 in./90 ft

PRESSURE EXPANSION

$$PF = \left(\frac{r}{2t_r E_t} - \frac{v_{\min} r}{t_r E_h} \right) (100\,ft) \left(\frac{12 in.}{1 ft.} \right) (P) \tag{4}$$

$$v_{\min} = v \left(\frac{E_h}{E_t} \right)$$

$$r = \frac{ID + 2 * t_l + t_r}{2}$$

PF - Pressure expansion, in./100 ft
r - Radius, in.
t_r - Structural wall thickness, in.
t_l - Liner thickness, in.
ID = Inside diameter, in.
E_t - Axial tensile modulus, psi
E_h - Hoop tensile modulus, psi
v - Poisson's ratio
v_{min} - Minor Poisson's ratio
P - Internal pressure, psi

Example 3 Calculations:
Consider a pipeline made of 12in. Series 20HV 200psig piping with a design pressure of 200psig and a design temperature change of 30°F. Calculate the pressure expansion.

r = 6.26 in.
t_r = 0.48 in.
t_l = 0.02 in.
E_t = 1,400,000 psi
v = 0.4
E_h = 2,200,000 psi
P = 200 psig
v_{min} = 0.63
PF = 0.22 in./100 ft
C_t = 0.000010 in./in./°F
Δ T = 30°F
$\Delta_{Thermal}$ = 0.36 in./100 ft

ANCHOR LOADS

$$P_A = A_t E_t \Delta \tag{5}$$

P - Anchor loads, lbs
A_t - Cross-sectional area, total, sq. in
E_t - Axial tensile modulus, psi
Δ - Expansion, in./in.
- Note that the anchor load is not a function of the total length; expansion is dimensionless.
- Modulus values are not degraded at design temperature (for conservative results).

Example 4 Calculations:
For a 16in. 110 Series (150psig) system calculate the anchor loads along a straight run of piping with the following design data: design temperature = 140°F, installation temperature = 70°F, and design pressure = 50psig. First, the total expansion of the system needs to be calculated:

$A_t = \pi /4\,(17.50^2 - 16.25^2) = 33.1$ in^2
E = 1,400,000 psi
C_t = 0.000010 in./in./°F
Δ T = 70°F
r = 8.375 in.
t = 0.39 in.
E_t = 1,400,000 psi
v = 0.4
E_h = 2,200,000 psi
P = 50 psig
v_{min} = 0.63
Δ = 0.84 + 0.09 = 0.93 in./100 ft = 0.000778 in./in.
P = 36,052 lbs

If the layout does not require pressure expansion to be included as part of the design, then:

Δ = 0.84in./100 ft = 0.0007 in./in.
P = 32,438 lbs

GUIDE SPACING

$$L_g = \sqrt{\left(\frac{\pi^2 E_b I_r}{A_r E_c \Delta}\right)} * \left(\frac{1\,ft.}{12\,in.}\right) \qquad \textbf{(6)}$$

L_g - Guide spacing, ft
π - 3.14159
I_r - Moment of inertia, reinforced, $in.^4$
A_r - Cross-sectional area, reinforced, $in.^2$
Δ - Expansion, in./in.
E_b - Axial flexural (bending) modulus, psi
E_c - Compressive modulus, psi

- Refer to the Support Spacing section for notes.

Example 5 Calculations:
Consider a piping system operating at 125°F and 150psig with an installation temperature of 75°F. Calculate the recommended guide spacing for a 6in. 20FR-E system.

π = 3.14159
E_b = 1,400,000 psi
I_r = B/64 (6.625^4 - 6.04^4) = 29.23 $in.^4$
A_r = B/4 (6.625^2 - 6.04^2) = 5.82 $in.^2$
E_c = 1,400,000 psi
C_t = 0.000010 in./in./°F
Δ T = 50°F
r = 3.3166 in.
t = 0.2925 in.
E_t = 1,400,000 psi
v = 0.4
E_h = 2,200,000 psi
P = 150 psig
v_{min} = 0.63
Δ = 0.6 + 0.14 = 0.74 in./100 ft = 0.000617 in./in.
L_g = 23.6 ft
Neglecting pressure expansion,
Δ = 0.6 in./100 ft = 0.0005 in./in.
L_g = 26.2 ft

GUIDE SPACING FOR DIRECTION CHANGES

For pipe:

$$L_{D1} = \sqrt{\left(\frac{(2.3)(3)E_b D\Delta}{2\sigma}\right)} * \left(\frac{1\,ft.}{12\,in.}\right) \qquad \textbf{(7)}$$

L_{D1} - Guide spacing for direction changes, ft
E_b - Axial flexural (bending) modulus, psi
D - Outside diameter, in.
Δ - Total expansion, in.
σ - Allowable bending strength, psi = 1,500 psi
ID - Inside diameter, in.
- Expansion is the length change from the anchor to the first direction change.
- includes a 2.3 stress intensity factor.

Example 6 Calculations:
For a 14in. 20HV system, operating at 155°F (installation temperature = 75°F) and 150psig, calculate the guide spacing at a direction change. The distance from the elbow to the anchor is 24.0 ft.

E_b = 1,400,000 psi
D = 15.125 in.
C_t = 0.000010 in./in./°F
T = 80°F
r = 7.335 in.
t = 0.42 in.
v = 0.4
P = 150 psig
E_t = 1,400,000 psi
E_h = 2,200,000 psi
v_{min} = 0.63
Δ = 0.96 + 0.07 = 1.03 in./100 ft = 0.25 in. for 24 ft run
L_{D1} = 9.2 ft

For systems where the fitting/joint may be weaker in bending than the pipe, such as many adhesive-bonded "socket" systems, the strength of the fitting/joint should be taken into account with this equation:

$$L_{D2} = \left(\frac{(2.3)(4.5)E_b D\Delta(ID)}{2\sigma}\right)^{1/3} \left(\frac{1\,ft.}{12\,in.}\right) \qquad \textbf{(8)}$$

EXPANSION LOOP LEG LENGTHS

For pipe:

$$L_{A1} = \sqrt{\left(\frac{(2.3)(1.5)E_b D\Delta}{2\sigma}\right) * \left(\frac{1\,ft.}{12\,in.}\right)} \tag{9}$$

- Refer to the previous section for notes.
- Expansion is the length change along both straight runs on each side of the loop, not one straight run.

Example 7 Calculations:
For a 24in. Series 110 piping system, operating at 200°F (installed at 75°F) and 50psig, calculate the leg lengths needed to alleviate the stresses along a 200 ft section of pipe between two anchors.

D = 26.00 in.
E_b = 1,400,000 psi
σ = 1,500 psi
C_t = 0.000010 in./in./°F
ΔT = 125°F
r = 12.50 in.
t = 0.265 in.
E_t = 1,400,000 psi
E_h = 2,200,000 psi
v = 0.4
P = 50 psig
v_{min} = 0.63
Δ = 1.5 + 0.20 = 1.70 in./100 ft = 3.40 in. for a 200 ft run
L_{A1} = 31.4 ft

For systems where the fitting/joint may be weaker in bending than the pipe, such as many adhesive-bonded "socket" systems, the strength of the fitting/joint should be taken into account with this equation:

$$L_{A2} = \left(\frac{(2.3)(2.25)E_b D\Delta(ID)}{2\sigma}\right)^{1/3} \left(\frac{1\,ft.}{12\,in.}\right) \tag{10}$$

HYDRAULICS

Head Losses in Straight Lengths of Pipe

Turbulent flow (Darcy-Weisbach equation):

$$H_f = \frac{0.000216\, fLQ^2 \rho}{D^5} \tag{11}$$

H_f - Turbulent head loss, psi
f - Moody’s friction factor, dimensionless
L - Pipe length, ft
D - Fluid density, lb/cu ft
Q - Volume flow rate, GPM
D - Inside diameter, in.

Laminar flow:

$$H_f = \frac{0.000273 LQ\nu}{D^4} \tag{12}$$

H_f - Laminar head loss, psi
v - Absolute (dynamic) viscosity, cP
L - Pipe length, ft
Q - Volume flow rate, GPM
D - Inside diameter, in.

Friction Factor

$$f_o = 0.25\left[\log\left(\frac{e/D}{3.7} + \frac{5.74}{\mathrm{R_e}^{0.9}}\right)\right]^{-2} \tag{13}$$

$$\frac{1}{f^{0.5}} = -2.0\log\left(\frac{e/D}{3.7} + \frac{2.51}{\mathrm{R_e}\, f_o^{0.5}}\right) \tag{14}$$

f_o - Moody’s friction factor, first guess, dimensionless
f - Moody’s friction factor, dimensionless
e - Absolute roughness = 0.0002 in.
D - Inside diameter, in
R_e - Reynold’s number, dimensionless

When, Re < 100,000, an alternate equation for the friction factor is:

$$f = \frac{0.3164}{R_e^{0.25}} \tag{15}$$

HYDRAULICS (continued)

Reynolds number

$$R_e = \frac{d \times v}{12 \times \mu} \qquad \textbf{(16)}$$

Re – Reynolds number
v – velocity, ft/sec
μ – Kinematic viscosity, ft^2/sec
d - Inside diameter, in.

1 SSU = 0.22 CSt = $2.365*10^{-6}$ ft^2/sec

Head Losses in Straight Lengths of Pipe

Hazen-Williams equation (valid for water, 40 to 75F)

$$H = \frac{4.52 \times Q^{1.85}}{C^{1.85} \times d^{4.875}} \qquad \textbf{(17)}$$

H – head loss, psi per foot
Q – flow rate, GPM
C – Hazen-Williams coefficient, typically 150 for fiberglass
d - Inside diameter, in.

WATER HAMMER

Celerity (velocity of sound in the liquid)

$$c = \sqrt{\frac{Kg}{\rho} * \frac{144in^2}{1\,ft^2}} \qquad \textbf{(18a)}$$

Pressure Wave Speed

$$a = c \;\; for\ rigid\ pipes \qquad \textbf{(18b)}$$

$$a = \frac{\sqrt{\frac{Kg}{\rho} * \frac{144in^2}{1\,ft^2}}}{\sqrt{1 + \frac{K * ID * C_1}{E * t}}} \;\; for\ non-rigid\ pipes \qquad \textbf{(18c)}$$

c - Celerity (Speed of sound in the fluid), ft/sec
a - Pressure wave speed, ft/sec
K - Liquid bulk modulus, psi
g - Gravity = $32.2ft/sec^2$ at sea level
ρ - Density, lbm/ft^3
ID - Inside diameter, in.
E - Tensile modulus, psi
t - Wall thickness, in.
C_1 = Pipe restraint coefficient, typically 0.84 (for a fully anchored system) to 1.0 (for a system with expansion)

Water Hammer for Instantaneous Closure

(Joukowsky's Formula)

$$P_{ins\tan t} = \frac{au\rho}{144g}$$

(16)

Water Hammer for Timed Closure

$$P_{time} = \frac{2Lu\rho}{144gT} \;\; for\ T > T_{quick} \qquad \textbf{(19a)}$$

$$P_{time} = \frac{au\rho}{144g} \;\; for\ T \le T_{quick} \qquad \textbf{(19b)}$$

Definition of Quick Closing Valve

$$T_{quick} = \frac{2L}{a} \qquad \textbf{(20)}$$

$P_{instant}$ - Water Hammer due to instantaneous valve closure (in addition to line pressure), psi
a - Pressure wave speed, ft/sec
u - Flow rate, ft/s
ρ - Density, lbm/ft^3
g - Gravity = $32.2ft/sec^2$ at sea level

P_{time} - Water Hammer due to a timed valve closure (in addition to line pressure), psi
L - Pipe length, ft
T - Valve closure time, sec

T_{quick} - Closing time for quick closing valve, s